Taking into account multi-scale analysis in economic modeling of vulnerability to floods. Study of Cooperative Winery Systems by a Multi-Agent Model

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Prise en compte de la multiscalarité dans la modélisation économique de la vulnérabilité aux inondations

Apport d'un modèle multi-agent appliqué aux systèmes coopératifs viticoles

Présentée par David NORTES-MARTINEZ
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Sous la direction de Stefano FAROLFI
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Taking into account multi-scale analysis in economic modeling of vulnerability to floods

Study of Cooperative Winery Systems by a Multi-Agent Model

A dissertation by

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Résumé

Les conséquences néfastes des inondations sur la société sont le résultat probable de facteurs socio-économiques. Les nouvelles pratiques en matière de prévention des dommages causés par les inondations se sont éloignées de la mise en œuvre de mesures structurelles pour inclure également des mesures non structurelles. Ces derniers intègrent, entre autres, les services des écosystèmes, exploitant ainsi le potentiel des écosystèmes pour prévenir, réguler et réduire les risques liés aux inondations. Ce changement, même s'il poursuit des niveaux plus élevés de prévention des risque et des dommages, ainsi qu'une volonté de durabilité économique, renforce la protection des zones urbaines et industrielles au détriment des zones rurales et agricoles (plus exposées). Mais les secteurs agricoles ont en réalité des structures singulières qui les rendent particulièrement vulnérables aux fluctuations des revenus et des cash flows. L'agriculture est aussi de plus en plus considérée comme un système socio-écologique complexe (SES), constitué de l'ensemble des activités agricoles, du territoire, de l'environnement et des relations établies entre ces trois éléments. En tant que tels, il existe des facteurs qui, à plusieurs niveaux, jouent un rôle fondamental dans la détermination de la vulnérabilité du système agricole.

Dans la mesure où la discrimination entre les types d'exploitations est essentielle pour fournir des évaluations des impacts et des vulnérabilités fiables, cette thèse se concentre sur la production de vin et propose une étude micro-économique du Système Coopératif de Vinification (SCV). Ce système présente des caractéristiques qui le caractérisent comme une SES. Nous cherchons donc à étudier dans quelle mesure l'intégration de plusieurs échelles d'analyse contribuent à la détection, à la compréhension et à la caractérisation des facteurs de vulnérabilité d'un SCV aux inondations. Nous considérons la vulnérabilité comme une propriété intrinsèque de tout élément/système qui dépend de la sensibilité à subir des dommages et de la capacité à faire face aux conséquences de l'aléa. En conséquence, nous pouvons évaluer la vulnérabilité d'un système et de ses facteurs déterminants grâce à l'estimation des dommages causés par les inondations..

Nous proposons et construisons un nouveau modèle d'évaluation des dommages aux inondations pour le SCV (modèle COOPER), basé sur des données obtenues de deux cas d'étude dans le Sud de la France : les départements de l'Aude et du Var. Pour développer le modèle COOPER, nous utilisons une approche multiagent qui nous permet de faire une description du système "bottom-up", en identifiant les entités clés, leurs interactions et l'environnement dans lequel elles se déroulent.

L'utilisation du modèle COOPER comme laboratoire d'évaluation ex-ante des dommages causés par de multiples inondations met en évidence l'importance d'une identification correcte des interactions entre les éléments du système. Si les interactions ne sont pas bien identifiées, les dommages sur le système (et par autant la vulnérabilité) peuvent soit être surestimés, soit sous-estimés. Aussi, la possibilité de décrire en détail les agents et les règles du système productif, ainsi que la présence d'interactions explicites, nous permettent d'identifier et d'estimer le poids que différents facteurs significatifs ont dans la susceptibilité du système à subir un préjudice ou la capacité à faire face aux conséquences d'un risque d'inondation.

Mots clés : Vulnérabilité, Inondation, Modélisation agent, Estimation des dommages, Indicateur, Agriculture, Interaction, Secteur viticole, Cash flow

Abstract

Harming consequences of floods in societal systems are the likely consequence of socioeconomic factors. New practices in flood damage prevention have moved away from the implementation of structural measures, embracing as well non-structural measures that integrate ecosystem services, taking advantage of the ecosystems' potential to prevent, regulate and scale down water-related hazards. This shift, even though it pursues higher levels of risk prevention, damage reduction and economic sustainability, is increasing the exposure of rural and farming areas for greater protection of urban and industrial ones. But agricultural sectors have in fact singular structural patterns that make them particularly vulnerable to income and cash flow shifts. Moreover, agriculture is increasingly considered as a complex Socio-ecological system (SES), formed by the ensemble of farming activities, territory, environment, and the relations established among these three elements. As such, there might exist factors that, acting along several scales, play a fundamental role in the determination of the vulnerability of the agricultural system.

Insofar farm-type discrimination is essential to provide reliable assessments of impacts and vulnerabilities, this dissertation focuses on wine production and proposes a microeconomic study of the cooperative winemaking system (CWS). This system exhibits features that characterize it as a SES. Thus, we seek to study to what extent the integration of several scales of analysis contributes to the detection, understanding and characterization of the drivers of vulnerability of a CWS to flood hazards. We consider vulnerability as an intrinsic property of any element/system that depends on the sensitivity to suffer harm and the capacity to cope in the aftermath of the hazard. Accordingly, we can evaluate and asses the vulnerability of a system and its drivers through the estimation of flood damages.

We propose and build a novel model for the assessment of flood damages of a CWS (the COOPER model), based on data elicited from two study cases in southern France: Aude and Var counties. To develop the COOPER model we use an agent-based model approach, which enables us to describe the system from the bottom-up identifying the entities of interest, their interactions and the environment in which they take place.

The use of the COOPER model as laboratory for the ex-ante assessment of damages of multiple flood events highlights, despite scales the importance of the correct identification of interactions between elements in the system. Their misidentification may lead to either the overestimation or the underestimation of damages, thus vulnerability of the system. Furthermore, the possibility to describe in detail both agents and rules within the productive system, together with the presence of explicit interactions, enable us to identify and estimate the weight that different significant factors have in the susceptibility of the system to suffer harm or the capacity to cope with the consequences of the a flood hazard.

Keywords: Vulnerability, Indicator, Flood, Agent-based model, Damage estimation, Agriculture, Damage, Interaction, Modeling, Wine sector, Cash-Flow

Nihil enim est opertum quod non revelabitur,
aut occultum quod non scietur
Matthew 10:26

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"He who has suffer'd you to impose on him knows you"

— William Blake's *Proverbs of Hell*

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* * * * *

To reduce the assistance received to the aforementioned social core of companions would not be entirely fair. This dissertation has been entirely built using free software and Open Source tools [1]. Thus I would like to, here and now, also thank, first of all, my father for introducing me to the open source world, and, second, the different foundations and projects out there for all their efforts in the development of robust, yet, flexible tools.

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If the development of those tools has been important for this work, so has been the community of users. Forums like *StackExchange*, *StackOverflow* and *TeX–LaTeX Stack Exchange*, among others, became sites of daily visit. Without the expertise of that whole community it is hard to imagine how would I have climbed such a "steep learning curve".

1. I have made extensive and intensive use of environments and tools like, among others, Netlogo (Wilensky, 1999), R (R Core Team, 2017), JabRef, LaTeX (Mittelbach et al.) and Geany, running on a Linux Mint OS 17.1 'Rebecca', Cinnamon Edition

Contents

Introduction

> *"Scholars and policy analysts face compound puzzles nested in compound puzzles."*
>
> — Elinor Ostrom

Floods are common occurrences in the European territory (European Environment Agency, 2012a,b). They are part of natural cycles of riverine ecosystems, and, as such, they present a wide variety of functions. Just to mention a few, they are associated with natural dragging processes, maintenance of natural biodiversity in the floodplain, carriage of nutrients or groundwater stocks recharge.

However, the transformation of riverine ecosystems to serve socio-economic development has favored the apparition of huge economic losses in societal systems associated to natural hydrological floods. This interaction between societal systems and natural phenomena has enabled the apparition of the so-called *damaging floods* (European Environment Agency, 2010). This term refers to those floods impacting infrastructures, properties, and arable lands. It also includes the potential of floods to turn into drivers of environmental harm due to the interaction with societal systems —e.g. in the accomplishment of their "ecological duties", floods may spread out pollutants from flooded industrial areas to downstream aquifers or arable lands— (European Environment Agency, 2010; Mitchell, 2003).

In France, according to the available information [2], floods are, by far, already the most frequent natural catastrophe [3]. At European level, the available evidence predicts a most likely further increment in magnitude and, especially, frequency of floods (Alfieri et al., 2015a,b; European Environment Agency, 2010). Worldwide, flood hazards are already among the most damaging and expensive natural hazards (Dubbelboer et al., 2017; Erdlenbruch and Bonté, 2018; Tonn and Guikema, 2017).

Harming consequences of floods in societal systems can be understood as a problem of sustainability in the strategies of economic development of societies (Green et al., 2011; Villagrán de León, 2006). Indeed, the available studies at European level, do not find conclusive evidence linking past climatic-related flood trend(s) with flood losses trend(s) in Europe (European Environment Agency, 2010). Instead, what data

2. GASPAR database. It includes all declarations of natural catastrophe from 1982: http://www.georisques.gouv.fr/dossiers/telechargement/gaspar

3. 114 840 declarations of natural catastrophe in the period 1982-2017. 71.6% of the existing natural catastrophe declarations.

do suggest is that growing populations and increasing assets in exposed areas are the main drivers of the increasing economic losses due to floods over the past decades (European Environment Agency, 2010, 2012a). Rather than unavoidable outcomes linked to nature's caprices, the existence of damaging floods is therefore the likely consequence of socioeconomic factors. The correct understanding of the way in which those factors drive flood risk becomes thus basic for the efficient design of policies oriented towards economic sustainability, risk prevention and damage reduction.

Precisely in the study of risk to floods and natural disasters in general, the analysis of vulnerability has become a powerful, central tool (Adger, 2006; Birkmann et al., 2014b). Indeed, in nowadays scientific literature on risk assessment, risk is seen as a combination of three different factors (see, among others, Birkmann, 2007; Hiete and Merz, 2009) [4]. In first place, a hazard, characterized by the probability, severity and timing with which the triggering event will manifest itself [5]. Second, the exposure, i.e. the degree, duration, and/or extent to which a system is in contact with, or subject to, the perturbation [6]. Third and last, the vulnerability, that we will define, for now, as the latent sensitivity of a given system to suffer harm. Accordingly, a flood (or any other natural catastrophe) —the hazard— is simply a triggering mechanism acting upon the exposed elements of the system. The probability of suffering losses (the risk) will exist to the extent that those elements exposed —directly or indirectly— are sensitive to such a hazard. In consequence risk cannot be fully understood nor assessed without a deep comprehension of the vulnerability (sensitiveness) of each element.

This key role of vulnerability in the assessment and understanding of risk is even more evident when we look at how current risk prevention measures target areas differently, depending on their nature. Indeed, new practices in flood damage prevention have moved away from the implementation of *structural* measures [7] (Kreibich et al., 2009). Nowadays risk management practices also integrate *non-structural* measures [8], that include the ecosystems' potential to prevent, regulate and scale down water-related hazards (Hooijer et al., 2004; Kreibich et al., 2009). This shift in pursuit of higher levels of risk prevention, damage reduction and economic sustainability is nonetheless turning risk management practices into spatial planning problems. Indeed, a practical consequence of the implementation of *non-structural* measures, such as floodplains and water retention areas, is an increment in the exposure of rural and farming areas for greater protection of urban and industrial ones (Barbut et al., 2004; Brémond et al., 2013; Decrop, 2014; Erdlenbruch et al., 2009; Hartmann and Driessen, 2013; Le Bourhis, 2007; Penning-Rowsell et al., 2013).

While it is true that damages and losses in rural areas are expected to be much lower than those in urban and industrial areas (Förster et al., 2008), the utilization of certain kinds of *non-structural* measures, like floodplains, is directly targeting

4. For alternative proposals a good starting point is Villagrán de León (2006)
5. For alternative definitions see Thywissen (2006, pages 18-20)
6. Thywissen (2006, pages 17-18)
7. Dikes, engineering solutions for fast water evacuation, etc.
8. *Non-structural* measures should not be understood as only dependent on ecosystem services though. They include measures, among others, as insurance, emergency management, household adaptations...

farm income. Studies conducted in England have shown that it is possible to engage farming communities in the implementation of this kind of *non-structural* measures for flood risk management (Morris et al., 2008; Posthumus et al., 2008). However, Agricultural sectors have in fact singular structural patterns that make them particularly vulnerable to income and cash flow shifts (see Barry and Robison, 2001).

The importance of microeconomic analysis of business viability and economic vulnerability, especially in case of farming activities, should not be therefore neglected. Notwithstanding, these microeconomic studies on the evolution of economic/financial viability of these businesses are scarce (Marshall et al., 2015). More so if they focus on farming activities (Nicholas and Durham, 2012; Reidsma et al., 2018).

Furthermore, one of the potential solutions appointed for the long term success of floodplains for flood risk prevention would be the design of income compensation mechanisms for those businesses affected. However, the design of fair and efficient income compensation mechanisms seems unattainable without knowledge on the degree with which activities could be impacted both short and long terms. The efficient use of natural floodplain areas for risk management demands therefore knowledge on the features that make businesses in those areas vulnerable. Thus, further research is necessary on the identification of the drivers of economic vulnerability to flooding of businesses operating in flood-prone areas, especially in the case of farming activities (Johnson et al., 2007; Morris et al., 2008; Posthumus et al., 2009).

The present dissertation focuses on this microeconomic level and seeks to contribute to the understanding and characterization of the vulnerability of agricultural activities to flood hazards. Farm-type discrimination has been recognized as essential in order to provide models capable of reliable assessments of impacts and vulnerabilities (Reidsma et al., 2018). In such regard, viticulture plays a prominent role in the local economy, agricultural orientation and land occupation in our areas of study. Furthermore, already in 2009, Battagliani et al. (2009), in their study on perceptions of vinegrowers to climate change, collect the awareness of french vinegrowers to an increasing frequency of floods[9]. More recently, authors like Sacchelli et al. (2016b) highlight the need to widen the knowledge on vulnerability, climate change effects and adaptations on winegrowing and wine-producing activities.

In our study cases coexist two different profiles of vinegrowers (based on data gathered from FranceAgriMer (2012)): *independent* and *cooperative*. The so-called *independent* profile represents a vinegrower who controls the whole vinification process within the boundaries of his farming business. He is in charge of grape cultivation, fermentation, bottling and commercialization of the final product. The *cooperative* profile, on the contrary, is only in charge of grape cultivation. The rest of the phases in the winemaking process are undertaken in a cooperative winery, whose property is shared between all the associated vinegrowers. Hence it is the cooperative winery who owns the means of wine production, and centralizes production, stocks and commercialization of the ensemble of associated vinegrowers (Knox, 1998). Risks, revenues and winemaking costs in the productive chain are thus mutualized among

9. "*[...] flooding was so often mentioned in the list of perceived climate change traits.*" (Battagliani et al., 2009, p. 69)

vinegrower members.

Although not numerous, it is possible to find studies of vulnerability of individual vinegrowers to climate change in general (Nicholas and Durham, 2012), or more particularly to floods (Brémond, 2011). To date, however, research addressing specific matters related to vulnerability to floods (or climate change in general) in cooperative wineries seem to have been overlooked. Works like Lereboullet et al. (2013) or Brémond (2011) have pointed out that, due to their mutualizing practices and networked productive structure, cooperative winemaking processes are going to have different vulnerability drivers than those of *independent* vinegrowers. Yet, these factors have not been explicitly investigated. In fact, to date, we could not find a published article/study addressing vulnerability of cooperative wineries to floods or climate change in general. Cooperative winemaking is not unique to our study areas though. According to the Confédération des Coopératives Vinicoles de France (CCVF), 50% of the french wine is produced under cooperative schemes [10]. This importance in the wine production and the prior knowledge gap mentioned motivate us to focus this dissertation on the vulnerability of cooperative winemaking to floods.

Additionally, agriculture can be considered as a complex Socio-ecological system (SES), formed by the ensemble of farming activities, territory, environment, and the relations established among these three elements (Benoit et al., 1997; Brémond, 2011; Rivera-Ferre et al., 2013). Scoped this way, there might exist factors that, acting along several scales, play a fundamental role in the determination of the vulnerability of the agricultural system (Anderies et al., 2004; Michel-Kerjan, 2000; Redman et al., 2004; Turner et al., 2003a).

This dissertation will seek thereby to study how the integration of several scales of analysis contributes to the understanding and characterization of the vulnerability of a Cooperative winemaking system (CWS) to flood hazards. Namely: What are the factors that drive vulnerability to floods of a CWS? To what extent the integration of several scales of analysis contribute to the detection, understanding and analysis of such factors?

It is noteworthy though that this work does not pretend to model and analyze a particular case study. In that sense, it is not conceptualized as an ex-post study of a concrete flood event. On the contrary, it seeks to reproduce the way the CWS works, feeding a modeling phase and a subsequent phase of simulation with qualitative and quantitative data from the case studies. In such way, the resulting model can be used as a laboratory for the ex-ante analysis of the exposure of a CWS to a variety of floods scenarios.

10. `http://www.vignerons-cooperateurs.coop/fr/french-wine-co-operatives/french-wine-co-operatives_434.html`. Last access: May 2018

1 The notion of system in the present work: hierarchic systems, Socio-Ecological System (SES) and the Cooperative Winemaking System (CWS)

1.1 Understanding the foundation: hierarchic systems

The kind of system with which we will work in this dissertation can be classified under the hierarchic paradigm. Hierarchic systems present certain distinguishable characteristics that are going to influence/limit the way the system can be conceptualized, analyzed and/or modeled. In this subsection we condense the main properties that characterize hierarchical systems, according to the works of Costanza et al. (1993); Feibleman (1954); Giampietro (1994); Liu et al. (2007); Potochnik and McGill (2012) and Simon (1962).

First of all, hierarchic systems are composed by interacting entities. Each entity itself is, at the same time, i) decomposable in smaller entities (subentities); and ii) part of a larger entity (supraentity). This last feature enables us to establish levels that will depend hierarchically on each other. Eventually those levels are going to facilitate different performance assessments within the same system. Namely, once a scale is fixed, it is possible to analyze the performance of each entity and the system along the different existing levels in the aforementioned scale.

Furthermore, the properties that a given entity, A, displays at a given level, L, are the result of the interaction of "its" composing subentities at lower levels. This idea is behind the concept of *emergence*: the properties of an entity cannot be predicted from the individual analysis of the subentities insofar their interactions are essential to the property's formation. Emergent properties in hierarchic systems make complexity grow as levels are ascended.

At the same time, the same given entity, A, is going to feed back "its" subentities with limits and/or directions. Said limits/directions result from i) the interactions of A with other entities in its own level, L; and ii) the limits/directions imposed from upper levels. Interactions in hierarchical systems will have, therefore, a twofold nature: *intra-level* interactions between the entities at a given level; and *inter-level* interactions in a sort of infinite feedback between hierarchical levels of entities.

Consequently, levels are not only nested, but also codependent. Disturbances faced by entities at one given level spread along (*reverberate*) all levels in the scale. Stability in one level depends, therefore, on the stability in any other levels; and such stability depends, ultimately, on the behavior of the entities in each level in the face of a disturbance.

Hierarchic systems are also dynamic and display different evolution paces along the levels. This dynamism is as well responsible for the apparition of non-linearity: the response of any entity to a perturbation in a moment t is linked to its state in such moment t. Hence, the response of a given entity A to multiple identical perturbations in multiple moments, t_n, will be dependent on the state of A in each t_n.

Finally, hierarchic systems are what the specialized literature call *"near/nearly-*

decomposable" or, alternatively *"partially decomposable"* (Ostrom, 2007). Such property, based on the assumption that certain entities might work independently from each other to achieve certain functions, allows for the analysis in isolation of parts and/or levels of the system. Entities and levels falling out of the bounds of the analysis become either constrains (when imposed from higher levels and/or units in the same level) or noises (when they originate in lower levels).

1.2 The Socio-Ecological System

Socio-ecological systems (SESs) have been defined in several ways. Likely, the most comprehensive definition to date was provided by Redman, Grove, and Kuby, who define SESs as i) a coherent system of biophysical and social factors that regularly interact in a resilient, sustained manner; ii) a system that is defined at several spatial, temporal, and organizational scales, which may be hierarchically linked; iii) a set of critical resources (natural, socioeconomic, and cultural) whose flow and use is regulated by a combination of ecological and social systems; and iv) a perpetually dynamic, complex system with continuous adaptation [11] (Redman et al., 2004).

The SES framework emerges as an interdisciplinary bridge to help scholars and policy makers find a common place for theory and diagnostic tool development [12]. Although still a work in progress (McGinnis and Ostrom, 2014), the SES framework has gradually widened its presence since its systematization by Ostrom (see McGinnis and Ostrom, 2014, p. 1, referring to Ostrom's *A diagnostic approach for going beyond panaceas*, published in 2007) [13].

The framework rests upon several postulates of the hierarchic systems theory. In its broadest formulation, Ostrom's SES (figure 0.1), focusing on a given level, distinguishes 4 different, yet interrelated, entities: a resource system (RS), the resource units (RU) issued by said system, its users and other actors (A), and the governance system (GS). In Ostrom's own terminology, these entities are the highest level of variable tiers in a SES; and as in any hierarchical system, they can be decomposed in several lower tiers, depending on the level(s) in which the SES wants to be studied. (See McGinnis and Ostrom, 2014; Ostrom, 2007, 2009a, among other works of Ostrom).

Resource systems provide resource units, that are harvested/extracted/used and maintained by resource users according to the set of rule emanating from the gover-

11. Anderies, Janssen, and Ostrom define SES as a *subset of social systems in which some of the interdependent relationships among humans are mediated through interactions with biophysical and non-human biological units* (Anderies et al., 2004). Alternatively, in a posterior work, Janssen and Ostrom do it as *systems composed of both biophysical and social components, where individuals self-consciously invest time and effort in developing forms of physical and institutional infrastructure that affect the way the system functions over time in coping with diverse external disturbances and internal problems, and that are embedded in a network of relationships among smaller and larger component* (Janssen and Ostrom, 2006a).

12. Framework is then understood in the same term than McGinnis and Ostrom (2014): *"[...] A framework provides the basic vocabulary of concepts and terms that may be used to construct the kinds of causal explanations expected of a theory. Frameworks organize diagnostic, descriptive, and prescriptive inquiry"*.

13. Alternative/parallel attempts can be found in the literature. For a fair review, the reader can consult Binder et al. (2013).

nance system. Resource units are then transformed into outcomes by other multiple actors, according to their set of rules (given by the governance system), in the space of *Action-Situations*. An action-situation is, in McGinnis's definition (McGinnis, 2010, p. 9), a situation where *"individuals (acting on their own or as agents of organizations) observe information, select actions, engage in patterns of interaction, and realize outcomes from their interaction"*[14]. The entities considered (all or a subset of them) get feedback from the action-situation realm, which eventually will influence their own evolutions, hence the system's.

Ostrom's framework gets completed with the Social Economic and Political (S), and ecological (ECO) sets of settings. They both are assumed to influence exogenously the dynamics at the chosen level of analysis. Said exogeneity is due to the fact that although those settings emerge from dynamics at certain levels in the system, neither those dynamics nor those levels are part of the objective of the study. As we explained in the prior section, once the boundaries of the SES object of study are set (i.e. levels, scales, resource systems and units, users and rules), what falls out of the bounds of the analysis becomes either constrains or noises. They influence the behavior of the SES object of study but are not influenced by it. They help to set the scene but they are not part of the drama.

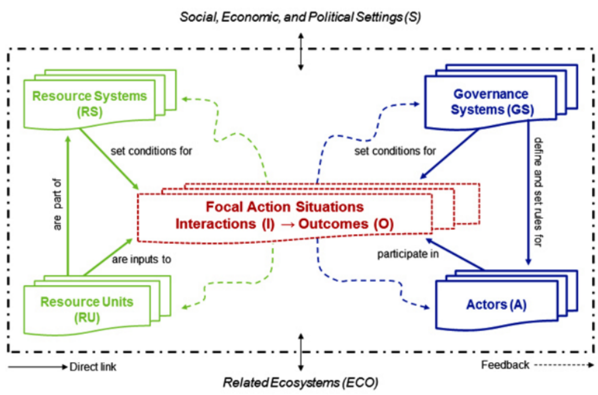


Figure 0.1 – Ostrom's SES framework —source: McGinnis and Ostrom (2014)

The need of coupling ecological and human systems has been recognized by all disciplines that concern us in this work. Economic sustainability research bases its interest upon a threefold argument: i) both systems share features and properties related to complex hierarchical systems; ii) both systems interact with each other; and iii) their isolated treatment has unfolded in causal misinterpretations and eventual policy misconstructions —when not directly failures (Costanza et al., 1993; Janssen and Ostrom, 2006a; Liu et al., 2007; Ostrom, 2007; Redman et al., 2004; Rivera-Ferre et al., 2013). Agricultural systems research highlights the importance of elements like interactions, system hierarchy, multiple scales, or non-linear relations in the analysis of the dynamics of agricultural systems (see Benoit et al., 1997; Brémond, 2011; Dalgaard et al., 2003; Rivera-Ferre et al., 2013). Last, there exists a research line within the vulnerability community that considers joint analyses of social dynamics and ecological systems key to understand

14. They are also the core component of the Institutional Analysis and Development (IAD) Framework of the Bloomington School of Institutional Analysis (Indiana University), *dedicated to understand the ways in which institutions operate and change over time* (McGinnis, 2010; Ostrom, 2009b). Links between SES and the IAD through the concept of action situations can be read in Ostrom (2009b).

the vulnerability of human systems to natural hazards (see, for example, the works of Birkmann et al., 2013, 2014a; Eakin, 2005; Eriksen et al., 2005; Gallopin, 2006; Kienberger et al., 2014; Papathoma-Köhle et al., 2014; Turner et al., 2003a; Welle et al., 2014).

1.3 The Cooperative Winemaking system

The SES approach is still timidly applied to wine-related subjects (Lereboullet et al., 2013). Nonetheless, as we are going to see, the Cooperative winemaking system (CWS) displays all the elements needed to fall into the category of systems we have reviewed.

First, the CWS is the result of a biophysical realm (land, crops...) interacting with organized socio-economic activity (vinegrowing and wine production). In this system there exist two main actors: the vinegrowers and the cooperative winery. Vinegrowers perform vinegrowing tasks over their lands (resource system)) and harvest the grapes (resource units) that grow in them. The amount harvested each year depends on the interaction of several different biophysical elements: soil conditions, weather, vinegrower's performance... The grapes harvested are provided to the cooperative winery as basic input for the wine production. The cooperative winery integrates under the same structure several stages in the supply chain (fermentation, bottling and commercialization). The final performance of the system eventually relies on the performance in each stage.

Vinegrowers and cooperative winery depend therefore on each other to ensure production and revenue. Moreover, relations between vinegrowers and cooperative winery are framed by a set of concrete rules (governance system): the CWS mutualizes the winery's assets, costs and revenues between its associated vinegrowers, linking them all together. The rules for cost-revenue sharing among associates (see Biarnès and Touzard, 2003; Jarrige and Touzard, 2001; Touzard et al., 2001) have the potential to drive impact propagation [15] from one vine-grower to another. As well, the centralization of production, storage and commercialization in the cooperative winery can cause problems for its associates in case of flood. Thus there is potential for the *reverberation* of disturbances in the system. In addition, each of the associated vinegrowers is going to possess its own characteristics and patterns of business evolution. Disturbances and reverberations in the system are therefore expected to impact each vinegrower differently. On such matter, Brémond (2011, p.277) points out the need for further study of the interactions along the supply chain operators for the characterization of indirect effects of floods.

In addition, the CWS itself can be part of much larger systems. It can be studied as part of larger wine production systems, commercialization networks or, also, as part of a local economic system to see the synergies created between sectors. Nonetheless, the ensemble of cooperative winery and its associated vinegrowers can be treated as a sort of encapsulated subsystem. In this sense, the CWS presents intuitive, straightforward boundaries that help us delimit our SES.

The presence of indirect impacts in such a capsule is very plausible, and may play

15. See chapter 4, article's annex

an important role in the vulnerability of each associated vine-grower and the whole CWS.

2 Vulnerability. Dissertation's working definition

Studies on natural catastrophes (such as floods) have been approached by manifold disciplines, searching to fulfill existing knowledge gaps in risk assessment and vulnerability factors. As a consequence, a multiplicity of meanings can be found in today's specialized literature. Indeed, the works of Cutter (1996) and Thywissen (2006) collect 54 different definitions of vulnerability [16]. Aligning our work with what has been suggested in, among others, ADR (2005); Felbruegge and von Braun (2002); Gallopin (2006); Pelling et al. (2004); Rashed and Weeks (2003); Reveau (2004) or Balica et al. (2013), the vulnerability analysis conducted is based on the following definition of vulnerability:

> The sensitivity or susceptibility of an element/system to be impacted by a hazard. Such sensitivity:
>
> i) is defined as the *degree to which the system is modified or affected by an internal or external disturbance/s* (as in Adger, 2006; Gallopin, 2006) [17];
>
> ii) includes the concept of coping capacity, defined as *the system's ability to adjust to a disturbance, moderate potential damage, take advantage of opportunities, and cope with the consequences of a transformation that occurs* (Gallopin, 2006);
>
> iii) is, together with the referred coping capacity, the product of the interaction of entities framed by different dimensions and, therefore, co-evolves with them;
>
> iv) does not include exposure as a qualifying factor.

The inclusion of the system's ability to cope with the disaster is based on the premise that the behavior displayed by each entity in the aftermath of the catastrophe has the potential to either amplify or reduce the initial shock. According to the evidence gathered (Birkmann, 2007; Okuyama, 2003; Wisner, 2002), during the phases of emergency response and, later on, restoration information becomes highly uncertain [18] and behavior may turn erratic. In such a context, restoration actions and investment decisions may vary widely from the optimum reachable, and cause problems observable only later in time.

16. Already in 1996, Cutter identified 20 different definitions (Cutter, 1996, pages 531-533). Since then, progress in vulnerability research has not been able to provide us with increasing consensus about what should be understood as vulnerability. Instead, Thywissen, in 2006, collects 36 different definitions, 34 of them not included in Cutter's (Thywissen, 2006, pages 28-34).

17. *Modification* and *affection* should not be taken as synonyms.

18. Uncertainty is understood by Okuyama (2003) as the state in the aftermath of a disaster where the situations and consequences cannot be expressed in terms of specific mathematical probabilities in a post-disaster context. The degree of uncertainty is nor fixed and varies with the information surfacing in the aftermath of the disaster.

Contrary to existing frameworks of vulnerability valuation in SES (see Birkmann et al., 2013, 2014a; Turner et al., 2003b) we do not consider exposure in our definition. As authors like Alexander (2000), we consider that exposure is a component of risk, not of vulnerability. To forsake exposure as factor of vulnerability implies that vulnerability is not a property of the interaction between the system and its surrounding environment, but an intrinsic feature of the system whether or not exposure exists. In other words, and perhaps risking *reductio ad absurdum*, conceptualizations including exposure as a vulnerability factor might classify as vulnerable/non-vulnerable two identical elements/systems in relation to, *ceteris paribus*, whether or not they are exposed to a hazard. However, as Gallopin (2006) wittily states, "*[...] a person with low immunological defenses would be called vulnerable to infectious diseases, whether or not he or she is exposed to the infectious agent*". So shall it be in regard to SES. Therefore, in this work, rather than a qualifying factor to explain vulnerability, exposure will be included as a tool to surface both impacts and propagation mechanisms.

In such manner, the notion of adaptation, also present in Birkmann et al. (2013, 2014a), is not present in our definition. The goal is to characterize and describe the vulnerability of the system. Namely to find and described the factors driving the susceptibility of the system, not to offer and test solutions to soften the influence of such factors. Furthermore, in a recent article, Atteridge and Remling (2018) discuss how no adaptation shall be considered purely local, even though when they are frequently thought as such. Their thesis can be easily translated and explained in terms of hierarchical complex systems. One of the axioms which these kind of systems rest is the complete interconnectedness of all elements and levels in the system. Any "local" change at any level is thus expected to trigger effects along the whole system. This way, when a certain entity or group of entities implement adaptations searching to reduce vulnerability, their actions may cause an increment of vulnerability in a different point of the system [19]. From this point of view, when we consider the system as a whole, we might not be talking about adaptation but about redistribution of vulnerability from certain points in the system to others. Atteridge and Remling go even further and affirm that, from certain levels up, a coordinated adaptation might not be even possible (how feasible is to coordinate a strategy of adaptation to climate change at global level?)

In parallel with its polysemy, vulnerability is also a multidimensional concept (Müller et al., 2011). Indeed, the MOVE project [20] (Birkmann et al., 2013, 2014a), identifies 6 different dimensions of analysis [21] (figure 0.2):

— Social, which makes reference to disruptions of social systems (e.g. health issues, marginalization)

— Physical, related to damages over physical assets (e.g. infrastructures)

— Economic, focused on business disruption and economic impacts

19. The reader may consider as an example the construction of a dike to protect an urban area that eventually overexposes agricultural land.

20. Methods for the Improvement of Vulnerability Assessment in Europe (`www.move-fp7.eu`). To date and to my knowledge, the last attempt to establish a framework to guide vulnerability analysis

21. Earlier mentions to multidimensionality can be found in Villagrán de León (2006).

— Cultural, whose focus is on impacts on cultural heritage
— Environmental, concentrated in impacts over the ecosystem
— Institutional, fixed on impacts over governance systems and rules

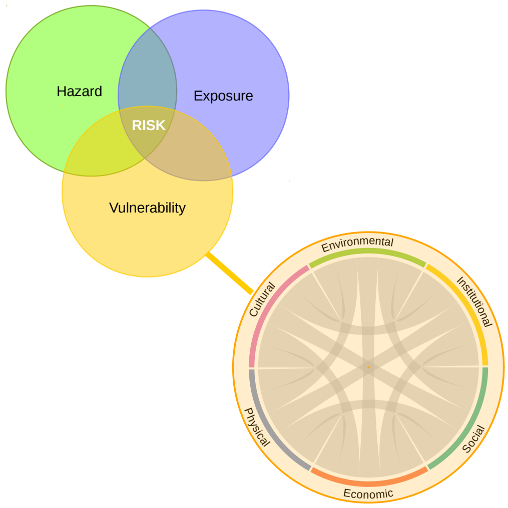


Figure 0.2 – Vulnerability as a multidimensional phenomenon within the risk assessment framework. Illustration of inter-dimensional connection, based on the dimensions identified in Birkmann et al. (2013, 2014a)

Our study will contemplate the following four dimensions in its modeling/simulation phase: physical, economic, institutional and environmental. The presence of the economic dimension is self explanatory in a work on the economic vulnerability of farm systems to flooding. Elements belonging to physical and institutional realms are needed to define the system. On the one hand, a system is composed by several entities, as stated, each of them with its own sensitivity to floods. Thus the physical dimension is needed to define the susceptibility of each individual element to the impacts of a flood. On the other hand, any given system counts on rules that guarantee certain performance. Such rules may be drivers of vulnerability, ergo we consider that they should be present and explicit. Last, conceiving agricultural systems as SESs and studying their vulnerability to natural hazards such as floods, obliges to the inclusion of the environmental realm, even if only as origin of hazard. On the contrary, both social and cultural dimensions, although potentially influential on economic processes and decisions at long term, are considered out of the scope of the work. Hence social impacts of floods, potential casualties, harm to cultural heritage, etc, will not be included.

Both the multidimensionality and the mishmash of definitions of vulnerability have made of it a concept difficult to manage. Such situation, provoked by the adaptation of the notion of vulnerability to the needs and goals of each discipline, has deeper implications than mere semantics. At the very least, it makes difficult i) the quantification/characterization of vulnerability [22]; ii) the intercomparability of studies; and iii) the potential for integration of multidimensional studies, which is, eventually, what helps researchers build over the base of existing works, and day-to-day policy-makers propose more informed policies [23].

22. In Miller et al. (2010), *""[...] meta-analyses of vulnerability concepts and methodologies have shown that there was often little coherence between the theoretical definitions and the methodologies applied"*. In Villagrán de León (2006) *"[...] some social scientists and professionals even go as far as stating that it cannot be measured at all and that only proxies can be used to represent it"*.
23. *Idem.*

As a consequence, attempts to summarize the existing trends and classify the different approaches have proliferated as well (for example, Adger, 2006; Brémond, 2011; Briguglio et al., 2008; Cutter, 1996; Dow, 1992; Gallopin, 2006; Green, 2004; Joakim et al., 2015; Miller et al., 2010; Turner et al., 2003a; Villagrán de León, 2006; Wolf, 2012, among others). Their fruitfulness has been somehow limited, though [24]. To this day, no agreement on a generalized definition exist between the referred disciplines, even when the need has been clearly stated (Cardona, 2003).

3 Vulnerability, systems and scales

3.1 Vulnerability in hierarchic systems and SES

The analysis of vulnerability in systems reveals high usefulness when it is able to identify i) the vulnerability of particular entities, ii) the vulnerability along nested levels in a scale, and finally, iii) the factors and mechanisms determining the latter (ii) in relation to the former (i) (Adger, 2006; Birkmann, 2005; Hiete and Merz, 2009; Turner et al., 2003a; Vogel and O'Brien, 2004).

Indeed, the fully interconnectedness of entities in hierarchic systems entails that *"a disturbance introduced into an organization at any one level reverberates at all the levels it covers"* (Feibleman, 1954, 6th law of Levels, p. 61). Vulnerability analysis in this kind of systems should therefore include the notion of the so-called *domino effect* (Michel-Kerjan, 2000; Turner et al., 2003a) [25]: when a hazardous event —e.g. a flood— takes place, impacting any entity in a given system, the initial shock is expected to ripple through the system in a series of chained effects.

Inasmuch as that interconnectedness is driven by inter- and intra- level interactions in the given system, the spreading of the impact shall be considered bidirectional. First, intra-level interactions will spread impacts from the entities directly exposed to the hazard to the rest of the entities in the same level. Second, due to inter-level interactions, impacts in one level will reverberate through all levels in the system.

Furthermore, considering that the properties of entities at one given level emerge from lower levels, entities and subentities might be differently susceptible to the impacts of the hazard. As a consequence, some effects might not be observable but

24. Two reasons can be argued:

— Lack of output homogenization in classifying trends: for instance, Jacqueleen (2013) identifies 6 schools of thought —*double structure of vulnerability, global environmental change community, school of political economy, holistic approach* and the so-called *BBC conceptual framework*—, Villagrán de León (2006) identifies 3 approaches to vulnerability —*physical exposure, pre-existing condition* and *benchmark vulnerability*— and Joakim et al. (2015) gets 4 —*as a threshold, as exposure, as outcome* and *as a pre-existing condition*.

— Divergent output interpretations: The reader can compare any of the three cases cited above with the point of view of, for example, Birkmann (2007) that interprets that the vulnerability concept has been widened towards more comprehensive approaches; or Green (2004), that points out that the meaning of vulnerability may simply be linked to the context of our analysis rather than a universal concept

25. This notion has been identified as *exposure beyond the presence of the perturbation* in Turner et al. (2003a) or *ubiquity of the perturbation—Ubiquité du sinistre* in the original french— in Michel-Kerjan (2000)

at certain specific levels, whereas the factors that explain them (or originate them) should be searched for in lower levels of the system.

Ultimately, the way the intra- and inter- level interactions either mitigate or amplify the magnitude of the initial shock in its spreading along the system depends on the system's topology; i.e. the arrangement of system's composing entities, pattern of interconnections between them and functional form adopted by those connections (Dekker, 2007).

3.2 Scales of analysis in the present work

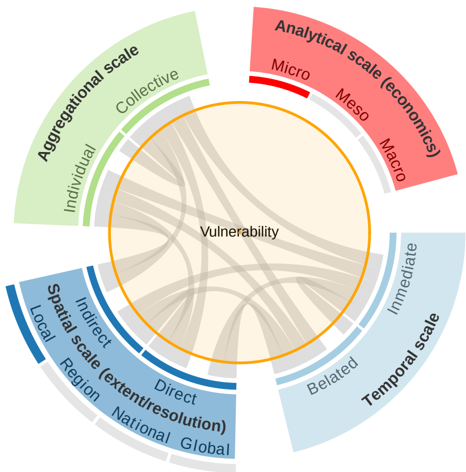
Up until this point, the idea of scale and level has been somewhat abstract in this exposition. The scales in which we can distinguish the levels we have been referring to are multiple though. The selection of both scales and levels to be included in the study is an arbitrary decision driven by the research goals.

Hierarchic systems are dynamic. So is vulnerability according to our definition (see subsections 1.1 and 2). In effect, vulnerability is a property of the system that, emerging from the system's bosom, co-evolves with it (Adger, 2006; Birkmann, 2005; Birkmann and von Teichman, 2010; Felbruegge and von Braun, 2002; Turner et al., 2003a; Vogel and O'Brien, 2004, among others). Time scale shall be thusly present in our analysis. Furthermore, the consequences of a concrete disruption (a flood) due to such vulnerability are not all observable in the same time span (Brémond et al., 2013; Merz et al., 2010). Hence, regarding levels in our time scale, we shall approach our study by using two different ones: immediate and belated time spans.

Observable consequences of floods are also going to be linked to the extent span of the geographical areas considered in the analysis. Namely, if the studied territory is limited to the flooded area, we would be focusing our analyses most likely on the consequences over the entities directly impacted. Larger territories would give the opportunity to also include the consequences over entities not directly impacted. Insofar in the study of flood impacts geographic distributions of entities play a fundamental role in the dynamics of observable impacts in the system, the present work also includes a spatial scale to measure the extent of the territory. As in the prior case, two main levels will be set: the territory corresponding to the flooded area (direct consequences) and the territory outside the flooded area (indirect consequences).

We have already stated that in a hierarchic system as the one we study i) the effect of the disturbance affects each entity according to its properties and state; and ii) the interaction of entities at a given level makes new different properties emerge at higher levels. Thus vulnerability analysis displays all its potential when capable of identifying vulnerability of individual entities and along nested levels. Therefore there is yet a third scale worth considering. We will refer to such a scale as aggregational scale.

Levels along this scale might be a little more complicated to establish though. Vulnerability analysis available in the literature have been accomplished at different levels in what geographers call *spatial resolution* scales. In the context of SES, such a scale makes reference to the degree of detail with which the system is represented. Common levels along this scale are global, national, regional, local, even sublocal (e.g. communities). Levels alike are used by sociology and political economy when approaching the study of SES (compare the so-called "*spatial levels of political jurisdiction*" in Gibson et al., 2000, with Birkmann (2007); Birkmann and von Teichman (2010); Birkmann et al. (2013, 2014a)). Such correspondence is not surprising though. Those levels of jurisdiction can be associated with decisional levels, capable of influencing the evolution of the system by the encouragement/discouragement of adaptations.



Legend: levels colored in gray are out of the scope of the present work

Figure 0.3 – Scales and levels considered in present's work analysis of vulnerability. Illustration of scale interconnectedness — source: own elaboration

The goals pursued with the study of vulnerability in each of these levels are however different. Lower resolution levels (e.g. global, national) use historical data on hazard impacts to develop indexes that allow country comparisons. In contrast, higher resolution levels (e.g local), given the higher degree in detail in the depiction of the system, present advantages in the comprehension of the roots of vulnerability and its driving factors (Birkmann, 2007; Fekete et al., 2010; Villagrán de León, 2006). Inasmuch as our study pursues to accomplish the understanding of factors and mechanisms that make vulnerable farming activities in floodplains, we must circumscribe this work to a local level. Nonetheless, the existence of transversal interactions between the different entities at any level (*intra level* interactions) enables us to consider at least two sublevels per each level of resolution in the aggregational scale: individual and collective. In other words, whilst our study will be bound to a local level in the so-called aggregational scale, our analysis will consider both the individual entities in the system and the ensemble of entities in the level.

In standard economic theory levels of analysis do not relate to any spatial resolution whatsoever (Van der Veen and Otter, 2002, p. 163). Instead they are built over sequentially larger social units [26]. Economic analysis focuses its analysis on either producer/consumer behavior (micro level), sectoral dynamics (meso level) or the evolution of large economic aggregates (macro level). Insofar our work focuses on a cooperative winery and its associated vinegrowers, it will rest in a microeconomic level. The upscaling of results from this level to any of the higher ones —meso, macro— are out of the scope of the present work.

26. A social unit is a unit of a society. E.g. an individual, a family, or a group (*Merriam-Webster dictionary*).

4 Approach to vulnerability assessment in this work

Intuitively speaking, vulnerability arises from the confrontation of an entity/system with a perturbation. If the entity/system is vulnerable to that perturbation, such confrontation will harm, damage or, more generally speaking, impact the entity/system (Wolf, 2012). Harm/damage/impact assessments are, thus, subjacent to any vulnerability assessment (Aven, 2016, p. 4).

Both damage and vulnerability assessments are therefore based on the susceptibility of elements to stressors. However, the vulnerability analysis is going to look for the factors that determine such susceptibility (Vogel and O'Brien, 2004). In this sense, impact assessments are indirect tools that enable the vulnerability analysis to reveal where, and to what extent, systems are sensitive to stressors.

In our work, we are going to base our approach on the interpretation of risk of, among others, Birkmann (2007) or Hiete and Merz (2009). These authors suggest that risk, i.e. the expected value of losses/damages, can be seen as a function of the hazard, the exposure and the vulnerability (figure 0.2). Accepting such a premise, it is conceptually plausible to assess the vulnerability of a system and surface its driving factors by evaluating the value of losses, assuming that both hazard and exposure remain unchanged. Namely, if for a given hazard and exposure the variation of a feature of an entity/system leads to a variation of the value of losses, then that feature shall be taken as a factor that influences the vulnerability of the entity/system.

This notion can indeed be found among a handful of the existing practical approaches to vulnerability assessment [27]. The *Explanation of causal processes and attributes identification* approach (Eakin and Luers, 2006) mixes qualitative and quantitative methods to, first, identify tuples of institutional and social factors (e.g. degree of poverty of certain communities, access to resources, political frameworks, etc). Next it analyzes which combinations of factors drive the vulnerability of the specific system/population. Examples of this approach are, among others, Oliveira Tavares et al. (2015) or Eakin (2005) that, based on census data, seek to identify the main factors of vulnerability by the application of statistical methods.

As well, the so-called *Attribute-outcome association* approach (Eakin and Luers, 2006) develops solid functions and indicators linking the stress or stimuli applied over a specific attribute of the system with the impact caused. For instance, Wang et al. (2013) applied this approach in their assessment of vulnerability to flooding in southwestern Taiwan. In it, they link flood parameters to economic losses and, eventually, those losses to the development of a vulnerability index.

There exist yet another approach. Such approach is committed to the identification of *harm threshold(s)*. To fully understand the notion of harm threshold, the best

27. Practical approaches to vulnerability assessment are fairly less numerous than definitions (Villagrán de León, 2006), most likely due to constrains imposed in data availability and data gathering. Eakin and Luers (2006), throughout the evidence gathered in the available literature, identify no more than 6 approaches still valid nowadays: i) stakeholder feedback and participation, ii) Explanation of causal processes and factor identification; iii) attribute-outcome association; iv) identification of harm thresholds; v) index development; and vi) vulnerability mapping. See Eakin and Luers (2006) for more information.

way is to recur to its simplest expression: the *dose-response* function. This kind of function identifies the existing relation between the observed effects in an entity and the degree of exposure (time, intensity, etc) to an stressor. The observable relation between the effect and the exposure enables the determination of thresholds of significant variation/change.

As simplistic as this notion could seem, the translation/application to more complex systems is not straightforward. Given the characteristics displayed by hierarchical complex systems, the *dose-response* function turns into a *stimulus-multiresponse* function driven by a multiplicity of factors and causal processes. Works including thresholds of vulnerability can be found, among others, in Luers et al. (2003); Oliveira Tavares et al. (2015) or Sendhil et al. (2018)

All of these approaches are complementary though (Eakin and Luers, 2006). Indeed, recent works, like Letsie and Grab (2015), integrate several approaches in order to reach more comprehensive characterizations and assessments of vulnerability. In their study of social vulnerability to natural hazards, they combine interviews with census data and other statistics, to identify certain indicators of vulnerability. Making use of statistical methods they build a vulnerability index. Then they identify 5 different thresholds to classify their results. Finally their index is spatialized to measure its spatial variability. Other works following this integrative approach are, for instance, Kienberger et al. (2014) or Müller et al. (2011)

In our work we will follow a similar procedure. Based on interviews and statistical data we build a model of a CWS that we intend to use as laboratory for the ex-ante evaluation of flood impacts. After the identification of the potential attributes, we employ *Attribute-outcome association*, *harm threshold(s) identification* and eventually index elaboration to give answer to our research questions —i.e. understanding and characterization of the vulnerability of a CWS.

4.1 Limitations to the vulnerability assessment in systems

To describe and measure how each factor and their potential combinations drive the vulnerability of every entity and the whole system, comprehensive vulnerability analyses should encompass the system in its totality. Nonetheless, in the type of system we are attempting to analyze —hierarchical complex systems coupling environmental and human realms—, such degree of comprehensiveness remains unrealistic [28] (Turner et al., 2003a).

Indeed, in hierarchic systems, studies are accomplished by setting clear boundaries that confine the dynamics of the particular processes at the specific levels we wish to study (McGinnis and Ostrom, 2014) [29]. Such process though is rather arbitrary insofar it is based in research interests, hypotheses and assumptions that eventually results in a simplified landscape of the subjacent system. As a result, vulnerability analyses are performed on subsystems whose boundaries are artificially set according

28. For very practical reasons, among which we can cite the lack of available data, the lack of knowledge of the systems themselves, the lack of computational capacity and the need to prevent models becoming black boxes useless to isolate, explain and describe the effect of factors

29. Such statement can be consider as a consequence of Feibleman's *rules of explanation* (Feibleman, 1954, pp. 63-64).

to the actors, interactions, outcomes and rules considered relevant a priori. Variables and levels out of bounds will be treated as constrains and noises that affect the system but are not affected by it.

Vulnerability assessments are therefore heavily case-dependent [30]. They are also subject to a high degree of uncertainty, coming from three different sources: i) incompleteness, derived from the existence of arbitrary, yet necessary, boundaries to the study; ii) arbitrariness linked to the analyst choices and initial values; and iii) data quality and availability.

5 From vulnerability assessment to flood damage assessment

Insofar impact assessments are subjacent to vulnerability valuations and characterizations, the core of this work will rest upon flood damage assessments. Their implementation do not come absent of problems though.

5.1 Nature of damages included in this work

Floods impact economic systems in a wide range of ways, turning the assessment of the consequences a bit knotty (Hallegate and Przyluski, 2010; Przyluski and Hallegatte, 2011). For this reason, the existing literature discusses and establishes different typologies of flood impacts (see, for example, Brémond et al., 2013; Bubeck and Kreibich, 2011; Green et al., 2011; Hallegate and Przyluski, 2010; Merz et al., 2010; Meyer et al., 2013; Penning-Rowsell et al., 2013; Penning-Rowsell and Green, 2000, among others).

The first typology distinguishes between direct and indirect impacts. The former is commonly defined as the impact related to direct exposure to the flood (physical flooding). Regarding the latter, the literature is however less settled as we are going to see.

There are authors that understand indirect impacts as the impacts caused by the consequences of the disaster, not by the disaster itself (for example Hallegate and Przyluski, 2010; Przyluski and Hallegatte, 2011). Other authors though see the necessity of going further and establish subtypologies of indirect impacts. Thusly they distinguish between primary and secondary indirect impacts (Penning-Rowsell et al., 2013; Penning-Rowsell and Green, 2000). The first ones — primary indirect impacts— encompass both emergency costs and consequences over the economic activity of the elements directly flooded. Secondary indirect impacts, on the other hand, are understood as the impacts spreading further away from the flooded area, through economic linkages.

Further, some authors introduce the notion of *business interruption costs* (Green et al., 2011; Merz et al., 2010; Meyer et al., 2013). They are defined as impacts due to the interruption of economic processes in the flood aftermath in the areas directly affected by the flood. They can be presumed as a sort of alternative to *primary*

30. See annex B, section B.1

indirect impacts, yet their proponents point out that they should not be understood as pure indirect impacts. Instead, *business interruption costs* are intended to serve as a bridge between direct and indirect impacts[31]: they are caused by direct impacts in the aftermath of the flood, yet their scope is much more limited than the one considered for indirect impacts.

The practical reach of such abundance of typologies and classifications of indirect impacts is nonetheless debatable. Doubtlessly their existence enables analysts to accomplish thorough analyses of the consequences that a flood might bring over a system. However such richness in applied studies might be extremely difficult to reach, especially insofar it demands a high level of detail in the information needed.

In addition, all the prior definitions and classifications mix both spatial and temporal scales in a rather implicit way. In such regard, Brémond et al. (2013) propose to classify impacts discriminating explicitly along the two aforementioned scales. In such manner, they move along the spatial scale to distinguish between direct and indirect flood impacts. The latter are then defined as those which occur in an area that has not been exposed directly to flooding, whilst the former are defined in the same terms already stated at the beginning of the section. Similarly, they discriminate between instantaneous (or immediate) and induced (in the sense of belated) impacts based on a temporal scale. Instantaneous impacts are then defined as those ones which occurs during or immediately after the flood event. Induced impacts, in the other hand, denote those ones which occur later in time.

The explicit inclusion of both time and spatial scales give Brémond et al. (2013) the possibility of classifying flood impacts as[32]:

— Immediate Direct impacts: impacts due to direct exposure to flood, and manifested during the flood or immediately after

— Immediate Indirect impacts: impacts occurred outside the flooded area, and manifested during the flood or immediately after

— Induced Direct impacts: impacts due to direct exposure to flood, manifested later in time This category would encompass both *business interruption costs* and *primary indirect cost*

— Induced Indirect impacts: impacts occurred outside the flooded area, manifested later in time

In regard to their classification of impacts according to a time scale, Brémond et al. (2013) do not establish any prefixed time span to classify impacts in one category or another. It is therefore a matter left to the analysts' discretion and the concrete effect(s) they are trying to capture (Kelly, 2015).

There exist yet two more typologies of flood impacts lapping over the ones already presented. The first one follows the transferability to monetary value. Based on that criterion, we will differentiate between tangible impacts, understood as those ones

31. Their inclusion in one group or another depends eventually on the study. See Meyer et al. (2013, p. 1553) or Green et al. (2011, p. 41).

32. See Brémond et al. (2013) for more detailed explanations

easily specified in monetary terms, and intangible impacts, defined as those ones which are not traded in markets.

The second typology is founded on the nature of the analysis itself (Gissing and Blong, 2004; Merz et al., 2010) This typology of impacts discriminates between actual and potential impacts. The former are understood as the *ex post* estimation of impacts of a specific flood. The latter is defined as the *ex ante* estimation of impacts that could take place in a system given its state.

The work presented in this dissertation does not address the complete spectrum of typologies of impacts described. As it was stated in the prior section, we pretend to give answer to our research questions through ex-ante evaluations of flood impacts. Hence our focus will rest upon potential, tangible direct and indirect impacts. Furthermore, we consider Brémond et al.'s classification of impacts more accurate and aligned with the work we pretend to accomplish. In consequence, the impact classification in this work will follow their proposal (Impacts and their classification are detailed in section 2.12).

5.2 Assessment methods for the considered impacts. Exposition of main techniques and associated problems

Intangible impacts are out of the scope of this work. Therefore, their methods of assessment and potential drawbacks will not be reviewed here. The interested reader can however see the work of Markantonis et al. (2011) for a complete review.

Generically speaking, flood impact assessment can be accomplished following a fairly straightforward method based on 3 sequential steps: i) identification of elements at risk, ii) assessment of assets value at risk and iii) analysis of susceptibility to floods. Indeed, these very steps usually guide the assessment of direct impacts (Bubeck and Kreibich, 2011; Green et al., 2011; Merz et al., 2010; Penning-Rowsell et al., 2013).

To make the review of the challenges that our work might be facing as illustrative as possible we are going to follow those steps in our exposition.

5.2.1 Identification of elements at risk.

The objective of the first step is to identify the entities in the system that might be harmed, impacted or hit by the flood. However, to clearly delimit what entity is in that situation is not always clear. Green et al. (2011) name them *receptors*, and classify them according to sequentially higher orders, depending on how directly they suffer the harm. This way, receptors of first order would be the entities physically impacted by the flood. Their identification is nowadays easy, thanks to the development of Geographical Information Systems (GIS) and the existence of flood risk maps [33]. They are located in the flood area and the consequences come given by the physical contact with the flood.

Much less evident is the identification of the so-called *receptors of higher order* [34].

33. At least in Europe. See DIRECTIVE 2007/60/CE, Article 6, p. 288/30

34. Green et al. (2011) identifies two higher orders: the first one —*receptor of second order* in Green et al.'s terminology—, defined as receptors that suffer harm indirectly as a consequence of

Those entities will suffer impacts because of the disturbance caused by the flood in the system, either in time or space; not because of any direct contact with it. Their activities will be affected by i) the rippling of the initial shock through the topology of the system; ii) the functional relations between entities in the topology, that will mitigate or amplify the magnitude of that initial shock; iii) the time horizon considered; and iv) the magnitude of harm experimented by those directly impacted (the higher the initial consequences, the longer the recovery and the broader the impact over third parties).

At the same time, the determination of the aforementioned topology depends on i) the boundaries with which the analyst choose to define its subsystem object of study; and ii) the degree of detail with which both entities and their relations are established in the subsystem.

Consequently, flood impact assessments, as well as vulnerability assessments, are going to be case- and context-dependent [35] (Merz et al., 2010).

5.2.2 Assessment of assets value at risk.

Once elements at risk are identified, the second step in flood damage assessment is to determine the economic value of assets at risk. Ideally, the estimation of such a value would take into account the specific features and characteristics of each single object identified in the prior step (subsection 5.2.1). The realism of such endeavor is however linked to i) the degree of detail with which the elements at risk have been identified; ii) the availability/existence of information on the features and characteristics of the elements identified, with the proper amount of detail; and iii) the balance between the time available/needed to perform the analysis, the effort required and the result obtained in the analysis.

Usual practices tend to simplify this valuing task by clustering elements. Asset valuations are then performed grouping elements in clusters based on their characteristics, and assume intra-cluster homogeneity while accounting for inter-cluster heterogeneity (Green et al., 2011). For instance, buildings might be classified in households and industrial buildings. We can assume that, despite their own characteristics, all households will suffer the same kind of impacts. Likewise regarding industrial buildings.

Generally, in the analysis of economic impacts of floods, assets are classified according economic sectors. Subclusters then might be added if the needs of the study require it. It is noteworthy though that more detailed-oriented valuations do not necessary lead to more accurate damage assessment. In fact, if the degree of detail is not accordingly backed by reliable sources of information, the final assessment may result mislead (Green et al., 2011).

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the flood, due to their link to the flooded area. *Receptors of third order* refer to those impacted in the aftermath of the flood and the recovery phase.

35. See annex B, section B.2

5.2.3 Analysis of susceptibility to floods.

Once elements at risk are identified, classified and valued, the third and final step in flood impact assessment is the analysis of their susceptibility to the flood impact. This last step is also the nexus between vulnerability analyses and impact assessments.

Indeed, despite the presence of other elements in the interpretation of the concept, vulnerability is always referred as a sensitivity or susceptibility. As well, we have established that such susceptibility is the degree to which the system is modified or affected by an external perturbation. This step in the flood impact assessment method is aimed precisely at identifying that degree.

Nonetheless, as Vogel and O'Brien (2004) point out, vulnerability assessments differ from mere impact assessments because of their focus on factors that drive and shape the susceptibility/sensitivity of the entity/system to the perturbation. Thus improvements in the knowledge of the vulnerability of an entity/system have a positive effect on assessment of impacts. Likewise, more accurate impact assessment over individual elements make easier the identification of factors and mechanisms driving the vulnerability of the system. However, as it was stated in prior subsections 5.2.1 and 5.2.2, the nature of the impacts that may be potentially involved in a concrete study is widely heterogeneous. Linked to each different impact, it exists a different methodology available.

Tangible direct impacts. Direct impacts of floods have received most of the attention in the literature. Their assessment is done through damage functions. Such functions link flood parameters [36] with degree of damage in elements exposed. Four approaches can be distinguished (Green et al., 2011; Merz et al., 2010):

— Empirical (ex post) vs synthetic (ex ante) approaches. Each of these approaches rely on a different data type in order to build the damage function: empirical approaches use historical data of flood events, whereas synthetic ones are based on expert opinions.

— Absolute vs relative functions. Damage functions can be expressed in absolute terms (monetary valuation of the damage) or in relative terms, as a percentage of the total value of the asset.

No approach represent absolute advantage over the other. For instance, empirical approaches, in theory, would be more accurate and could account for the adoption of mitigation measures; however, thorough ex post damage surveys are not that common. Synthetic approaches are more standardizable, hence potentially applicable to several areas. Yet they rest upon the subjectivity of the experts' opinion. On the other hand, absolute damage functions do not need asset values (just valuation of the damage) but do need periodical recalibration. Relative damage functions have better

36. Functions may consider only one factor —the standard approach in urban flood damages considers commonly depth— or several —e.g. depth, velocity, duration, seasonality—, which, according to the existing literature, improves the accuracy of the the assessment. See Brémond et al. (2013); Bubeck and Kreibich (2011).

time/space/study transferability, but they demand values of reference for the assets (see Merz et al., 2010, for a more complete review of advantages and disadvantages).

In our work, we incorporate synthetic damage functions based on both absolute and relative values (for more details, see section 2.11)

Tangible indirect impacts. In contrast to direct impacts, indirect ones have received less attention from the research community (Brémond et al., 2013; Green et al., 2011; Merz et al., 2010; Meyer et al., 2013). Indirect impacts are more complicated to capture given i) more scarce data sources than in the case of direct impacts; and ii) their dependence on the boundaries and knowledge of the topology underlying the system. This dependency also makes necessary the use of models. The most commonly used models are listed below [37]:

— Statistical methods and econometric approaches (e.g. Cunado and Ferreira, 2014; Kajitani and Tatano, 2014; Okuyama, 2014; Yang et al., 2016)

— Input-Output analysis (I-O) (e.g. Arto et al., 2015; Jonkeren and Giannopoulos, 2014; Koks and Thissen, 2016; Okuyama and Santos, 2014; Steenge and Bočkarjova, 2007; Yamano et al., 2007; Yu et al., 2014)

— Computer General Equilibrium Models (CGEMs) (e.g. Carrera et al., 2015; Kajitani and Tatano, 2017; Tsuchiya et al., 2007)

— Hybrid models (e.g. CGEM—I-O/Econometric I-O) (Donaghy et al., 2007; Hallegatte and Ghil, 2008; Rose and Wei, 2013; Santos et al., 2014, e.g.)

  This last hybrid branch results from the attempts within the community to overcome the limits traditionally pointed out for each model. I-O are, in comparison with CGEMs, simpler to implement. They are capable to provide detailed information on economic interdependencies within a regional economy, yet are criticized because of their rigidity, that allows neither substitution nor price effects. On the other hand, CGEMs, in addition to overcome those critics, are able to account for exogenous interventions in the flood's aftermath and supply/demand changes. Their drawbacks, however, include the nonexistence of technical limits to substitution —even in the short term— and perfect adjustable markets (Hallegate and Przyluski, 2010; Kelly, 2015; Koks et al., 2015; Okuyama and Santos, 2014; Przyluski and Hallegatte, 2011; Rose, 1995b).

It is noteworthy though that these models have received critics regarding their adequacy to the level of resolution in which we want to focus our work. Indeed Green et al. (2011) point out that the aforementioned models are mostly unable to provide useful information to stakeholders involved in decision processes at local/sublocal levels. In the same sense, Meyer et al. (2013) recognize that more work is needed, especially at local/sublocal-level, to narrow the existing knowledge gap on how economic systems would react to flood hazard. Both in terms of finer tuning of the initial shock and the analysis of system's evolution trajectories (Green et al., 2011). This last element is especially important in our context since the kind of systems we

37. See Przyluski and Hallegatte (2011, pp. 24-28) or Hallegate and Przyluski (2010, pp. 17-20) for more detailed explanations.

are dealing with exhibits non linearity. Precisely this non linearity small variations in the disturbance faced by the system can lead to very different impact ad recovery trajectories[38] (Dawson et al., 2011)

As it has been stated already, our focus in this work is circumscribed to the analysis of the behavior of a system in presence of floods at local/sublocal level. Furthermore, we have also stated that the analysis of vulnerability in systems should account for *domino effects*. Robust analysis of indirect impacts and adequate modeling tools are thus essential for a work like ours. The flood impact assessment research community acknowledges that local/sublocal level studies have the potential to improve i) the understanding of the connections between direct and indirect impacts; ii) the topology mapping of economic systems, detecting nature and emplacement of nodes, links and hubs within the system; and iii) the understanding of mutual influence of nodes, links and hubs, and their reactions to external shocks, like floods (among others, see Green et al., 2011; Merz et al., 2010; Meyer et al., 2013).

Our work is thus directly challenged by the referred knowledge gaps, and therefore we expect to contribute to lessen them.

5.3 Specificity of flood impacts in agricultural activities. What are the main elements to account for?

The assessment of flood impacts in agricultural areas and farming activities needs to take into account a few peculiarities according the available literature (see, among others, Brémond, 2011; Brémond et al., 2013; Förster et al., 2008; Kreibich et al., 2009; Morris and Hess, 1988; Penning-Rowsell et al., 2013; Pivot and Martin, 2002; Posthumus et al., 2009). We have outlined such peculiarities in the following 14 stylized facts:

Regarding flood parameters for damage functions

1. Due to intra-annual crop cycles and schedule of critical field tasks, *flood damage is subject to seasonality* (Brémond et al., 2013; Penning-Rowsell et al., 2013, among others).
2. *Flood damage depends on flood duration*, due to a twofold circumstance: i) damage due to crop hypoxia during submersion time; and ii) damage to soil in relation to drying time (the longer the worse) (Förster et al., 2008; Penning-Rowsell et al., 2013; Pivot and Martin, 2002).
3. *Flood depth determines the potential for crop submersion and infrastructure* (buildings, farming material...) *damage* (Brémond, 2011; Brémond et al., 2013; Penning-Rowsell et al., 2013).
4. *Flood damage depends on flood velocity and turbulence.* It is involved in potential soil erosion, plant uprooting, and infras-

38. The weight that trajectories represent in the assessment can be appreciated, for example, in the differences between scenarios with different reconstruction paces; in gains from additional activities created during the reconstruction, or for the reconstruction phase; or even in extinction of businesses in the area, either because they are not viable anymore or because they can move elsewhere (Hallegate and Przyluski, 2010; Przyluski and Hallegatte, 2011).

tructure damage (Brémond, 2011; Penning-Rowsell et al., 2013; Pivot and Martin, 2002).

5. *Flood damage in farmed areas is linked to flood geographical extent* (Penning-Rowsell et al., 2013; Pivot and Martin, 2002).

Regarding land and land use

6. *Flood damage is linked to the type of crop* —which determines productivity, resistance and added value— in the flooded areas (Penning-Rowsell et al., 2013; Posthumus et al., 2009).
7. *Soil type and draining conditions affect crop growth and field work*, which eventually affect harvest quantity and quality (Förster et al., 2008; Pivot and Martin, 2002; Posthumus et al., 2009).
8. *Yields of quality-oriented crops are likely to become unsaleable after a flood* (Penning-Rowsell et al., 2013).

Regarding plant cycles

9. *Stages of plant growth are relevant for flood damage assessment* (Penning-Rowsell et al., 2013).
10. In terms of seasonality, *floods during autumn and winter seasons have less damaging consequences than those of spring and summer*. Nonetheless, autumn floods can result in complete yield loss for certain crops (Förster et al., 2008; Penning-Rowsell et al., 2013).
11. *Flood impacts during vegetative phases do not necessarily translate in complete plant loss*, although they likely reduce yield (Penning-Rowsell et al., 2013).
12. *Floods prior to harvesting may materialize in total yield loss* (Penning-Rowsell et al., 2013).

Regarding farm viability

13. *Effects on scheduled critical field tasks —primarily those related to cultivation— and damage in perennial crops can cause belated impacts over farms* (Brémond, 2011; Brémond et al., 2013; Penning-Rowsell et al., 2013).
14. *The potential damage of a given farm, thus the potential risk for its business viability, is related to its amount of surface flooded* (Pivot and Martin, 2002).

Our study is not going to take into account all of these stylized facts though. To do so will require too many details at levels of modeling that do not necessarily help us to improve our estimations of results, but surely would add layers of complexity to our analysis. In this sense, we will retain the parameters of seasonality and flood extent, whilst depth, velocity/turbulence and duration will be assumed both implicit and constant to our damage functions. Soil conditions and impacts will be simplified as much as possible, as well as plants' stages of growth. Thus stylized facts regarding these elements will not be taken into account either. In the other hand, the inclusion of seasonality will enable us to reproduce the behavior in the stylized facts number 10 and 12. Similarly, our study will take into account both facts related to farm viability.

6 Modeling method

Summarizing quickly what has been reviewed in this introduction, we want to base our work on a cooperative winemaking system, framed as a SES (thus displaying features of complex hierarchic systems). The key variable in the study is vulnerability, which is seen as an endogenous property of the system. Any property in these systems is the result of the interaction of the different entities within the system (inter- and intra- level along several scales) and their specific states and properties. Interactions come defined by the system's topology, and such topology is, as well, key for damage assessment (which, in turn, is the underlying method to any vulnerability assessment) insofar it drives the apparition and intensity of indirect impacts. Notwithstanding, since the study we want to accomplish is bound to a local level, the standard modeling techniques applied to the determination of those indirect impacts are not adequate.

In complex system modeling, local dynamics are best tuned through *bottom-up* approaches (Crespi et al., 2008; Sabatier, 1986). These approaches are characterized by starting the system's design from the base layer, identifying the entities of interest, their interactions and the environment in which they take place. The trajectory followed by the system emerges then from said interactions [39].

One of the available modeling and simulation techniques to implement bottom-up approaches is Agent-Based Models (ABMs) (Balbi and Giupponi, 2009; Bonabeau, 2002; DeAngelis and Grimm, 2014; Jenkins et al., 2017; Loomis et al., 2008; Macy and Willer, 2002; Smajgl and Barreteau, 2017; Tesfatsion, 2002; Zheng et al., 2013, among others). Originally developed in the field of computer science [40], ABMs are nowadays a multidisciplinary tool, applied in and by a wide variety of research communities, e.g. ecology (DeAngelis and Grimm, 2014), biology (Walpole et al., 2013), economics (Heckbert et al., 2010; Judd, 2006; Rouchier, 2013; Tesfatsion, 2006), sociology (Macy and Willer, 2002), psychology (Hughes et al., 2012; Smith and Conrey, 2007) or for the study of SES (Barreteau et al., 2004; Deffuant et al., 2008; Janssen and Ostrom, 2006a; Rouchier et al., 2001; Schulze et al., 2017; Udumyan et al., 2014).

ABMs have also been used for the study of agrarian systems (see, for instance, Berger and Troost, 2014; Bontkes and van Keulen, 2003; Deffuant et al., 2008; Zheng et al., 2013). Authors like Acosta-Michlik and Espaldon (2008) have tried to approach vulnerability to climate change in farming systems. In a recent article, Reidsma et al.

39. The alternative approach used traditionally in complex system modeling is the *Top-down* approach (Crespi et al., 2008; Gore et al., 2017). This one defines the system, dynamics and requirements first at the top level. From this layer down, each subsystem is then featured with the required capabilities that ensure the coherency of the upper layer.

40. They emerge from the object-oriented paradigm, although another disciplines, like artificial intelligence, have made contributions to its development and expansion.

(2018) census 28 works [41] based on ABMs addressing impact assessments of policy measures over agricultural systems at European level.

Within the flood impact research community we have successfully tracked 13 published works. Despite their small number, it is possible to distinguish already 4 different research trends. The first of these trends would encompass the works of Filatova (2015); Filatova et al. (2009, 2011) and Putra et al. (2015). Their main focus rests over the effects of floods on land and housing markets. Pioneering the trend, Filatova et al. (2009) proposed an ABM to study land market dynamics, where flood probability is integrated as a spatial disamenity that affects the agents utility maximization. Using the same model, Filatova et al. (2011) focus on the effects of flood perception over land markets. In their recent works, both Filatova (2015) and Putra et al. (2015) present ABMs to address price formation and urban housing market dynamics through buyer-seller confrontation in presence of flood risk.

Another block of literature groups the works of Haer et al. (2016a,b); Tonn and Guikema (2017) and Erdlenbruch and Bonté (2018). Their focus moves to household adaptation for flood damage reduction. Haer et al. (2016b) address the effects on damage estimation of the presence of adaptive human behavior with a model in which their agents choose to invest in loss reduction measures or get insurance cover. In both Haer et al. (2016a) and Erdlenbruch and Bonté (2018) the focus moves to capture the effectiveness of communication strategies and policies to influence households in the adoption of protective measures. Tonn and Guikema (2017) propose an ABM to evaluate flood risk evolution of a city. Their agents have the possibility to adopt measures to prevent flood damages either individually (depending on risk perceptions) or collectively (as a result of individual requests).

A third trend, shaped by the works of Brouwers and Boman (2010); Jenkins et al. (2017) and Dubbelboer et al. (2017), tackles questions related to insurance in presence of flood risk. Brouwers and Boman (2010) present a spatialized ABM with which they intend to prove the tool's value to discuss policy measures. Concretely, they model the implementation of private insurance systems versus government compensations to mitigate financial burdens due to floods in the upper Tizsa river. Jenkins et al. (2017) and Dubbelboer et al. (2017) over the approach of Putra et al. (2015) build a model for the London Borough of Camden housing market. Their ABM is then used to assess the effects of the UK's flood insurance scheme reform, its synergies with other flood risk management options and the very sustainability of the scheme in presence of climate change.

The fourth trend we will point out, focus on the study the emergency respond to floods. Dawson et al. (2011) propose a spatialized model to analyze the effectiveness of incident management practices. In their model, each agent decides where and when to go using the traffic network. Depending on the location of the agents, their behavior when the flood strikes and the hazard management measures, the authors are able to estimate the number of human casualties in case of flood event.

None of the works presented in this four trends make explicit mention either to agriculture or impact propagation. Regarding the latter nonetheless, in a recent

41. Over 184 published between 2007 and 2015.

work, Otto et al. (2017) propose an ABM to analyze economic loss propagation. Their model does not focus on floods though. Instead they address the disruptions of natural disasters in general for producers and consumers along a supply chain. Nonetheless, their model is neither spatially explicit nor defined for more detailed resolution level than regional aggregations.

Despite the fact that ABMs are increasingly better known and used, their presence as tool is still marginal, especially in what concerns us. Neither agriculture research nor vulnerability research nor the flood impact assessment research community count ABMs within their respective standard toolboxes. Notwithstanding, within the agriculture community, authors like Jansen et al. (2016) and Reidsma et al. (2018) highlight the advantage of ABMs when it comes to interaction representation and simulation of decision-making in agricultural systems. Similarly, in flood impact assessment research, Meyer et al. (2013) recognize the potential of ABMs to contribute to the better understanding of flood shock propagation.

Insofar the existing ABMs on flood impacts focus on urban areas and direct impacts, a work like this one —focused on agricultural systems at local levels, searching to surface factors and mechanisms that make them vulnerable to flood— is a novelty in nowadays scientific literature.

Research questions and dissertation outline

This dissertation pursues to study how the integration of several scales of analysis contributes to the understanding and characterization of the vulnerability of a Cooperative winemaking system (CWS) to flood hazards. Or in other words,

> *What factors drive or influence the vulnerability of a CWS to floods? To what extent the integration of several scales of analysis contribute to the detection, understanding and analysis of such factors?*

To meet our research goal and offer an answer to our question, we build an Agent-Based Model (ABM) of a CWS, in which we integrate the following scales and levels:

- Aggregational scale: local level. Within this level there will be two sublevels: Collective and individual
- Spatial scale: Directly and indirectly flooded levels
- Temporal scale: Immediate and belated (induced) levels

We also include elements in the following four dimensions of vulnerability: economic, physical, institutional and environmental (figure 0.4).

This ABM is coded «from scratch», based on the abstraction of a CWS we are able to build with information gathered from two study cases. We use a combination of several data elicitation methods: Geographical Information Systems (GIS), census, statistics and interviews. Chapter 2 offers the reader a thorough description of both the CWS and model.

The thesis aims to contribute to several research communities. First, to our knowledge, there exist no works on vulnerability of CWS to floods or any other natural hazards. Our study on floods is therefore a novelty itself. Second, our approach is found on ABM, which has been timidly used in vulnerability research. Both points altogether turn this dissertation into a complete novel work in vulnerability research. Furthermore, no similar model to analyze the effects of floods over CWSs has been found in the literature. In this sense, the model itself is also a novelty. In addition, we have built it with enough flexibility to study the impacts of other natural hazards with minimum modifications/transformations.

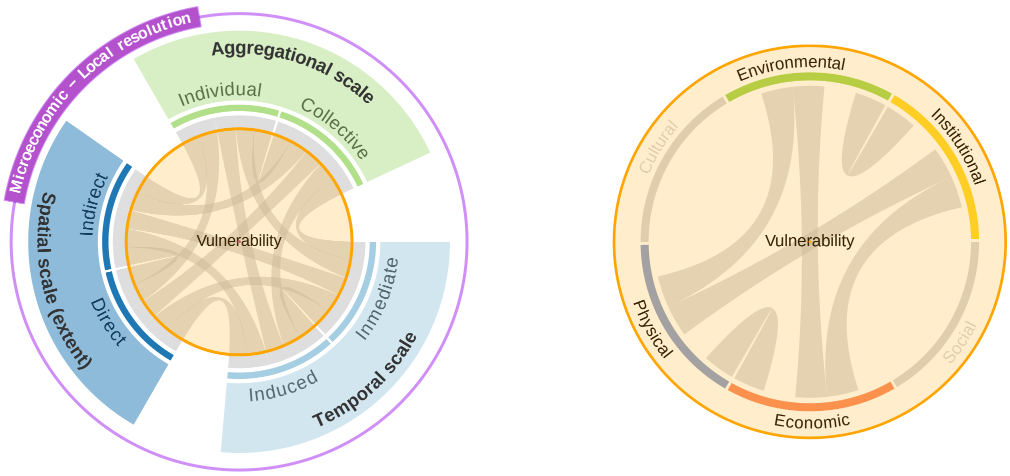


Figure 0.4 – Scales and dimensions of analysis considered in the economic modeling of the cooperative winemaking system object of study. Scales have been adapted to Brémond et al. (2013)'s terminology

Third, we have already stated that this tool (ABMs) can take into account explicit system topologies and several scales and levels of analysis. It provides a new perspective to flood impact assessment at local levels, already pointed out in the literature as worthy of exploration.

The fourth contribution of the dissertation is in regard to the economics of farming businesses and systems. Models of individual farming businesses are still scarce; much more those that can offer analyses of both individual farms and their interactions within a closed system.

Eventually, the dissertation aims to increase the awareness of agents and decision-makers in CWSs in relation to their own vulnerability. Thus flood risk management practices can be improved, updated or implemented. At the same time, our findings can contribute to the design of compensation mechanisms, financial aids and funds, and the risk prevention and management policy-making in general.

The dissertation is structured as follows: it is divided in 5 chapters. The first one introduces the methodology of ABMs to the reader, reviewing the key points around the concept of ABM (what is an ABM?), the advantages that the methodology present as well as their main shortcomings. The chapter finishes with a review of the procedure to build an ABM «from scratch» based on case studies.

The second chapter is dedicated to show the first product/result of our research. It is divided in three parts. The first part summarizes the relevant information upon which the hypotheses that drive and support our model rest (metamodel construction phase). The second and third part of the chapter are dedicated to a thorough description of the resulting ABM: the COOPER model.

Our third chapter focuses on the **collective** sublevel in the aggregational scale. Namely, we will be studying the ensemble of entities, not any individual entity whatsoever. It moves around a first article titled *Are interactions between economic entities determinant for the estimation of flood damage of complex productive systems? Insights from a micro modeling approach applied to wine cooperative system.*

This chapter can be seen as accomplishing a double goal. On one hand, the article tackles the following question: Does taking into account explicit topologies of interactions have an effect on impact damage assessment in comparison with current practices? if so, How does it influence the assessment? It aims therefore to contribute to the use of ABM in flood damage assessment. Point already marked relevant to the flood impact assessment research community.

On the other hand, the experiments and results conducted offer us the opportunity to reflect on some factors of vulnerability. In such manner, in the context of the dissertation, we will be able to consider the effects that factors like topology or coping tactic may have on the vulnerability of the CWS. Without the limitations in extent imposed by articles, we will also be able to accomplish a thorougher review of indicators in search for triggers and mechanisms of vulnerability.

Our forth chapter builds upon the potential of sharing rules to spread financial impacts along the network of associated farmers. It is going to focus more on the **individual** sublevel of the aggregational scale. As well, the analysis of factors of vulnerability will turn to a more financial perspective.

The chapter revolves around the article *Floods, interactions and financial distress: testing the financial viability of individual farms in complex productive systems and its implications for the performance of the system.* This article seeks to study the long run viability of both individual farming exploitations integrated in a CWS and the CWS itself in presence of flood risk. That is, What is the influence that the CWS, as specific productive environment, can have in the financial distress of its associated farms? At the same time but in an opposite way, when individual farms are in financially distressful situations, could its potential bankruptcy cause significant effects on the whole CWS?

The reflections on financial vulnerability factors and drivers that we can find in the chapter will be guided by the following questions:

— Could farms find themselves in financially distressful situations in a CWS? Why?

— What are the key elements in the sharing rules that allow the spreading of impact along the system's topology? If any of those elements suffer any variation, how does such variation translate into the impact spreading?

— If so, How many farms find themselves in financial default positions? Could this number affect the stability of the system?

— Does the system have a threshold of damage/impacts above which the system collapses?

— In an affirmative case, How close can floods bring the system to such a point? Why?

To close the dissertation, we include a short chapter to shortly summarize our work in this dissertation, discuss the results obtained and draw the main conclusions. This short chapter also includes a reflection on the perspectives of further research opened.

CHAPTER 1

From the bottom up: Agent-Based modeling

"No organization can be explained entirely in terms of a lower or higher level (5^{th} Rule of Explanation)"

— Jame K. Feibleman

"It is generally not believed that any ant in an ant colony knows how the ant colony works. Each ant has certain things that it does, in coordinated association with other ants, but thereis nobody minding the whole store"

— Thomas C. Schelling

As we stated in the introduction to this dissertation, the use of Agent-Based Models (ABMs) to model a cooperative agricultural productive system circumscribed to a local level, searching to surface factors and mechanisms that make it vulnerable to floods is a novelty in nowadays scientific literature. The presence of ABMs in agriculture research, vulnerability research or flood impact assessment research is still scarce despite the recognition of the respective communities of their potential to improve/enlarge the existing knowledge on the way systems are impacted by natural hazards (see Jansen et al., 2016; Meyer et al., 2013; Reidsma et al., 2018)

Insofar ABMs are not part of the standard toolbox to approach questions like ours, we consider convenient to offer a panoramic review of the ABM methodology prior to describe our model and its development [1]. Such is the goal of the current chapter. With it, we intend to provide the reader with the key points to understand what is an ABM, what are their general advantages and drawbacks, and, finally, how we shall approach the building of an ABM.

1.1 The Agent-Based Model

An ABM is a computational tool for the description and dynamic simulation of complex systems. As such, they serve as *computational laboratories* where to conduct computational experiments over specific systems in order to test their behavior (Bruch and Atwell, 2015; Dibble, 2006; Macy and Willer, 2002; Seppelt et al., 2009).

ABMs account for three main elements in their formulation: individual and autonomous entities —agents—, interactions, and the particular environment in which and with said agents interact (Smajgl and Barreteau, 2014a).

1.1.1 Entities – agents

Each of the individual entities included in the modeled system is characterized by its own set of attributes. These include the very nature of the entity, its behavior, its capacity to sense its surroundings and own state (self consciousness), and its capacity to communicate with other entities (Balbi and Giupponi, 2009; Bonabeau, 2002; DeAngelis and Grimm, 2014; Ferber, 1999; Tesfatsion, 2006; Treuil et al., 2008). The defining features of a given entity are not limited, nonetheless, to these attributes. Agents can incorporate as well state variables, e.g. initial endowments, that may evolve dynamically with the simulation, providing information about each agent's individual state.

Entities can be of very different nature (individuals, social groups/communities, institutions, animal/plants, cells, land...), and a given model can be composed of entities of different nature, sharing the same environment. Each of these entities will have, to a greater or lesser extent, capacity to sense its own state and part of its surrounding space (including other entities). Actions performed by entities will, ultimately, depend on their programmed behavior.

Behavior of entities in ABMs can adopt a wide range of representations, from very simple systematic actions —reactive agents— to complex human behavior based on

1. Model's description and development details are the focus of the chapter 2

learning and beliefs —cognitive agents— (in such regard, see, for example, Aguilera-Ontiveros and Contreras-Manrique, 2008; Balke and Gilbert, 2014; Bousquet and Le Page, 2004; Brener, 2006; Duffy, 2006; Moulet and Rouchier, 2008; Rouchier and Tanimura, 2012; Shoham and Leyton-Brown, 2009). Yet, contrarily to mainstream economic models, agents in ABMs might display bounded rationality. In other words, agents are usually more limited in their cognitive and optimization capabilities than the hyperrational *homo economicus* (Gilbert, 2008; Hare and Deadman, 2004, 2008; Simon, 1955, 1972). In addition, depending on said cognitive capabilities, entities will show different communication capacities. Them, together with the communication possibilities available, may allow entities to establish new connections and interactions (Vriend, 2005). Furthermore, the number of agents in a given ABM can be object of endogenous variability. Thus ABMs, either due to communication skills or population dynamics, allow for the evolution of their underlying system's topology

1.1.2 Interactions

An interaction can be broadly understood as the way entities affect one another. In its simplest expression, interactions might be mere data transfers (Gilbert, 2008). Yet, following Bousquet and Le Page (2004), three different categories of interactions can be identified. The first one is the so-called *direct interactions*. This kind of interactions is displayed by entities with communication skills, i.e. entities able to produce a message understandable for other entities withing the system, and at the same time understand messages produced by other entities. The second kind of interaction is the *physical* one. These interactions require "physical contact" between entities, e.g. predation, plant growth (soil-plant interaction), harvesting, etc. The last type of interaction refers to the one that happens between the entities and their environment. The actions performed by each individual in the system can have an impact in the system's environment. The modifications in the environment feedback other individuals in the system, that will adjust (if able), and provoke other environmental transformations, and so forth. Interactions with the environment do not have to be tied to those provoked at system level. For instance, natural catastrophes induced by global climate change trends can be included in simulations of lower levels as phenomena originated in the upper levels. Individuals at those lower levels cannot "influence" the likelihood of suffering a natural catastrophe, but they will have to deal with the consequences of such an interaction with their environments.

Further, the interaction-cognition binomial have been used by some authors to identify two conceptual approaches to ABMs (see Balbi and Giupponi, 2009; Hare and Deadman, 2004, 2008). Works whose focal point is on interactions tend to make use of models with relatively simple behaviors. But, if the emphasis of the study is on cognition, entities in the model are provided with more complex cognitive attributes. The interactions between entities are then generated endogenously according to each entity's behavior.

1.1.3 Environment

ABMs' environments provide the frame for both agents and their topology. Environments range from those with no effect at all over the agents and their interactions, to those that can interact with the agents in the model, i.e. they provide data to agents. Further, environments can be either aspatial or spatialized, aka *spatially explicit* (Dibble, 2006; Gilbert, 2008). The first kind is fairly self-explanatory: spatial information is either not expected to have any effect on the systems modeled or it has not been considered in the modeling process.

Spatialized, aka *spatially explicit*, environments refer to environments representing virtual spaces in which agents are spatially distributed. These virtual spaces correspond with abstractions of specific geographic areas or landscapes, which may influence the interaction of the agents, thus the outcomes of the experiments.

1.2 The advantages of the Agent-Based Modeling

Beginning with the most obvious one, ABMs provide utter flexibility to the modeler in relation to the model's specification (Bonabeau, 2002; Richiardi, 2004). The plasticity in the definition of the entities —attributes and state variables— gives the modeler the capability to include, in a given model, tiers of variables representative of several dimensions of analysis. Thus, applied to vulnerability, ABMs offer the potential to accomplish multidimensional studies of systems.

In like manner, the potential for both topology definitions and their endogenous evolution, enables the modeler/analyst to perform analysis along several levels of aggregation of individuals within the same modeled system: individual agent, collectivity of agents, the whole system (Bonabeau, 2002). Thus allowing to study, to quote Schelling, "the micro-motives of the macro-behavior" observed in the system (Gilbert, 2008; Schelling, 1978); i.e. the behavior in different aggregation levels based on the incentives that govern the individual conduct. As it was mentioned in section 2, the analysis of vulnerability in systems turns more useful when it is able to identify nested vulnerability along different levels of aggregation of entities.

Not only levels of agents' aggregation can be accounted for in ABMs. As it was stated, an ABM is a tool for the dynamic simulation of a system. Thus ABMs enable us to perform analysis according different terms in the time scale. Moreover, for our particular case, to be able to define spatially explicit environments is highly appealing. Insofar it facilitates the definition of flood prone areas, direct impacts of floods can be delimited. Making use of both the topology and the dynamic nature of the simulation, we should be capable of tracking down triggers, causes, and factors of impact spreading along the existing topology.

As well, ABMs may help us to tune alternative output trajectories (Loomis et al., 2008). As we stated, the output of a system in a bottom-up approach emerges from the interaction of the entities that compose the system. However the presence of characteristics such as:

1. Heterogeneity in the nature of entities
2. Heterogeneity in entities' attributes
3. Heterogeneity in entities' initial endowments
4. Potential for topology evolution
5. Flexibility in the initial topology construction

6. Potential presence of random/stochastic processes

Will influence the output of a given experiment. Thus the possibility to use ABMs as computational laboratories provide us with a robust tool for ex ante trajectory evaluations. Such potential is essential to address problems of uncertainty linked to the adoption of policy measures and and choices of individual agents (Janssen and Ostrom, 2006a). ABMs might perfectly be used for the engagement of stakeholders and local governments in the implementation of flood risk management plans addressing the awareness of populations at risk (Roos et al., 2017)

Last, ABMs have been successfully hybridized with other modeling techniques proven effective at higher levels (in such matter, you can see the works on physiology of Biggs and Papin, 2013; Thorne et al., 2011; Walpole et al., 2013). Nonetheless, the potential for such hybridization in economics will still have to deal with inherent assumptions in more classical economic models. For instance, agent rationalities, or the fact that in Computer General Equilibrium Models (CGEMs) the system always return to an equilibrium, even if frictions appear in the process, whereas in ABMs, system's behavior is subject to agents behavior and neither the return to the equilibrium nor its stability are guaranteed [2].

1.3 The drawbacks of the Agent-Based Modeling

No simulation tool or technique is perfect, and ABMs are not an exception. Nonetheless, a few drawbacks commonly attributed to the technique can be traced back to the characteristics of the underlying kind of systems we represent with ABMs.

Inasmuch as what we eventually model is a subsystem of a much larger and complex hierarchic system (based on the property of *near-decomposability*), ABMs are always conceptualized with a concrete purpose. The model has to be designed at the right level(s) along the different scale(s) considered relevant to fulfill the purpose. Otherwise, the ABM can end up overfitting the submodel, i.e. fitting both main processes and noises in the system due to a too detailed design (Richiardi, 2004).

Depending on the available information and degree of comprehension of the subsystem that such information allows us, there might be several alternative designs to achieve the same purpose (so-called *equifinality* or *multiple realizability*). Each of those potential designs will require, to a greater or lesser extent, the formulation of different assumptions in relation to very different instances, such as unknown processes, unknown behaviors or initial endowments. This binomial design-assumptions sets the conditions to observe the emergence of particular sets of outcomes (Bonabeau, 2002; Norling et al., 2013; Richiardi, 2004; Sawyer, 2013). Given the complex nature of the systems we are studying, small deviations or modifications in the model specification (assumptions included) and/or initial conditions may result in great outcome variation (so-called *butterfly effect*). Such dependency of the outcomes on

2. Authors like Arthur (2013) maintain a different point of view, and affirm that *equilibrium economics* is an special case of the broader economic dynamics that can be studied with ABMs. From that point of view, in economics there would be no need for hybridization of models since the special cases explained by CGEMs can be as well explained by ABMs

the model's architecture, assumptions and initial conditions limits the capacity of ABMs to provide generalizable results.

Concerning assumptions in ABMs' specification, Galán et al. (2013) introduce the notion of *artefact*. They first establish two overlapping categories of assumptions:

1. *Core* assumptions —which are those essential to attain the purpose of the model— and *accessory* assumptions —that encompass all of those not considered essential for the purpose of the model, but are needed to complete it.
2. *Significant* assumptions —those capable to influence the outcome of the model— and *non-significant* assumptions —which play a neutral role in relation to the outcome obtained.

Then, they define the *artefact* as the fail in identifying *accessory* assumptions as significantly influential in the outcome of the model. Such *artefacts* are especially problematic when the purpose of the model is to describe, characterize and/or explain causal processes in a given system [3]. In these cases, the misunderstanding in the identification of relevant mechanisms or factors, namely to deem significant assumptions as non-significant, entails a problem of representativeness of the model in relation to the real system. As a consequence, both explanatory power of the model and its validity will be compromised.

Nonetheless, our ability to avoid the misidentification of significant hypothesis relies on the adequacy, quantity and quality of the information available. The amount of data required to build an ABM is related to its purpose and degree of detail. Higher degrees of detail and complexity in ABMs lead to the utilization and combination of several data sources and elicitation methods (Smajgl and Barreteau, 2014a). Nevertheless, sources of available information might not be representative of the same level of resolution, which will eventually force the establishment of additional hypotheses and the loss of detail. Moreover, the kind of systems we try to model can include what Bonabeau (2002) call *soft factors*. In business jargon, *soft* factors identify all factors not easily calculable, measurable and/or systematizable, often characterized by unpredictability and need of interpretation.

Verification and validation tasks in ABMs raise another two issues in relation to ABMs. Neither of them should be considered in this context as simple phases in the modeling process. Rather they often refer to the practices used in building the model. Furthermore, both validation and validity of ABMs are going to be linked to the specific purpose of each model (David, 2013). In terms of verification, such link means that the computational model (comprehending inputs, structure and outputs) is consistent with the metamodel specified according the analyst's intentions. To assess said consistency there exists several methods, such as good programming practices, defensive programming, participatory methods and model replication. Regarding validation, such connection with the model's purpose make things a little trickier, since the validation method should be chosen in relation to such purpose (David, 2013). Validation, however, can be also limited by data availability. Such limitations bring

3. For a complete review on the different purposes with which a model can be built see Epstein (2008)

authors like Rykiel Jr. (1996) to distinguish between the so-called *operational* and *conceptual* validation. The former is broadly based on the comparison of simulated and real data to examine the model fitting. The latter, on the other hand, relies on the theoretical plausibility, accuracy and justifiability of the relations cause-effect built in the model[4]

Communication and explanation of ABMs are difficult tasks given the complex nature of metamodels and the resulting computerized models. It makes works based on ABMs cumbersome to read and does not facilitate the model replication (important for verification and transparency). In an attempt to set communication standards, several protocols have been proposed. Among them we can find Mr POTATOHEAD (Parker et al., 2008), Dahlem ABM guidelines (Wolf et al., 2013) or the ODD protocol (Grimm et al., 2006, 2010, with extensions in Laatabi et al. (2018); Müller et al. (2013))

The last issue raised by ABMs has to do with computational capacities. ABMs can be highly demanding in terms of computational resources. Depending on the amount of detail, scales, levels and processes with which a model is built, the computational requirements might be a problem.

1.4 Balancing the pros and cons of ABMs for the purpose of this dissertation

After our exposition of advantages and drawbacks it may seem that the disadvantages of ABM overwhelmingly outstand their conveniences. An it may be so. In fact, the use ABMs as modeling approaches is linked to the research goal pursued (see Epstein, 2008; Taylor et al., 2016)

What we are trying to accomplish in this work is a sort of exploratory research, for which ABM have proven to be useful and revealing (Taylor et al., 2016, see). We want, in fact, to be able to describe a specific system (the Cooperative winemaking system (CWS)) to explain the factors that may be driving its economic vulnerability to a concrete natural hazard (floods). Such a system is composed by entities of different nature (see section 1.3) that interact with each other in a specific, organized way to obtain a final product. The obtaining of such product depends on the correct performance of each entity and the interaction of all of them within the system. What we seek is therefore to build a model to evaluate the impacts of a disturbance over both each of the entities within the system and the system itself. In this kind of system the specification of entities and their interactions can capture key details and aspects. Aspects that may surface in different levels along several scales like time, space or aggregation of entities (macro phenomena versus micro factors)

The potential that ABMs offer to integrate those features seems to be especially appealing. ABMs will permit us to take into account specific topologies linking each entity to one another (which in turn will define their interactions). ABMs will allow us to test whether the influence of the concrete geographic locations of agents may have

4. Doubtless, this kind of validation does not guarantee accurate predictions coming from the model. Notwithstanding it is perfectly valid always that the model is not used to predict.

some repercussion. Moreover, the explicit introduction of the time scale will enable us to observe how the interactions between different entities affect them in different terms, and if new relevant vulnerability factors may surface long term. ABMs will also allow us to test the system, getting information on its responses to disturbances and the mechanisms that guide them, which is precisely our goal. Both de facto and potential vulnerabilities can therefore be acknowledge from a micro base, as so can their triggers and drivers. Hence ABMs have a lot of potential to improve our knowledge on how impacts spread out in economic systems and productive chains.

Inconveniences like model overfitting, equifinality and the potential present of artefacts are bluntly problems of information and data availability. While the modeler's discretion and the the errors it may cause cannot be complete discarded, information (quality and quantity) helps to reduce uncertainty upon the modeler's choices. Of course it can be argued that the information available is often fragmented and lacks the same degree of detail in all its sources. However, in the process of creation of ABMs, especially in those like in our case are based on study cases, several data elicitation methods can be combined (Smajgl and Barreteau, 2014a). Doubtlessly, such combination shall help to create a solid and reliable base of facts upon which build the ABM.

Indeed, in a recent article, Laatabi et al. (2018) present an addition to the ODD protocol (Grimm et al., 2006, 2010) to formalize the use of data in empirical models. The existence of such a protocol has tackled another of the issues raised in the previous section: communication and explanation of ABMs. The ODD protocol, emerged as a solution to document these kind of models, has been extensively used after his first release in 2006 (Laatabi et al., 2018).

Regarding computational capacities, performance improvement are constantly being made. Current ABM desktop frameworks (i.e. Netlogo) can be nowadays parallelized using cluster computing. Indeed we apply this approach in our design. See annex E) Furthermore, some successful experiences based on Graphics Processing Unit (GPU) computing, instead of Central Process Unit (CPU), have been already developed with substantial performance increment (see, for example Lysenko and D'Souza, 2008; Richmond and Romano, 2008).

Regarding issues on verification and validation, insofar what we seek is not an ex-post study of a concrete flood event but rather to reproduce the way the CWS works, we will rest upon a *conceptual* validation.

1.5 Implementation of an Agent-Based Model upon study cases

As we have mentioned in the prior section, our model is going to be build upon study cases. The utilization of study cases is in fact a common implementation approach used in agricultural ABMs (Janssen and Ostrom, 2006b). In our particular case, it has also been established that both vulnerability and flood impact assessments are *case-* and *context-* dependent. Indeed, all the flood impact ABMs reviewed are either based or applied to specific case studies.

To approach the construction of an ABM based on a case study demands the prior elaboration of a metamodel. Such metamodel contains the assumptions, hypotheses and observations that, depending on our research purpose, we have deducted and extracted from the real case. In other words, the metamodel, guided by our research goal, should be a picture of agent classes (either by behavior, attributes or a mix of both), relations between them, relations with their environment and, finally, any other observable factor/element that would help reproduce the main mechanism we are interested in. Subsystem boundaries should also be made explicit in this metamodel in order to avoid model overfitting.

Frequently, the characterization of all these elements comes up against incomplete sources of information. In these cases, the correct description of model components demands the eventual combination of multiple data sources. Thus data elicitation for a given ABM may include the use of census, surveys, interviews (either to agents or experts), field observations, field/lab experiments, proxy data, role-playing games, statistical analyses (regression, clustering) or Geographical Information Systems (GIS) [5] (Janssen and Ostrom, 2006b; Smajgl and Barreteau, 2014a, 2017).

Ideally, the elaboration of the metamodel sets the conditions to implement a computational structure that transforms inputs into outputs according to a specific parametrization —quantitative, qualitative or both— (Smajgl and Barreteau, 2014a, 2017). Said simulation parameters are not only link input with output within the model. They also act as nexus between model and targeted system. Thus coherency between inputs, parameters and outputs should be assured prior to any simulation experiment. Inasmuch as ABMs provide us with data-based induced behavior of the targeted system (An et al., 2005), it is crucial to ensure the validity of the model parameters (at least in a conceptual way if data is not available (Rykiel Jr., 1996)).

Consequently, prior to the utilization of the ABM as laboratory, it is necessary to foresee a "quality control" phase of the model. This phase shall use the model's simulated results as feedback to ensure, as much as possible, i) the metamodel-model coherence, ii) the absence of artifacts, and iii) the absence of coding errors.

5. For an exhaustive relation and description of data elicitation methods, see Smajgl and Barreteau (2014a)

CHAPTER 2

The COOPER model

"...all models are approximations. Essentially, all models are wrong, but some are useful."

— George E. P. Box

The purpose of this chapter is to offer the reader a complete description of the model built (COOPER model hereafter) as well as the metamodel in which it is based. The need to face the complexity of building a new model «from the scratch» is due precisely to the lack of availability of Agent-Based Models (ABMs) on Cooperative winemaking systems (CWSs).

As it has been stated in our introduction, vulnerability and flood impact assessments are case-sensitive. So will be any ABMs with those assessments as main purpose. The use of case studies is common ground in agricultural ABMs. We will build our model upon two study cases located in southern France —Aude and Var regions. These two study cases are also the base upon which the research project Résilience des territoires face à l'inondation. Pour une approche préventive par l'adaptation post-événement (RETINA) [1], that also frames this dissertation, is founded.

The chapter is organized in three different parts. The first one (The COOPER metamodel) provides an overview of the main information we count on to build the model, both from databases and interviews. We consider this first part essential for two main reasons: first it is indispensable to establish the model's main hypotheses and to ensure a correct calibration of the model too. Second, this overview of information will allow the reader to fully understand the pillars upon which our model design rests.

The information included in this part does not correspond however to the full evidence gathered in the terrains object of study. Rather than overwhelm the reader with irrelevant information to understand the current version of the COOPER model, we have preferred to include only those stylized facts germane to build said current version. Notwithstanding, for the interested reader, the full relation of stylized facts summarizing the information gathered has been included in the annex D.

The second part of the chapter (The COOPER ABM) offers the description of the resulting ABM model. In such regard we are well aware that works based on ABMs might result cumbersome, especially when hypotheses, rules and mechanisms within the model are not clear. In our case, insofar there exist no similar model, a robust description becomes all the more important. It not only will favor the understanding of the model, but also will facilitate its potential replication and analysis. We choose therefore to offer a rather thorough description where we explain the models key elements, hypotheses and processes (both within the model and in relation to coding environments). Such description follows, but is not limited to, the precepts of the ODD protocol (Grimm et al., 2010; Müller et al., 2013). This description corresponds to the model we use to generate the results in chapter 3.

Finally, the third part (The COOPER ABM. Financial analysis: extra hypotheses and model modifications) reviews the changes and inclusions of hypotheses and values done in the COOPER model to obtain the results that enabled the analysis performed in chapter 4

1. Resilience of territories facing flood risk. Preventive approach with post-events adaptation. This research project is dedicated to the exploration of the potential for adaptation of systems in the aftermath of natural flood hazards.

The COOPER metamodel

As it has been said already, our work will be based on two study cases: the Aude and the Var departments, located in southern France (see figure 2.1). Our goal will not be nonetheless to tune up the consequences of the flood hazards suffered by those areas. Rather we are going to use these two study cases to extract both qualitative and quantitative information on how a CWS works and it may plausibly react to floods. Such information will feed the construction of our model that, ultimately, will be used as a laboratory to test the potential consequences of floods over the CWS. The goal is therefore to use the case studies to provide reasonable hypotheses for the ex-ante analysis of flood impacts over CWSs according selected parameters.

2.1 Brief case study presentation

This first section intends to offer the reader an overview of the main features of these two areas. The exposition of such features at this point searches to accomplish a double mission. It pretends to bring the reader closer to specific events that made each case study eligible. Then, by moving our focus to their agricultural sectors, we will show the practical interest of the study of the CWSs.

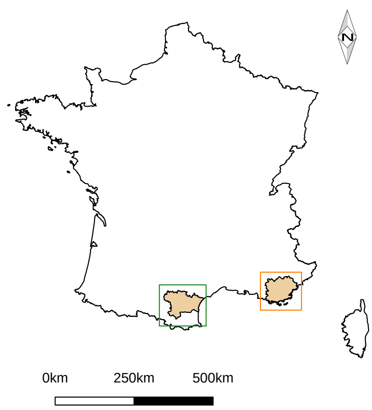


Figure 2.1 – Geographic location of Aude (green) and Var (orange) departments

Both departments present similar structural features. Their economic structure is based on tertiary sectors —services occupy more than 80% of the employed work force— followed by industry and construction —around 13%— and agriculture (6% and 1.8% respectively) (INSEE, 2016). Despite its small weight in terms of employment, agricultural activities are one of the main economic engines in both Aude and Var (e.g. the added value generated in the Aude is around €550 millions. (PAPI, 2014)).

In terms of surface, both areas present, as well, a close structure. It is characterized by low rates of urbanization (smaller than 5% in the Aude and around 7.83% for the Var) [2]. Although there exist some large urban nuclei in both cases. The rest of the

2. Own calculations based on CORINE Land Cover database

territory is shared between natural areas and arable lands. By surface dedication, vineyards represent the biggest share in the ensemble of arable lands [3] (see figure 2.2). Indeed, agricultural activities in both regions present a strong vitivinicultural orientation (Agreste, 2011), accounting for the production of the 11% (Aude) and 5% (Var) of french red and rosé wine varieties (FranceAgriMer, 2017).

As stated in the introduction to this dissertation, in our study cases coexist two different profiles of vinegrowers: *independent* and *cooperative* (FranceAgriMer, 2012). Cooperative vinification is, in fact, an institution rooted in both territories. The first cooperative wineries were established in the very beginning of the XXth century (Chevet, 2004; Touzard, 2011). They originally emerge as a mechanism to defend small vine-growers from market and institutional rigors (Chevet, 2004; Knox, 1998), counting even with the support of the public powers in terms of fiscal advantages, credit access and subventions.

The orientation of vinification activities in the Aude is mostly cooperative. There exist 48 cooperative wineries, processing around the 74% of the wine production (2.6 millions of hl). The var area presents a fairly close number of cooperative wineries: 42. However the orientation of the vinification process in the region is more balanced, with around the 54% of the wine production (687 407 hl) processed by the cooperative wineries (Figure 2.3 displays the proportion of wine produced under a cooperative profile in each territory by *commune*).

It is noteworthy though that the choice of one or another wine production profile does not obey any particular quality-related demand [4]. Indeed, by wine types, the Aude focuses in the production of wines with *Indication Géographique Protége (IGP)* (70.9% of the total production; 71.4% of the cooperative production), followed by wines with *Apellation d'Origine Protége (AOP)* (23.4% of the total production and 25% of the cooperative production) and other wines (5.7%; 3.6% in cooperative production). The Var focuses much more in the production of *AOP* wines (68% of the total production; 73.3% of the cooperative production), followed by *IGP* wines (29.5% of the total production and 25.1% of the cooperative production), and other wines (2.5%; 1.6% in cooperative production).

2.1.1 Floods of reference and level of damages

The Aude department has suffered recurrent flood episodes. In the period 1982-2017, 2 440 declarations of flood-related natural catastrophe can be traced [5]. (74% of the department's declarations [6]). The Aude basin suffered in 1999 one the major flood disasters occurred in France in the past few years —together with the floods over the Rhone in 2002 and 2003— (European Environment Agency, 2010). The

3. The two geographical databases consulted (CORINE Land Cover (CLC) and Registre Parcellaire Graphique (RPG)) present discrepancies regarding the amount of surface dedicated to arable lands and vineyards. Numbers are not contradictory though: according both of databases vineyards occupy the biggest proportion of arable lands. To avoid redundancies we only display the map corresponding to the RPG database.

4. On wine quality and denominations, see annex C

5. Using the GASPAR database, we are able to trace back all declarations of natural catastrophe from 1982. `http://www.georisques.gouv.fr/dossiers/telechargement/gaspar`

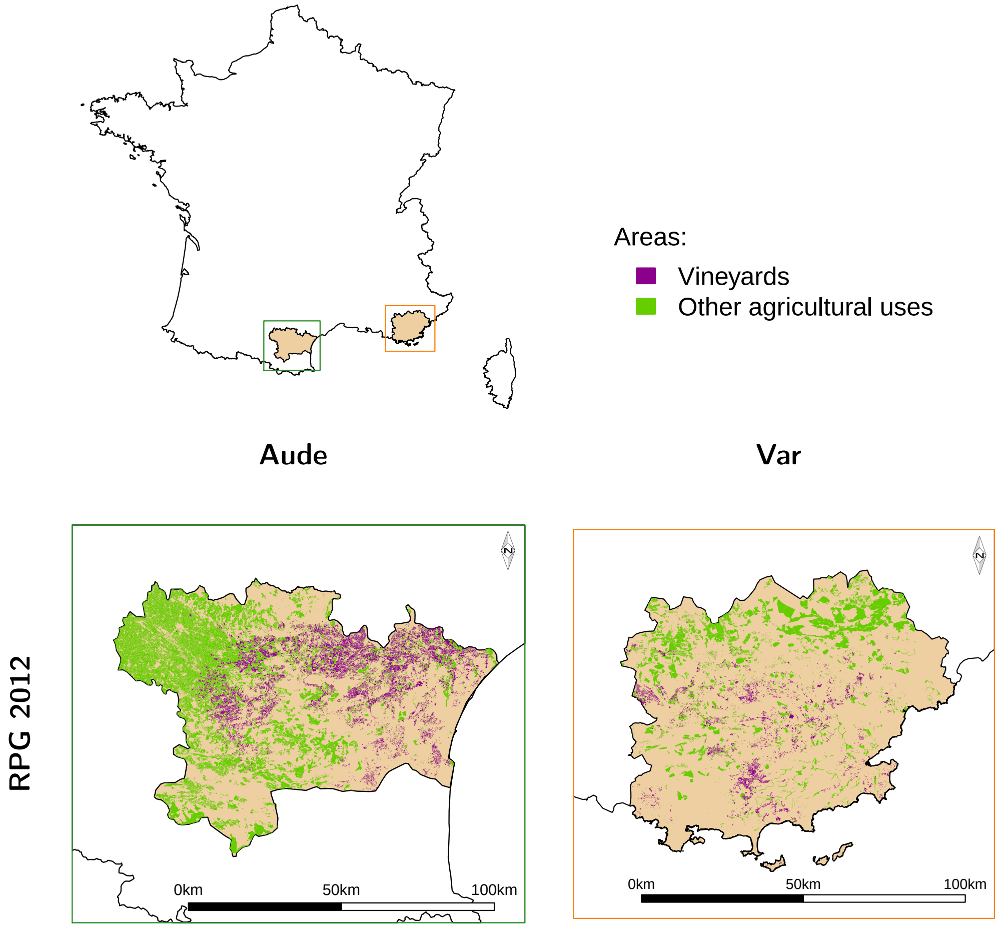
6. Higher than the national french average (71.6%)

whole socioeconomic system of the area resulted affected by the floods. Looses were quantified in €620 millions distributed as follows: 40% in households and private goods, 30% in public infrastructures and 30% in businesses (Vinet, 2003). Damages over agriculture represented the 10% of the total. Viticulture suffered 60% of the direct damages and the destruction of more than the 80% of the establishments. In terms of production and extension, the 66% of the losses in production and the 80% of the surface affected corresponded to vineyards (Bauduceau, 2001).

The Aude department was the most impacted in the area, with damages rising to €363 millions (58% of the total damage in the area). Damages over agriculture were quantified in €33 millions. In relative numbers, it represents the 9% over the total damages in the Department and the 70% of the damages over businesses. It also stands for the 55% of the total damage over agriculture in the Aude basin (Vinet, 2003). The main agricultural activity impacted in the department was viticulture (Bauduceau, 2001).

The Var region registers 695 declarations of natural catastrophe linked to floods in the same time span (79% of the declarations [7]). The territory has been impacted several times by floods in the last years. The floods of June 2010 in the Argens river basin were specially dramatic: 23 mortal victims and €1.2 billions in material damages (Collombat, 2012). From them 12.5% correspond to damages to agriculture (€150 millions) affecting 250 farming businesses (Grelot et al., 2017); in average, farmers lost 57% of yields and 40% of perennial plants (Chambre d'agriculture Var, 2014). The municipality of La Londe les Maures endured two flood episodes in 2014 separated by only a few months, again with human casualties. Unfortunately, the existing damage reports on the Var catastrophes are less detailed than those of the Aude, which eventually impedes thorougher characterizations of damages.

7. Also higher than the national french average (71.6%)

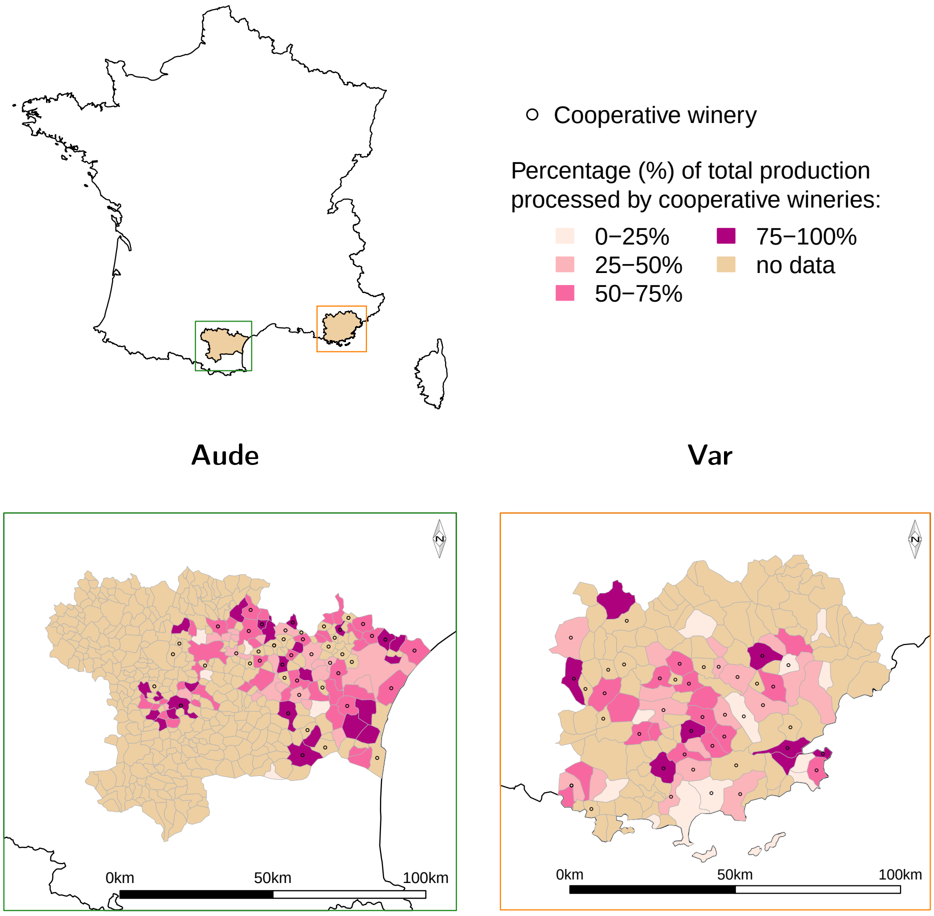


RPG 2012 data

Use	Aude	Var
Cereals	20.37	5.15
Grains and seeds	1.42	0.64
Oleaginous	11.59	2.35
Other cultures	7.64	5.02
Pastures, prairies, fodder and heathlands	35.58	68.77
Vineyards	23.32	18.08
Total	100.00	100.00

Source: own elaboration with data from RPG

Figure 2.2 – Agricultural land extents in Aude and Var regions according the RPG



Source: own elaboration with data from France Agrimer (2012)

Figure 2.3 – Wine production orientation

2.2 The cooperative winemaking system (CWS)

From the interviews conducted in the frame of the RETINA project (RETINA, 2014-2016) we can state the following stylized facts. These facts are going to on the one hand, allow the reader get a clear idea of what is the CWS, while, on the other hand, they assist us to set hypotheses and mechanisms for the design of the ABM:

1. The CWS is composed by three fundamental entities: vineyards (also called plots), vinegrowing farms (also known as vinegrowers) and wineries
2. Young vineyards need a time window of 3 to 5 years to be productive.
3. Vinegrowers (thus their plots) are associated with one, and only one, cooperative winery [8]. They provide the main production input (grapes) and leave in hands of the managerial team of the cooperative winery the rest of the wine-making process.
4. Cooperative wineries split the difference between revenues (from wine sales) and wine-making cost (benefits hereafter) among vinegrowers associated [9]. Delays of, at least, one year from the harvest date to split the benefits are common.
5. Remuneration policies can include some kind of policy of incentives [10], that favors some varieties over others [11]. Notwithstanding, they, essentially, remunerate associates in relation to the input delivered
6. Wine making cost are split proportionally to each vinegrower amount of input (grape) provided.
   Corollary: When a vinegrower does not transfer any input to the cooperative winery, he is not charged with wine-making cost nor receives revenues.
   Exception: It is foreseen the possibility of charging wine-costs to a vinegrower that has not supply any grapes to the cooperative. Such situation takes place when the said vinegrower does not deliver due to negligence of his activities. This mechanism is never used when floods hit the system, though.
7. Wine-making cost can include debt cost and amortization of loans. The structure of cost of a cooperative winery presents both structural (fixed) and operational (variable) costs.
8. Cooperative wineries do not stock financial reserves. Although a common operation in the past, it has been abandoned nowadays.

2.3 The cooperative winemaking system (CWS): geographical aspects

The COOPER model is conceptualized as a spatialized model, thus element disposition matters. In order to provide a realistic configuration to our simulated territory (section 2.8.2), we have integrated in our model geographical information from our study cases.

8. Article R 522-3 of the *Code rural et de la pêche maritime*
9. Consistent with literature. See Biarnès and Touzard (2003); Touzard et al. (2001) and Jarrige and Touzard (2001)
10. Idem
11. Systems of quotas can be found as well

As we have said, the CWS is fundamentally composed by plots, vinegrowers and wineries. To build an spatialized model capable to discriminate between flood prone and non-prone areas demands reasonable knowledge on the proportions of elements in each of those areas. The next three subsections summarize such a knowledge.

2.3.1 Winery spatial location and flood prone areas

The interviews conducted included three different cooperative wineries. Two of them resulted flooded: one in 1999, another one in 2014. Figure 2.4 summarizes the geographical situation of the three of them in relation to the flood-prone areas identified in the *Atlas des Zones Inondables de France.*

Method followed to establish the geographic location of the winery:

1. Identification of the exact geographical coordinates of each winery building using Google Maps,2017
2. Each building is then incorporated to the map of its corresponding local administrative unit *commune*
3. The prior information is the crossed with the flood prone areas available in the *Atlas des Zones Inondables de France* database

2.3.2 Spatial location of vinegrowers and flood prone areas

Unfortunately, we have not been able to find information on geographic locations of farm buildings in our territories. Such information does not exist. To follow a similar method of geographic location than the one used in the prior subsection is not possible either, given the existing difficulties for the identification of vinegrowing farm's buildings in use and their function.

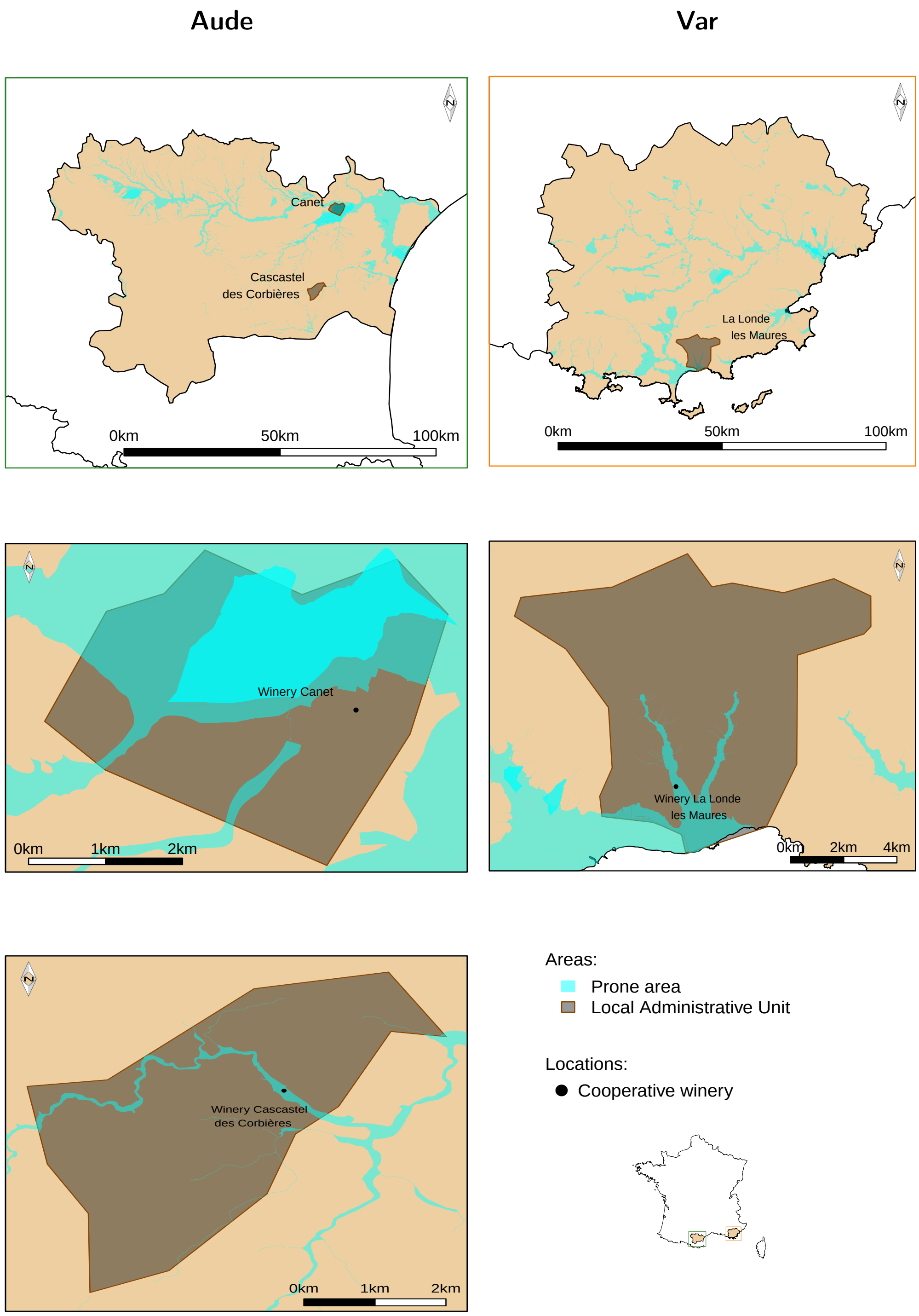
In such a situation, to establish a plausible distribution of farm buildings between flood prone/non-prone areas has demanded an alternative method. We have recur to experts in the field to formulate a reasonable hypothesis of territorial distribution. In standard conditions, we assume 20% of farms' building are located in prone area.

2.3.3 Spatial location of vineyards and flood prone areas

Crossing the two different available data sources for vineyard extent and distribution (CLC and RPG) with the prone areas from the *Atlas des Zones Inondables de France*, we are able to calculate the values in table 2.1.

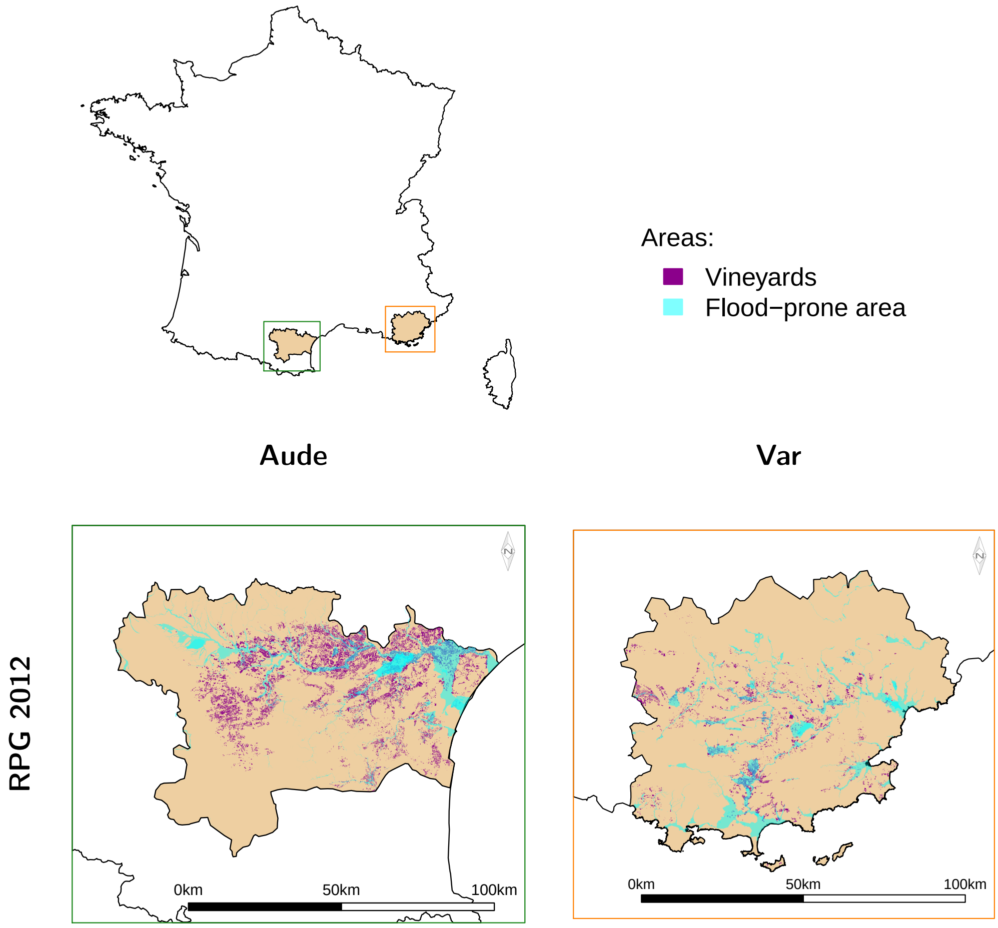
Discrepancies between both CLC and RPG databases are evident. We have chosen to be conservative and keep the proportion given by the RPG database to produce territorial configurations with the highest proportion of plots in prone area (30%). This choice allows us to cover all potential options displayed by controlling the simulated flood extent.

A graphical representation of the vineyards located in prone areas according the RPG database is in figure 2.5



Source: own elaboration with data from Google Maps and *Atlas des Zones Inondables de France*

Figure 2.4 – Position of interviewed wineries in relation to prone areas



Source: own elaboration with data from RPG and *Atlas des Zones Inondables de France*

Figure 2.5 – Flood prone areas and vineyard extents in Aude and Var territories

	RPG 2012	CORINE 2012
Aude	18.28	15.08
Var	29.71	25.50

Table 2.1 – Percentage of total ha of vineyards in each case study's prone areas. Own calculation based on CLC, RPG and *Atlas des zones inondables de France*

2.4 The cooperative winemaking system (CWS): analysis of the production

To design a plausible CWS also demands us, as well, knowledge on elements such as realistic soil productivity or cooperative winery production, number of associates or surface associated to a cooperative winery.

2.4.1 Size of the cooperative wineries operating in the territory

Figure 2.6 represent each existing cooperative winery (according to data from FranceAgriMer, 2012) proportionally to its size [12]. The average size of cooperative wineries in the Aude region is 54 thousand of hl, with a maximum size of 208 000 hl. The distribution of cooperative wineries by size of yield processed can be characterized by a large dispersion [6 000hl - 208 000hl] and a concentration of values (around 64%) under 50 000 hl; 83% of the wineries present amounts processed not bigger than 100 000 hl.

By wine types, we find a big dispersion in the amounts processed, with wineries practically dedicated to AOP wines (around 8% of the wineries are over 80%), while other ones barely process more than 1% of their productions (31% process less than 2%). 54% of the cooperative wineries process 10% or less of yield to AOP.

Cooperative wineries in the Var are smaller: average size around 16 000 of hl with a maximum of 44 000 hl. Their distribution tends to concentrate in small-average sizes: 69% of the cooperatives present productions under 20 000 hl. 90% of the wineries present sizes no bigger than 30 000 hl.

By wine types, wineries are practically dedicated to AOP wines: around 88% of the wineries are over 50%; 66.6% over 70%; the least in this territory is 28%.

In the case of our three interviewed cooperative wineries, Canet declares to produce around 100 000hl per year, whilst La Londe les Maures 13 000 hl. Cascastel des corbières does not declare its production

2.4.2 Number of associates per cooperative winery

The three cooperative wineries interviewed declare an uneven number of associated vinegrowers. Canet's cooperative winery has the biggest number of associates, with 200 vinegrowers. The winery of Cascastel des corbières declares 150 associated vinegrowers (80 in 1999 —Aude's flood of reference). Last, the cooperative winery of La Londe les Maures inform us of 62 associates.

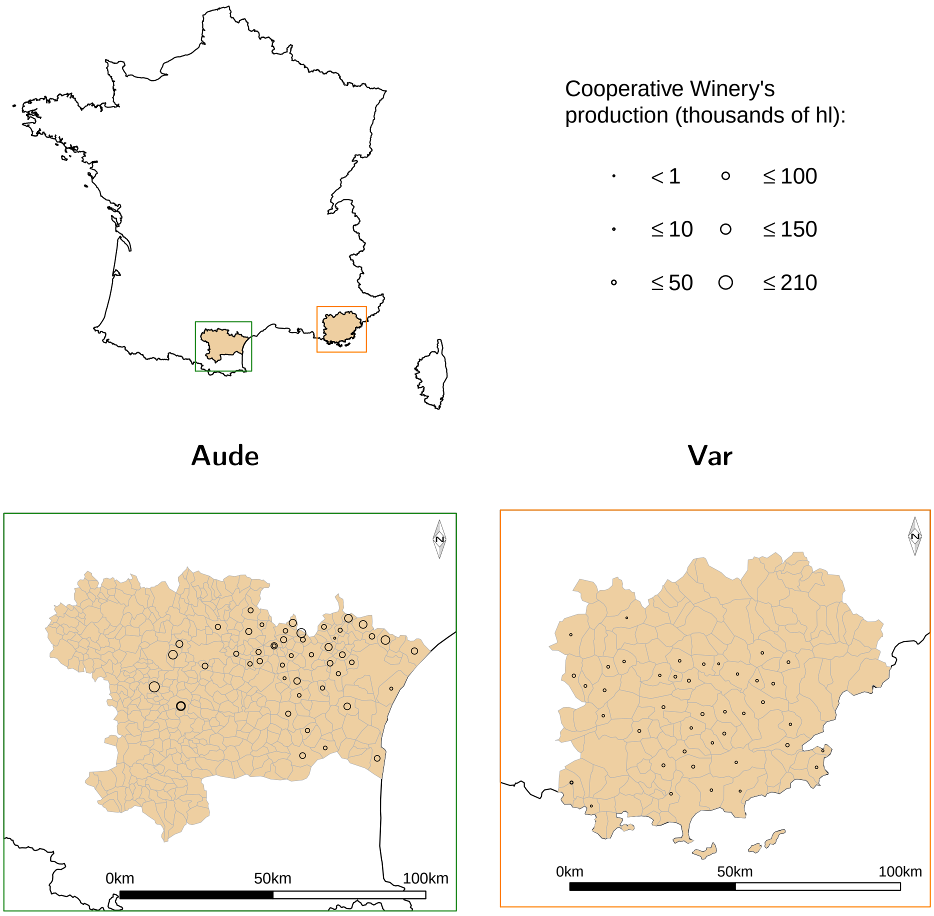
2.4.3 Surface of vineyards associated to cooperative wineries

The associated vinegrowers of the cooperative winery of St. Marcel sur Aude had altogether a surface of 500 ha. Cascastel des corbières' cooperative winery inform us of 300-400 ha in 1999 (flood of reference for the Aude) and 800 ha nowadays. La Londe les Maures declares that its vinegrowers altogether have available a surface of 250ha

2.4.4 Size of vinegrowers in terms of surface owned

On this matter, available data is unevenly disclosed. The Aude region present a general average of 13.82 ha per vinegrower, which can be decomposed in the three

12. We assign each cooperative winery to the *commune* in which they are located. The localization over the map corresponds nonetheless to the barycenter of each *commune*'s polygon. Therefore the geographic location of the winery over the map should not be taken as its real position within its *commune*.



Source: own elaboration with data from France Agrimer (2012)

Figure 2.6 – Size of cooperative wineries

different groups included in table 2.2 (Agreste, 2011). Unfortunately, the Agreste's report on the Var territory is not as insightful. Yet, despite this circumstance, we are able to extract the necessary information to calculate a general average for the territory. According such data, the surface per vinegrower in the Var region is 9.22 ha[13].

Both territories together present a total of 8 198 vinegrowers and 98 600 ha of vineyards. Thus the joint average surface per vinegrower results in 12 ha. This average is not far from the study of Battagliani et al. (2009). They find two average sizes of surfaces per vinegrower in France: 10 ha and 5 ha.

13. Over a total of 5 420 farms, 3 198 correspond to vinegrowers. 29 500 ha are dedicated to vineyards

Size	Average surface (ha)
Small	2.9
Medium	11.5
Large	48

Table 2.2 – AGRESTE report for Aude's region. Year 2010

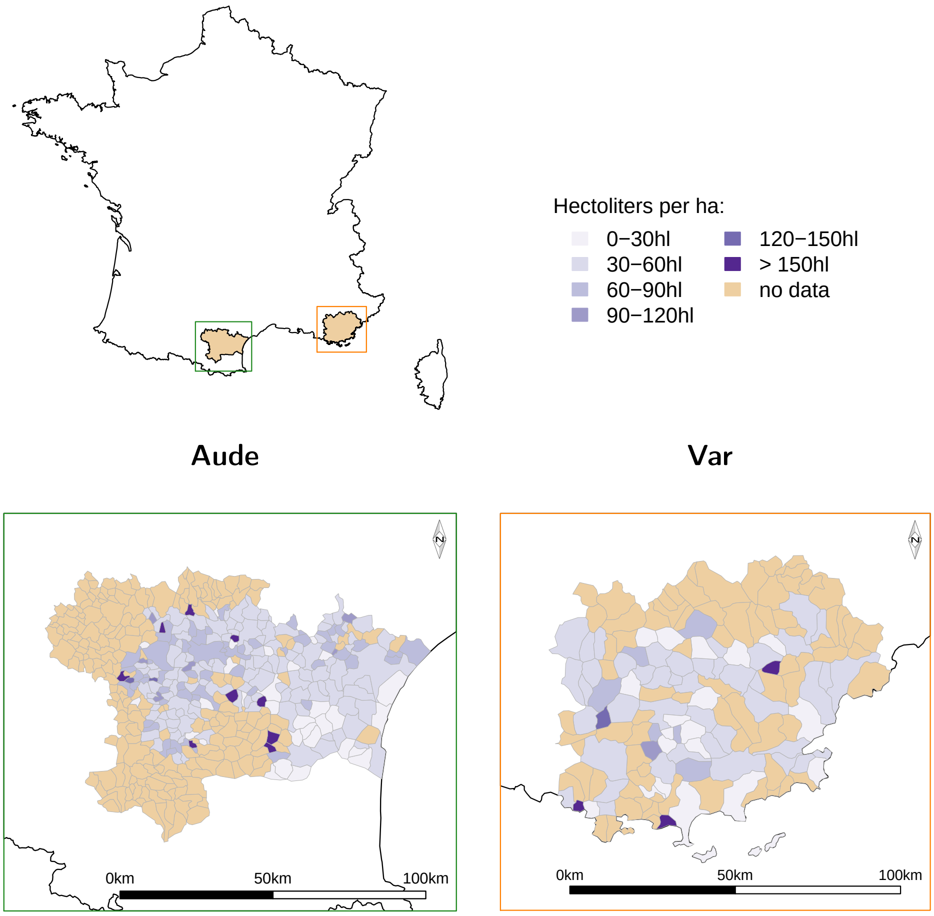
2.4.5 Productivity of soils in terms of final production of wine

Productivities in both areas display different patterns (figure 2.7). In average, the Aude almost practically doubles the Var productivity (table 2.3). Such observation is coherent with the different production orientations displayed by the cooperative wineries in each area: AOC lands are less productive than IGP ones, with prices for the final product following the opposite path.

Department	Average productivity (hl/ha)
Aude	87
Var	46

Source: Own elaboration with data from FranceAgriMer (2012)

Table 2.3 – Average productivity of vineyards in the case studies



Source: own elaboration with data from France Agrimer 2012 data

Figure 2.7 – vineyard's productivity per ha. Display by *commune*

2.5 The cooperative winemaking system (CWS) in face of flood hazards

In the following subsections we are going to summarize the empirical evidence gathered through the different interviews conducted. It has been chosen to be presented as stylized facts to enhance the key points that allow the reader to get a complete picture of the way the CWS works when facing flood hazards

2.5.1 Winery

1. Cooperative wineries directly impacted by floods did not have action plans in case of flood hazard.
2. The nature and amount of damages is highly heterogeneous and may include production losses and structural impacts. The monetary valuation of the

reparations can rise above the yearly turnover [14]

3. The behavior can be characterized as reactive: the main objective is either keep the activities ongoing or restart them as soon as possible.
4. Impacts of flood hazards during grape collecting season from associated vinegrowers could be really problematic due to business losses. Same thing if they get hit around June, when they begin to sell
5. Part of the insurance compensations can be used to compensate vinegrowers for production losses
6. Insurance payments are usually split in several times. In addition they do not normally cover all damage registered. Insurance statements can take several months of preparation as well as additional expert staff to act as intermediary between the winery and the insurance companies/institutions.
7. Financial resources for reconstruction are highly homogeneous. They include compensations from insurance, loans (in some cases banks offer special, favorable conditions post-disaster —0 to 1% of interest rate), subventions and solidarity funds (marginal role)

2.5.2 Vinegrowers

As in the case of the wineries, we can establish the following stylized facts:

1. Damages over individual vinegrowers are widely heterogeneous, affecting from just small portions of surface to buildings. The responses given in the aftermath of the flood are, however, more homogeneous.
2. When floods hit the vineyards, behavior among vinegrowers is homogeneous and reactive. Cleaning and reconditioning begin as soon as possible to avoid further damages. In case the plants are damaged and cannot be saved, vinegrowers replant immediately, trying to return to their initial states.
3. If floods sweep the plots, dragging the soil downstream, vinegrowers should replenish the lost soil, which increases their reparation budget [15] and risks to affect soil productivity. In lands qualified as *AOC* (Appellation d'Origine Contrôlée [16]) the situation worsens as soil can only be replenish with material from the same AOC. Nonetheless, the majority of vinegrowers declared to have lost the no AOC lands, since AOC lands are commonly located farther away from the rivers.
4. Priority is always given to vineyard surfaces in relation to other investment projects: if hit by floods, investment projects are stopped or re-planned to meet the vineyard's financial needs. In case that all vineyards cannot be replanted at the same time because of financial constraints, the surface the replant process is split among several years, but keeps its priority over other investments.

   Four types of different motivations drive their actions in this case:

   a) The plots are the core of their activities and the base of their economic activities.

14. chiffre d'affaires
15. €400 000 for 7ha is declared in one of the interviews
16. Controlled designation of origin

b) Even if some of them consider that it is better to let the soil recover from the impact —using the land for alternative cultures and balancing the nutrients— there is a limit in the time span allowed to replant a vineyard (4-5 years). Once such time span reaches its limit, the land's legal status changes and cannot be used as vineyard anymore. In other words, if the vinegrower does not replant, they can lose their rights to use the surface as vineyard. [17].

   Yet, some vinegrowers prefer to prepare their soils. In such cases, even when the replant is delayed, they should begin as soon as possible since only the recondition of soil takes one year.

   Even if the vinegrower do not wish to continue with the activity —some of the vinegrowers are aged people whose heirs are not interested in keeping the activity— they prefer to keep the vineyards active, well aware that their value is higher as active vineyards [18].

c) It is not uncommon that cleaning and reconditioning work result more expensive than replant.

5. Vinegrowers with experience in different floods tell that damages and the way they happen are different each time. That transmits certain feeling of uncertainty and impotence regarding adaptation and emergency response plans.

2.5.3 Role of existing insurance schemes

1. The evidence gathered suggest that no specific private insurance for floods is available.
2. Compensations after floods come mainly from the public french insurance systems: *Calamité Agricole* and/or *Cat-Nat* [19].

2.5.4 Role of public institutions and legal frameworks

1. Institutions and authorities play a double role in the aftermath of the flood. On the one hand, they are in charge of both crisis management and to revert key infrastructures to their original state or, at least, offer plausible alternatives that help people do their emergency management. On the other hand, they exert a strict control to avoid the proliferation of uncontrolled flood contention infrastructures, based on the precept that not well planned and coordinated flood control infrastructures can cause more harm than benefit.

17. According one vinegrower, planting rights can be demanded again. The time between the moment the vinegrower initiates the process until the rights are granted again is unknown, as well as the probability with which such rights are granted again. Competition between housing and agricultural activities is told to be there

18. one of the vinegrowers in la Londe-lès-Maures inform us that the price per ha is at least €10 000

19. *Calamité Agricoles* are uninsurable damages of exceptional importance due to natural hazards of abnormal intensity, and that cannot be either prevented or remedied with the technical means usually used in agriculture.
Cat-Nat is an specific insurance scheme created by the french government for natural hazards like floods, earthquakes or droughts, considered uninsurable in private terms.

2.6 Overview of key hypotheses retained

This section offers an overview of the main hypotheses included in the model. We expect that the inclusion of this section enables a better understanding of the description of the ABM we have developed.

The hypotheses have been established upon the information summarized in the prior five sections, the stylized facts in section 5.3, plus the databases and literature cited in the beginning of the chapter: Battagliani et al. (2009); Biarnès and Touzard (2003); Brémond (2011); Jarrige and Touzard (2001); Touzard et al. (2001); Agreste (2011); CER France (2014); Folwell and Castaldi (2004.); FranceAgriMer (2012). Figures 2.9 and 2.8) synthesize those hypotheses.

Virtual terrain display

1. Spatialization
2. Wineries in flood prone/non-prone area. Cases handled as mutually exclusive
3. Vinegrowers distributed along flood prone/non-prone area in accordance with 20%/80% in/out flood prone area
4. Vineyard distribution along flood prone/non-prone area following RPG values for the Var area. Rounded to 30%/70% in/out flood prone area
5. Random distribution according to uniform distribution
6. Distribution of elements over terrain stable along/across simulations
7. Population remains stable. No one leaves, no one comes.
8. 3 entities present: Winery, vinegrowers, vineyards

Model's calendar

1. Seasonal calendar

Winery

1. Fixed size. 50 associates and 500 ha, thus potential maximum production of 40 000 hl
2. Efficiency in production = 100%
3. Winery's patrimonial value calculated proportionally to maximum potential production. Value used to determine damage in case of impact

Vinegrower

1. Sizes. Two cases contemplated. Mutually exclusive:
   a) Homogeneous size along farms (10 ha/vinegrower)
   b) Heterogeneous size along farms. Two groups: small farms (5 ha/vinegrower) and great farms (30 ha/vinegrower)
2. Random plot assignation, following uniform distribution.

Vineyard

1. Homogeneous size: 1 ha per vineyard

Figure 2.8 – Overview of hypotheses and assumptions. General hypotheses not framed in any specific vulnerability dimension

Regarding soils:

1. Homogenous soil conditions

Regarding plants:

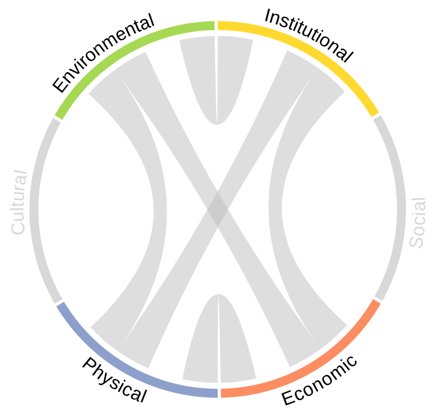
1. Homogeneous plant productivity (80 hl/ha)
2. Reached productive age, plant's productivity is constant
3. Heterogeneous plant age
4. Short term/long term life cycle. Long term life span = 30 years

Regarding floods:

1. Only extent parameter taken into account

---

1. Winery's winemaking cost sharing rules proportional to yearly individual contributions of yield
2. No incentives in remuneration policies. Remuneration proportional to yield delivered
3. Sharing rules do not establish financial reserves in winery
4. No explicit role of authorities. Real life limitations implicitly included in *return to statu quo ante* rule



Damage functions:

1. Simplified damage functions due to no consideration of flood parameters like depth and speed
2. Seasonal effects
3. Inter-entity heterogeneity
4. Intra-entity homogeneity
5. Randomized component in plant damage (uniform distribution)

Flood impacts:

1. Only material damage. No casualties considered
2. Inter-entity hierarchy of impacts
3. Soil dragging is not considered.

---

1. Constant market price
2. Market absorbs yearly production entirely
3. Input data homogeneity
4. Wineries present structural (fixed) costs linked to their maximum potential production
5. Wineries present operational (variable) costs linked to the yearly production
6. Each individual farm presents structural (fixed) costs linked to the surface owned
7. Each individual farm presents operational (variable) costs linked to the productive surface
8. Wine sales are the only source of revenue of the system
9. Insurance does not exist in the basic version of the model

Figure 2.9 – Overview of hypotheses and assumptions. Detail by dimension of vulnerability

We do not wish to be redundant in our exposition, thus hypotheses that will be developed later on in the description of the ABM will be briefly exposed here. The COOPER model includes elements and hypotheses in four of the six dimension of vulnerability identified: environmental, institutional, physical, and economic. When possible, the hypotheses have been organized according the vulnerability dimension they belong to (figure 2.9). The COOPER model's multidimensionality allows for the inclusion of a wide variety of factors that may potentially influence/drive the vulnerability of the whole system. We expect that this exercise clarifies how the different dimensions of vulnerability get involved in the design and posterior programming of the model. And, at the same time, it helps illustrate the potential of ABM to the study of multidimensional vulnerability in systems.

First, our model includes three main material elements: plots, vinegrowing farms' buildings and wineries' buildings. The ensemble of a number of plots and a farm's building is considered an economic agent (vinegrower). A winery building is also considered an agent (winery). They are spatialized over a virtual terrain, according different patterns:

- Winery(ies) may either be in flood-prone areas or out of it. These two situations conform two different and mutually exclusive scenarios. This proceeding helps to isolate the effects that direct impacts on the cooperative winery may have, given its role of neuralgic center in the productive chain.
- Vineyards and vinegrowing farms' buildings are distributed randomly over the terrain according a uniform distribution. Their distribution respects the following proportions:
  - 30% of vineyards in flood prone area. 70% out of the flood prone area. These proportions are guided by the values calculated for the Var region according the data in RPG. We consider that by using the largest extent the rest of the cases calculated are automatically included.
  - 20% of vinegrowing farms buildings in flood prone area. 80% out of the flood prone area. As stated, plausible distribution suggested by experts

Distribution over the terrain is kept fixed along and across simulations. Thus the degree of exposure to floods of the system remains stable, mooting any potential noise its variation may cause.

The system's topology is established through explicit links between elements. These links are assigned randomly according to a uniform distribution. Topologies remain the same along simulation exercises to enable and ensure the comparison of results (unless indicated otherwise).

We have chosen to limit the surface associated to a cooperative winery to 500 ha. Such a choice is within the range defined by our study cases, and also acceptable from a point of view of computing performance [20] Regarding number of associates, we have fixed them indirectly. Insofar the joint average surface per farm in our study cases (12 ha) is close to Battagliani et al.'s average (10ha), we have decided to keep the latter as size of reference. We will keep as well the value that Battagliani et al. (2009) provide for smaller vinegrowers: 5ha This choice does not jeopardize the scenario's

20. Tests done showed that the model is highly consuming in terms of computational resources.

plausibility but simplifies calculus and enables the enunciation of two hypotheses in relation to farm size: i) homogeneous size of 10 ha, which results in 50 associates for the winery; and ii) heterogeneous size of 5 ha and 30 ha, preserving the 50 associates to ensure comparison.

This population of entities is intended to remain stable along and across simulations. Thus rules about when or how to leave the discipline of the CWS are not considered necessary.

To each of these hectares we have assigned a constant productivity of 80 hl/ha. Hence soil conditions are homogeneous along our virtual world, and variations in harvest are not expected as a consequence of local soil/climatic variations. Plant's age rests indeed as the only source of productivity variation. Plants present a life span of 30 years, of which the first 5 are unproductive (long term cycle). They provide an annual yield (short term cycle) over their productive span. The productivity assumed is close enough to the average calculated for the Aude region, and enables us to develop the economic structure of vinegrowers based on data from CER France (2014).

Both vinegrowers and cooperative winery are going to have their own structure of costs. Such a structure has been simplified to a two big blocks of cost: structural costs and operational costs. For both entities, the structural cost represents all fixed costs associated with their mere existence (e.g. salaries, electricity, general insurance, etc). For wineries, the structural cost has been linked to their potential of production. We define such potential of production as the maximum production they would have if all their associated vinegrowers kept all their vineyards productive. Regarding vinegrowers, their structural cost is calculated according to the number of hectares owned (see section 2.13.2).

Operational costs are associated with their volume of production. As in the prior case, for wineries it is linked to their yearly production level, whereas for vinegrowers it will linked to the productive surface.

For both wineries and vinegrowers the only source of revenue available in the system is wine selling. On such regard, it is assumed that i) the market always absorbs the production (no remnants for one year to another); and ii) prices are stable along and across simulations. Thus price distortions are not taken into account in our model.

Wineries share both revenues and costs between vinegrowers proportionally to their individual yields. Varieties planted by vinegrowers and the incentives to make their choices are out of the scope of this work. Hence no special remuneration policy has been introduced. As well, sharing rules do not contemplate the possibility of creating financial reserves in the bosom of the cooperative wineries. All revenue is therefore shared between farmers.

Floods are introduce in the system using the parameter `extent`. Other parameters like duration, depth or velocity are not taken into account. Consequently, damage functions in our model are going to be simplified. First, damage functions are going to present intra-group homogeneity and inter-group heterogeneity. In other words, damage functions will be different for each type of entity (plot, farm's building and winery's building), but they will assume the same degree of susceptibility for all entities of the same type. This assumption helps highlight factors/drivers/triggers of vulnerability due to the interaction of entities, in detriment of entity's physical susceptibility.

Second, damage functions of wineries and farms' buildings assume a constant physical degree of susceptibility. Thus the level of material damage is going to be constant each time a winery or a farm's building is reached by a flooded (though material damages in farms and wineries will differ insofar they belong to two different groups of entities). Concerning vineyards, soil damages follow the same premise than buildings: each time a plot is flooded, soil damages are considered constant. Soil dragging and soil erosion have not been considered in the model. Neither have been potential effects of floods over soil composition that might eventually affect the crop's productivity.

Damage functions in our model do display seasonal behavior nonetheless (i.e. the degree of damage or impact the flood has over the entity varies with the season). Regarding farms and wineries, damage functions include different effects on the performance of each entity With respect to vineyards, damage functions include seasonal behavior in relation to production damages and plants' death. That reflects the importance of crop cycles in the vulnerability of the system to floods, insofar those crops are the base of the productive-economic system Damage functions of vineyards also have aleatory components as an approach to simplify the mechanisms of physical damage reviewed in section 5.3(i.e. crop hypoxia, water turbulence, etc).

To avoid potential superpositions of impacts between damage functions (thus double accounting for impacts) we establish a hierarchy of impact/damages in those cases in which different types of entities are flooded at the same time. That hierarchy obeys as well a bottom-up logic: in the base of the system we find the plots, on which the farmer relies to obtain his income. When plots result impacted, all stages up in the production chain result impacted. At the same time, plots depend on the vinegrower's capability to perform to yield properly. Impacts over vinegrowing farmers will affect therefore the plots' yield, and with it, upper stages in the production chain. Last but not least, all vinegrowers associated to a cooperative winery, depend on it to eventually obtain their income (production, bottling and commercialization). Thus impacts over wineries are on top of the production chain but affecting all stages down the production chain (this hierarchy of damages is more developed in section 2.11.4). Impacts of floods in the COOPER model are limited though. No casualties or threats to human life have been taken into account.

The ultimate goal of all these hypotheses put together is to study a system taking into account elements and interactions that are not usually taken into consideration in more standard methodologies of impact/damage/vulnerability evaluation. We expect that the presence of all these elements altogether helps us deliver a thorougher understanding of the factors that might be driving vulnerability in systems like the CWS.

The COOPER ABM

The following description of the model is based on the precepts of the ODD protocol (Grimm et al., 2010) and its two extensions (Laatabi et al., 2018; Müller et al., 2013) for describing individual and agent-based models. Nonetheless the specifications of the model's architecture have required a few adaptations of such protocol.

This part of the chapter is organized in 8 sections (sections 2.7 to 2.14) plus an annex (annex E). It attempts to provide all the information needed to ensure both full comprehension of the model and its replicability.

Sections 2.7 and 2.8 are dedicated to state the main goals pursued with the model and explain how it is conceived. Sections 2.9 to 2.11 are used to describe thoroughly elements in the model, agents, associations between agents, dynamics and expected consequences of floods. Together with sections 2.7 and 2.8, they should be enough to understand how the model works. Section 2.12 completes the exposition with an overview of impact calculation, indicators built to recover the proper information, and different scales of measure in our model. Section 2.13 covers information relative to model calibration and hypotheses. The model description finishes with section 2.14, dedicated to inform of the concrete numerical values provided to the model in the set-up. We expect it to allow researchers to be able to replicate our experiments if wished, as well as feed discussions about the convenience/realism of concrete values.

The model's general architecture as well as the architecture of each of the main procedures is presented in the annex E. Such an annex is a *must-read* for all of those interested in understanding how the model works at code level, and/or recode/extend it. Those readers not familiar with flowcharting have a cheatsheet of flow chart symbols available (annex's section E.2) to facilitate the understanding of the flowcharts provided.

To favor the comprehension of the text, we will use the next **convention**:

— Variables, processes, functions and code in general, when part of the text, will be written in `teletypefont`. When summary tables of variables are shown, such variables are written in standard font.

— As a special case, when R is written as R (blue), it refers to the programming language in a general way, while when written as `R` (black teletype font), it refers to the environment in which procedures, variables, functions or processes exist. Likewise for Netlogo.

2.7 Purpose

The main objective of this model is to simulate the impacts of flood hazards over the economic and financial performance of a Cooperative winemaking system (CWS).

To do so, the model has to be able to, on one hand, simulate the "day-to-day" performance of the aforementioned system. This simulation(s) in normal conditions allows the construction of the so-called Business as Usual scenario or Zero Flood Scenarios (BAUs). On the other hand, the model is endowed with a flood simulator that will expose the CWS to floods hazards, creating the so-called Simulated Flood Scenarios (SFSs). These SFSs provide us with data about the performance of the system under the new conditions created by the hazards.

Differences between BAUs and SFSs reveal disruptions, damages and consequences —direct, indirect, immediate, delayed— of the flood hazards on the normal performance of both each of the elements in the system, and the very system as a whole.

2.8 Model conceptualization and design concepts

2.8.1 Conceptualization

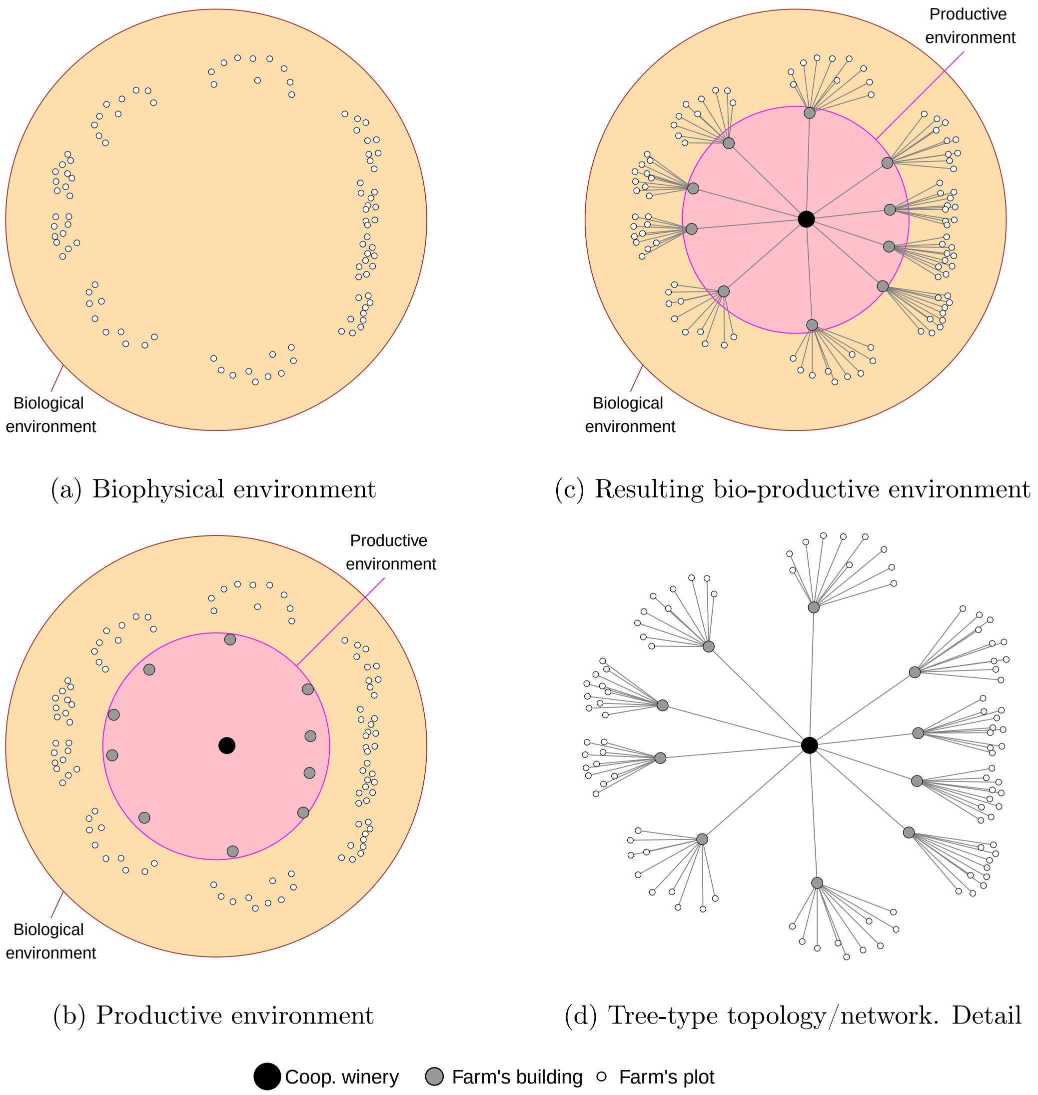
The model is conceptualized as a Socio-ecological system (SES). As such, it comprehends the interaction of, on one hand, a biophysical environment and, on the other, a productive-economic environment through a productive system (figure 2.10). The CWS we are simulating is composed by the three aforementioned main entities: cooperative winery, vine-growing farms (also named vine-growers or, simply, farms) and vineyards (hereafter known as plots too).

The biophysical environment (figure 2.10a) is responsible for plant cycles, soil basic productivity and yield availability at plots' level, as well as for floods. The productive-economic environment (figure 2.10b) uses the referred yield as its basic input and deals with the social, productive and economic functioning.

This way, links between elements in the system (figure 2.10c) ensure not only the interaction between those same elements, but also the interaction of both environments at different levels and time spans. The consequences of the floods in this productive economic system are the result of the interaction between the two environments.

The topology of the CWS (figures 2.10c and 2.10d) is characterized as a tree-type network (Wilhite, 2006). In this kind of topology/network, all elements in the system are connected one to each other through a central element. The role of central element in the tree-type topology/network is assigned to the cooperative winery. It both centralizes wine-making means and mutualizes costs, risk and revenues among its associated vinegrowers. Completing the "tree", each vine-growing farm branches in the several plots it owns.

The model is also a spatialized model. Such a feature responds to the need for the discrimination of those elements that might be directly impacted by a flood, from those who would not. Thus, presence of elements and, if information is available, proportions of elements (over their respective totals) are represented on the terrain as close as possible to real cases. An example of geolocation of the tree-type network in figure 2.10c, distinguishing between prone and non-prone areas is shown in figure 2.11.



(a) Biophysical environment

(c) Resulting bio-productive environment

(b) Productive environment

(d) Tree-type topology/network. Detail

Figure 2.10 – Model's environments

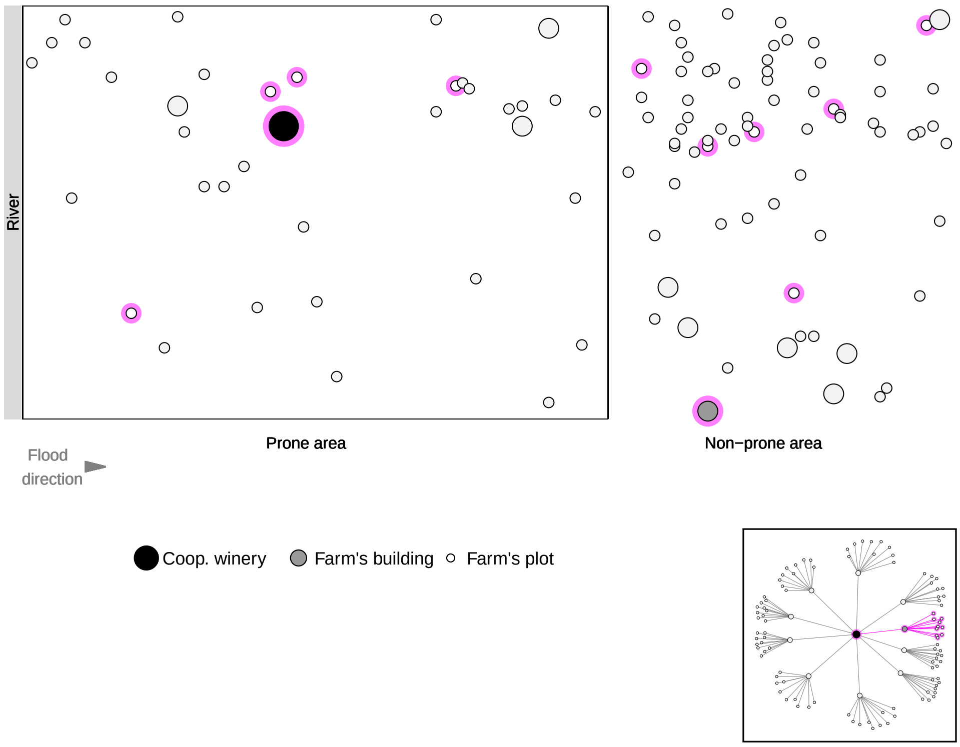


Figure 2.11 – Example of geolocation of a tree-type network in the model. Links between the cooperative winery, one of the farms and its plots have been highlighted to show one of the potential displays.

2.8.2 Design concepts

Rationality of agents: Based on the information collected from the case studies, agents are assumed to have a reactive behavior.

In any BAU scenario agents are assumed to be in their optimal performance path. Thus they will not perceive any incentive to change their productive means nor their investment-reinvestment-production pattern.

In SFSs, when the vine-growers and/or any of their belongings are flooded, the agents will always seek to reverse immediately their current situation to the *statu quo ante* (namely pre-flood status), minimizing the immediate losses caused by the flood.

Emergence: relation between defining features of agents in the system and disruptions, damages and consequences —direct, indirect, induced and/or immediate— of floods, both at individual and system's' level.

Adaptation: when agents are flooded, they can choose between two possible coping tactics: to perform the tasks assuming losses due to lack of means (direct impacts reduce the agent's coping capacity) or to outsource the tasks to be performed during the season they are flooded with an extra cost.

Notwithstanding, their autonomy to choose their coping strategy in SFS has been limited in this version of the model. As a consequence, the respond gets homogenized and the effects of choosing one or another tactic can be compared.

Sensing: sensing capabilities are different depending on each element. Plots sense their own state through 3 key variables: i) `flooded/not flooded`; ii) if so flooded, `destroyed/not destroyed`; and iii) if so flooded and not destroyed, `proportion of harvest lost`.

Wineries will perceive their state through `flooded/not flooded`. It will allow them to start reparations to preserve the *status quo*, and determine whether they are able to perform their tasks. As well, the winery "senses" which of the farms, and in what amount, has provided it with input for production.

Farms, together with plots and wineries, sense their state through `flooded/not flooded` variable. In this version of the model, when `flooded`, it triggers the need for action: immediate reparation and adoption of coping tactic. Additionally, each farm receive information of the state of its plots —and only its plots; the state of the neighbor's plots cannot be perceive— and of the state of the winery, and its ability to perform tasks.

Interaction: different kinds of interactions can be assumed:

- Among environments: interaction of a productive and a biophysical environments, as already explained in subsection 2.8.1.
- Among agents:
  - A so-called *direct* interaction: interaction of farms with their plots, and farms with the cooperative winery, following the production links
  - A so-called *indirect*: interaction of farms with farms through the cooperative winery. It is reflected by the fluctuations of costs and revenues from the winery

Stochasticity: Flood damages depend on a large amount of factors, which explanation and influence are not among the goals of this model. Thus, to model the consequences over plants depending on a multitude of elements that are unknown inside the model, we have chosen to simulate plant destruction at plot's level through random processes.

Collectives: each tree-type network is considered a collective. In the model several collectives can coexists at the same time, and their definition comes preset in the setup of the model.

This version of the model does not include any mechanism of network evolution through time.

Observation: data to be collected is focused on 4 key aspects: production, revenues, costs, and investments (further information in section 2.12) Such data is collected at agent's level, once every four time steps —or `ticks` in Netlogo terminology—, coinciding with the autumn season, on both BAUs and SFSs. Comparisons between both allow us to analyze the evolution in time and magnitude of the impacts of floods.

2.9 Entities, state variables, and scales

The model is composed by three main material elements: plots, farms' buildings and wineries' buildings. The ensemble of a handful of plots and a farm's building is considered an economic agent: the vinegrower (also named vinegrowing farm or simply farm). A winery building is also considered an agent: the winery (also referred as cooperative winery or simply cooperative). Thus two main agents operate and interact in the model along time: farms and cooperative wineries. (Figure 2.12).

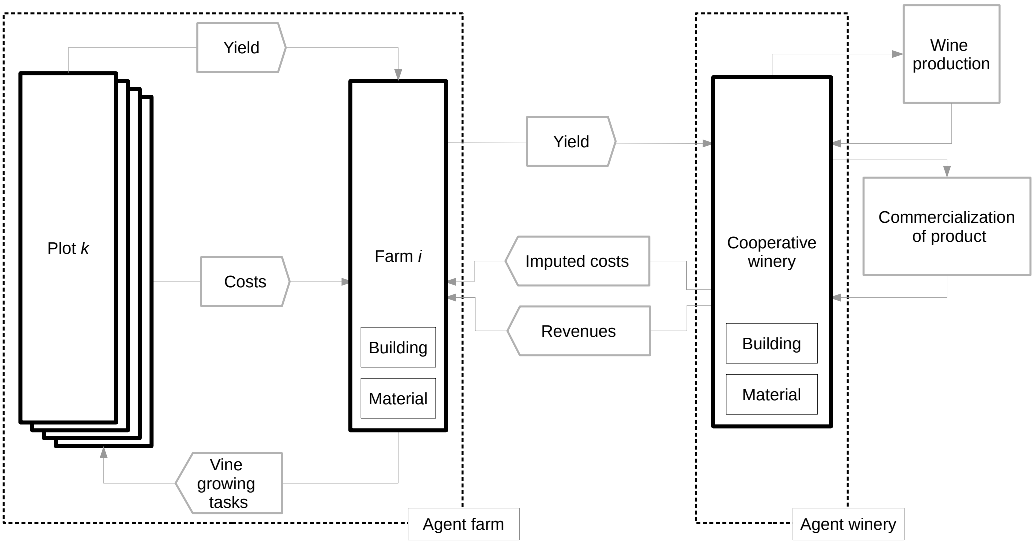


Figure 2.12 – Main elements in model

Farms perform vine-growing tasks over the amount of plots owned, providing, this way, the main productive input to the system. Buildings are considered the core of the farms. They determine where the farm is physically located, thus the level of exposure to floods. Additionally, when in SFS, its state —`flooded/not flooded`— will determine the farm's capacity to perform its inherent duties.

Each plot is defined by: `location` —which establish the `distance to the river`, therefore the exposure to floods— and `age` —which determines whether the plot is productive or not, as well as the investment's lifetime— of the plants. Together with `extent`, they determine the plot's yield in harvesting season. Furthermore, plots are kept with different ages, which has three different consequences: one, there is rotation in crops; two, the production is variable and lower than the potential; three, agents have heterogeneous productions.

As well as it occurs with farm's buildings, in the SFS, its state —`flooded/not flooded; destroyed/not destroyed`— will contribute to determine the amount of yield available in each one.

Each farm is associated with one, and only one, cooperative winery. These wineries, once they receive the yield from their associated farms, produce the wine and commercialize it in the markets, sharing both revenues and cost with their associates. In the same way it happens in the case of farms, the location of its building over the terrain determines the level of exposure to floods. Again, in SFS, its state —`flooded/not flooded`— will determine the winery's capacity to perform its tasks.

In addition, both wineries and farms have assigned a determined `size`. In case of farms it comes given by the number of plots they own, whilst in the case of wineries it comes given by the sum of maximum potential production of their associate farms. That `size` is used to calculate the initial value of the `structural cost` inside each agent's `cost structure` (see section 2.14)

The time step has been set to one season. This way, each time step, or `tick` in Netlogo terminology, represents a quarter of a year. Thus each year corresponds to 4 time steps or `ticks`, starting always in winter. Simulations are run over 30 years to take into account damage propagation in time.

2.10 Process overview and scheduling

For both farm and winery, we count on simplified —and seasonally adjusted— versions of their own real-life complex schedules linked to biological cycles of plants (more details will be given in subsection 2.13.1). As a result, the global internal schedule in the model is given by the coexistence and interaction of those individual schedules. To illustrate the point, figure 2.13 outlines the global model schedule and each agent's own schedule in the BAU scenario. A year begins in winter and ends in autumn.

Assuming we are in year $t = 1$, The dynamic goes as follows:

1. Vine-growing tasks are done over plots during the four seasons (table 2.4). Such tasks have been translated to hours of labor, then split among seasons following Brémond (2011)

	Winter	Spring	Summer	Autumn	total
Total (hours)	49	18	31.5	10.5	109
Proportion over total	0.45	0.16	0.29	0.1	1

Table 2.4 – Seasonal attribution of vine-growing tasks based on Brémond (2011)

2. In winter, the cooperative winery produces wine with the yield obtained from the farms in $t = 0$
3. In spring, the cooperative winery commercializes the wine produced during winter with the yield obtained in $t = 0$
4. In spring, once everything is sold, the cooperative winery splits both revenue and cost among farms proportionally to their yield in $t = 0$.

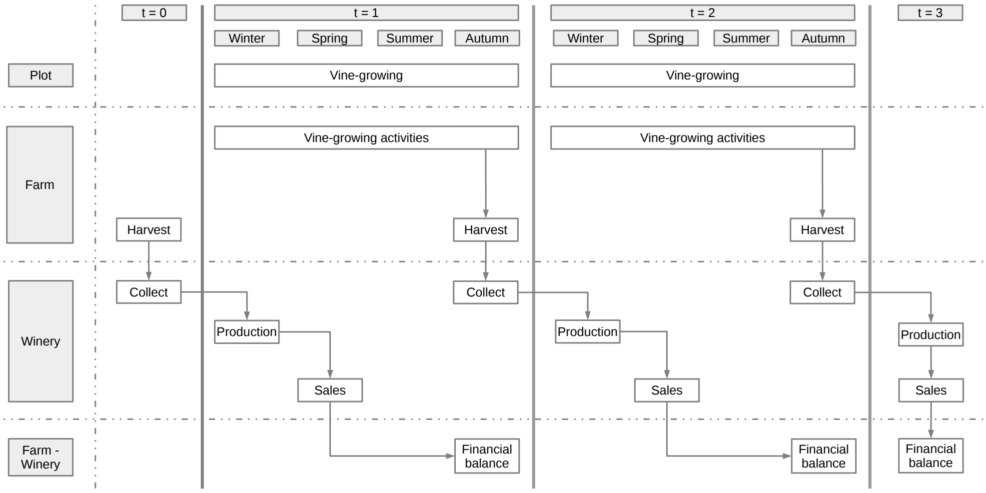


Figure 2.13 – Process overview and schedule in the BAU scenario

5. In autumn, the farms harvest their plots again
6. In autumn, the cooperative winery collects the yield from the farms.
7. In autumn, both farms and winery make their financial balances. Farms' financial balance includes vine-growing costs of $t = 1$, and wine-making costs and revenues from $t = 0$ (wine-making cost and revenues are delayed one year). At winery's level this financial balance is done on the revenues and wine-making cost of $t = 1$ over input collected in $t = 0$
8. At the end of autumn, plots reaching `age` $= 30$ get replanted and rest unproductive for 5 years (20 time steps or `ticks`). Agents always choose to replant the plot at the end of each plot's investment lifetime (`age` $= 30$), and renew the vineyards.
9. In winter of $t = 2$, the cooperative winery produces wine with the yield obtained from the farms in $t = 1$
10. In spring of $t = 2$, the cooperative winery commercializes the wine produced during winter with the yield obtained in $t = 1$
11. In spring of $t = 2$, once everything is sold, the cooperative winery splits both revenue and cost among farms proportionally to their yield in $t = 1$. Both farms and winery make their financial balances of $t = 1$, where farms' financial balance includes vine-growing costs of $t = 2$

    To split cost and revenues, the cooperative winery proceeds according to the following rule (Biarnès and Touzard, 2003; Jarrige and Touzard, 2001; Touzard et al., 2001):

$$TC_i = \left(\frac{F+V}{\sum_{i=1}^{n} q_i} q_i \right) \quad (i = 1, 2...n) \tag{2.1}$$

$$B_i^o = pq_i - TC_i = pq_i - \left(\frac{F+V}{\sum_{i=1}^{n} q_i} q_i \right) \quad (i = 1, 2...n) \tag{2.2}$$

Where:

— TC_i is the share of the wine-making cost in the winery for the farm i

— B_i^o is the share of the benefit in the winery for the farm i

— pq_i is the share of revenue of the farm i.

— $\frac{F+V}{\sum_{i=1}^{n} q_i} q_i$ is the decomposed wine-making cost in the winery for the farm i

  — F is the structural wine-making cost

  — V is the operational wine-making costs

  — $\sum_{i=1}^{n} q_i$ is the total production in the cooperative winery, as a sum of the individual productions of the associated farms.

  — q_i is the production of the farm i.

2.11 Submodels: flood impacts

2.11.1 Floods

In our model floods are programmed to cover a variable extent of a predefined *potential maximum prone area* (see figure 2.14) during a given season.

Regarding the time span, two remarks are worth mention at this point: on the one hand, floods hit the system once per season. The model is not ready to simulate two, or more, flood events during the same season. On the other hand, as a convention, we assume floods hit the system at the beginning of the season. Such hypothesis, far from trivial, has consequences on damages, cost variations, etc.

Regarding flood extent, our formulation keeps the flood's y coordinate constant, and equal to the maximum value of y ($y = y_{max}$), while the x coordinate varies in the interval $[0, 100]$. This way, the area covered by floods comes expressed by the function $f(x) = xy_{max}, x \in [0, 100]$. That formulation allows us to liken the value of the flood extent's 'x coordinate with the percentage of the maximum prone area flooded. As well, it simplifies the identification of flooded elements: every material entity —plot, farm and cooperative winery— will declare itself `flooded` when the x coordinate of the entity is less or equal than the x coordinate of the flood extent, entities declare themselves flooded.

Entities declared `flooded` will then register and declare consequences depending on their own damage functions. Thus, it is foreseeable that the normal performance, described in section 2.10, gets disrupted by those same impacts. Additionally, we expect non-intuitive effects to emerge from the interaction of the different entities and schedules.

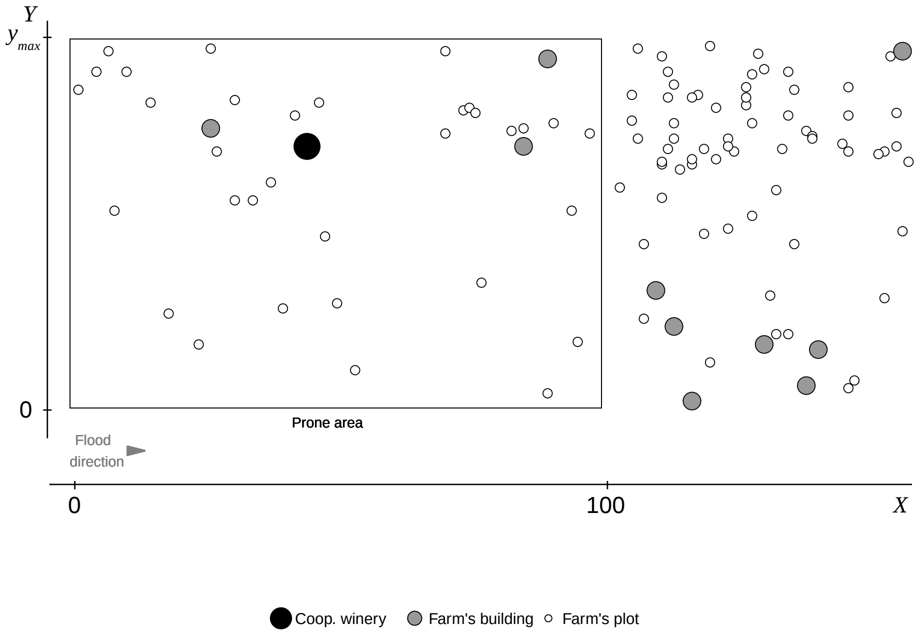


Figure 2.14 – Detail of coordinate axes in the geolocated representation of the tree-type network

The next two sections explain in detail both each entity's damage functions, and the consequences over the system dynamics.

2.11.2 Farm's damage function and system dynamics

As stated in section 2.9, farm units are considered the union of two different elements: plots and farm's buildings and materials. For pedagogical purposes we are going to analyze separately each element's damage functions and consequences for the system's dynamics.

2.11.2.1 Plot's damage function and system dynamics

Damage function. The damage function at plot's level presents the seasonal behavior detailed in table 2.5. As we can see, each time a plot is hit by a flood, effects are threefold:

1. The probability that plants result destroyed differs from one season to another:
   — Winter: $p = 0$
   — Spring: $p = 0.5$
   — Summer: $p = 0.2$
   — Autumn: $p = 0.1$
2. The proportion of harvest lost will depend on the season as well, but also on plant destruction:

- On plots where plants are not destroyed
  - Winter: no loses
  - Spring: 50% of the plot's harvest is lost.
  - Summer and Autumn: the plot loses all its available harvest
- On plots where plants are destroyed
  - Winter: no losses
  - Spring, Summer and Autumn: the plot loses all its available harvest

3. Soil-conditioning should always be performed after a flood

	Winter	Spring	Summer	Autumn
Probability of plant destruction	$p = 0$	$p = 0.5$	$p = 0.2$	$p = 0.1$
Harvest destroyed if plants not destroyed (%)	0	50	100	100
Harvest destroyed if plants destroyed (%)	0	100	100	100
Soil	reconditioning	reconditioning	reconditioning	reconditioning

Table 2.5 – Plot's damage function

Effects. Regarding system's dynamics, we consider necessary to distinguish the combo spring-summer- autumn (figure 2.15) from winter (figure 2.16). As it is shown in figure 2.15, when the flood hit a plot —let's assume in $t = 1$— two potential situations are possible: i) plants are not destroyed; ii) plants are destroyed.

In the first case, plants keep their integrity but the harvest is lost according to the seasonal proportion indicated in table 2.5. Also soil reconditioning should be performed. At farm's level, the yield harvested will depend on the number of plots flooded. At the same time, plots whose yield is completely lost, save vine-growing cost to the farm, due to the fact that tasks not essential for the plant survival are not performed by the farm [21]. At winery's level, as it happens at farm's level, the yield collected will be affected by the number of plots hit owned by the winery's associates, and so will be the annual production and the sales. Ultimately the financial balances of the winery and the farms will reflect the impacts of the flood.

21. Since floods happen at the beginning of the season, plots whose yield is destroyed will not be attended. Thus no vine-growing cost will be paid for them until the next campaign

The second case have further ramifications: at plot's level, plants are destroyed, ergo all harvest is lost. At farm's level, impacts in the aftermath of the flood will be of the same nature but different magnitude. Plant destruction introduces however a longer term effect: destroyed plots need to be replanted. Assuming they are replanted immediately (next winter), as told in sections 2.9 and 2.10, they will need 5 complete years to be considered productive. Therefore, *ceteris paribus*, farm's yield will reflect the impact of the flood during 5 more years. At winery's level, those longer term impacts will be reflected too.

By time spans, damages in soils and harvest will become part of impacts in $t = 1$, as well as variations in vine-growing costs. Variations in production (ergo in revenues and wine-making costs), always plants are not destroyed, will be delayed one year ($t = 2$); if plants are destroyed, they will last until $t = 7$, assuming plots are replanted in $t = 2$.

Winter (figure 2.16) is an special case. Damage functions limit losses in winter, when plots are hit directly, to soil-reconditioning. It provokes a direct financial impact over farms who own impacted plots (benefits will decrease as a consequences of the extra reconditioning cost), but not further damages over yield, thus production, thus revenues, will take place.

2.11.2.2 Farm's buildings damage function and system dynamics

Damage function. Table 2.6 details the damage function for farm's building in the system. It can be split into two kind of consequences: consequences due to buildings and materials flooded, and, once it happens, consequences due to the coping strategy chosen.

Farm's choices and actions. As said in section 2.8.2, agents are assumed to be in their optimal production point, thus motivated to preserve their *statu quo*. It means, in absence of constraints, buildings will be repaired and materials substituted right away, so the farm is fully operational next season [22]. Same principle applies to plot's replant: in absence of constraints, it is done first winter season following the flood. But when the building is hit, we assume that part of the vine-growing material is lost/hit. Farms, consequently, will have to pay for reparations and , additionally, they cannot fully perform their seasonal tasks. To cope with the situation, they can choose between two tactics:

— Outsourcing, also referred as external: the farm pays external service providers to perform the task in its place. Such strategy saves all the yield in productive plots since the tasks are fully performed, but increases the seasonal vine-growing costs 80%

— Insourcing, also referred as internal: the farm only counts on its own resources to perform the seasonal tasks. Since part of the material is lost, we assume the farm can only perform the half of the tasks planned for the season. As a

22. After the flood hits the farm in the beginning of the season, we assume that, in absence of financial constraints, farms have enough time during the season to repair and be fully operational next one

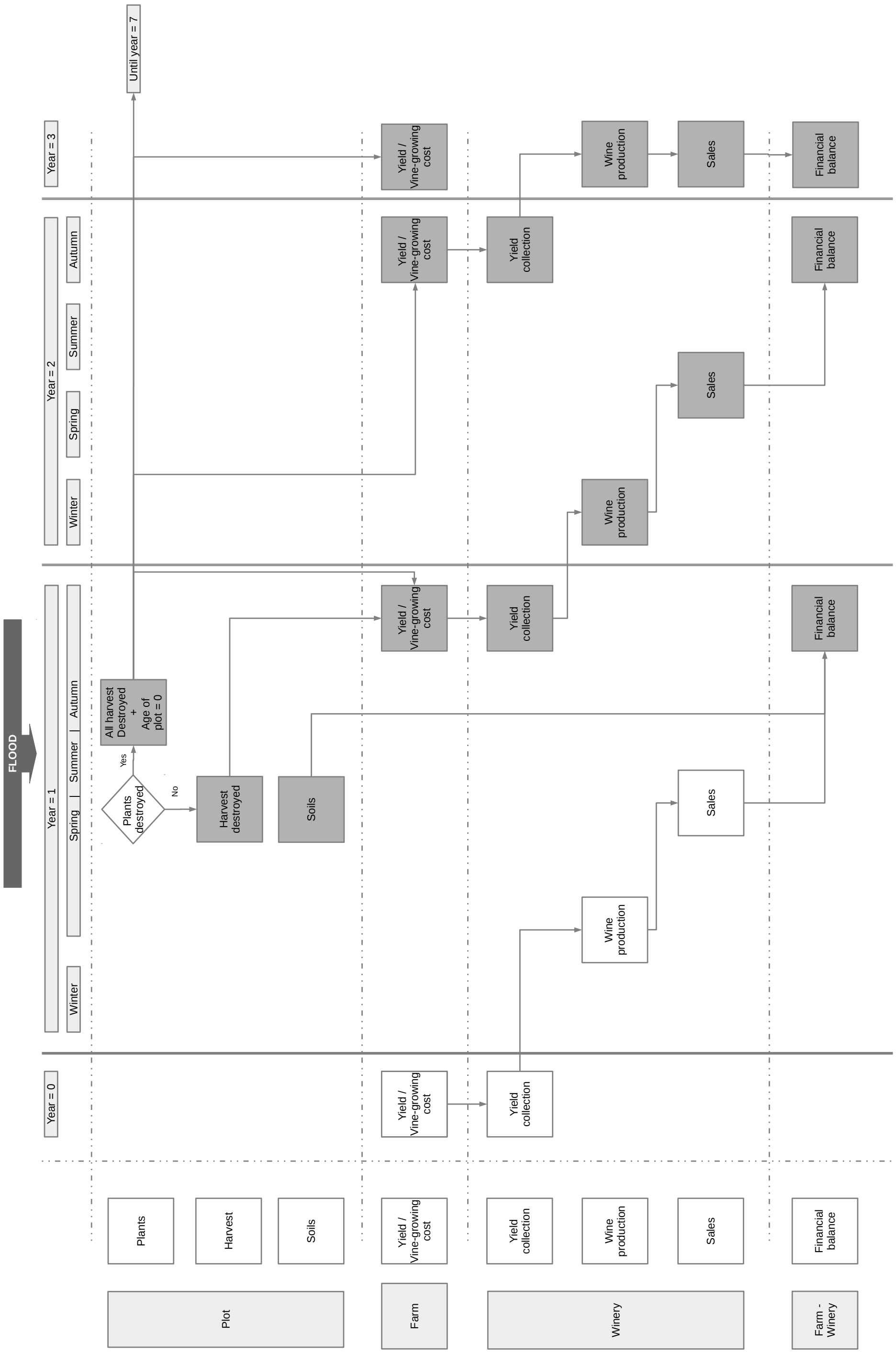


Figure 2.15 – Consequences of a flood over a plot in the system's dynamic. Season spring to autumn

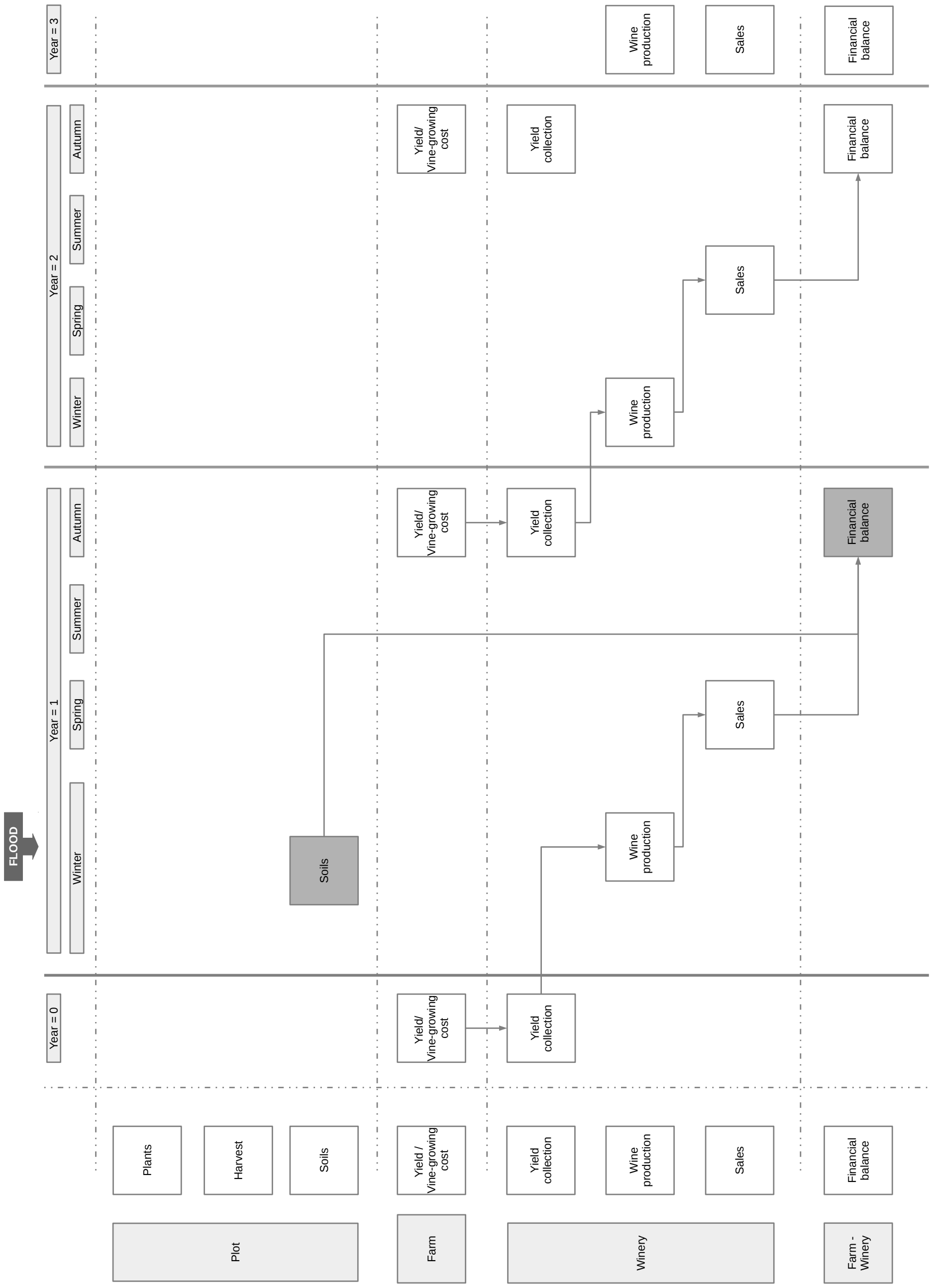


Figure 2.16 – Consequences of a flood over a plot for the system's dynamic. Special case of winter

consequence, seasonal vine-growing cost decreases 50% but there is an associated lost in yield.

For an explanation on the origin of the values, see section 2.13

			Winter	Spring	Summer	Autumn
Material damage			Building and material all seasons			
Performance	Outsourcing tactic	Δ vine-growing cost	+80	+80	+80	+80
		Yield lost	none	none	none	none
	Insourcing tactic	Δ vine-growing cost	-50	-50	-50	-50
		Yield lost	36.5	18.5	21.5	50

Unit: Percentage (%)

Table 2.6 – Farm's damage function

Effects. Impacts on the system dynamics are outlined in figures 2.17 and 2.18. Figure 2.17 illustrates the process already described: if the farm's building is impacted, we assume material damages that will have consequences over the farm's performance, forcing it to use a coping tactic.

If the coping tactic used is *outsourcing* here will not be effects over yield, only over the season's vine-growing cost. On the contrary, if the farm decides to go *insourcing* both vine-growing costs and yield will be impacted. The time span for both impacts is different though: assuming the flood hits the system in year $t = 1$, effects over vine-growing costs become part of impacts in $t = 1$, while effects over yield will be felt in year $t = 2$, once the yield is processed, turned into wine and sold.

Eventually financial balances get affected, but, while the *outsourcing* tactic limits impacts to the year in which flood hits the system, the *insourcing* one generates more persistent impacts.

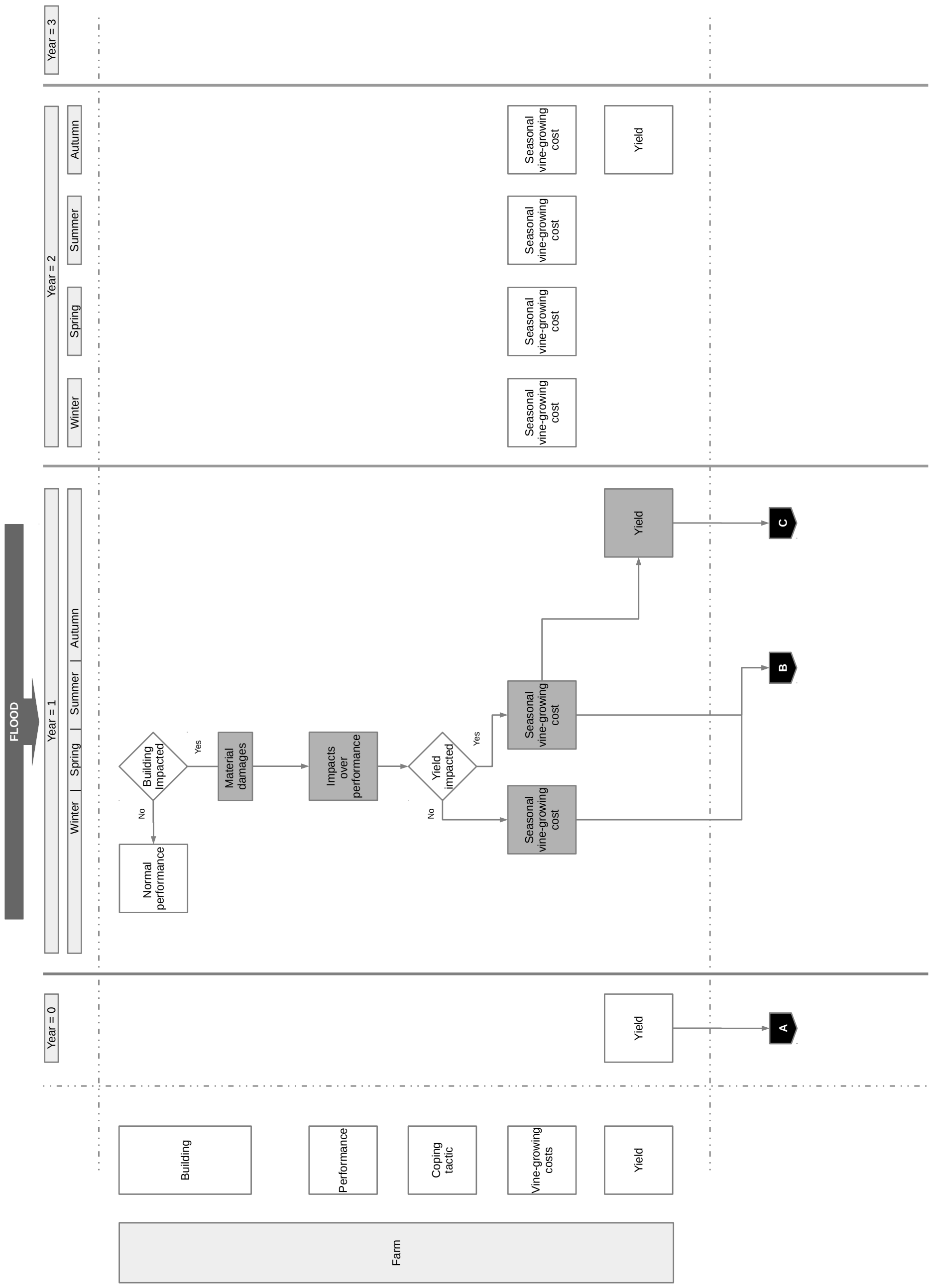


Figure 2.17 – Consequences of a flood over a farm for the system's dynamic. All seasons

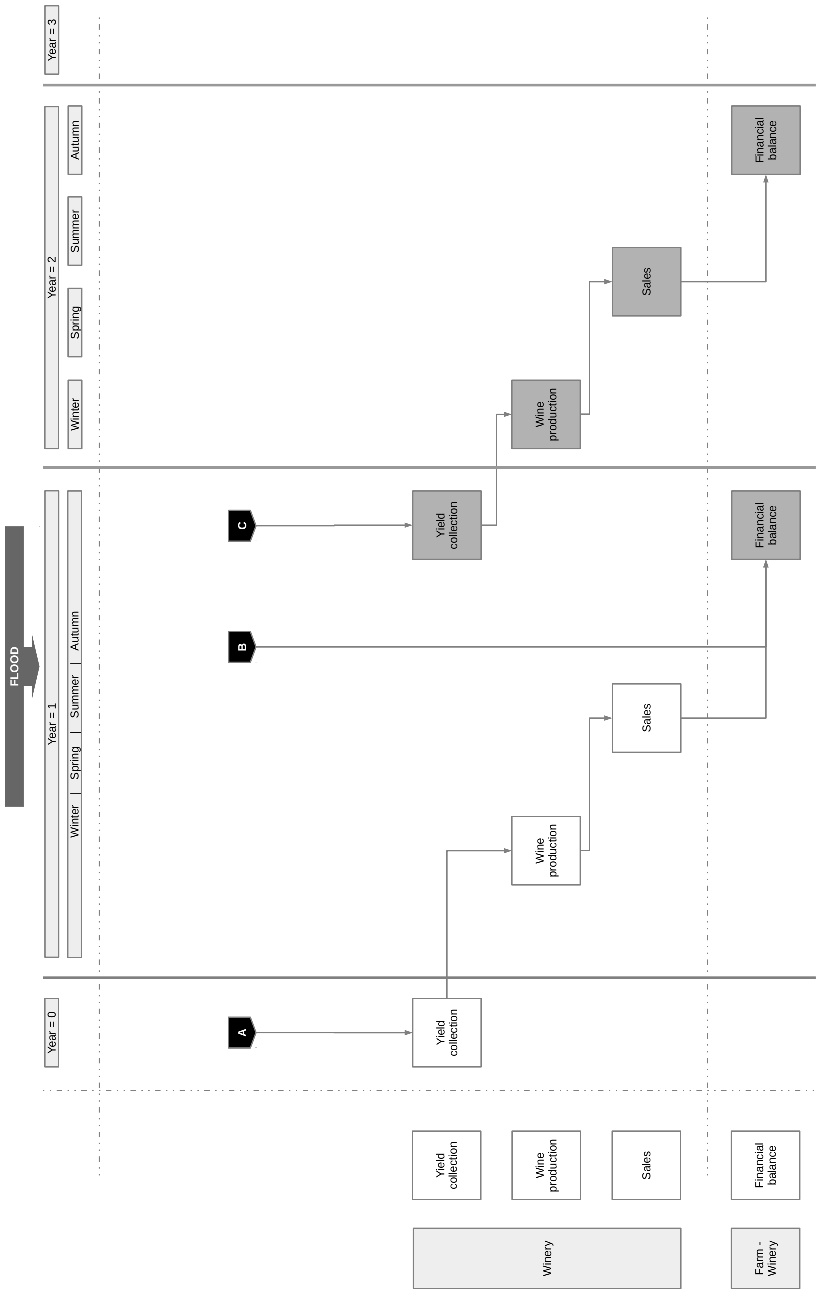


Figure 2.18 – Consequences of a flood over a farm for the system's dynamic. All seasons (continuation)

2.11.3 Winery's damage function and system dynamics

Damage function. Table 2.7 displays the damage function for wineries in the system. As with farms, we can differentiate two sequential types of consequences:

- In spite of the season, when a cooperative winery is hit by a flood, the model assumes buildings and materials flooded.
- Damages over buildings and materials affect winery's capacity to perform their assigned tasks. Therefore, depending on the season the flood hits the winery, in addition to material damages, the following consequences are assumed:
  - When the flood hits in winter, wine production cannot be accomplished.
  - If the flood takes place in spring, the production is lost and sales cannot be performed
  - Floods in autumn make impossible to collect the yield coming from its associated farms.

	Winter	Spring	Summer	Autumn
Material damage	Building and material all seasons			
Performance	No production	No sales	—	No collection

Table 2.7 – Winery's damage function

Effects. Dynamics in the system get altered in different ways and time spans, depending on the season the winery is hit. Assuming flood occurs in $t = 1$, figures 2.19 to 2.22 display those alterations.

When the winery gets hit during winter, we assume the material damage suffered impedes the winery's normal performance. Therefore it will not be able to process the yield collected during $t = 0$ and produce the wine. As a consequence there will be no production to sell[23], thus no revenues nor wine-making cost, beside the structural cost. Insofar all production and sales are done in and through the cooperative winery, all the associated farms will lose all production and revenues. They will be imputed, though, with their share of the structural cost and reparations. Eventually, financial balances will reflect such situation.

If the winery is flooded in spring, we consider wine-making processes finished and production ready to be sold. However, material damages will make the winery lose the production and, as in winter, no revenues over the yield of $t = 0$ will be perceived. Contrary to winter, in spring, since wine-making activities are done, farms will be

23. Since floods happen at the beginning of the season, the winery will have time to fully functional for the next season, and to perform sales. However, to not be able to produce the wine, has left it with no production to be sold

imputed with all the wine-making cost corresponding to its share plus the reparations needed.

During summer season, wineries are not expected to perform any essential task. Therefore, when they are flooded, impacts are "reduced" to reparations, with no further effect besides the ones over the financial balance of the winery and its associated farms.

Floods over the winery's buildings in autumn, hinders the winery from collecting the yield coming from its associated farms. Under such circumstances, all farms lose their yields, which prevents the system from having input to produce wine during winter of $t = 2$. Without production, effects are the same than the already described for winter, but delayed one period: no sales, ergo no revenues and wine-making cost reduced to the structural cost.

Agent's actions. As we said, when the winery's buildings are flooded, there is always an imputation of cost of reparation to each associated farm. According to the disruptions described, we can differentiate two cases: the first one is when the winery is flooded, but production can be done or has been done. In such case, reparation costs are imputed among associated farms according the rule in equation 2.3

$$R_i = \left(\frac{R}{\sum_{i=1}^{n} q_i} q_i \right) \tag{2.3}$$

Where:

1. R_i is the reparation costs imputed to farm i
2. R is the total monetary value of reparations
3. $\sum_{i=1}^{n} q_i$ is the total production in the cooperative winery, as a sum of the individual productions of the member farms.
4. q_i is the production of the farm i.

The second case is when the production-commercialization process gets disrupted, and production cannot be done. In this case, wine-making cost is reduced to the winery's structural cost. Added to reparation costs, both are imputed according equation 2.4

$$CT_i = \frac{R + F}{N} \tag{2.4}$$

Where:

1. CT_i is the total cost imputed to farm i
2. F is the monetary value of the fixed vinification costs
3. R is the total monetary value of reparations
4. N is the number of farms members in the cooperative winery

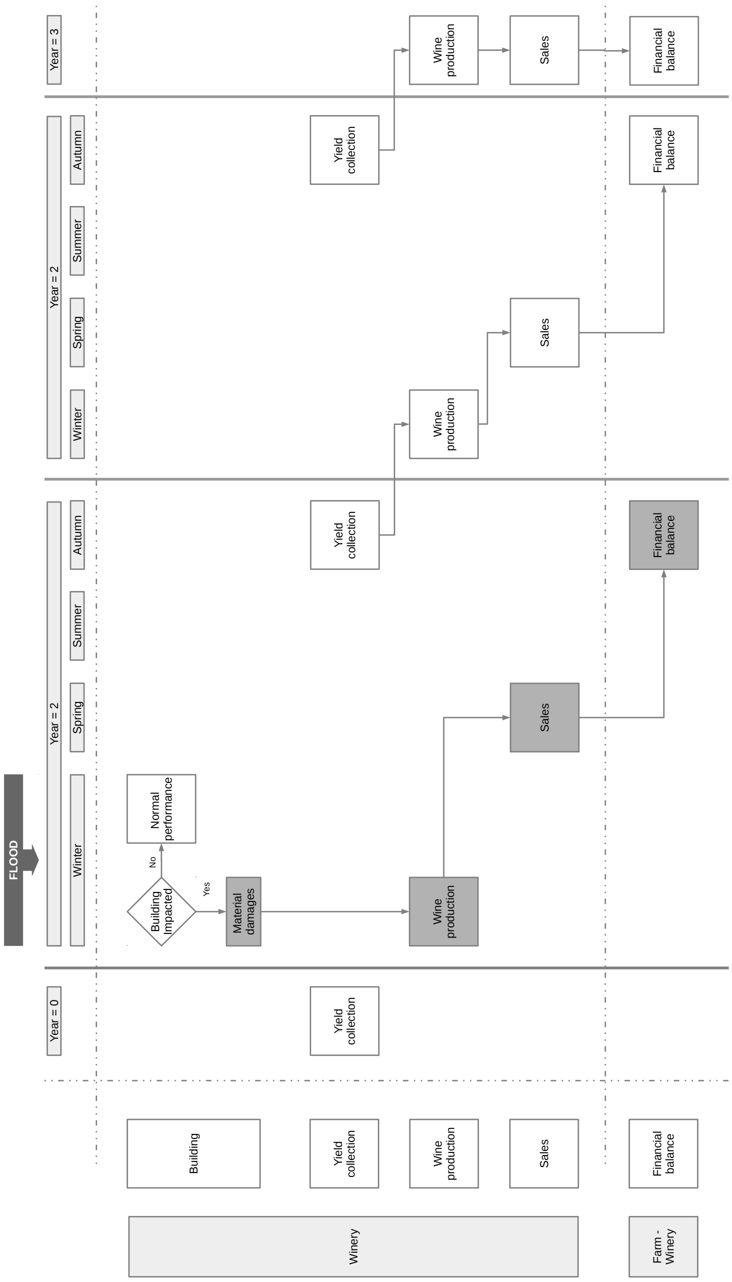


Figure 2.19 – Consequences of a flood over a winery in winter in SFS

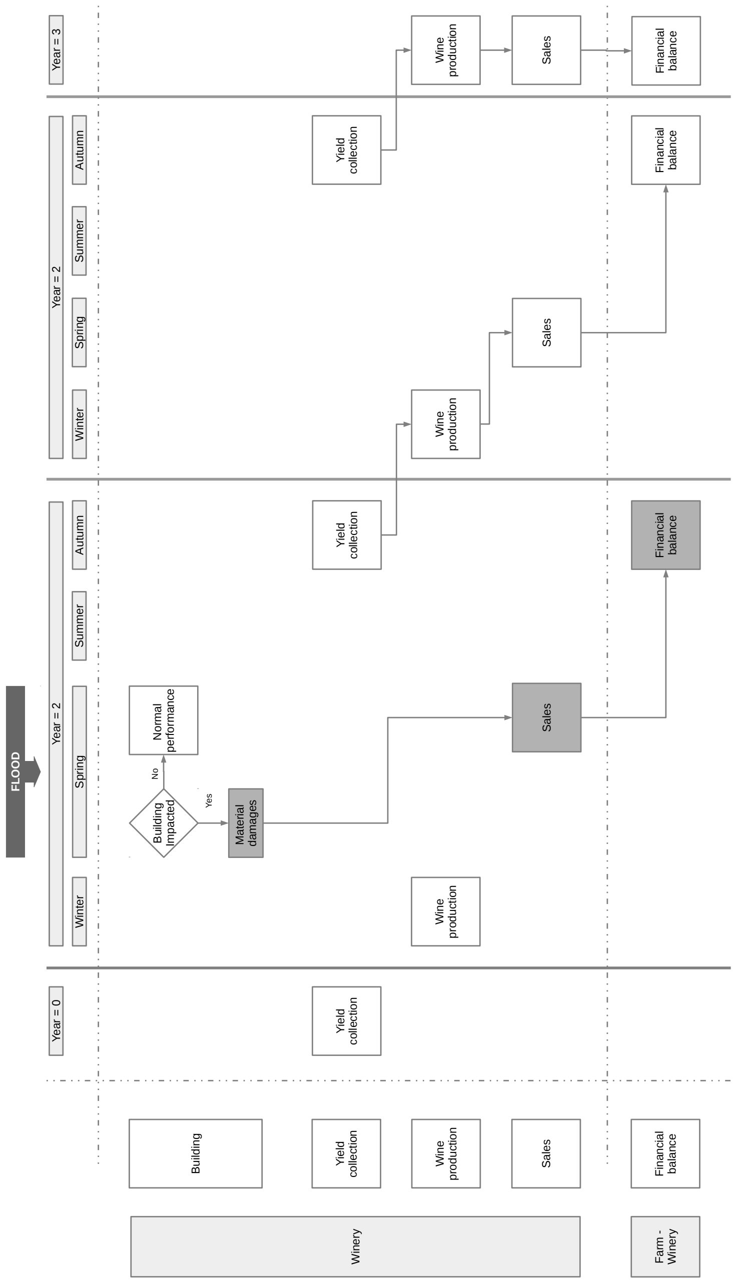


Figure 2.20 – Consequences of a flood over a winery in spring in SFS

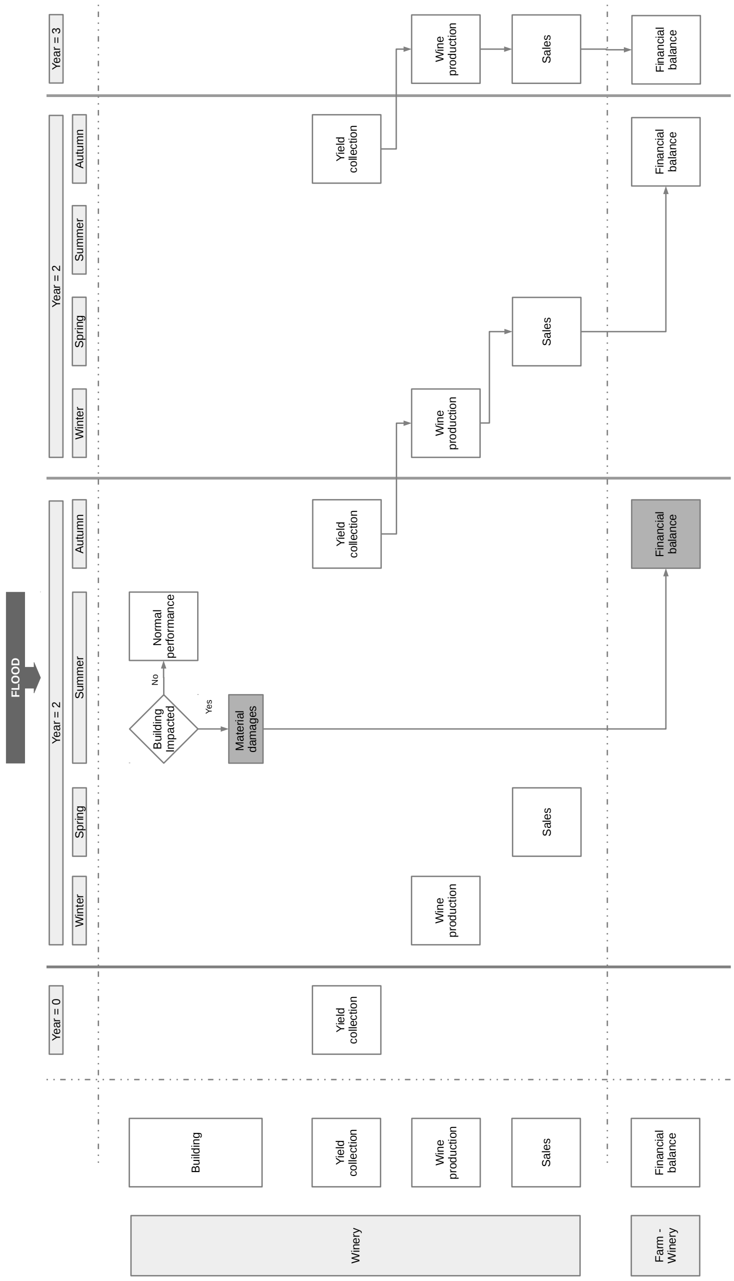


Figure 2.21 – Consequences of a flood over a winery in summer in SFS

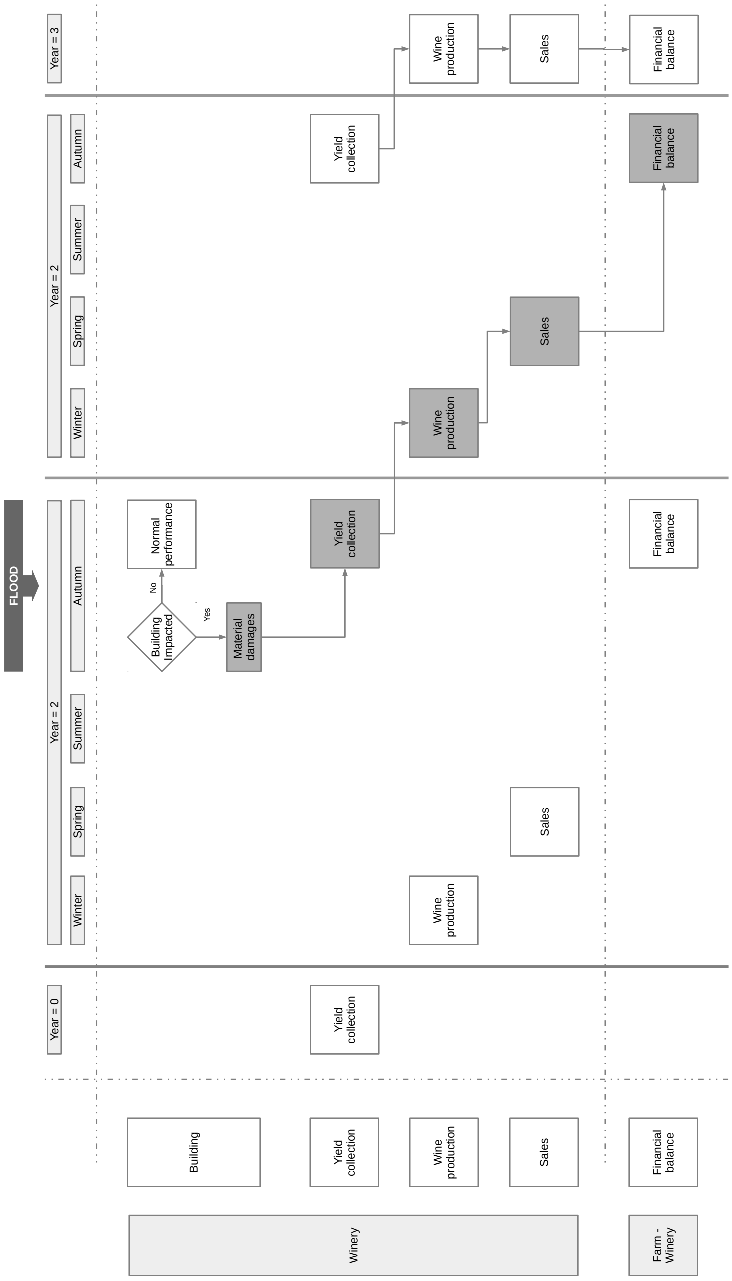


Figure 2.22 – Consequences of a flood over a winery in autumn in SFS

2.11.4 Combining damage functions

Floods can affect at the same time cooperative wineries, farms and plots. Therefore the effects described in the prior sections can be summed. Notwithstanding, since in our network, impacts of floods over one entity have effects over every other entity, we have decided to introduce hierarchy levels over the impacts of floods. This way, problems related to double accountability can be avoided, and the the impact can always be scouted to its origin.

Figure 2.23 sketches out the hierarchy levels by entities. Before we can analyze it , we need to introduce the following new nomenclature and definitions: for each productive plot γ_κ, owned by farm i, we can express its yield as

$$q_{i_T\kappa} = q_{i\kappa} + q_{i_D\kappa} \tag{2.5}$$

Where:

1. $q_{i_T\kappa}$ is the potential harvest in plot γ_κ of farm i
2. $q_{i\kappa}$ is the effective harvest in plot γ_κ of farm i
3. $q_{i_D\kappa}$ is the damaged harvest in plot γ_κ of farm i by the flood

The term $q_{i_D\kappa}$ "stores" the total of harvest damaged, whether its origin is in the direct submersion of the harvest or provoked by plant damages.

In our system, each farm i owns a number n_i of plots. Aggregating all those plots, each farm i owns a total extent Γ_i that can be expressed as:

$$\Gamma_i = \sum_{\kappa=1}^{n_i} \gamma_{i\kappa} \tag{2.6}$$

Using equation 2.6, we can express equation 2.5 at farm level as:

$$\sum_{\kappa=1}^{n_i} q_{i_T\kappa} = \sum_{\kappa=1}^{n_i} q_{i\kappa} + \sum_{\kappa=1}^{n_i} q_{i_D\kappa} \tag{2.7}$$

Where:

1. $\sum_{\kappa=1}^{n_i} q_{i_T\kappa}$ is the potential yield of farm i
2. $\sum_{\kappa=1}^{n_i} q_{i\kappa}$ is the effective yield of farm i
3. $\sum_{\kappa=1}^{n_i} q_{i_D\kappa}$ is the damaged yield of farm i

And the term $\sum_{\kappa=1}^{n_i} q_{i_D\kappa}$, as in the individual case, "stores" the total of harvest damaged, whether its origin is in the direct submersion of the harvest or provoked by plant damages.

At the same time, we know that, depending on the coping strategy the farm adopts, we can have additional damages over the harvest. To take such effect into account, and, therefore, know the real value of $\sum_{\kappa=1}^{n_i} q_{i\kappa}$, we need to modify equation 2.5 introducing the new term, $q_{i_\beta\kappa}$:

$$q_{i_T\kappa} = q_{i\kappa} + q_{i_D\kappa} + q_{i_\beta\kappa} \tag{2.8}$$

Where:

1. $q_{i_T\kappa}$ is the potential harvest in plot γ_κ of farm i
2. $q_{i\kappa}$ is the effective harvest in plot γ_κ of farm i
3. $q_{i_D\kappa}$ is the damaged harvest in plot γ_κ of farm i by the flood
4. $q_{i_\beta\kappa}$ is the damaged harvest in plot γ_κ of farm i caused by the coping strategy of the farm i

Then equation 2.7 becomes:

$$\sum_{\kappa=1}^{n_i} q_{i_T\kappa} = \sum_{\kappa=1}^{n_i} q_{i\kappa} + \sum_{\kappa=1}^{n_i} q_{i_D\kappa} + \sum_{\kappa=1}^{n_i} q_{i_\beta\kappa} \tag{2.9}$$

Where:

1. $\sum_{\kappa=1}^{n_i} q_{i_T\kappa}$ is the potential yield of farm i
2. $\sum_{\kappa=1}^{n_i} q_{i\kappa}$ is the effective yield of farm i
3. $\sum_{\kappa=1}^{n_i} q_{i_D\kappa}$ is the damaged yield of farm i
4. $\sum_{\kappa=1}^{n_i} q_{i_\beta\kappa}$ is the damaged yield of farm i caused by the farm i's coping strategy

Or alternatively,

$$q_{i_T} = q_i + q_{i_D} + q_{i_\beta} \tag{2.10}$$

Where:

$$q_{i_T} = \sum_{\kappa=1}^{n_i} q_{i_T\kappa} \qquad q_i = \sum_{\kappa=1}^{n_i} q_{i\kappa} \qquad q_{i_D} = \sum_{\kappa=1}^{n_i} q_{i_D\kappa} \qquad q_{i_\beta} = \sum_{\kappa=1}^{n_i} q_{i_\beta\kappa} \tag{2.11}$$

Up-scaling a level in the production chain, we can express the amount of yield provided as input to the cooperative winery, Q_w, as the aggregation of the individual yields of its associates:

$$Q_w = \sum_{i=1}^{n} q_i = \sum_{i=1}^{n}\sum_{\kappa=1}^{n_i} q_{i\kappa} \tag{2.12}$$

Where n_i is the number of plots, γ_κ, of farm i, and n is the number of farms

Returning to figure 2.23, we can use the new nomenclature to clearly scout damages when different entities are flooded at the same time. As always let's assume i) the flood hits the system in year $t = 1$, and ii) seasonal sequence is winter-spring-summer-winter. Then, if the flood its the system in:

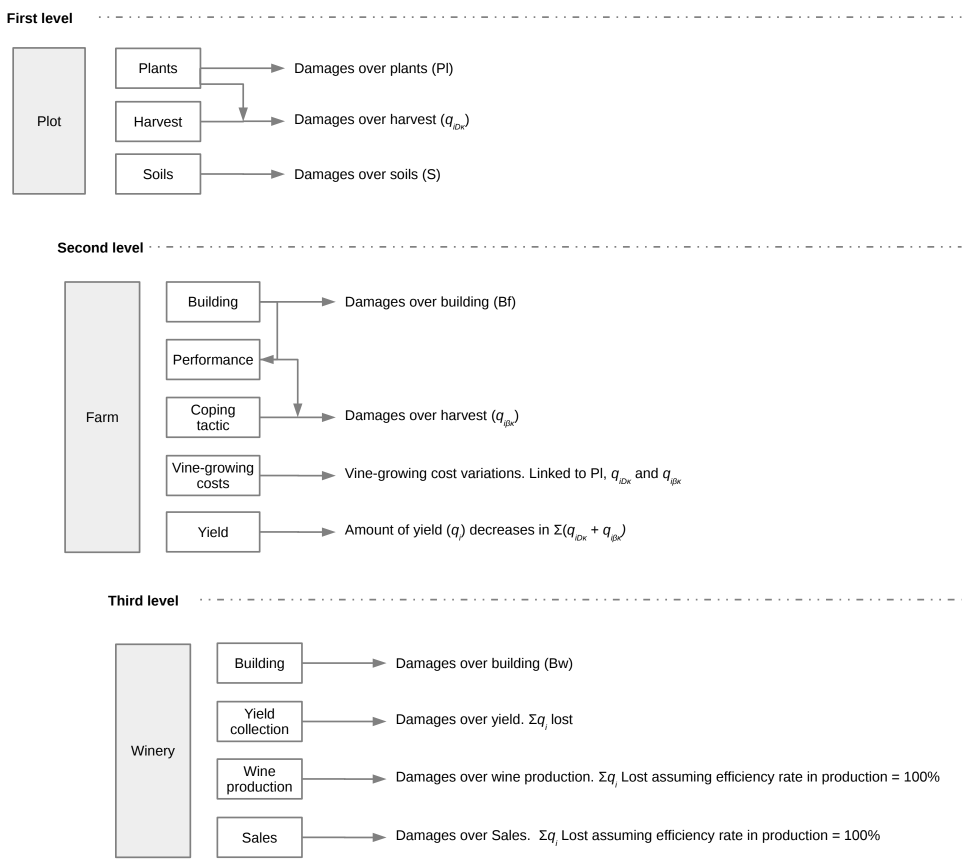


Figure 2.23 – Hierarchy of damages for a flood hitting entities altogether in SFS

1. **Winter**. Impacts over plots flooded are reduced to reconditioning of soils (S)
   Impacts over farms flooded include buildings (B1) and performance. If opting for *outsourcing*, $q_{i_\beta\kappa} = 0$, in each plot owned by flooded farms. Therefore in autumn, when harvest is done, in each productive plot owned by those farms $q_{i\kappa} = q_{i_T\kappa}$, thus $q_i = q_{i_T}$ at farms level for $t = 1$. If opting for *insourcing*, $q_{i_\beta\kappa} > 0$, in each plot owned by flooded farms, so in autumn $q_{i\kappa} < q_{i_T\kappa}$ in each plot owned by flooded farms, and $q_i < q_{i_T}$ at farms level for $t = 1$. In any case, vine-growing cost will vary
   Impacts over wineries incorporate damages over buildings (B2) and performance. It will make the system lose Q_w of $t = 0$, but will have no effect over Q_w of $t = 1$. Since Q_w is lost, there will be no revenues for farms in $t = 1$, and the ones expected in $t = 2$ will be linked to the farms coping tactic. Wine-making cost will vary reflecting both situations.
2. **Spring**. Impacts over plots flooded include reconditioning of soils (S), losses of harvest $q_{i_D\kappa} > 0$ and plant destruction (Pl)
   Impacts over farms flooded include buildings (B1) and performance. If opting

for *outsourcing*, $q_{i_\beta\kappa} = 0$, in each plot owned by flooded farms. Therefore in autumn $q_i < q_{i_T}$ in the amount given by q_{i_D} at farms level for $t = 1$. If opting for *insourcing*, $q_{i_\beta\kappa} > 0$, therefore in autumn $q_i < q_{i_T}$ too, but in the amount $q_{i_D} + q_{i_\beta}$. As in winter, vine-growing-cost will vary

Impacts over wineries are the same than for winter. Since in spring destruction of plants is likely to happen, the impacts over wine-making cots and revenues can last longer in time

3. **Summer**. Impacts over plots and farms are the same as exposed for spring, while impacts over wineries are reduced to reparation costs over buildings and materials (B2). Impacts over revenues and wine-making cost in $t = 2$ —and potentially further in time— will reflect the level of destruction in plots and the coping tactics chosen by farms
4. **Autumn**. Impacts over plots and farms are the same as exposed for spring. Impacts over wineries comprise damages over buildings (B2) and performance. It will make the system lose Q_w of $t = 1$.

   As we can see, in $t = 1$ eventually all production gets lost. However but for different reasons:

   — It exists $q_{i_D\kappa} > 0$ at each flooded plot. Therefore at systems level we have $\sum_{i=1}^{n} \sum_{\kappa=1}^{n_i} q_{i_D\kappa} > 0$ provoked by the direct impact of floods over plots

   — If farm's coping tactic is *outsourcing*, then $q_{i_\beta\kappa} = 0$. There is no added damage by the farm, and the yield lost by the winery is:

$$Q_w = \sum_{i=1}^{n} \sum_{\kappa=1}^{n_i} q_{i_T\kappa} - \sum_{i=1}^{n} \sum_{\kappa=1}^{n_i} q_{i_D\kappa} \tag{2.13}$$

   — If farm's coping tactic is *insourcing*, then $q_{i_\beta\kappa} > 0$, the added damage by each farm is $\sum_{\kappa=1}^{n_i} q_{i_\beta\kappa}$, and the yield lost by the winery is

$$Q_w = \sum_{i=1}^{n} \sum_{\kappa=1}^{n_i} q_{i_T\kappa} - \sum_{i=1}^{n} \sum_{\kappa=1}^{n_i} q_{i_D\kappa} - \sum_{i=1}^{n} \sum_{\kappa=1}^{n_i} q_{i_\beta\kappa} \tag{2.14}$$

   Revenues in $t = 2$ will be null and wine-making cost will be reduced to the winery's structural cost. Due to plant destruction at plot's level, as it happens in spring and summer, effects over revenues and wine-making cost are expected to last longer in time, reflecting such plant destruction.

2.12 Output

2.12.1 Indicators and scales

Our productive system rests, both at collective and individual level, over a vector of four key variables: production —Q_t—, revenues —R_t—, costs —C_{vg} (vine-growing) and C_{wm} (wine-making)— and investments and reinvestments —I_t. This last variable (I_t) serves us to group all reparations to be done in the system after a flood, reinvestments in plants and materials and, also, planed investments independent of the flood.

Every time any element of the system is flooded, as explained in section 2.11, one or more of those variables are going to experiment certain level of change. Thus, assuming that $\vec{BAU}_t$ and $\vec{SFS}_t$ are two vectors of key variables for their respective BAU and SFS scenarios:

$$\vec{BAU}_t = (I_t, Q_t, R_t, C_{vg_t}, C_{wm_t}) \tag{2.15}$$
$$\vec{SFS}_t = (I'_t, Q'_t, R'_t, C'_{vg_t}, C'_{wm_t}) \tag{2.16}$$

We can define the impact of a flood for each moment t as:

$$\vec{Imp}_t = \vec{SFS}_t - \vec{BAU}_t \tag{2.17}$$

For each farm i we can define C_{vg_t} and C_{wm_t} as:

$$C_{vg_{i,t}} = F_{vg_i} + v_{vg_i} q_{i,t} \tag{2.18}$$
$$C_{wm_t} = \frac{F_{wm}}{\sum_{i=1}^{n} q_{i,t}} + v_{wm} q_{i,t} \tag{2.19}$$

Where:

1. F_{vg_i} is the structural or fixed vine-growing cost of the farm i. Assumed constant over time
2. v_{vg_i} is the operational or variable vine-growing cost of the farm i. Linked to the impacts over the farm and its coping tactic
3. $q_{i,t}$ is the yield of farm i in the moment t
4. F_{wm} is the structural or fixed cost of the winery or fixed wine-making cost. Assumed constant over time
5. v_{wm} is the operational or variable cost of wine-making. Assumed constant over time
6. $\sum_{i=1}^{n} q_{i,t}$ is the sum of yields of all farm $i \in [1, n]$ in the moment t, where n is the total number of farms

Using equations 2.17, 2.18 and 2.19, we can calculate the impacts for both each farm i, and the whole system, at any moment t (table 2.8)

It is worth noting that $q'_{i,t} - q_{i,t}$ in table 2.8 is not the same than q_{i_D} in equation 2.10. In the equation, we refer only to the yield damaged by the flood, while $q'_{i,t} - q_{i,t}$ also includes the yield lost because of disability of an agent to perform an assigned task due to the flood. That is to say, it includes q_{i_β} and Q_ω

Aggregating the different components of the vector of impacts and regrouping terms, we can express the total impact for each individual farm as in equation 2.20:

Variable	Impact ($Imp_t = \vec{SFS}_t - \vec{BAU}_t$)	
	Individual level	Collective level (system)
I_t	$I'_{i,t} - I_{i,t}$	$I'_t - I_t$
Q_t	$q'_{i,t} - q_{i,t}$	$\sum_{i=1}^n q'_{i,t} - \sum_{i=1}^n q_{i,t}$
R_t	$p(q'_{i,t} - q_{i,t})$	$p\left(\sum_{i=1}^n q'_{i,t} - \sum_{i=1}^n q_{i,t}\right)$
Cvg_t	$v_{vg_i}(q'_{i,t} - q_{i,t})$	$v_{vg_i}\left(\sum_{i=1}^n q'_{i,t} - \sum_{i=1}^n q_{i,t}\right)$
Cwm_t	$v_{wm}(q'_{i,t} - q_{i,t}) + F_{wm}\frac{\sum_{i=1}^n q_{i,t} - \sum_{i=1}^n q'_{i,t}}{\sum_{i=1}^n q'_{i,t} \sum_{i=1}^n q_{i,t}}$	$v_{wm}\left(\sum_{i=1}^n q'_{i,t} - \sum_{i=1}^n q_{i,t}\right)$

I_t = Investment | Q_t = Production | R_t = Revenues

C_{vg} = Vine-growing cost | C_{wm} = Wine-making cost

Table 2.8 – Impacts of floods over investments, production, revenues, vine-growing and wine-making costs, at individual ($\forall$ farm i) and system's level in a moment t

$$Imp_{i,t} = (I'_{i,t} - I_{i,t}) + (p + v_{vg_i} + v_{wm})(q'_{i,t} - q_{i,t}) + F_{wm}\frac{\sum_{i=1}^n q_{i,t} - \sum_{i=1}^n q'_{i,t}}{\sum_{i=1}^n q'_{i,t} \sum_{i=1}^n q_{i,t}} \tag{2.20}$$

And for the whole system as in equation 2.21:

$$Imp_t = (I'_t - I_t) + (p + v_{vg} + v_{wm})\left(\sum_{i=1}^n q'_{i,t} - \sum_{i=1}^n q_{i,t}\right) \tag{2.21}$$

Where p is the market price of the wine produced with the yield of the farm i.

That is, the impact of a flood in any moment t comes given by the differences in investment and yield/production. In addition, at individual level, such impact comprises the redistributing effect driven by the individual share of the winery's fixed cots. In other words, the indirect effect that the winery's financial structure has over its associates. Therefore, for us, the collectivity has not the same properties of the individuals when up-scaling; rather the collectivity is an aggregation of the individuals with their own features involved in such collectivity. As a result, in our model, impacts of floods are level-dependent.

Using Brémond et al. (2013), we are able to build a damage time scale with two time spans: i) immediate impacts —"those ones which occurs during or immediately after the flood event"—, and ii) induced impacts —"those which occur later in time". Such scale will allow us to discriminate and follow up the impacts over elements that cannot be solved immediately, as well as their consequences during the aftermath of the flood in a time span of our choice.

Assuming the flood occurs in $t = t_1$, the mathematical formulation of individual immediate impacts will be as follows

$$\begin{aligned} Imp_{i,t=1} = {} & (I'_{i,t=1} - I_{i,t=1}) + (p + v_{vg_i} + v_{wm})(q'_{i,t=1} - q_{i,t=1}) + \\ & + F_{wm} \frac{\sum_{i=1}^{n} q_{i,t=1} - \sum_{i=1}^{n} q'_{i,t=1}}{\sum_{i=1}^{n} q'_{i,t=1} \sum_{i=1}^{n} q_{i,t=1}} \end{aligned} \tag{2.22}$$

And for the whole system as in equation 2.23:

$$Imp_{t=1} = (I'_{t=1} - I_{t=1}) + (p + v_{vg} + v_{wm}) \left(\sum_{i=1}^{n} q'_{i,t=1} - \sum_{i=1}^{n} q_{i,t=1} \right) \tag{2.23}$$

For induced impacts, such formulation can be enounced as in equation 2.24, at individual level, and as in equation 2.25, at system level:

$$\begin{aligned} Imp_{i,t\in[t_2,t_n]} = {} & \sum_{t=2}^{t_n} (I'_{i,t} - I_{i,t})(1+r)^{1-t} + (p + v_{vg_i} + v_{wm}) \sum_{t=2}^{t_n} (q'_{i,t} - q_{i,t})(1+r)^{1-t} + \\ & + F_{wm} \sum_{t=2}^{t_n} \left(\frac{\sum_{i=1}^{n} q_{i,t} - \sum_{i=1}^{n} q'_{i,t}}{\sum_{i=1}^{n} q'_{i,t} \sum_{i=1}^{n} q_{i,t}} \right) (1+r)^{1-t} \end{aligned} \tag{2.24}$$

$$\begin{aligned} Imp_{t\in[t_2,t_n]} = {} & \sum_{t=2}^{t_n} (I'_t - I_t)(1+r)^{1-t} + \\ & + (p + v_{vg} + v_{wm}) \sum_{t=2}^{t_n} \left(\sum_{i=1}^{n} q'_{i,t} - \sum_{i=1}^{n} q_{i,t} \right) (1+r)^{1-t} \end{aligned} \tag{2.25}$$

Where $(1+r)^{1-t}$ is the discount factor [24] of the period t for a discount rate r.

Brémond et al. (2013) allows us to introduce another scale. Our so-called *spatial scale*, where impacts are identified as direct impacts —those ones "related to direct exposure to the disaster" (physically flooded in our case)— or indirect impacts —"those which occurs in a area that has not been exposed to flooding". Such classification is, nonetheless, agent-dependent (or system-dependent), thus, we are forced to predefine the entity we assume is the elementary unit in the system, before making any potential classification of damages based on this scale. The presence of the two scales gives us the additional possibility of, crossing them, classify impacts in:

24. Discount factors have been introduce to ensure the comparability of financial flows over time

— Immediate Direct impacts: impacts due to direct exposure to flood, and manifested during the flood or immediately after.

— Immediate Indirect impacts: impacts occurred outside the flooded area, and manifested during the flood or immediately after

— Induced Direct impacts: impacts due to direct exposure to flood, manifested later in time.

— Induced Indirect impacts: impacts occurred outside the flooded area, manifested later in time

Impact information on those 5 key variables is presented through a collection of 12 different indicators, founded on Barbut et al. (2004); Brémond (2011); Brémond et al. (2013) and Hiete and Merz (2009) (figure 2.24). Over such battery of indicators, different complementary classifications are possible. The first, and probably the most intuitive one, classifies the indicators by entities —plot, farm and winery (central part of figure 2.24)—, so it is possible to identify where in the model the impact is originated, or, in other words, which entity has been impacted.

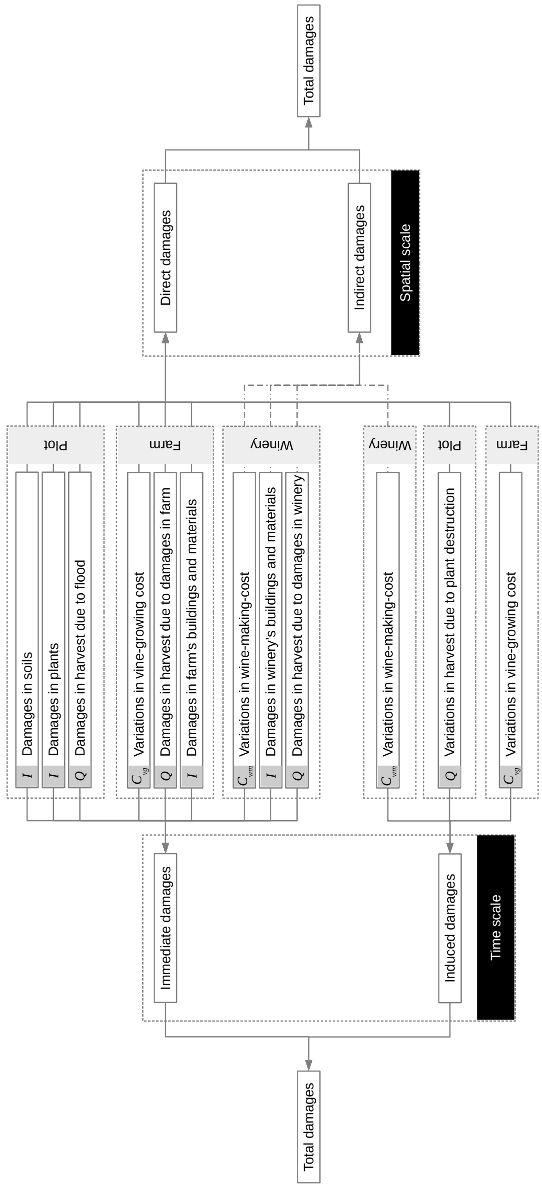
Additionally, following the scales based on Brémond et al. (2013), indicators present two alternative categorizations. Figure 2.24 shows, in its left side the resulting classification according our time scale, whereas, in its right side, we have the so-called *spatial scale*, assuming the point of view of the agent farm.

The structure of indicators in figure 2.24 can be replicated for every individual farm in the system. As it has been said, in our model, the collectivity is an aggregation of the individuals —and their individual features— involved in such collectivity (table 2.8), rather than an extrapolation. Thus, aggregating each of the individual values, we will be able to replicate the same structure at system's level [25], and impacts would reflect the same values than if the would have been calculated following table 2.8's formula (figure 2.25).

To prevent metrics from showing potential scale effects induced by entities and systems' sizes, we build a synthetic measure of impacts, dividing each indicator by the so-called *Yearly Potential Gross Benefit (YPGB)* (equation 2.26). Under our point of view, it presents three different advantages: i) as metric, the YPGB is easy to understand; ii) at the same time, it is also available at all the levels we would like to consider; and iii) it is a metric of the entity/system's annual gross capacity for resource generation. Therefore it provides a final synthetic measure easily interpretable.

$$YPGB = npv(p - C_{wm} - C_{vg}) \tag{2.26}$$

25. If The system is composed by different cooperative wineries coexisting in the same terrain, the structure is replicable at individual level, winery level and subsystem level.



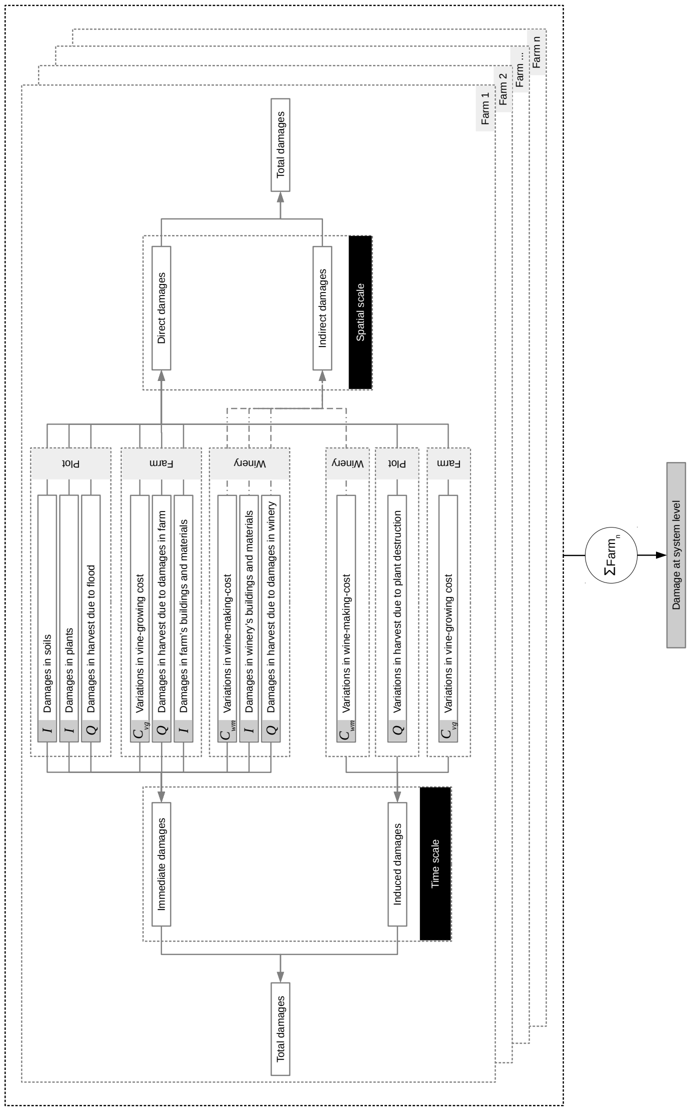
Source: own elaboration based on Brémond et al. (2013)
Remarks:
Each indicator includes in the left side of its frame the variable to which it refers, according to the nomenclature included at the beginning of this section: I_t = Investment | Q_t = Production | R_t = Revenues | C_{vg} = Vine-growing cost | C_{wm} = Wine-making cost

Spatial scale classified assuming the ensemble of farm and its owned plots as elementary unit of the system.

Figure 2.24 – Indicators

Where:

1. $YPGB$ = Potential gross benefit
2. n = number of plots (all of them. Not only productive ones)
3. p = price of wine
4. C_{wm} = wine-making costs by hl
5. pv = productivity by ha
6. C_{vg} = vine-growing cost per ha



Source: own elaboration based on Brémond et al. (2013)

Remarks:

Each indicator includes in the left side of its frame the variable to which it refers, according to the nomenclature included at the beginning of this section: I_t = Investment | Q_t = Production | R_t = Revenues | C_{vg} = Vine-growing cost | C_{wm} = Wine-making cost

Spatial scale classified assuming the ensemble of farm and its owned plots as elementary unit of the system.

Figure 2.25 – Individual-global duality of indicators

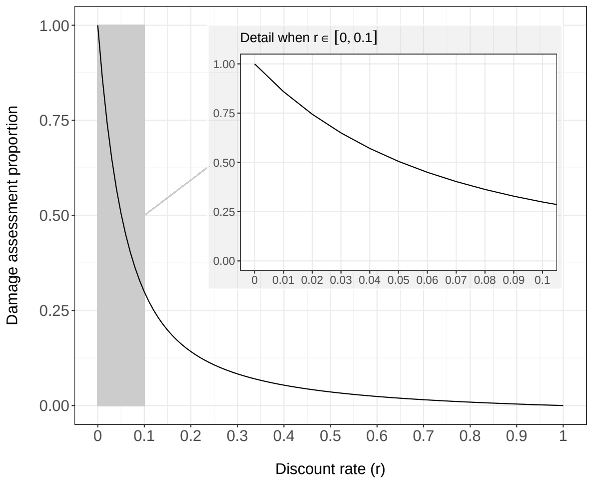
2.12.2 Influence of the discount factor over the damage assessment

Our indicators consider discount factors to assess damages along time. While it takes into account the economic idea that assessment of future values is not independent from the moment they occur, its presence will influence the magnitude of induced impacts, hence total ones.

To show the influence of the discount rate over the different variables that conform the indicator, we have, first, isolated the discount factor from any variable. Then tested it over a period of 30 years (biologic cycle of a plot in our model) for values of the discount rate ranging from 0 to 1, with increments of 0.01 units.

Figure 2.26 displays the value of the sum of discount factors over the 30 years chosen. Numerical values for discount rates from 0 to 0.1 are also provided in the table attached to the figure. As we can see, the most sensitive area is found when $r \in [0, 0.1]$. In this area $Imp_{t\in[t_2,t_30]}$ can drop the 70% of their values. When $r \in [0, 0.05]$, impacts present a faster decreasing evolution —dropping 50% of the value— than values of $r \in (0.05, 0.1]$ —remaining 20%.

The choice we make about the discount rate is far from trivial. It will affect directly the weight future impacts have in relation to the immediate impacts of the flood, and the importance of the induced impacts in the final mix of damages. In the interval $[0, 0.05]$, each percentage point of variation in the discount rate is translated approximately in 10% of variation of the induced damages. With $r \in [0.05, 0.1]$, such multiplier drops to -4 for each percentage point. Values of $r \in [0.1, 0.15]$ will present a multiplier of -2, while when $r \in [0.15, 0.23]$ it will be -1. For values of r beyond 0.23, each percentage point of increment will make variations in the total impacts inferior to -1%.



Discount Rate (r)	$\Delta Imp_{t\in[t_2,t_n]}$ in $t=1$, $\forall r \in [0.01, 0.1]$ in relation to $r=0$ (%)
0.01	- 14.05
0.02	- 25.56
0.03	- 35.04
0.04	- 42.92
0.05	- 49.50
0.06	- 55.03
0.07	- 59.72
0.08	- 63.72
0.09	- 67.15
0.10	- 70.11

Figure 2.26 – Variations in damage assessment in t = 1 for discount rates $r \in [0, 1]$ with $\Delta r = 0.01$, over a time span of 30 years

2.13 Model calibration

2.13.1 Vine-growing

Tasks. Brémond (2011) identifies 14 different vine-growing tasks, with the annual distribution pattern showed in figure 2.27, assuming an standard 52 weeks' year.

In our model, seasons come defined by whole months, instead of weeks. Thus, we need to find the way to summarize all information in figure 2.27 in data that can be handle by our model. To do that we follow a two-steps approach: first, over the initial distribution of Brémond (2011), we are able to calculate the number of hours spent per task each month, using the standard ISO week numbers and their monthly correspondence (table 2.9).

Second, defining seasons as:

— Winter: December - January - February

— Spring: March - April - May

— Summer: June - July - August

— Autumn: September - October - November

And attributing tasks to the season where they have more working hours[26], we obtain the assignation in table 2.10

26. If a task has the same weight over two seasons, the criterion has been to attribute such task to the season it is started

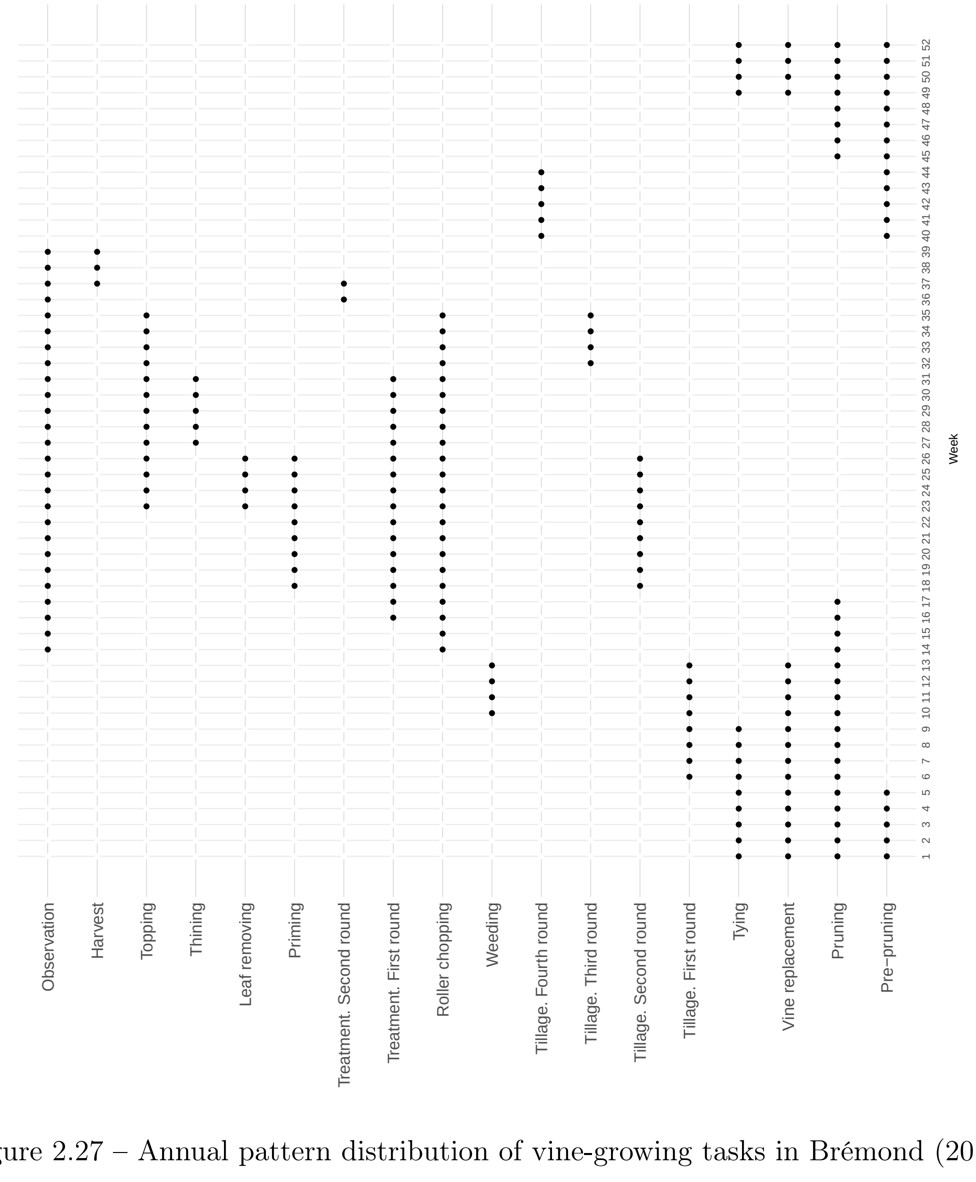


Figure 2.27 – Annual pattern distribution of vine-growing tasks in Brémond (2011)

Weeks	1-4	5-8	9-13	14-17	18-22	23-26	27-30	31-35	36-39	40-43	44-48	49-52	
Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Total**
Prepruning	0.44	0.11								0.44	0.56	0.56	2
Pruning	6.72	6.72	8.4	6.72							6.72	8.4	42
Vine replacement	0.47	0.47	0.59									0.47	2
Tying	0.92	0.92	0.23									0.92	3
Tillage 1 round		1.5	2.5										4
Tillage 2 round					2.22	1.78							4
Tillage 3 round								2					2
Tillage 4 round										1.6	0.4		2
Weeding			2										2
Chopping				0.91	1.14	0.91	0.91	1.14					5
Treatment 1 round				1.31	3.28	2.62	2.62	0.66					10.5
Treatment 2 round									1.5				1.5
Priming					4.44	3.56							8
Leaf removing						4							4
Thinning							0.8	0.2					1
Topping						0.92	0.92	1.15					3
Harvest									7				7
Observation				0.92	1.15	0.92	0.92	1.15	0.92				6
Total	8.56	9.72	13.72	9.86	12.24	14.71	6.18	6.3	9.42	2.04	7.68	10.35	109

Table 2.9 – Monthly repartition of tasks based on Brémond (2011) and ISO week numbers for standard 52 weeks' year. Unit: hours of labor

	Winter	Spring	Summer	Autumn
Prepruning	2			
Pruning	42			
Vine replacement	2			
Tying	3			
Tillage 1 round		4		
Tillage 2 round		4		
Tillage 3 round			2	
Tillage 4 round				2
Weeding		2		
Chopping			5	
Treatment 1 round			10.5	
Treatment 2 round				1.5
Priming		8		
Leaf removing			4	
Thinning			1	
Topping			3	
Harvest				7
Observation			6	
Total	49	18	31.5	10.5
Proportion over total	0.45	0.16	0.29	0.1

Table 2.10 – Seasonal attribution of vine-growing tasks based on Brémond (2011). Unit: hours of labor

Damages associated with *insourcing* coping tactic As explained in prior sections, when a farm uses the *insourcing* tactic, we assume such farm do not perform all its tasks, which is going to translate in certain level of damages in each of its productive plots. In Brémond (2011), tasks not performed are translated into losses (table 2.11).

Task	Damage	Task	Damage
Prepruning	0.1	Chopping	0.01
Pruning	0.4	Treatment 1 round	0.3
Vine replacement		Treatment 2 round	0.3
Tying	0.5	Priming	0.01
Tillage 1 round	0.05	Thinning	0.01
Tillage 2 round	0.05	Topping	0.01
Tillage 3 round	0.05	Harvest	1
Tillage 4 round	0.05	Observation	0.01
Weeding	0.3	Leaf removing	0.1

Table 2.11 – Proportion of yield lost per task, based on Brémond (2011)

To calculate the seasonal attributed damage to each task, we have followed a cumulative method. To illustrate it, let's take winter as reference; according table 2.10, tasks to be done in this season are:

- Prepruning, which, if not done, provokes losses of 10% of the harvest per plot. Let's call it a
- Pruning. If not performed, losses of 40% of the harvest per plot. Hereafter known as b
- Tying. responsible of losing 50% of the harvest per plot when not done. Hereafter c
- Vine replacement, which, if not done, does not provoke any loss

The cumulative approach used establishes that total losses can be expressed as:

$$harvest_{flood=winter} = (1-a) - b(1-a) - c((1-a) - b(1-a)) \tag{2.27}$$

Operating...

$$\begin{aligned} harvest_{flood=winter} &= (1-a) - b(1-a) - c((1-a) - b(1-a)) = \\ &= (1-a)(1+bc-b-c) = \\ &= (1-a)(1-b)(1-c) \end{aligned} \tag{2.28}$$

Therefore...

$$\begin{aligned} harvest_{flood=winter} &= (1-0.1)(1-0.4)(1-0.5) = 0.27 \\ losses_{flood=winter} &= 1 - harvest_{flood=winter} = 0.73 \end{aligned} \tag{2.29}$$

For the rest of the seasons, results are summed up in table 2.12

	Winter	Spring	Summer	Autumn
Proportion of harvest damaged	0.73	0.37	0.43	1.00

Table 2.12 – Seasonal attribution of damages based on Brémond (2011), in case seasonal vine-growing tasks are not performed

Vine-growing costs variations associated to coping tactics. Consequences of insourcing and outsourcing tactics are represented respectively in tables 2.13 and 2.14.

They both display the consequences over vine-growing costs and harvest over one productive plot —which has not been directly hit by the flood— when the farm it belongs to is flooded. Seasonal costs in absence of flood is calculated over a total per ha of 2 312.64€, applying the seasonal proportions of table 2.4.

First, table 2.13 shows the situation in which the farm opts for an *insourcing* tactic. The amount of task that can or cannot be done during the season, when the farm is hit by a flood, depends on multiple factors. Those factors, their behavior and the level of detailed analysis they require, are not the objective of our model nor they are implemented on it. Hence, we need a working hypothesis that allow us to compare the different outcomes of coping strategies.

Such working hypothesis has been to fix the amount of tasks the flooded farm is unable to perform to 50%. This way, every time a farm is flooded, automatically half of the tasks cannot be performed. Therefore, half of the vine-growing cost of the season in which the flood occurs will not be spent. Additionally, using table 2.12, we are able to know the level of damage it will cause to the harvest (all has been summarized in table 2.6). For instance, when a flood hits the farm in winter, the seasonal costs pass from €1 040.68 to €520.34; annual vine-growing cost then decreases from €2 312.64 to €1 792.30, and the farm loses 29.2 hl of production.

As it happens for *insourcing tactic*, when flooded farms opt for *outsourcing* tactic, we have no information about how much cost can increase [27]. Therefore, we will have to use, as well, working hypothesis to be able to simulate the effect of the tactic. For this case, we have set an increment of seasonal cost of 80% (table 2.14). Using the same example, now when the farm is flooded in winter, the seasonal cost pass from from €1 040.68 to €1 837.24, while annual vine-growing cost increases to €3 145.19, and the farm does not lose any production.

27. To normal services prices we would have to add the emergency situation, the potential increment in the demand of such services in the aftermath of the flood, and, as well, the potential solidarity of agents, as it happens in real cases

		Not flooded	Flooded in: Winter	Spring	Summer	Autumn
Vine-growing costs	Winter	1040.68	520.34	1,040.69	1,040.69	1,040.69
	Spring	370.02	370.02	185.01	370.02	370.02
	Summer	670.66	670.67	670.67	335.33	670.67
	Autumn	231.26	231.26	231.26	231.26	115.63
	TOTAL	2312.64	1,792.30	2,127.63	1,977.31	2,197.01
Harvest (hl)		80.00	50.80	65.20	62.8	40.00

Table 2.13 – Consequences on costs and harvest of *insourcing* tactic per productive plot, by flooding season. Units in euros (€); otherwise, explicitly indicated

		Not flooded	Flooded in: Winter	Spring	Summer	Autumn
Vine-growing costs	Winter	1040.68	1,873.24	1,040.69	1,040.69	1,040.69
	Spring	370.02	370.02	666.04	370.02	370.02
	Summer	670.66	670.67	670.67	1,207.20	670.67
	Autumn	231.26	231.26	231.26	231.26	416.28
	TOTAL	2312.64	3,145.19	2,608.66	2,849.17	2,497.65
Harvest (hl)		80.00	80.00	80.00	80.00	80.00

Table 2.14 – Consequences on costs and harvest of *outsourcing* tactic per productive plot, by flooding season. Units in euros (€); otherwise, explicitly indicated

2.13.2 Financial structure

Both farms and wineries are provided with a simple financial structure, which distinguishes between fixed or structural cost, and variable or operational cost. Calculations for both parts are based on data from CER France (2014).

2.13.2.1 Vine-growing farms

CER France (2014), based on a study of 2010 with 771 vine-growers, states that total cost per ha is €3 522. For vineyards with an average production of 80 hl per ha, the report establishes that, over such total cost, a proportion of 72% corresponds to operational costs (€2 538) whilst structural cost represents the 28%.

To calculate the structural cost of farms, the following mechanism has been implemented:

1. The total cost per ha in year t, according CER France (2014), can be expressed as

$$f_{vg} = \lambda \overline{C}_{vg_t} \qquad (2.30)$$
$$v_{vg} = (1-\lambda)\overline{C}_{vg_t}$$

Where

- f_{vg} is the structural cost per ha of the vine-grower i
- v_{vg} is the operational cost per ha of the vine-grower i
- $\overline{C}_{vg_t}$ is the total cost per ha of the vine-grower i
- λ is the proportion of structural cost over the total cost per ha

2. Assuming that the structural cost of the vine-grower, F_{vg}, is linked his total surface owned (measure of farm's size):

$$F_{wm} = \lambda \overline{C}_{vg_t} \Gamma_i \qquad (2.31)$$

Where Γ_i is the number of ha owned by the vine-growing farm:

$$\Gamma_i = \sum_{\kappa=1}^{n_i} \gamma_\kappa \qquad (2.32)$$

It is worth to point out that those accounts include outsourcing of harvesting services (€310). To be coherent with our reasoning on coping tactics, we proceeded to reduce such total cost per ha in the amount of the outsourcing service. As a result we get a total cost per ha of €3 212, of which 28% corresponds to structural cost and 72% to operational cost.

Let's see an example. If a farm owns 10 ha, its structural cost will be:

$$F_{wm} = \lambda \overline{C}_{vg_t} \sum_{\kappa=1}^{n_i} \gamma_\kappa \qquad (2.33)$$
$$F_{wm} = 0.28 \text{ x } 3\ 212 \text{ x } 10 = 8\ 993.6$$

The structural cost of that farm is €8 993.6, whether it has or has not production. To such amount, we will add:

$$v_{vg} = (1-\lambda)\overline{C}_{vg_t} \qquad (2.34)$$
$$v_{vg} = 0.72 \text{ x } 3\ 212 = 2\ 312.64$$

The operational cost per productive ha will be €2 312.64 each year.

For unproductive plots, we assume an operational cost of 20% of total cost per ha (€622). This hypothesis has been made based on the price of phytosanitary products, herbicides, fertilizers, etc.

2.13.2.2 Cooperative wineries

For cooperative wineries, CER France (2014) fixes a total wine-making cost of €20 per hl of wine (based on a study conducted in 2008). Unfortunately details on the items included are not disclosed. Folwell and Castaldi (2004.) offer a detailed wine-making cost structure, from where we get fixed costs represent around 20% of the cost by hl.

Based on such information, we implement the following mechanism to calculate the winery's structure of costs:

1. The total cost in year t in the cooperative winery comes expressed by the following formula:

$$C_{wm_t} = F_{wm} + v_{wm} \sum_{i=1}^{n} q_{i_t} \tag{2.35}$$

2. Dividing by $\sum_{i=1}^{n} q_{i_{t=0}}$, we can express the average unitary value of wine-making cost per hectoliter, $\overline{C}_{wm_t}$

$$\overline{C}_{wm_t} = \frac{F_{wm}}{\sum_{i=1}^{n} q_{i_t}} + v_{wm} = f_{wm} + v_{wm} \tag{2.36}$$

3. Dividing by $\overline{C}_{wm_t}$, we obtain:

$$1 = \frac{f_{wm}}{\overline{C}_{wm_t}} + \frac{v_{wm}}{\overline{C}_{wm_t}} = \lambda + \beta \tag{2.37}$$

   Therefore we can express the different components of the average unitary cost as a linear combination of the average unitary total cost:

$$\begin{aligned} f_{wm} &= \lambda \overline{C}_{wm_t} \\ v_{wm} &= (1-\lambda)\overline{C}_{wm_t} \end{aligned} \tag{2.38}$$

   Where the value of λ express the specific weight of the fixed cost in average cost paid per hectoliter.

4. Linking structural costs to the potential of production, we can express F_{wm} as:

$$F_{wm} = \lambda \overline{C}_{wm_t} Q_p \tag{2.39}$$

   Where Q_p is the potential of production in the winery:

$$Q_p = \sum_{i=1}^{n} \sum_{\kappa=1}^{n_i} q_{i_T \kappa} \tag{2.40}$$

   Assuming all $\gamma_{i\kappa}$ plots owned by farm i are productive.

5. From Folwell and Castaldi (2004.) we can fix $\lambda = 0.2$.
6. From CER France (2014) we can fix the initialization value of $\overline{C}_{wm_t}$, namely $\overline{C}_{wm_{t=0}}$, to €20

   As an example, let's assume we have a cooperative winery with ten associates, and, each of them, own ten plots of extent 1 ha and an average yield of 80hl per ha. Structural cost, F_{wm}, in that winery will be:

$$\begin{aligned} F_{wm} &= \lambda \overline{C}_{wm_t} \sum_{i=1}^{n} \sum_{\kappa=1}^{n_i} q_{i_T \kappa} \\ F_{wm} &= 0.2 \text{ x } 20 \text{ x } \sum_{i=1}^{10} \sum_{\kappa=1}^{10} 80 \\ F_{wm} &= 0.2 \text{ x } 20 \text{ x } 8000 = 32\ 000 \end{aligned} \tag{2.41}$$

   A winery as that one will have €32 000 of structural cost. The operational cost per unit, v_{wm}, will be:

$$\begin{aligned} v_{wm} &= (1 - \lambda) \overline{C}_{wm_{t=0}} \\ v_{wm} &= (1 - 0.2) \text{ x } 20 = 16 \end{aligned} \tag{2.42}$$

   The operational cost per unit, v_{wm}, is therefore €16 per hl

2.14 Initialization

This section is dedicated to specify the set up value every parameter and variable gets in the model.

Terrain
Terrain's size set to 150 patches from the origin of coordinates.
Prone area set to 100 patches from the origin of coordinates.
Origin of coordinates located in the bottom left corner.
Floods moving from the left edge to the right along the x axis.

Economic environment
Wine prices: €80 per hl[1]

[1] Average price using FranceAgriMer (2016). We assume it constant and not endogenously determined by the model.

Plot
Distribution over terrain: random
Extent: 1 ha per plot
Productivity: 80 hl per ha
Initial investment (replacement cost): €19 394 per ha
Life expectancy (investment life): 30 years[1]
Age unproductive: [0, 5) years
Age productive: [5, 30] years
Age: random in the range [0, 30]
State: all plots planted in the initialization
Reparation cost for plants and infrastructure: €19 394 per ha
Reparation cost for soils: €600 per ha[2]
Reparation cost for plot: €19 994 per ha
Owner: either random or preassigned by user

[1] Hypothesis made based on expected life of the investment (25 years) in CER France (2014)
[2] Hypothesis made based on the costs of phytosanitary products, herbicides and fertilizers. The sum corresponds to the costs of such element in a normal year. See CER France (2014)

Farm
Distribution over terrain: random
Extent owned: Variable
Total costs per ha (when plot productive)[1]: €3 212 per ha
Operational cost per ha (when plot productive): 72% of total costs[2]
Structural cost: 28% of total costs[3]
Total costs per ha (when plot unproductive): 20% of total costs[4]
Cumulative balance: €0
Reparation costs of damages: 30 times the value of the potential production[5]

[1] See CER France (2014)
[2] See section 2.13.2. €2 228 per ha
[3] See section 2.13.2. Calculated taking as reference the size of the farm: *Structural costs = 0.28 * Number of croplands * Total Costs per ha*
[4] €622 per ha. Hypothesis made based on operational costs (See CER France, 2014).
[5] €Hypothesis made based on Brémond (2011).

Cooperative wineries
Distribution over terrain: random
Number of associates: Variable
Vinification costs: €20 per hl
Fixed vinification cost proportion: 20%[1]
Variable vinification cost per hl: 80% of the vinification cost[2]
Efficiency : 100% (Every hl harvested corresponds to 1 hl of wine.)
Initial investment of winery: €290 per hl[3]
Reparation costs of damages: 30% of Winery's property value [4]

[1] See section 2.13. Adapted from information in Folwell and Castaldi (2004.)
[3] Adapted from information in Folwell and Castaldi (2004.). Winery's property value

is then calculated in the setup as:

$$Property\ value\ of\ winery = Initial\ investment\ of\ winery \text{ x } \sum_{i=1}^{n}\sum_{\kappa=1}^{n_i} q_{i_T\kappa} \quad (2.43)$$

Assuming all $\gamma_{i\kappa}$ plots owned by farm i are productive. Example with cooperative winery with ten associates, and, each of them, own ten plots of extent 1 ha and an average yield of 80hl per ha:

$$Property\ value\ of\ winery = 290 \text{ x } \sum_{i=1}^{10}\sum_{\kappa=1}^{10} 80 \quad (2.44)$$

$$Property\ value\ of\ winery = 290 \text{ x } 8000 = 2\ 320\ 000$$

[4] Hypothesis based in **?** and interviews with agents. When tested over a winery of around 6000hl, the amount of damage is similar to the amount declared in La Londe's interview.

The COOPER ABM. Financial analysis: extra hypotheses and model modifications

This part details the potential changes and additions needed to enable financial analysis of the performance of the CWS in the COOPER model, through the simulation of cash flows.

The changes and additions made affect several sections of the prior part (The COOPER ABM). Concretely: Process overview and scheduling, Submodels: flood impacts, Output and Initialization.

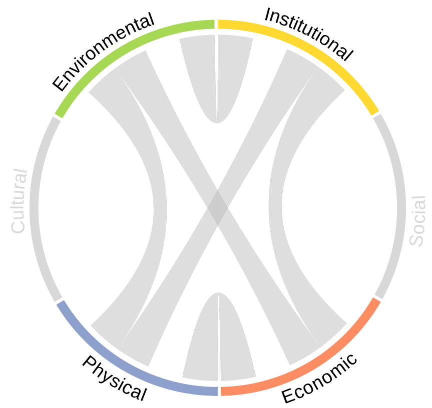
This part is organized as follows: first, section 2.15 offers an overview of the main hypotheses added to the COOPER model. Further, section 2.16 reviews the additions made to the model's Process overview and scheduling. The specificity of flood impacts from the point of view of the financial analysis and cash flow simulations are exposed in section 2.17 (Submodels: flood impacts). Section 2.18 describes the new set of outputs that can be simulated, while section 2.19 details the extra initialization values that should be added to the relation of variables and values already exposed in the Initialization section (section 2.14). Together with the aforementioned values, we provide the data sources mobilized.

2.15 Overview of changes in relation to hypotheses

The financial analysis in the COOPER model requires the addition of the extra hypotheses included in figure 2.9. With regard to the hypotheses included in figure 2.8 there has been no change nor addition whatsoever

No change

Passive role of financial sector: it acts as a mere lender without capacity to deny money lending



No change

1. Replant of vineyards is subsidized
2. Replant constitutes a replacement investment. Replacement investments are always financed with loans
3. Insurance include in the model. two mechanisms: *Calamité Agricole* and *catastrophe naturelle (CATNAB)*
4. In case of flood impact, vinegrowers and winery managers finance the part of reparations and reinvestments not covered by insurance with loans
5. Loans, subventions and insurance compensations are immediately granted (there is no time delay between the moment they are need and the moment they are granted)
6. Homogeneous loan conditions

Figure 2.28 – Overview of hypotheses and assumptions added in relation to hypotheses already exposed in figure 2.9. Detail by dimension of vulnerability

2.16 Process overview and scheduling

The description offered in section 2.10 does not suffer any modification. Rather we are going to detail more the financial process behind the replacement investments each vinegrower face during the simulations. As stated (section 2.10, bullet point 8) each plot is assumed to be replanted every 30 years. This replanting is considered a replacement investment.

To finance these replacement investments, vinegrowers borrow money from financial institutions. These institutions have a passive role in this version of the model. Four different hypotheses are relevant at this point:

— Financial institutions do not perform credit risk analysis. As a consequence of this hypothesis we can establish the next three ones.

— Funds demanded by vinegrowers are always lent.

— Loan conditions are homogeneous and stable.

— Loans are immediately granted

To finance those replacement investments, vinegrowers also count on government subventions. As in the case of loans, these subventions are assumed to always be both demanded and granted without delay. Thusly, vinegrowing farms only need to finance the part of the replacement investment not covered by the subvention (values are included in section 2.19)

2.17 Submodels: flood impacts

As it occurred with the prior section, the processes described in section 2.11 do not suffer any modification. Once again we are just detailing the financial process that accompanies a flood impact.

Such a process is going to mobilize two kind of mechanisms. On the one hand, when agents are impacted by a flood certain losses are going to be partially covered by insurance compensations. The evidence gathered shows that two main public insurance program are mobilized when the system is impacted by a flood: CAT-NAT and Calamité agricole On the other hand, those losses not covered by insurance compensations, are going to be financed through loans. As we stated in the prior section, financial institutions are play a passive role in the model, thus loans are granted in case of flood.

The COOPER model is going to follow the rules of CAT-NAT and Calamité Agricole to compensate both wineries and vinegrowers for their losses:

— **Cat-Nat**:
Cover: damages in buildings, and materials and production stored in those buildings.
Rule: gent's franchise of 10% of damages with a minimum of €1 140; rest of damage covered in full by insurance.

— **Calamité agricole**:
Cover: damage at plot's level

Rule: Always the amount of damages exceed the 30% of the gross theoretical product [28]:

— 35% of damages in soils.
— 25% of damages in plants.
— 0% of damages in harvest.

The calamité agricole program calculates the base to apply to damages in plants according the two following formulas: equation 2.45 for those plots productive in the moment of the flood, and equation 2.46 for those plots unproductive in the moment of the flood.

$$(M\ x\ Yu) + \left(Cr - \left(\frac{Cr}{Yp} (A - Yu) \right) \right) \tag{2.45}$$

Where:

— M: margin of profits per ha
— Yu: Number of years unproductive between replant and first productive year
— Cr: Cost of replant
— Yp: Number of years productive between first productive year and next replant
— A: Age of the plants in the moment of the flood

$$(M\ x\ Yu) + \left(\frac{Cr}{2} + (A - 1)\ x\ C_{vg} \right) \tag{2.46}$$

Where:

— M: margin of profits per ha
— Yu: Number of years unproductive between replant and first productive year
— Cr: Cost of replant
— A: Age of the plants in the moment of the flood
— C_{vg}: vinegrowing cost of plot during unproductive years

2.17.1 System dynamics

2.17.1.1 Impact over winery

— When a winery is flooded, reparations are partially financed (90%) with insurance compensations (CAT-NAT)
— The amount not covered (10%) is financed through a loan (conditions in section 2.19). The annuities of this loan increase the structural cost of the winery from the moment they are payable.
— In winter and spring SFSs, insofar production is considered to be in the winery's building(s), the insurance compensations partially cover production losses (90%).

28. Market value of plots' yield per farm

— In autumn SFSs, inasmuch as floods over wineries leave them unable to collect grapes hence grapes are not physically in the winery's building, CAT-NAT does not cover any production loss

2.17.1.2 Impact over vinegrowing farm

— All impacted vinegrowers get compensations, calculated according the aforementioned rules .

— The amount corresponding to the franchise (10%) is financed through a loan (conditions in section 2.19). Damages are always higher then €1 140

— Compensations are immediate. They are received the same year than the flood takes place. Therefore, there is no delay nor incertitude around it (simplification of the reality). Neither are we going to find cash flow problems linked to compensations that do not arrive on time.

— Replant due to flood impacts is also subsidized

2.18 Output

The financial analysis in the COOPER model rests upon the individual output vectors aforementioned in section 2.12:

$$\vec{BAU}_t = (I_{i,t}, Q_{i,t}, R_{i,t}, C_{vg_{i,t}}, C_{wm_{i,t}}) \tag{2.47}$$

$$\vec{SFS}_t = (I'_{i,t}, Q'_{i,t}, R'_{i,t}, C'_{vg_{i,t}}, C'_{wm_{i,t}}) \tag{2.48}$$

Where:

— $I_{i,t}$ and $I'_{i,t}$ are the flows of replacement investments of vinegrower i in year t

— $Q_{i,t}$ and $Q'_{i,t}$ are the flows of production of vinegrower i in year t

— $R_{i,t}$ and $R'_{i,t}$ is the flows of revenues of vinegrower i in year t

— $C_{vg_{i,t}}$ and $C'_{vg_{i,t}}$ are the flows of vinegrowing cost of vinegrower i in year t

— $C_{wm_{i,t}}$ and $C'_{wm_{i,t}}$ are the flows of winemaking cost of vinegrower i in year t

Insofar i) what we search is to analyze monetary flows, and ii) revenues depend on production, the latter variable ($Q_{i,t}$) is not taken into account in this analysis. On the other hand, a realist analysis of monetary flows originated in our simulated production process needs the addition of the following variables:

— Taxes (T_t): Amount paid each moment t to public treasury over the revenue of the prior year.

— Owner's remuneration (O_t): Amount assigned each moment t as remuneration of the owner. Expressed as a proportion of the Guaranteed Minimum Wage (GMW)

— Subventions to investments and reinvestments (Sb_t): amounts of public money granted to vinegrowers for specific investments.

— Insurance compensations(IC_t): compensations from public and private insurance schemes in case of harm.

— Penalization for treasury overdrawing : amount of money paid in case of treasury overdrawing.
Overdrawing situations in our model are penalized. They will generate additional payments in concept of interest over the amount overdrawn.

The monetary flows (cash flows) for each individual vinegrower are then simulated according a simplified adaptation of the Lawson's identity (Foster and Ward, 1997), interpreted as in Lee (Sharma, 2001):

$$R_t - C_{vg_t} - C_{wm_t} - FO_t - T_t - OR_t + FI_t - I_t = \pm Tr_t \tag{2.49}$$

Where:

— R_t is the flow of revenues from wine selling in year t
— C_{vg_t} is the flow of vinegrowing costs in year t
— C_{wm_t} is the flow of winemaking costs in year t
— FO_t are the financial outflows (overdrawing penalization + loan/s annuity/ies) in year t
— T_t is the flow of taxes in year t
— O_t is the flow of owner's remuneration in year t
— FI_t are the financial inflows (loans + subventions) in year t
— I_t are the flows corresponding to replacement investments in year t
— Tr_t is the treasury inflow(+)/outflow(-) in year t

Regrouping elements in equation 2.49 we have:

$$NCFO = R_t - C_{vg_t} - C_{wm_t} \tag{2.50}$$
$$CFI = I_t \tag{2.51}$$
$$CFF = FI_t - FO_t - OR_t \tag{2.52}$$

Where:

— $NCFO$ is the Net Cash Flow of Operations
— CFI is the Cash Flow of Investing activities, also known as net capital investment
— CFF is the Cash Flow of Financing activities

Thus equation 2.49 can be alternatively expressed as:

$$\pm NCFO_t - T_t \pm CFF_t - CFI_t = \pm Tr_t \tag{2.53}$$

We consider the owner's remuneration in the CFF, thus assimilating it as the dividend paid to shareholders (so far, the vinegrower is the only shareholder of his own exploitation). If that remuneration is rather considered part of the operational costs it should be included in the $NCFO$

2.18.1 Need for depreciation

The initialization values used to calculate vinegrower's structural cost include depreciation of assets. The value of depreciation is however not disclosed. We have calculated our own depreciation based on data fro the Languedoc-Rousillon from the FADN database (see 2.19). Thus in the COOPER model, equation 2.50 becomes

$$NCFO = R_t - C_{vg_t} - C_{wm_t} + depreciation_t \tag{2.54}$$

Otherwise equation 2.50 expresses the $EBIT$ (Earnings Before Interest and Taxes) instead of the $NCFO$.

2.19 Initialization

To accomplish the financial analysis the COOPER needs the following extra initialization values:

Farm
Guaranteed minimum wage (GMW)[1]: €17 763.24
Remuneration[2]: variable
Initial treasury[3]: variable
Subvention: 11500/ha[4]
Interest rate overdraft penalization: 10%[5]
Depreciation: €640/ha[6]
Taxes: 2.3% over revenue[7]
Loan's maturity: 15 years[8]
Loan's interest rate: 1.4%[9]
Loan's principal[10]: €7 893
Loan's amortization method: French amortization
Loan's annuity: calculated according previous conditions by the COOPER model
Vinegrowing cost of plot during unproductive years (insurance)[11]: €1 542
Margin of profit per ha (insurance)[12]: €1 313

[1] France's Minimum Salary 2017
[2] For simulations it has been fixed as $0.5GMW$. According to the information from CER France (2014), the structural cost already includes a basic remuneration to the owner. The total remuneration that the owner would eventually get adding the amount here assumed is considered plausible in consonance with the information from CCMSA (2017)
[3] Average value if not used as parameter: €500/ha (own calculation based on FADN)
[4, 8, 9] Interview CERfrance
[5] Information from Credit agricole bank
[6, 7] own calculation based on FADN
[10] It corresponds to the difference between replanting cost per ha (€19 393) and the subvention (€11 500)
[11] Operational cost per ha when plot unproductive plus structural cost per ha (implicit assumption farm size = 10ha)
[12] Implicit hypothesis fixed vinification cost proportion = 20%

Cooperative wineries
Loan's maturity: 30 years[1]
Loan's interest rate: 3%[2]
Loan's principal: reparation not covered by CATNAT

[1,2] See Chevet (2004, pg 8)

CHAPTER 3

Results I: system level

"Whatever is affected as an organization has some effect as an organization (12th Law of Levels)"

— Jame K. Feibleman

3.1 General discussion of the results obtained in the article *Are interactions between economic entities determinant for the estimation of flood damage of complex productive systems? Insights from a micro modeling approach applied to wine cooperative system* in relation to the dissertation's research goal

3.1.1 The article in the light of the dissertation

The article upon which we build this chapter analyzes to what extent to account for explicit interactions between entities in the CWS improves flood damage estimation in comparison with current approaches. Furthermore, the article also analyzes how, over a constant spatial distribution of elements, variations in the links between material elements influence the amount of damage in the system.

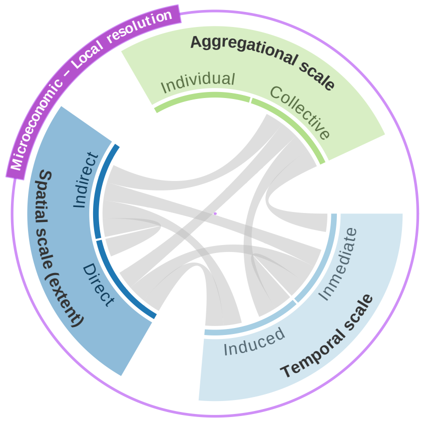


Figure 3.1 – Scales and levels taken into account in this chapter in relation to set of scales and levels considered in the dissertation. In the frame of our work, the analysis at individual level falls out of the focus of this first chapter of results, whilst the collective level likens to the study of Cooperative winemaking system (CWS) as a single organization

Insofar our premise is that the amount of damage is an indicator of the susceptibility of the system to suffer harm, the characterization of the vulnerability depends on, first, whether interactions are taken into account, and, second, the way those interactions are established (what interacts with what). Moreover, when both both hazard and exposure remain unchanged, any variation of a feature of an entity/system leading to a variation of the value of losses shall be taken as a vulnerability driver.

The indicator of damages is build according to the specifications included in chapter 2,section 2.12. The analysis of the CWS presented in this chapter is focused on the collective level in our so-called aggregational scale.

The article is completed with an addendum of figures that display the decomposition of total damages used in the article. This addendum is included to detail the effects that the different extents of floods simulated, and the season in which they are simulated, have over the set of indicators built in the COOPER model (see chapter 2, section 2.12, figure 2.25). The addendum assists in the identification of the underlying factors that might be driving the vulnerability of the system.

3.1.2 Summary of main results of the article

As we have said above, the article tackles the question of to what extent modeling interactions between entities can improve the estimation of flood damage compared to current approaches which do not take into account any of these interactions.

Using the COOPER model, the article tests the following 7 parameters over a fixed spatial distribution of material components to analyze the impact of interactions in flood damage estimation: i) presence of explicit interaction; ii) vinegrower's coping tactic ; iii) configuration of interactions between material components; iv) size heterogeneity; v) spatial location of the cooperative winery; vi) season; and vii) flood extent

The article finds that to take into account interactions does have an effect on damage estimation. Indeed, when compared with current practices, misrepresented interactions may lead to either underestimation or overestimation of damage at the system level, depending on whether the misrepresentation induces the misidentification or the double accounting of damages.

Furthermore, the way in which those interactions are established among material components also has effects on damage estimation. Thus the configuration of links (what is linked to what) between material components, *ceteris paribus*, is also relevant. In other words, if interactions are to be taken into account, their specification needs to be done completely.

3.1.3 Discussion of results of the article in the light of the main question of this dissertation

3.1.3.1 Coping tactic

According to the results obtained in the COOPER model, differences between the two chosen coping tactics are significant. Due to the adoption of the coping tactic `external`, the amount of total damage in the system can be, in general terms, reduced. Restricting our analysis, at first, to the observable differences between both tactics in the `homogeneous` topology we can appreciate that the magnitude of that reduction depends on the interaction of different components and parameters in the model (see addendum, section 3.4, figures 3.14 to 3.18). Those parameters include the season in which the system is hit, the extent of the flood, and the location of the winery.

As explained in chapter 2, section 2.11.2.2, the tactic `external` allows vinegrowers to prevent further yield losses provoked by misperforming their assigned tasks once their buildings are physically impacted by the flood. It also implies a reduction in the variation of immediate vinegrowing cost and both immediate (short term) and induced (long term) winemaking costs. The cumulative effects that the `external` tactic generates in the system reduce, in general terms, the final susceptibility of the system to suffer harm.

There is a noteworthy exception though (see addendum, section 3.4, figures 3.16 and 3.18). When floods hit the system in autumn and the cooperative winery is impacted by them, the winery is unable to collect the plots' yield to perform the posterior production. As a result, even though the coping tactic `external` reduce damage to the system in terms of yield lost, all yield in the system is eventually lost because of damages in the winery. In such a scenario, a coping tactic as `external` would only bring vinegrowers an extra monetary cost, insofar further activities in the production chain cannot be performed and all yield will be lost anyway.

3.1.3.2 Topology

The characterization of relevant interactions between material elements within the system matters for the valuation of the degree of vulnerability of said system and the identification of its drivers. Indeed, the results displayed in the article's figure 6 show how, over a fixed spatial distribution of material components, to take into account the interactions between those components, *ceteris paribus*, influences the total damage caused by a flood.

Furthermore, assuming i) all relevant interactions have been taken into account (article's *full interaction* modality) and ii) spatial distribution of material components do not vary, variations of the map of links that bind material components together lead to variations in the magnitude of the damage. Hence, the susceptibility of the system to suffer harm, *ceteris paribus*, depends on the aforementioned map of links (also referred as configuration of interactions).

Interactions are thus a driver of vulnerability in systems, both because of its presence and because of the way they bind elements together.

This result is interesting, not only inasmuch as it confirms that accounting for explicit interactions and topologies improve damage assessment and vulnerability valuations in economic systems, but insofar it has implications in the very definition of vulnerability with which systems shall be analyzed.

Indeed, the result around the role of interactions in vulnerability analysis implies that when different elements conform a system, with links between them, the susceptibility showed by the system at a given level may depend of the eventual degree of exposure at inferior levels. For instance, in the COOPER model, the vulnerability of material components is an intrinsic property independent from exposure. When we analyze the system at a collective level the degree of exposure of the material components does not change (the spatial location of elements is constant across simulations). However, with every different configuration of links what does change is the degree of exposure of the agent «vinegrower» [1], insofar the spatial location of his material components changes. Thus the susceptibility with which the CWS reacts to floods depends on the degree of exposure of each vinegrower, although in any case simulated the degree of exposure of the system changes.

In the light of these results, the inclusion of the exposition ceases to be a purely conceptual discussion, and becomes a driver of vulnerability but only at certain levels of aggregation within the system.

1. The agent «vinegrower» is considered the ensemble of a given number of plots and a building (material components). See chapter 2, section 2.9

3.1.3.3 Spatial location of the cooperative winery

In the same line of reasoning than the last section, but much more specific, the spatial position of the cooperative winery plays a central role in the susceptibility of the system. As we have shown in figure 2.4 (see chapter 2, section 2.3) the presence of wineries' buildings in flood-prone areas is plausible.

The inclusion of the cooperative winery in the flood-prone area has a significant effect in the susceptibility of the system to flood impacts (see addendum, section 3.4 figure 3.13). When the cooperative is located out of the prone area, maximum damages are equivalent to 2.5-3 times the system's Yearly Potential Gross Benefit (YPGB) (see chapter 2,section 2.12). As soon as the winery is located in the prone area (thus flooded), damages multiply reaching 10 times the system's YPGB in the worst case scenarios.

The inclusion of the winery in the flood-prone area also changes the pattern of seasonal behavior. When the winery is outside the flood-prone area, damages are driven by the evolution of damages at plots' level: spring presents the highest amount of damages despite the flood extent, followed by summer and autumn while winter is practically zero. When the winery is flooded, spring Simulated Flood Scenarios (SFSs) still show the highest amount of damages, whereas autumn and winter SFSs now display similar level of damages, and summer becomes the least damaging season.

3.1.3.4 Size of vinegrower

Heterogeneity in the size of vinegrowing farms do not provoke significant effects on the amount of damage of the system. Both `homogeneous` and `size` configurations of interactions present damages similar in magnitude (see article's figure 7 and addendum's figures 3.19 to 3.25) Hence, it is not considered a driver of vulnerability of the CWS.

Are interactions between economic entities determinant for the estimation of flood damage of complex productive systems? Insights from a micro modelling approach applied to wine cooperative system

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Abstract

Flood damage evaluation is a crucial step in the process of risk exposure evaluation and to evaluate flood mitigation measures. Given the stochasticity of flood events, evaluating flood risk and the efficiency of flood mitigation measures requires to use models that foresee potential damage of flood events that have not necessarily happened. Using ex post damage data, some authors showed that indirect damage, i.e this that is not due to direct contact of flood water on assets, could represent a huge share of the total damage. The studies on this topic have mainly focused on low probability-high impact events at least at a regional scale. For these events, methods frequently used are input-output or general equilibrium models which do not look for a mechanistic modelling of damage propagation through complex productive systems. Few studies have been carried out at a micro scale, which is the only one that allows a mechanistic modelling. In this paper, we adopt this approach and analyze the need to consider interactions between economic entities in a complex productive system through the example of wine growing farms associated with a cooperative winery.

First, we show that neglecting such interactions in damage assessment can result either in overestimation (double counting) or underestimation (wrong estimation of induced consequences on activity). Second, we highlight that to considering interactions requires a thorough characterization of their spatial configuration. To conclude, based on the prior results, and taking into account that this approcah the collection of specific data, we propose balanced recommendations for flood damage estimation.

Keywords: Damage, Flood, Interaction, Modelling, wine sector

1. Introduction

Floods are natural disasters engendering very important damage, in particular economic one (SwissRE, 2017). Due to global warming impacts on hydrological regimes and development of territories that are exposed to floods, it is expected that this damage will increase in coming decades (Field et al., 2012). In this context, it is all the more important to understand the precise mechanisms through which floods produce economic damage. This understanding is particularly useful to evaluate the risk of an exposed territory (risk assessment) and estimate the efficiency of flood management projects, in particular through cost-benefit analyses (Merz et al., 2010; Penning-Rowsell et al., 2013a). A more precise understanding can help design finer analyses of the development of a territory exposed to floods, in particular these analyses that integrate the expected reactions of agents to the damage they experience (Viglione et al., 2014; Grames et al., 2016; Barendrecht et al., 2017; Grames et al., 2017).

For projects' appraisal purpose, damage assessment is used within cost-benefit analysis (Brouwer and van Elk, 2004; Penning-Rowsell et al., 2013b; Rouchon et al., 2018a). It requires to get an estimate of the benefits (respectively costs) of projects with regard to their impacts on flood risk by estimating flood damage avoided (respectively flood damage added). Cost-benefit analysis main purpose is to give an indication of expected efficiency of these projects in order to allocate public subsidies, funded at national level or above. Thus, damage assessment methods rely on assumptions which ensure the comparability between possible case studies.

In the research community of flood damage evaluation there is a distinction between direct and indirect damage (Merz et al., 2010; Cochrane, 2004; Meyer et al., 2012). A direct damage is due to the direct contact of flood on element exposed. An indirect damage is, terminologically, a damage that is not a direct one (Cochrane, 2004). Some authors only consider the spatial distinction: direct damage is the one that occurs inside the flooded area while indirect damage occurs outside (Jonkman et al., 2008; Meyer et al., 2013; Merz et al., 2010). In this case, these authors consider loss of business in the flooded area as direct damage and loss of business outside the flooded area as indirect damage Meyer et al. (2013). For Penning-Rowsell and Green (2000), this distinction is not necessary, and loss of business should be fully considered as indirect damage: primary indirect damage corresponds to loss of business due to direct impacts of flood on an economic entity and secondary indirect damage results from the production links between economic entities. Applying this distinction for damage is difficult when they occur in complex economic systems (for instance a company with different locations), which are highly interrelated. Defining whether such systems are directly or indirectly affected by a flood is not so easy: they may have some crucial parts directly damaged and others that remain safe. Thus, this distinction depends on the definition of the boundaries of the systems considered, and may appear somehow artificial. Nevertheless, it is useful to a discussion on the exhaustiveness of damage considered in an economic evaluation.

The current practice of damage estimation, which can rely on feedback (observing insurance data for example) or on models (like damage functions[1]), is often limited to direct damage to infrastructures (buildings or material) and to productive material stock. Most of the time, direct damage is estimated using damage functions which are defined at micro scale (see for instance Middelmann-Fernandes, 2010; Meyer et al., 2013; **?**). Some improvements to these methods considering, for example, the adaptive capacity of households can be done (Haer et al., 2016; Bubeck et al., 2012).

Evaluating direct damage only is considered as an usual cause of underestimation of the value of the impact (Field et al., 2012). As mentioned by many authors (Scawthorn et al., 2006; Meyer et al., 2012, 2013; Council, 1999), impacts other than the direct material ones take place and should be estimated as indirect damage. Among these impacts that are often neglected, we focus in this article on economic damage that is due to perturbations in a production process resulting from interactions between different economic entities which may or not belong to the same firm.

In practice, current methods to evaluate flood damage rely on the implicit assumption that economic entities can be treated separately, without considering how they are linked each together. Moreover, some economic entities may have different buildings, plots, etc., located at different places, which exposure to flood differs. In this case, current practice relies on the implicit assumption that all these material components can also be treated separately, without considering how the internal organization of these economic entities links them.

Concretely, damage assessment relies on crossing information on exposure and susceptibility of assets that have been previously pooled in homogeneous classes (Kreibich and Bubeck, 2013). When entities or material components are treated separately, it is possible to use common geographic information system (GIS), where stakes are characterized by their nature and their location. So this practice is appropriate because it fits with the way assets are geolocalized by GIS and damage functions are defined.

[1]A damage function is a simplified representation of how some asset is damaged by a flood: it gives a relation between flood intensity, measured by parameters such as height or duration, and expected damage that would occur if the given asset is flooded by an event of given intensity.

In these approaches at micro level, not considering the links between economic entities implicitly supposes not considering loss of business. In the agricultural sector, Hess and Morris (1988), Morris and Hess (1988) and more recently Brémond and Grelot (2012) proposed methods to evaluate loss of business by modelling agricultural productive systems considering the links between the productive components of a farm (cattle and grassland, land plots and building...). But this initiative remains isolated (Brémond et al., 2013) and has not yet been extended to other economic sectors. In practice, thee assessment of business interruption uses simplistic models or even static ratio of direct damage and needs to be improved (Meyer et al., 2013; Kreibich and Bubeck, 2013).

Indirect damage is nonetheless evaluated but in a totally different perspective with macroeconomic methods. Many studies on the evaluation of indirect impacts of disasters on national and regional economies have been conducted (Carrera et al., 2015). Methods classically used for the evaluation of indirect flood damage are (Meyer et al., 2013):

- Input-Output (IO) models (Hallegatte, 2008; Van der Veen et al., 2003; Hallegatte, 2014; Crawford-Brown et al., 2013; Xie et al., 2012), which can be regionalized (Marin and Modica, 2017);
- Computable General Equilibrium (CGE) models (Xie et al., 2014; Rose and Liao, 2005; OCDE, 2014);
- Intermediary models between IO and CGE (Hallegatte and Ghil, 2008).

These macroeconomic approaches estimate the links between economic sectors at a large scale. They are powerful to estimate the potential damage of extreme events at national scale. Nevertheless, Meyer et al. (2013) underline the lack of knowledge in macro models to link the estimation of direct costs with that of indirect costs. Moreover, at smaller scale, e.g. to support decision making for flood prevention at the watershed level, these models are not appropriate (Meyer et al., 2013).

To go further, one option is to better characterize how production processes are affected by flood processes. This hat not yet been studied in detail. For instance, approaches like agent-based modelling (ABM) have been identified as a promising way to improve the evaluation of flood impacts in this direction (Safarzyńska et al., 2013), but no application has been done yet.

However, the literature on business recovery and resilience of economic activities introduces interesting elements (Rose and Krausmann, 2013). Some ex post analyses of disasters on supply chains (Haraguchi and Lall, 2015; Chongvilaivan, 2012; Linghe and Masato, 2012) have been carried out after the Thailand's flood in 2011. In particular, Haraguchi and Lall (2015) showed that damage propagation in a supply chain depends on the location of productive entities and on the links between the entities. They identify the challenges to better understand robustness of supply chains as follows: identifying critical nodes and links, direction of links in these complex networks, assessment of the effectiveness of bridge ties. This highlights the need for an in-depth understanding of the production processes involved and a characterization of the links between entities to finely determine indirect damage. However, current economic models that have been developed to evaluate flood damage fail to consider the complexity of these interactions, which may be impacted also by the flood itself and the different scales involved. Dealing with the complexity of these interactions requires specific modelling approaches.

In this article, to clarify our position, we introduce the notion of complex productive systems (CPS). CPS can be an economic entity whose productive components have different locations, or it can be a collection of economic entities interacting in a global production process (like a supply chain). We tackle the following question: To what degree modelling interactions within or between economic entities can improve flood damage estimation compared to current approaches which do not take into account any of these interactions? In section 2, we explain why we have chosen to focus our analysis on a cooperative winemaking system (CWS), an example coming from the agricultural sector. We present the main characteristics of this system, and the origin of the data used in the article. In section 3), we present our methodology, based on the use of the COOPER model, an ABM model we developed to represent how the CWS is impacted by floods. We also explain how we use it to perform the comparison between current practice, where no interaction is taken into account, and other modalities where only partial interactions (within economic entities) or full interactions (both within and between economic entities) are taken into account. We give the characteristics of the simulations we perform, and explain how we deal with the question of heterogeneity between economic entities. In section 5, we analyze the differences of damage over the CWS under the three modalities of the model (no interaction, partial interactions, full interactions), when economic entities are considered as homogeneous. The analysis is completed by results of section 6, where economic entities are heterogeneous. Finally, we discuss these results in section 7, focusing on the implications of our results for damage assessment practice, the generalization of results to other complex productive systems, the limits of the approach we proposed, and some perspectives to go further.

2. Case of application

2.1. Flood and agriculture

Damage to the agricultural sector rarely represents an important share of total flood damage in terms of economic value. Nevertheless, considering an example from this sector can be profitable. First, the agricultural sector is very often organized with a lot of interactions between different economic entities (farms, suppliers, equipment providers, food processing companies, traders). Even at the level of farms, the internal organization characterization is important to well estimate how floods impact the activity (Posthumus et al., 2009; Morris and Brewin, 2014). Secondly, the fact that the damage to agriculture is not that important is also counter-balanced by the fact that agricultural areas may be targeted to be more exposed to floods in order to protect urban areas (Brémond et al., 2013). As a result, agricultural areas may be negatively impacted by projects, and understanding in details how the agricultural sector is damaged is particularly important when designing compensation schemes due to such risk transfers (Erdlenbruch et al., 2009). Thus, there is a practical interest in comparing damage estimation that takes into account interactions within the agricultural sector with the current practice.

2.2. Cooperative Winery System (CWS)

In this article we have chosen to study a cooperative wine system (CWS) as a particular example of complex productive system (CPS). CWS puts into interaction two types of economic entities: winegrowers (farm) and winery cooperatives. It defines a shared property of the production means between all winegrowers that are part of the organization. This way, all costs, risks and revenues are split according to a rule determined within each CWS. The winery cooperative centralizes the production, stocks and sales of all its members, and distributes among them the result at the end of the year. This structure is very well adapted to build an agent-based model since not so many economic interactions are to be modeled, and representing them as simple and straightforward relations is not too sharp a simplification. The interactions between the entities in the CWS are illustrated in Figure 1.

2.3. Case studies

The modelling approach relies on empirical data collected on two areas located in the South of France, where CWSs are traditionally very common. More precisely, this study relies on the operation of CWSs present in the Aude and the Var counties (Figure 2).

Aude and Var counties produce respectively 11% and 5% of the French red and rosé wine (Agrimer, 2017). In both areas, the wine sector represents a critical share of local economy. The part of agricultural areas dedicated to wine growing represents 50% in Var and 37% in Aude (Agreste, 2010). Although some wine growers are independent, the prevailing organization to process winemaking is the CWS: it represents respectively 62% and 46% of the wine production in Aude and Var.

These two counties have endured major flood events. In 1999, the Aude river watershed suffered one of the major flood disasters of the past few years in France (European Environment Agency, 2010). Losses were

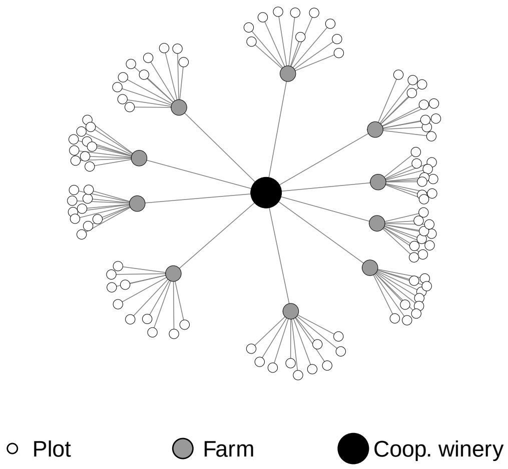


Figure 1: Cooperative Winery System (CWS)

estimated at €620 million. The Aude county was the most impacted, with damage rising to €363 million (58% of the total damage in the Aude watershed). The damage to the agricultural sector was estimated at €33 million which represents 9% of the total damage and 70% of the damage to the businesses sector (Vinet, 2003). The main agricultural activity impacted in the department was viticulture (Bauduceau, 2001).

The Var county was impacted several times by floods in the last years. The flood of June 2010 in the Argens river basin was specially dramatic: 23 fatalities and €1.2 billion in material damage (Collombat, 2012). 250 farming businesses were impacted, leading to a damage estimated at €150 million (12.5% of the total). In average, farmers lost 57% of yields and 40% of perennial plants (Chambre d'agriculture Var, 2014).

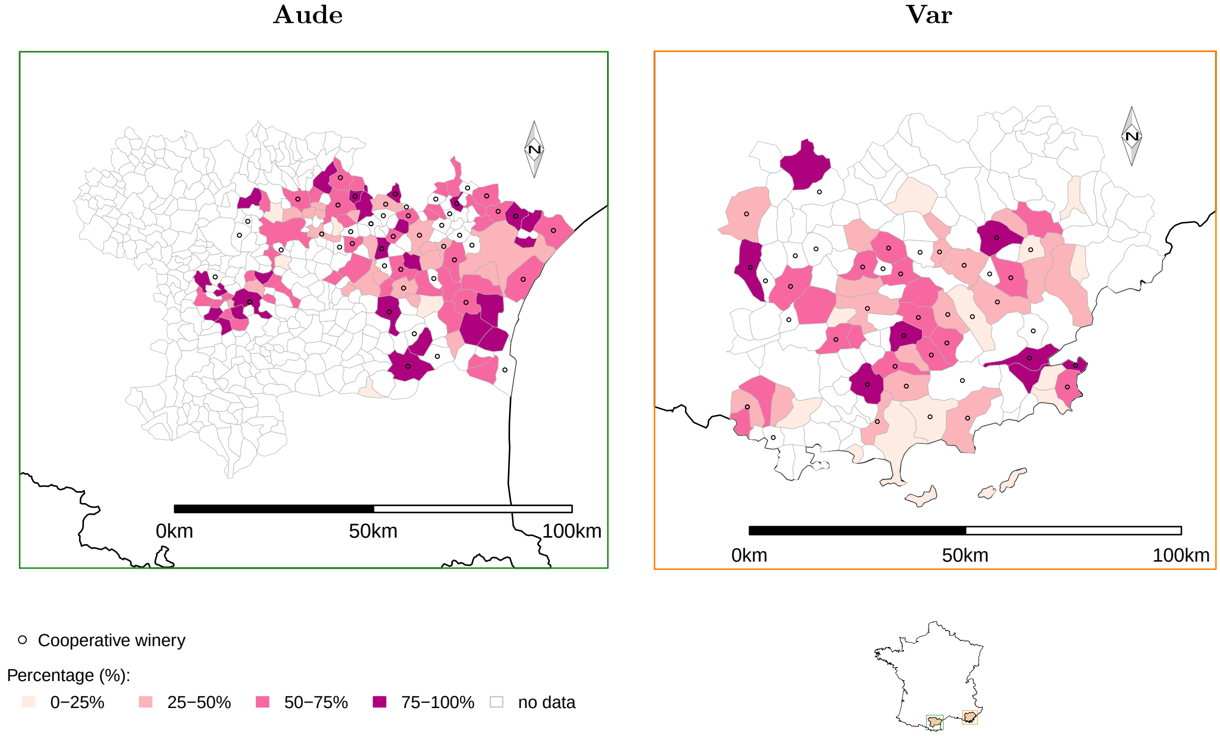
2.4. Data collection

On these two areas, qualitative interviews were conducted with wine growers and cooperatives during the project RETINA[2] which investigates more broadly adaptation to flood risk at several scales. Technical and financial data were also collected from technical institutes such as Agricultural Chambers. One of the goals of these data collections was to identify common patterns and processes related to CWSs, which are detailed in the following paragraphs.

Processes for wine growing. The sequence of technical operations done by the farmer to grow wine is based on technical information from Agricultural Chambers. These tasks may be done internally (only with resources available in the farm) or externally (mobilizing external resources). The extra costs if tasks are done externally are based on technical literature (CER, 2009; CER FRANCE, 2017). The loss of yield resulting from tasks undone is based on expert knowledge (Brémond, 2011).

Processes for winemaking and cost sharing. The schedule of technical operations done by the cooperative to make wine is based on interviews performed with cooperatives within the RETINA project. The costs of winemaking operations and the rules for cost sharing among wine growers is based on technical literature (CER, 2009; CER FRANCE, 2017).

[2]RETINA stands for *Résilience des territoires face à l'inondation. Pour une approche préventive par l'adaptation post-événement*, and was funded by the French ministry in charge of environment through the call "Risque Décision Territoire" (RDT).



Remark: Percentages give the part of production from cooperative wineries in the total production, at commune level.
Source: Data from France Agrimer (2012), treated by Nortes D.

Figure 2: Wine production orientation in case studies

Flood impacts. Material damage is modelled using existing damage functions adjusted to the local context knowledge (Brémond, 2011; Rouchon et al., 2018b). The damage coming from the disorganization of production processes is detailed in the section 3

Patterns of exposure. In both counties, contrasted case of exposure were encountered. This helped identify relevant configurations of CWS to analyze, which are detailed in section 4. For instance, in Var and in Aude, some wineries were totally safe but some others were severely impacted by flooding with material damage to equipment (e.g. bottling chain) and stocks (wine in vats) reaching huge monetary amounts (until €5 million). Also, some wine growers had plots and building impacted by flooding while others only endured damage on plots. Finally, the proportion of plots and buildings in flood-prone areas was established in Aude and in Var, and used as a baseline in the simulations performed for this article.

3. Model

The model used to simulate total flood damage on a CWS is the COOPER model. An extensive description of the model is available on line in a CoMSES repository. In this section, we present its main characteristics, and how we used it for the purpose of the article.

We chose to use agent-based modelling to build COOPER, as it is generally recognized as the best way to take into account interactions, spatial repartition and temporal dynamics in analysis (Tesfatsion, 2006). The theoretical framework relies on the description of a system as a collection of entities that are either passive (being acted on) or active and taking decisions to transform themselves or the other entities (through communication for example). Thus entities can interact, in the sense that the action of one can transform the environment and others. The models are used in simulations, in which the consequences of actions can be seen in time. It has been used in particular in discussions on agricultural practices and land use change for a long time (Polhill et al., 2001).

3.1. General overview

The COOPER model represents a CWS as two types of economic entities in interaction: farms (vine-growers) and a cooperative (winery). The CWS aims at producing wine as output through two interlinked processes: grape growing at farm level and winemaking at cooperative level. Each farm is linked to exactly one cooperative, to which they send their vine product, from which they receive the net result of wine selling. These interactions at system level are called hereafter "between activities" interactions or "between" interactions.

In the CWS, there are three types of material entities: farms land plots, farms buildings and the cooperative building. In this article we will use the term material component to refer to material entities. Land plots are linked to one building through the organization of one farm. It is assumed that all farms equipment, stocks and harvested products are located within the building. Links within farms imply interactions at farm level, called hereafter "within activity" interactions or "within" interactions. These "within" interactions represent the inter-dependency between the farm material components (plots and buildings), which are spatially spread. Cooperative owns only one building, were all equipment, stocks, products are supposed to be located. Thus, no interactions at cooperative level are explicitly considered as all possible sub-components are modelled as one indistinct material component, located in the same place.

The productive process may be disrupted because of the flood process, which can impact material components owned by economic entities. When it happens, material damage occurs, which generates reparation costs. It also alters the normal performance of the system, hence the expected flows of inputs and outputs of the productive process. Induced damage is defined as the balance between altered flows compared to normal flows. Total damage supported by the CWS is thus the sum of material damage and induced damage.

3.2. Time and spatial representation

In the COOPER model, the simulations last 30 years, each year being made up four seasons (spring, summer, autumn, winter). The CWS material components are located in a virtual territory, divided into cells. Each of these cells can host only one material component, either one farm plot, one farm building, or one cooperative building.

3.3. Production process

3.3.1. Grape growing process

Farms perform year-round grape-growing tasks on their own plots. Such tasks are organized according to a seasonal schedule, starting in winter. Farms replant their plots when the vineyard gets too old (30 years). Plots are unproductive during the first 5 years after replanting. Each farm covers its own vine-growing costs.

Altered process in case of flood. Farm may follow two tactics in case of flood:

- **internal** When the building of one farm with internal tactic is flooded, the disturbance implies that some tasks are not performed, even on non flooded plots: their costs are saved, but some yield is lost.
- **external** Farm pays for external assistance to conduct the tasks that it cannot make as usual. The associated disturbance implies that the cost of these tasks is increased.

3.3.2. Wine making process

The cooperative is in charge of producing wine with the input provided by farms and commercializing it in markets. It also follows a seasonal schedule: in autumn it receives the grapes coming from its associated farms. That input is transformed into wine during winter, and sold in spring. It is assumed that there is no stock in summer. The cooperative shares each year the revenues from the commercialization minus the wine-making cost incurred, proportionally to the quantity of grape given by each farm. Because of the design of the cooperative process, winemaking costs depend on the total grape input in a non-proportional relation. There are fixed costs and proportional costs.

3.4. Flood process

3.4.1. Intensity of flood

Floods are defined by two parameters: extent and season of occurrence.

The territory has been divided into two different areas: one subject to floods (flood-prone area), one not. For the cells inside the flood-prone area, we use their distance to the river (from 1 to 100) to precise their location. This distance is also used to give the extent of a given flood. So, for instance, a spring flood of extent 50 impacts all cells located within the band [1–50] in the flood-prone area in a spring season.

In this study, only one flood may occur over the whole period of simulation, thus a spring flood designates a flood occurring in the first spring after the simulation begins.

3.4.2. Impacts of flood

Floods can impact simultaneously farms plots, farms buildings and cooperative building. They generate first material damage and then disruption of activity compared to the normal processes.

Material damage on farms plots and associated disruptions. It is threefold: i) damage to soils, considered independent of the season; ii) damage to yields, dependent on the season; and iii) damage to plants, stochastic and dependent on the season (plant destruction depends on a probability function, which is not the same all along the year). If plants are destroyed, the plot needs to be replanted and the yield of that plot is lost. When plants get destroyed, replanting new ones is needed, probably before what was expected because of the age of plant. This effect is measured by comparing the disrupted net income flow of the CWS over the whole duration of simulations (30 years) with what would have occurred without flood.

Cost savings at farm level. On the plots where the yield has been destroyed, savings in vine-growing costs are estimated. Whether by plant destruction or by direct damage to the yield, as soon as the plot loses all its yield, the farm stops performing vine-growing tasks in said plot and saves the cost of the remaining tasks.

Material damage to the farms buildings. Material damage to farms building includes also the material damage to farms equipment. Moreover, the damage to buildings is simplified in the model and remains constant whatever the intensity of the flood.

Disruptions due to material damage to the farms buildings. Impacted buildings need to be repaired. Until such reparations are done, they lose their functionality and the vine-growing tasks can not be done by the farm. The damage related to this functionality loss depends on the farm tactic (cf subsection 3.3.1). It is estimated by an increase in vine-growing costs for the external tactic and a loss of yield for the internal tactic.

Material damage to the cooperative building. As for farms buildings, the cooperative building includes also its contents: equipment and stock (grape or wine). It is assumed that the cooperative stocks grapes in its building in autumn, then wine from winter to spring. When a flood occurs, it damages the building and completely destroys the stock present at this time.

Disruptions due to damage to the cooperative building. As for farms ones, impacted cooperative building need to be repaired. Until such reparations are done, they lose their functionality and, depending on the season, grape collection (in autumn), production (in winter) or commercialization (in spring) cannot be performed.

Cost savings at cooperative level. Fixed winemaking costs are never saved. Proportional winemaking costs are saved depending on the season of occurrence of the flood: wine transformation costs may be saved or not, commercialization costs may be saved or not. It is important to notice that the structure of winemaking cost, and the way these costs are shared between farms, create an implicit interaction between all farms. For instance, if one farm loses all its yield, it won't have any revenues from the cooperative, and won't have to support its "normal" share of fixed costs. Thus, all other farms will be indirectly impacted because they will now share the fixed costs.

3.5. Use of COOPER to compare methods of flood damage evaluation

In non-flooded plots, tasks are realized completely and at the normal cost, as if the buildings of the corresponding farms were not flooded.

3.5.1. Modality of interactions

To estimate the influence of interactions in flood damage evaluation, we compare three modalities of interactions, schematically represented in Figure 3:

no interaction The damage is assessed without considering any "within" nor "between" interactions. This modality corresponds to current practice for damage assessment.

partial interaction The damage is assessed considering "within" interactions but not "between" interactions. This modality follows partially observations from Posthumus et al. (2009), implemented by very few authors (Brémond et al., 2013).

full interaction The damage is assessed considering all interactions.

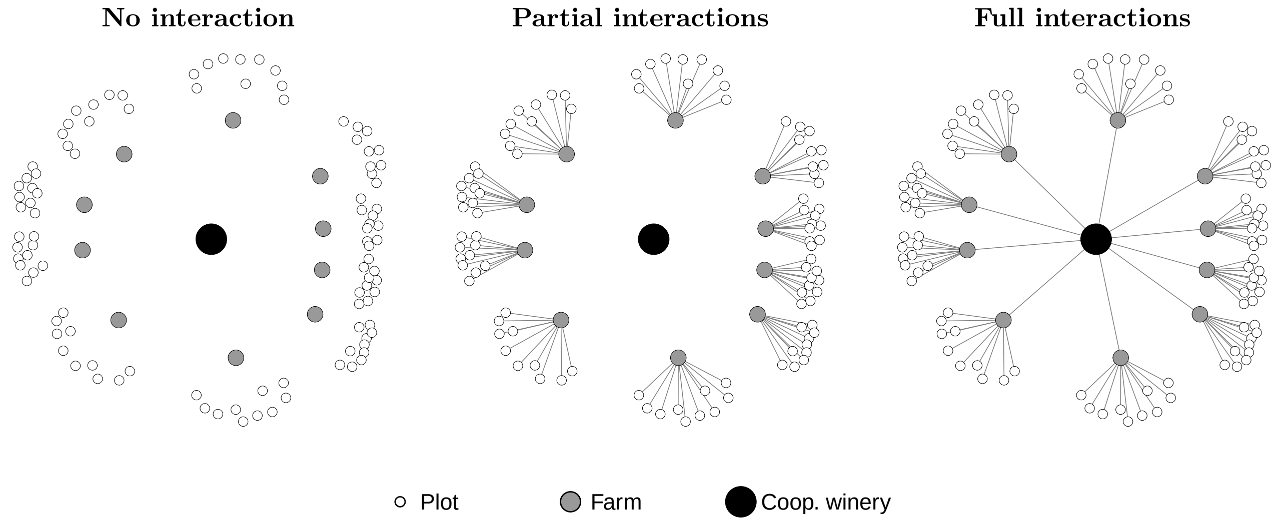


Figure 3: Levels of interaction

3.5.2. Assumptions

In the *full interaction* modality, tasks to be performed on plots depends on the availability of the building and tactic of the corresponding farm. In the *no interaction* modality, it is necessary to explicit how these tasks will be impacted. We have chosen to follow the implicit assumption that is made in current practice:

A1 In non-flooded plots, tasks are realized completely and at the normal cost, as if the buildings of the corresponding farms were not flooded.

Under assumption A1, grape production depends only on what occurs on plots. The damage at farms level can be estimated separately on plots and farms buildings.

In the *full interaction* modality, the cooperative receives grape production depending on how farms were effectively damaged, which allows to calculate the loss of wine products and impacts on winemaking costs. In the modalities *no interaction* and *partial interaction*, it is thus necessary to explicit how we treat these indirect impacts. As previously, we have chosen to follow implicit assumptions that are made in current practice:

A2 The winery receives the quantity of grapes computed as if no farm buildings or plots were flooded.

A3 The wine production cost is computed as if no farm buildings or plots were flooded.

Table 1: Modalities of interactions and assumptions for damage evaluation

Modality	Assumptions
no interaction	A1 + A2 + A3
partial interaction	A2 + A3
full interaction	—

Table 2: Common characteristics for location of material components in simulations

Element	Number of elements in		**Total**
	Flood area	Safe area	
Winery	depends	depends	**1**
Farm	10	40	**50**
Plot	150	350	**500**

Under assumptions A2 and A3, wine production and its valorization depend only on what occurs on the winery cooperative building. Damage at farms level can be estimated separately on plots and farms buildings.

Table 1 sums up the hypothesis that are done depending on the modality of interactions.

4. Simulation protocol

4.1. Spatial repartition of material entities

All simulations presented in this article share the following characteristics (see Table 2):

- One cooperative is present in the system.
- 50 farms are linked to the cooperative, 20% of which have their building located in the flood-prone area.
- 500 plots are exploited by the farms, 30% of which are located in the flood-prone area. Their assumed size is 1ha each.

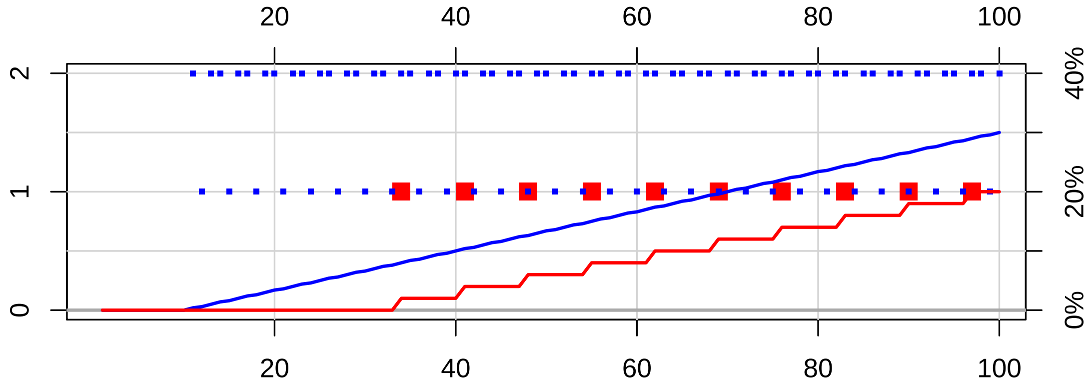
Within the flood-prone area (see Figure 4), 150 plots (30% of 500) are randomly distributed in cells within the band [10–100]. As for farms buildings, 10 are distributed within the band [30–100].

Spatial location is key in the assessment of flood impacts and their spreading along the system. To avoid the noise from variations in location in our simulations, the physical location of all material components belonging to farms (buildings and plots) remains the same for all the different simulations. This ensures that farms material components are always impacted in the same way by a flood of given extent and season.

Concerning the location of the cooperative building, we did two sets of analysis: one with the cooperative building located at the position 1 in the flood-prone area (and so always flooded), one with the cooperative building located outside the flood-prone area (and so never flooded).

4.2. Configurations of interactions

The configuration of the interactions has been realized by controlling the heterogeneity of farms. There are two main ways to modify the CWS. The first one is by adding some heterogeneity in the size of farms (having some big ones and some small ones). The second one is by adding some heterogeneity in the exposure of the plots (having some farms with a lot of plots exposed and some farms with a lot of plots safe from floods).



Legend: blue is for plots, red for farms buildings. The left y-axis gives the number of elements located at position of corresponding points. The right axis gives the corresponding cumulative percentage given by lines. For example 10% of the plots (blue lines) are located in the floodplain in a position of 40 or under, 2 plots are present at this precise position.

Figure 4: Spatial distribution of farms buildings and plots inside the flood-prone area

To illustrate the influence of both of these effects, we have chosen to compare the following configurations:

homogeneous In this configuration all farms have the same number of plots (10). The proportion of plots in the flood-prone area is equivalent between each farm.

size In this configuration, 10 farms are big (30 plots), 40 farms are small (5 plots). The total number of farms and plots remains identical to the homogeneous configuration. The proportion of plots in the flood-prone area is equivalent between each farm.

exposure-best In this configuration, all farms have the same number of plots. The farms which building is in the flood-prone area have also all their plots in this area. The remaining plots in the flood-prone area are more or less equally distributed between the remaining farms.

exposure-worst In this configuration, all farms have the same number of plots. The farms which building is in the flood-prone have all their plots out of the flood-prone area. Plots in the flood-prone area are more or less equally distributed between the remaining farms.

size-exposure-worst In this configuration too, 10 farms are big (30 plots), 40 farms are small (5 plots). All the big farms have their building in the flood-prone area but no plots inside. Thus, all plots in the flood-prone area are associated to small farms, which building is not in the flood-prone area.

size-exposure-best In this configuration too, 10 farms are big (30 plots), 40 farms are small (5 plots). 10 small farms have their building and all their plots inside in the flood-prone area. The remaining plots located in the flood-prone are allocated between the remaining small farms. The 10 big farms are not exposed at all to flooding.

Figure 5 gives a schematic representation of these configurations, while Table 3 gives the main characteristics of the spatial distribution of the different configurations.

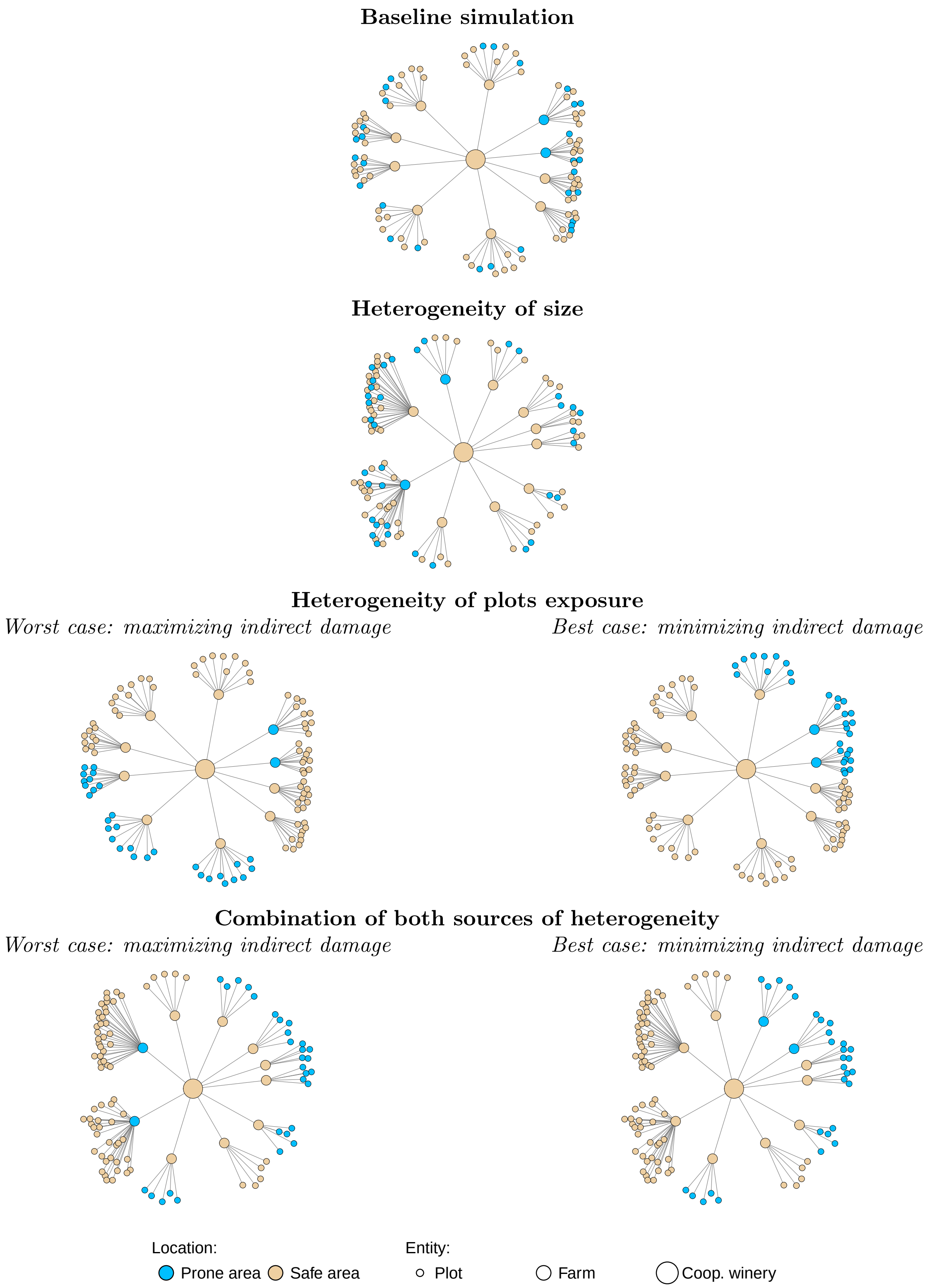


Figure 5: Levels of heterogeneity

Table 3: Main spatial distribution characteristics of the compared configurations

configuration	size	exposure	n_{farms}	building	n_{plots}	exposed plots
homogeneous	homogeneous	homogeneous	10	exposed	10	32%
			40	safe	10	30%
exposure-best	homogeneous	heterogeneous	10	exposed	10	100%
			40	safe	10	12%
exposure-worst	homogeneous	heterogeneous	10	exposed	10	0%
			40	safe	10	38%
size	heterogeneous	homogeneous	8	exposed	5	38%
			32	safe	5	32%
			2	exposed	30	33%
			8	safe	30	28%
size-exposure-worst	heterogeneous	heterogeneous	0	exposed	5	–
			40	safe	5	76%
			10	exposed	30	–
			0	safe	30	–
size-exposure-best	heterogeneous	heterogeneous	10	exposed	5	100%
			30	safe	5	66%
			0	exposed	30	–
			10	safe	30	0%

Remark: the first column gives the name of the configuration, the column "size" (respectively "exposure") indicates whether this configuration is considered as homogeneous or heterogeneous in terms of size of farms (respectively in terms of proportion of exposed plots). Following columns give quantitative indications. For the corresponding configuration, there is n_{farms} farms that have their building in the situation given by the column "buidling", connected each to n_{plot} plots. These farms have a proportion of exposed plots given by the column "exposed plots".

4.2.1. Simulations

The simulations used in section 5 follow the experimental design of Table 4. For each combination of tactic, modality, and exposure of cooperative building, simulations are made for all possible floods in terms of season and extent (with a step of 5).

The simulations used in the section 6 follow the experimental design of Table 5. For each combination of tactic, modality, and exposure of the cooperative building, simulations are made for all possible floods in terms of season and extent (with a step of 5).

As stated in section 3.4, our model presents stochastic processes to determine the impacts of floods on plots. To control for this aspect of the model, each flood scenario is simulated 50 times. The results presented in sections 5 and 6 correspond to the mean of these 50 repetitions.

5. Influence of interactions

In this section, we analyze how important the consequences of considering interactions between entities of a CPS may be in terms of flood damage valuation. We focus on a particular configuration of links, named *homogeneous*, to discuss more precisely what different levels of interactions bring to current practice, where no interaction is taken into account.

The results are shown in Figure 6. In this figure, the different lines show the relative differences of damage between the *partial interaction* (dashed lines) or *full interaction* modality (full lines) and the *no interaction*

Table 4: Experimental design for assessing importance of interactions

tactic	interaction modality	cooperative winery
external	*no interaction*	safe
external	*no interaction*	flooded
external	*partial interaction*	safe
external	*partial interaction*	flooded
external	*full interaction*	safe
external	*full interaction*	flooded
internal	*no interaction*	safe
internal	*no interaction*	flooded
internal	*partial interaction*	safe
internal	*partial interaction*	flooded
internal	*full interaction*	safe
internal	*full interaction*	flooded

For all modalities, 50 replicates have been made for each season (spring, summer, autumn, winter) and for flood extent from 15 to 100, increasing with a step of 5. In total this experimental design leads to 43 200 different simulations. 7 200 are shared with experimental design of Table 5.

modality, considered as the baseline. The results are split in sub-figures to show the effect of the seasons and of the tactics. The red lines correspond to the case where the winery building is flooded, and the blue lines to the case where it is not flooded (safe).

5.1. Qualitative analysis

Figure 6 shows two types of implications of assumptions A1 to A3 that may explain the differences between the different modalities.

The first type of implications comes from the fact that, when all interactions are not considered, some indirect damage is not spread, which leads to an under-estimation of damage for the *no interaction* and *partial interaction* modalities compared to *full interaction* modality. When the winery building is safe, this is observed in all seasons: the blue solid lines (*full interaction*) are always above the blue dashed lines (*partial interaction*), which are above 0 (*no interaction*). When the winery is flooded, this is also observed in all seasons but atumn: the red solid lines are always above the red dashed lines, which are above 0, except in autumn where the red solid lines are below 0.

The second type of implications is observed in autumn, when assumption A2 leads to some double counting, and thus to an over-estimation of the damage for the *no interaction* and *partial interaction* modalities compared to *full interaction* modality. Wine production depends on the grape production transmitted by farms, and thus on the losses of grape endured at farms level. With assumption A2, (*partial interaction* and *no interaction*), wine production present in the winery cooperative in autumn is independent of losses occurring at farms level. Thus, with assumption A2, a part of the wine production that is not in the winery building is considered lost. The bigger is the flood, the hight the losses at farms level, the more important the double counting. In other seasons there is no such double counting because what is present in the winery building does not depend on what is currently present in the farms. For instance in winter, the wine production present in the winery building depends on what was harvested in autumn, but not on the emerging production on plots which will be harvested the next season.

Coming back to explanations of the under-estimation of damage in the other cases, we can notice that whether or not the winery building is flooded has no impact on the the sign of the differences, even if the magnitude is much greater when the winery building is not flooded. This difference of magnitude comes

Table 5: Experimental design to assess the importance of links configuration

interaction configuration	tactic	interaction modality
homogeneous	internal	*full interaction*
size	internal	*full interaction*
exposure-best	internal	*full interaction*
exposure-worst	internal	*full interaction*
size-exposure-worst	internal	*full interaction*
size-exposure-best	internal	*full interaction*
homogeneous	external	*full interaction*
size	external	*full interaction*
exposure-best	external	*full interaction*
exposure-worst	external	*full interaction*
size-exposure-worst	external	*full interaction*
size-exposure-best	external	*full interaction*

For all modalities, 50 replicates have been made for each season (spring, summer, autumn, winter) and for flood extent from 15 to 100, increasing with a step of 5. In total this experimental design leads to 43 200 different simulations. 7 200 are shared with experimental design of Table 4.

from the fact that material damage is much more greater when the winery building is impacted, and thus the relative difference is mechanically lowered.

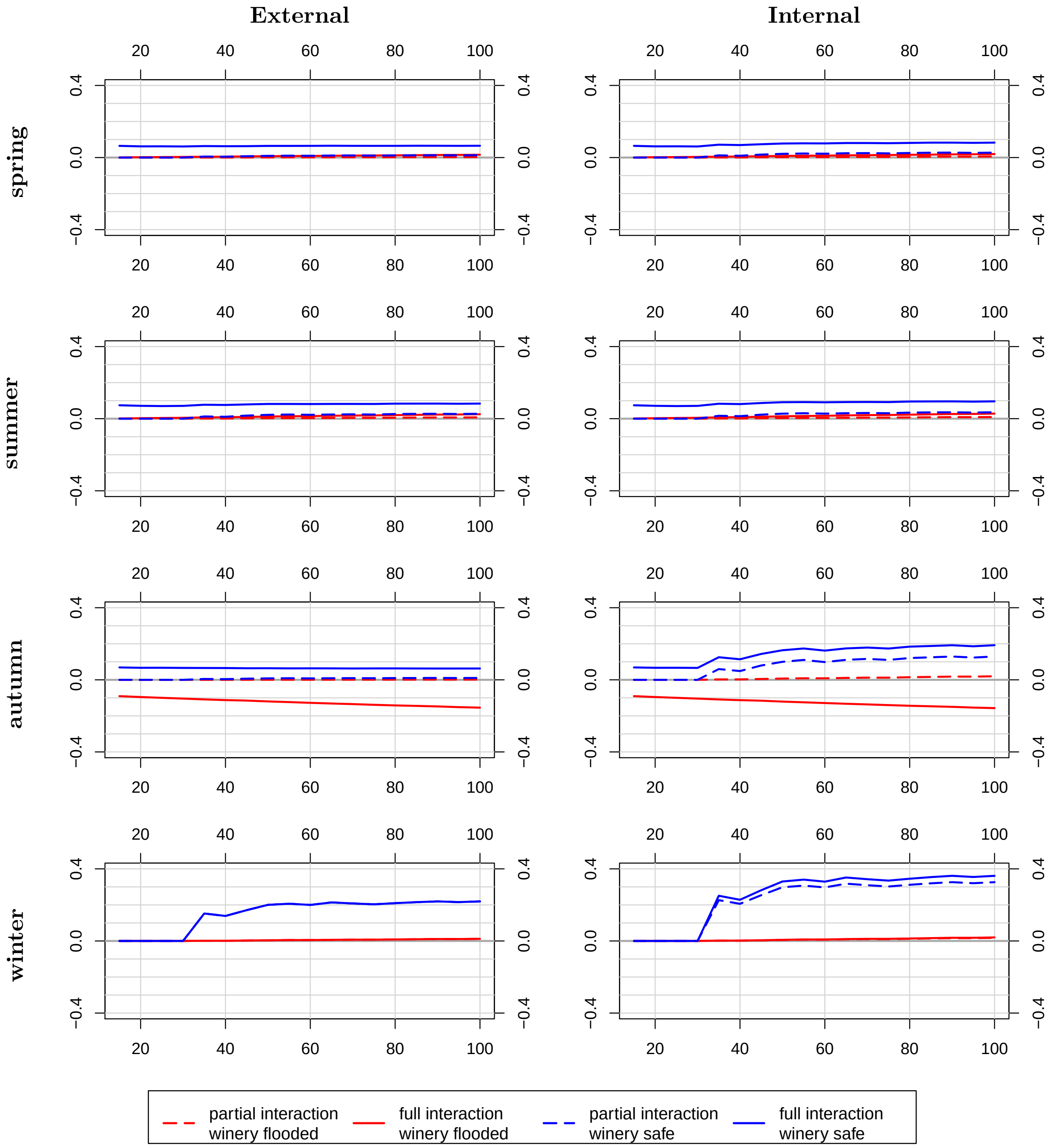
In spring and in summer, differences between the *partial interaction* and *no interaction* modalities exist but are less important than between the *full interaction* and *partial interaction* modalities. During these seasons it is assumption A3 that leads to this statement: for the *partial interaction* and *no interaction* modalities, winemaking cost of the year following the flood are over-estimated, because the losses in grape production occurring at farms level are not considered for their estimation. This is also observed in autumn.

In winter, there is no losses in grape production coming from flooded plots. Losses in grape production only occur for farms following the internal tactic, when their building is flooded, which implies that some tasks are not performed. It is assumption A1 that explains the difference. That is why dit starts when the flood extent is greater than 30 (first building impacted). The fact that the difference between *partial interaction* and *no interaction* modalities is noticeable in winter is related to the importance of the tasks performed in winter in terms of loss of yield. This is also the case in autumn, but not in spring and summer. In these last two seasons, tasks are less important for what will be yielded, and also plots are more vulnerable: losses in grape production are more directly linked to flooding of plots than to flooding of farms building. For the external tactic, it is also the assumption A1 that explains the difference, but the impact is not loss of grape, but over-cost of grape cost. In Figure 6, this over-cost is important only in winter. In this case (external tactic, winter), in Figure 6, curves for *partial interaction* and *full interaction* are matching exactly.

5.2. Quantitative analysis

First, differences when the winery building is flooded are growing with the importance of floods, but remain negligible, except in autumn. This comes from the fact that the material damage coming from the winery building is very important. In autumn, double counting leads to a difference of 10% to 20%, increasing linearly with number of plots flooded, and thus with flood extent (because of the spatial configuration chosen, see Figure 4).

When the winery building is not flooded, in spring, summer, and autumn, differences are about 10%, increasing up to 20% in autumn for the internal tactic when farms buildings are flooded. In winter difference are negligible till no farms building is flooded, otherwise it is about 20% for the external tactic and 40% for the internal tactic.



Remark: In each figure, the x-axis indicates the flood extent; the y-axis corresponds to the relative difference compared to the baseline simulation (*no interaction*, tactic depending on column).

Figure 6: Implications of the level of interactions taken into account for damage assessment (homogeneous case)

It is important to notice that for spring and summer seasons, differences are more marked between *partial interaction* and *full interaction*, than between *no interaction* and *partial interaction*, independently of the chosen tactic. This is also the case in autumn, but only for the external tactic. This means that in these cases it is more important to clarify the links between economic entities (farms and cooperative) than within economic entities (plots and farms building). In winter, for both tactics, and in autumn for the internal tactic, there is a clear difference between the three modalities. The gap between the *no interaction* and *partial interaction* modalities is more important than the one between the *partial interaction* and full interaction modalities. In these cases, it is thus more important to clarify the links within economic entities (between material components) than between economic entities. Finally, as floods may occur in any season, it is not possible to give an univocal conclusion on which type of interactions is more important to consider. Both are to be taken into account.

6. Influence of configurations of interactions

The analyses presented in section 5 apply to a particular configuration of these interactions. All farms possess exactly 10 plots (homogeneous size) and have, more or less, the same ratio of plots located in the flood-prone area (homogeneous exposure). For the *no interaction* modality, it is of no importance to know precisely to which farm plots belong: we explained that, with this modality, to assess damage, it is assumed that the farm to which a plot belongs is not flooded. This is not the case, neither for the *partial interaction*, nor for the *full interaction* modalities. Thus, even if all material components remain exactly at the same location, the way they are linked may have an influence on flood damage. In this section, we propose to analyse this influence.

In section 5 we have also shown that the influence of interactions is the highest when the cooperative winery is not flooded. In the current section, we thus detail the case when the cooperative winery is not flooded (Figure 7).

First, we quickly analyse, without any additionnal figure, the case when the cooperative winery is flooded. In this case, relative differences are very similar between configurations. In fact, damage coming from the winery cooperative is prominent and any difference that shall come from the heterogeneity at farms level is compensated at winery cooperative level. This statement has a direct implication for the significance of the double counting bias exposed in last section: it is almost independent of the heterogeneity at farms level (about 12% from the *no interaction* modality). This is also true for other seasons for which, the damage propagation bias is negative, but almost negligible ($1-2\%$ in spring, $1-3\%$ in summer, $0-2\%$ in winter).

6.1. Qualitative analysis

When the winery cooperative is not flooded, Figure 7 shows the relative differences of damage at the system level between simulations of configurations presented in Table 3 for the *full interaction* modality, compared to the *no interaction* modality.

First of all, it can be seen that for all seasons, the damage with *no interaction* modality is always less than the damage with the *full interaction* modality, for all configurations of links. The same bias as in section 5 is noticed for spring, summer and autumn: there is a postivie difference of about 10% between simulations with full interactions and simulations with no interactions. Differences between the configurations of links appear when the first farm building is flooded (floods of extent ≥ 30) and become more visible when the number of these buildings gets greater.

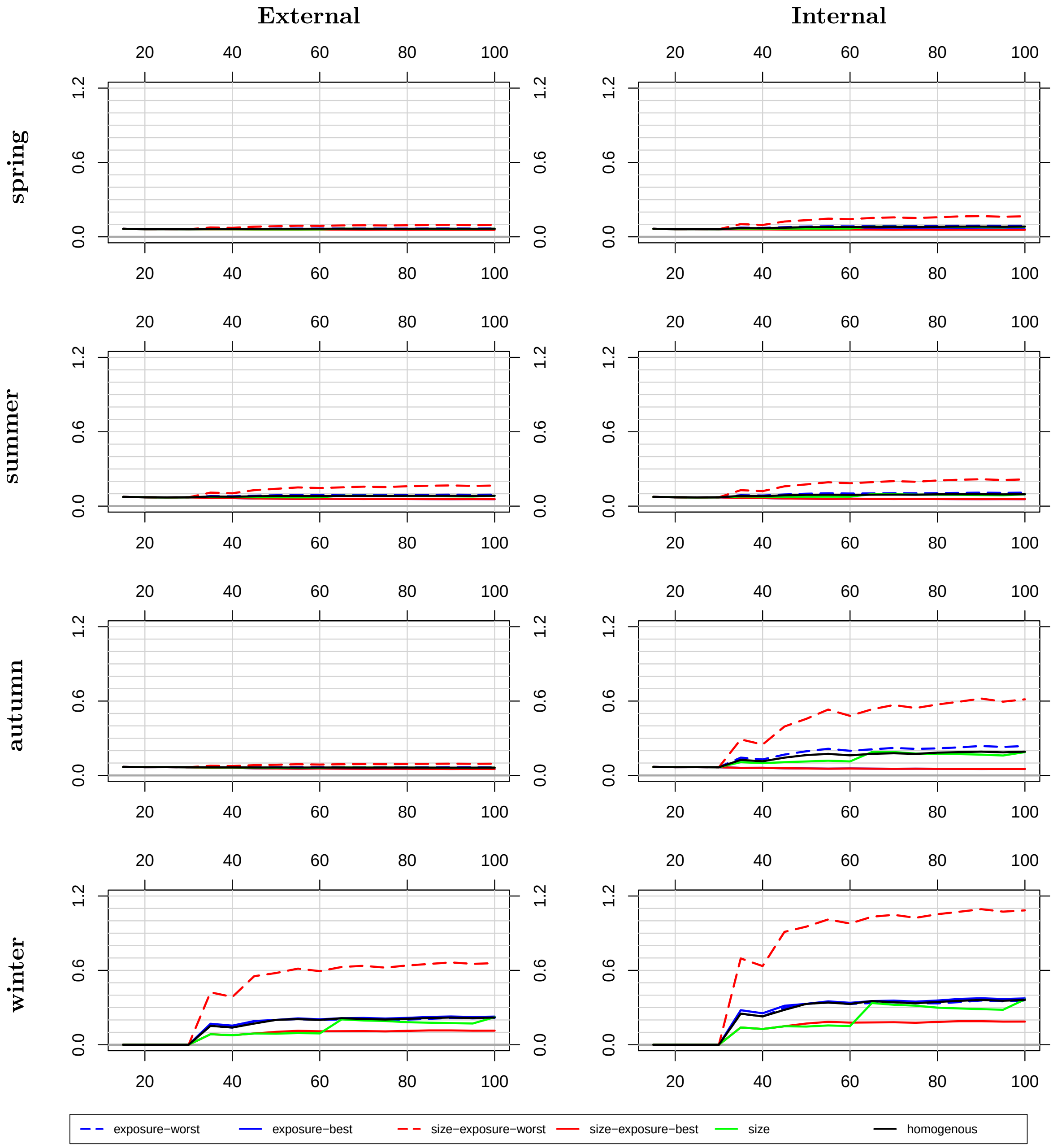
The *size* configuration (green line), which introduces big farms and small farms, with comparable exposure, does not introduce a big difference with the *homogeneous* configuration (black lines) where all farms are of the same size with equivalent exposure. This is also true for the two configurations that introduces an heterogeneity in terms of exposure: *exposure-best* (solid blue lines) and *exposure-worst* (dashed blue lines) but not in terms of size.

Clear differences only appear when both types of heterogeneity are introduced and combined. In this case, the configuration that gives the greatest damage is always the *size-exposure-worst* one (dashed red lines). In this configuration, all big farms have their building in the flood-prone area, but their plots are outside. When buildings are flooded, they suffer disruptions of tasks for all their production, which induces either extra costs (external tactic) or extra losses of yield (internal tactic). This is the worst configuration for such effects. The configuration that gives the lowest damage is always the *size-exposure-best* one (solid red lines). In this configuration, all big farms are totally out of the flood-prone area. Thus farms with their building in the flood-prone area are small ones, potential disruptions of tasks only concern a few plots. Moreover these plots are inside the flood-prone area and are suffering direct damage from flood, which implies that disruption of tasks is not that important. These difference are particularly noticeable in winter when a lot of tasks on plots are to be made for both tactics, and in autumn for the internal tactic when not harvesting implies a great loss of yield.

6.2. Quantitative analysis

Coming to the magnitude of differences between configurations, relative differences may be quite important. With the configuration generating the highest damage (*size-exposure-worst*), relative differences may be close to 110% in winter, 60% in autumn, 20% in summer and spring for the internal tactic, decreasing to 60% in winter, 20% in summer, 10% in autumn and spring for the external tactic. With the configuration generating the lowest damage(*size-exposure-best*), relative differences may be close to 20% in winter, about 5% in the other seasons for the internal tactic, decreasing to 10% in winter and about 5% for all seasons for the external tactic.

Compared to results from last section, it appears clearly that the configuration of links matters for quantitative analysis. To catch a significant difference, it is necessary to combine both sources of heterogeneity: in terms of size of farms and in terms of exposure of plots.



Remark: In each figure, the x-axis indicates the flood extent; the y-axis corresponds to the relative difference compared to the baseline simulation (*no interaction*, tactic depending on column).

Figure 7: Implications of the configuration of the interactions for damage assessment (Winery safe)

7. Discussion

As exposed in the introduction, current practice of damage assessment relies on the separation of entities: economic entities such as farms and cooperative wineries are considered separately, even material components such as plots and buildings within a farm are considered separately. The main motivation for such a simplification comes from how damage functions are built and how they are linked to available databases for the description of the location of stakes exposed to floods. It is relatively easy to know where buildings are located and which type of activity they host, and where plots are located and which type of culture are present. It is difficult to know which farms depend on which cooperative wineries, and which plots depend on which farms. Thus, current practice does not take into account how these entities are linked.

7.1. 'Bias' of current practice in damage assessment

When compared to a damage assessment procedure that relies on a model taking into account all possible interactions we have shown that the current practice may present two types of bias. First, in our analysis we have shown that, as expected, current practice may be affected by the fact that some interactions are mis-represented or even lacking. This leads to under-estimation of damage at the system level: as some disturbance are not spread in a proper manner, a part of the damage is not evaluated.

Secondly, our analysis has also shown a less expected effect, in contradiction with arguments of Penning-Rowsell et al. (2013b). In some cases not taking into account interactions leads to an over-estimation of damage. In fact, in current practice, as entities are considered separately, processes not taken into account, and their timing not considered, some material component may be considered present in two places at the same time, which may lead to double count some material damage.

These two types of 'bias' of current practice have no reason to be specific to the particular system we studied in this article. In fact, not considering interactions may lead to under-estimation of damage at a more global level, when some disturbances are expected between economic entities, and if no plausible substitution process is expected. This may be the case for systems organized as cooperative winemaking system where it is not allowed for some activities to change their dependency because of specifications in contract. This may also be the case for systems where substitution is not possible because of a lack of redundancy, for instance for very specific productions. This was observed by Haraguchi and Lall (2015) for the automobile and electronic industries after the 2011 flood in Thailand. Double counting of damage may also appear when some material components travel through different economic entities. In our system, the production is evolving from grape to wine, located firstly in plots, then in farms buildings, to end in the cooperative building. To have a clear idea of its location, it is necessary to have a clear idea of the production processes. It is also necessary to work at a time scale consistent with its move. There are many other sectors for which "production" is evolving and traveling.

7.2. Which interactions shall we consider?

Two types of interactions have been considered in our analysis. Within economic entities, material components are linked through internal production processes, which explicit how tasks to be performed depend on the availability of material components. Between economic entities, global production processes explicit how each economic entity relies on the others. In our analysis, we tried to estimate how important this two types of interactions may be compared to each other: are some types of interactions more important than the others? Results from section 5 show that there is not a general answer for CWSs: it depends on the season and thus on the underlying productive processes. The implication is that there is not a clear strategy that can be proposed to favor a focus on internal or external processes.

However, some economic activities have a more "ponctual" location than farms. For these activities, all material components involved in the production process may be flooded in the same condition. Thus, in this case, the characterization of internal interactions may not be so crucial.

7.3. Are configurations of interactions important?

The results of section 6 highlighted the importance of the configuration of links between material components. The demonstration is particularly relevant because we compared configurations where all material components remain at the same location, and keep their own material vulnerability. Thus, the spatial exposure of the material components remain identical, which leads to no difference when applying current practice for damage assessment. Moreover, all the rules governing the way material components are linked to each other remain identical.

At the beginning of our study, from a practical perspective, our assumption was that we could maybe assess damage without knowing exactly how farms were organized. At least in France, with current databases, it is quite easy to have a correct view of plots and farms buildings location, of the types of crop cultivated. Knowing which plots depend on which farms is more costly. Our analysis shows that if interactions are to be taken into account, their specification need to be done completely. There is not a clear strategy to estimate them in a inexpensive way that may not lead to more important bias than the benefit of taking into account interactions.

7.4. Importance of a wide exploration of events

In our analysis, we used simulations to estimate thedamage to a CWS for a wide range of flood events. This enabled us to analyze small, medium, and huge events. While we did not follow the same modeling approach as Koks et al. (2014), we think, like these authors, that it is particularly important to have this wide perspective, because mechanisms differ for events of different importance. For instance, our results show clearly that, at least for CWSs, contrary of what Kreibich et al. (2010) stated, it is not appropriate to follow the *approaches that calculate production losses using a fixed share of direct damages* (Meyer et al., 2013) for all types of events.

7.5. Main limits of the analysis

Our analysis suffers from several limits we discuss in the following section.

Whereas we developed a model that is far more complete than these used for damage assessment in current practice, the production processes were simplified in different ways. Firstly, we have chosen to simplify some temporal aspects. We split the year in four quarters, whereas processes occur at a finest time scale. We have also chosen to consider that the period of occurrence of processes was invariant, but they may differ greatly from one year to another. Secondly, we have also simplified the way both the farms and the cooperative were disorganized. For instance, we considered that the flooding of their building implied automatically that the present equipment was not available for tasks to be done within the quarter during which the flood occurred. This could be refined knowing more exactly how equipment is vulnerable to flood and how it is located within the building. Also, both farms and wineries may have some tactics to deal with floods (moving vulnerable equipment), or disruption of the production system (asking for external equipment to fulfill wine production capacity for wineries).

We also focused on some special interactions within the CWS, and completely neglected other types of interactions. There may be interactions within the CWS between farms concerning the organization of grape production (share of equipment, share of labor), either permanently or temporary when a flood occurs (solidarity between farms), also between farms and the cooperative (for instance share of labor when a flood occurs, in both direction depending of who is mostly impacted). There may be also interactions with important entities outside of the CWS, with input or equipment providers, sellers, insurers, banks. This representations of the CWS has also implications in the type of CPS we have chosen. We have chosen a CPS that is organized as a star, with a central element. This representation, while appropriate for the CWS, does not fit some other sectors which couls be best represented by a multi-nodes system, or even a no-node system.

7.6. Calibration of the model

While the model developed and the parameters chosen have been inspired from real cases, the results we presented are not calibrated on a specific case study. This could be easily done at two levels.

First, it would be possible to fix the parameters of the presented model to best represent a real case study:

- geographical location (and so exposure to flood) to all material component (plot, buildings);
- every parameter concerning the production process could be specialized at coherent level (for instance yield at plot level, cost of labor at farm level, winemaking cost at winery level);
- every parameter concerning flood damage could be specialized at coherent level.

Secondly, it would be possible to articulate our model with a hydrological / hydraulic model that would give a representation of floods scenarios in a particular place.

7.7. Adaptation of the model to real cases

regarding the development of the model, several perspectives may be possible. We develop them considering the CWS, but they can be seen as guidelines for other CPS.

First, in case a better representation of a CWS is aimed, it would be possible to specify some of the underlying hypothesis of the model. We think that it would be profitable to better represent the production processes, and especially their time representation. This would imply to have a finer time scale, for instance at a week or a month scale. Nevertheless, it is important to keep in mind that some limits may exist in the time representation of other phenomena. For instance, the time of flood occurrence is something that is quite hard to precise at a fine time scale, especially in a ex ante perspective.

It would also be profitable to enhance the way economic entities behave, mainly when enduring a flood. In the present version of the COOPER model, the behavior of economic entities follows what we encountered in our field surveys and past research experiences. Economic entities try to go back as quickly as possible to a situation that is comparable to their situation before the flood occurred: they repair every damaged material component; they follow, if it is possible, the normal production process. In "real life", depending on what they endured, on their financial health when a flood occurs, and on possible developments they may plan independently of flood, some adjustments or shifts may be taken after the occurrence of a flood. Such behavior would imply some adjustments on the damage estimation approach we followed, which consists, to be simple, in the comparison of two comparable evolution paths for the CWS: one without a flood, the other with a flood. In case of adjustments made by economic entities, it would be necessary to have a wider point of view on flood consequences. Maybe, it would be necessary to go so far as to consider flood as an opportunity for change, and balance flood damage (negative consequence) with flood benefit (positive consequence).

7.8. Improving damage assessment for what?

Applying such a methodology in economic evaluation of flood management projects requires an in depth characterization of links between and within economic entities. Characterizing these links is time demanding given the fact that no adequate GIS database exists for this task. However, for flood management projects which would increase impacts on economic entities of a supply chain, we highly recommend to use this approach to limit uncertainty on results of economic analyses.

References

Agreste. Recensement général agricole. 2010.

France Agrimer. Les chiffres de la filière viti-vinicole 2006/2016. Technical report, 2017.

Marlies H. Barendrecht, Alberto Viglione, and Günter Blöschl. A dynamic framework for flood risk. *Water Security*, 1 (Supplement C):3–11, 2017. ISSN 2468-3124. doi: 10.1016/j.wasec.2017.02.001.

Nicolas Bauduceau. Éléments d'analyse des répercussions des inondations de novembre 1999 sur les activités agricoles des départements de l'aude, des pyrénées orientales et du tarn. Technical report, Équipe pluridisciplinaire Plan Loire Grandeur Nature, Janvier 2001.

Roy Brouwer and Remco van Elk. Integrated ecological, economic and social impact assessment of alternative flood control policies in the netherlands. *Ecological Economics*, 50(1-2):1–21, 09 2004. doi: 10.1016/j.ecolecon.2004.01.020.

P. Brémond, F. Grelot, and A. L. Agenais. Review article: Economic evaluation of flood damage to agriculture – review and analysis of existing methods. *Nat. Hazards Earth Syst. Sci.*, 13(10):2493–2512, 2013. NHESS.

Pauline Brémond. *Caractérisation et évaluation économique de la vulnérabilité des exploitations agricoles aux inondations.* Thèse de doctorat, spécialité sciences Économiques, Université de Montpellier 1, Montpellier, France, 12 2011.

Pauline Brémond and Frédéric Grelot. Taking into account recovery to assess vulnerability: application to farms exposed to flooding. In Ralf Seppelt, Alexey A. Voinov, Susanne Lange, and Dagmar Bankamp, editors, *Managing Resources of a Limited Planet, 2012 International Congress on Environmental Modelling and Software*, Leipzig, Germany, 22-27 April 2012. International Environmental Modelling and Software Society.

P. Bubeck, W. J. W. Botzen, H. Kreibich, and J. C. J. H. Aerts. Long-term development and effectiveness of private flood mitigation measures: an analysis for the german part of the river rhine. *Nat. Hazards Earth Syst. Sci.*, 12(11):3507–3518, 2012. NHESS.

Lorenzo Carrera, Gabriele Standardi, Francesco Bosello, and Jaroslav Mysiak. Assessing direct and indirect economic impacts of a flood event through the integration of spatial and computable general equilibrium modelling. *Environmental Modelling and Software*, 63(0):109–122, 2015.

CER. Références technico-économiques d'une vigne palissée en languedoc roussillon. 2009.

CER FRANCE. La Viticulture du Languedoc Roussillon - Données économiques. 2017.

Chambre d'agriculture Var. *Action 25 du PAPI d'intention de l'Argens. Réalisation de diagnostics de vulnérabilité d'installations agricoles en zone inondable*, 2014.

Aekapol Chongvilaivan. Thailand's 2011 flooding: Its impact on direct exports and global supply chains, 2012.

Harold C. Cochrane. Indirect losses from natural disasters: Measurement and myth. In Yasuhide Okuyama and Stephanie E. Chang, editors, *Modeling Spatial and Economic Impacts of Disasters*, Advances in Spatial Science, pages 37–52. Springer Berlin Heidelberg, 2004.

P.-Y. Collombat. *Rapport d'information fait au nom de la mission commune d'information sur les inondations qui se sont produites dans le Var, et plus largement, dans le sud-est de la France au mois de novembre 2011*, 2012.

National Research Council. *The Impacts of Natural Disasters: A Framework for Loss Estimation.* The National Academies Press, Washington, DC, 1999.

Douglas Crawford-Brown, Mark Syddall, Dabo Guan, Jim Hall, Jun Li, Katie Jenkins, and Rachel Beaven. Vulnerability of london's economy to climate change: Sensitivity to production loss. *Journal of Environmental Protection*, 4(6):548–563, 2013.

Katrin Erdlenbruch, Sophie Thoyer, Frédéric Grelot, Robert Kast, and Geoffroy Enjolras. Risk-sharing policies in the context of the french flood prevention action programmes. *Journal of Environmental Management*, 91(2):363–369, 2009. doi: 10.1016/j.jenvman.2009.09.002. Accepté à Journal of Environmental Management http://dx.doi.org/10.1016/j.jenvman.2009.09.002.

EEA European Environment Agency. Mapping the impacts of natural hazards and technological accidents in europe. Technical report, European Environment Agency (EEA), 2010.

Christopher B. Field, Vicente Barros, Thomas F. Stocker, Qin Dahe, David Jon Dokken, Kristie L. Ebi, Michael D. Mastrandrea, Katharine J. Mach, Gian-Kasper Plattner, Simon K. Allen, Melinda Tignor, and Pauline M. Midgley. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* Intergovernemental Panel on Climate Change, 2012.

Johanna Grames, Alexia Prskawetz, Dieter Grass, Alberto Viglione, and Günter Blöschl. Modeling the interaction between flooding events and economic growth. *Ecological Economics*, 129(Supplement C):193–209, 2016. ISSN 0921-8009. doi: 10.1016/j.ecolecon.2016.06.014.

Johanna Grames, Dieter Grass, Peter M. Kort, and Alexia Fürnkranz-Prskawetz. Optimal investment and location decisions of a firm in a flood risk area using impulse control theory. ECON WPS - Vienna University of Technology Working Papers inEconomic Theory and Policy No. 01/2017, Vienna University of Technology, 2017.

Toon Haer, W. J. Wouter Botzen, Hans de Moel, and Jeroen C. J. H. Aerts. Integrating household risk mitigation behavior in flood risk analysis: An agent-based model approach. *Risk Analysis*, pages n/a–n/a, 2016. ISSN 1539-6924. doi: 10.1111/risa.12740.

Stéphane Hallegatte. An adaptive regional input-output model and its application to the assessment of the economic cost of katrina. *Risk Analysis*, 28(3):779–799, 2008.

Stéphane Hallegatte. Modeling the role of inventories and heterogeneity in the assessment of the economic costs of natural disasters. *Risk Analysis*, 34(1):152–167, 2014.

Stéphane Hallegatte and Michael Ghil. Natural disasters impacting a macroeconomic model with endogenous dynamics. *Ecological Economics*, 68(1–2):582–592, 2008.

Masahiko Haraguchi and Upmanu Lall. Flood risks and impacts: A case study of thailand's floods in 2011 and research questions for supply chain decision making. *International Journal of Disaster Risk Reduction*, 14(Part 3):256–272, 2015. Risking Disaster – the role of private investment and public regulation in disaster risk management.

T. M. Hess and J. Morris. Estimating the value of flood alleviation on agricultural grassland. *Agricultural Water Management*, 15(2):141–153, 1988.

S. N. Jonkman, M. Bockarjova, M. Kok, and P. Bernardini. Integrated hydrodynamic and economic modelling of flood damage in the netherlands. *Ecological Economics*, 66(1):77–90, 2008.

Elco E. Koks, Marija Bočkarjova, Hans de Moel, and Jeroen C. J. H. Aerts. Integrated direct and indirect flood risk modeling: Development and sensitivity analysis. *Risk Analysis*, 35:882–900, December 2014. ISSN 1539-6924. doi: 10.1111/risa.12300.

Heidi Kreibich and Philip Bubeck. Natural hazards: Direct costs and losses due to the disruption of production processes. Technical report, UNISDR GAR, 2013.

Heidi Kreibich, Isabel Seifert, Bruno Merz, and Annegret H. Thieken. Development of FLEMOcs – a new model for the estimation of flood losses in the commercial sector. *Hydrological Sciences Journal*, 55(8):1302–1314, 2010. doi: 10.1080/02626667.2010.529815.

Ye Linghe and Abe Masato. The impacts of natural disasters on global supply chains, 2012.

Giovanni Marin and Marco Modica. Socio-economic exposure to natural disasters. *Environmental Impact Assessment Review*, 64:57–66, 2017. ISSN 0195-9255. doi: 10.1016/j.eiar.2017.03.002.

Bruno Merz, Heidi Kreibich, Reimund Schwarze, and Annegret Thieken. Assessment of economic flood damage. *Natural Hazards and Earth System Sciences*, 10:1697–1724, 2010.

V. Meyer, N. Becker, V. Markantonis, R. Schwarze, J. C. J. M. van den Bergh, L. M. Bouwer, P. Bubeck, P. Ciavola, E. Genovese, C. Green, S. Hallegatte, H. Kreibich, Q. Lequeux, I. Logar, E. Papyrakis, C. Pfurtscheller, J. Poussin, V. Przyluski, A. H. Thieken, and C. Viavattene. Review article: Assessing the costs of natural hazards - state of the art and knowledge gaps. *Natural Hazards and Earth System Sciences*, 13(5):1351–1373, 2013.

Volker Meyer, Nina Becker, Vasileios Markantonis, Reimund Schwarze, Jeroen C J H Aerts, Jeroen C J M van den Bergh, Laurens M Bouwer, Philip Bubeck, Paolo Ciavola, Vanessa Daniel, Elisabetta Genovese, Colin Green, Stéphane Hallegatte, Heidi Kreibich, Quentin Lequeux, Bernhard Lochner, Ivana Logar, Elissaios Papyrakis, Clemens Pfurtscheller, Jennifer Poussin, Valentin Przyluski, Annegret H Thieken, Paul Thompson, and Christophe Viavattene. Costs of natural hazards - a synthesis. Technical report, European research project CONHAZ, 2012.

M. H. Middelmann-Fernandes. Flood damage estimation beyond stage-damage functions: an australian example. *Journal of Flood Risk Management*, 3(1):88–96, 2010.

Joe Morris and Philip Brewin. The impact of seasonal flooding on agriculture: the spring 2012 floods in somerset, england. *Journal of Flood Risk Management*, 7(2):128–140, June 2014. ISSN 1753-318X. doi: 10.1111/jfr3.12041.

Joe Morris and Tim M Hess. Agricultural flood alleviation benefit assessment: a case study. *Journal of Agricultural Economics*, 39(3):402–412, 1988.

OCDE. Étude de l'ocde sur la gestion des risques d'inondation : la seine en Île-de-france. Technical report, OCDE, 2014.

E. C. Penning-Rowsell and C. Green. New insights into the appraisal of flood-alleviation benefits: (1) flood damage and flood loss information. *Water and Environment Journal*, 14(5):347–353, 2000.

Edmund Penning-Rowsell, Sally Priest, Dennis Parker, Joe Morris, Sylvia Tunstall, Christophe Viavattene, John Chatterton, and Damon Owen. *Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal*. Routledge, 2013a.

Edmund C. Penning-Rowsell, Sally J. Priest, Dennis J. Parker, Joe Morris, Sylvia M. Tunstall, Christophe Viavattene, John Chatterton, and Damon Owen. *Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal*. Routledge, 12 2013b. ISBN 1 904750 51 6.

J. Gareth Polhill, Nicholas M. Gotts, and Alistair N. R. Law. Imitative versus nonimitative strategies in a land-use simulation. *Cybernetics and Systems*, 32(1-2):285–307, 2001. doi: 10.1080/019697201300001885.

Helena Posthumus, Joe Morris, Tim M. Hess, D. Neville, E. Philips, and A. Baylis. Impacts of the summer 2007 floods on agriculture in england. *Journal of Flood Risk Management*, 2(3):182–189, 09 2009. doi: 10.1111/j.1753-318X.2009.01031.x. DOI: 10.1111/j.1753-318X.2009.01031.x.

Adam Rose and Elisabeth Krausmann. An economic framework for the development of a resilience index for business recovery. *International Journal of Disaster Risk Reduction*, 5:73–83, 2013.

Adam Rose and Shu Yi Liao. Modeling regional economic resilience to disasters: A computable general equilibrium analysis of water service disruptions*. *Journal of Regional Science*, 45(1):75–112, 2005.

Delphine Rouchon, Natacha Christin, Cédric Peinturier, and Doris Nicklaus. Analyse multicritères des projets de prévention des inondations. guide méthodologique 2018. Théma - balises, Ministère de la Transition Écologique et Solidaire, Commissariat général au développement durable, Paris, France, Mars 2018a.

Delphine Rouchon, Cédric Peinturier, Natacha Christin, and Doris Nicklaus. Analyse multicritère des projets de prévention des inondations - guide méthodologique 2018. Technical report, MTES, 2018b.

Karolina Safarzyńska, Roy Brouwer, and Marjan Hofkes. Evolutionary modelling of the macro-economic impacts of catastrophic flood events. *Ecological Economics*, 88(0):108–118, 2013.

Charles Scawthorn, Paul Flores, Neil Blais, Hope Seligson, Eric Tate, Stephanie Chang, Edward Mifflin, Will Thomas, James Murphy, Christopher Jones, and Michael Lawrence. Hazus-mh flood loss estimation methodology. ii. damage and loss assessment. *Natural Hazards Review*, 7(2):72–81, 2006.

SwissRE. Natural catastrophes and man-made disasters in 2016: a year of widespread damages. Sigma No 2/2017, Swiss Reinsurance Company, Zurich, 10 2017.

Leigh Tesfatsion. Agent-based computational economics: A constructive approach to economic theory. In Leigh Tesfatsion and Kenneth L. Judd, editors, *Handbook of Computational Economics*, volume 2 of *Handbook of Computational Economics*, chapter 16, pages 831–880. Elsevier, 2006. doi: 10.1016/S1574-0021(05)02016-2.

Anne Van der Veen, A E Steenge, M Bockarjova, and Christiaan J J Logtmeijer. Structural economic effects of large scale inundation: a simulation of the krimpen dike breakage. Technical report, University of Twente, 2003.

Alberto Viglione, Giuliano Di Baldassarre, Luigia Brandimarte, Linda Kuil, Gemma Carr, José Luis Salinas, Anna Scolobig, and Günter Blöschl. Insights from socio-hydrology modelling on dealing with flood risk – roles of collective memory, risk-taking attitude and trust. *Journal of Hydrology*, 518(Part A):71–82, 2014. ISSN 0022-1694. doi: 10.1016/j.jhydrol.2014.01.018. Creating Partnerships Between Hydrology and Social Science: A Priority for Progress.

Freddy Vinet. *Crues et inondations dans la France méditerranéenne. Les crues torrentielles des 12 et 13 novembre 1999 (Aude, Tarn, Pyrénées-Orientales et Hérault)*. Questions de Géographie. Éditions du Temps, Nantes, France, 2003.

W. Xie, N. Li, J. D. Wu, and X. Q. Liu. Evaluation of indirect loss from hypothetical catastrophes in two regions with different economic development levels in china. *Nat. Hazards Earth Syst. Sci.*, 12(11):3325–3335, 2012.

W. Xie, N. Li, J. D. Wu, and X. L. Hao. Modeling the economic costs of disasters and recovery: analysis using a dynamic computable general equilibrium model. *Nat. Hazards Earth Syst. Sci.*, 14(4):757–772, 2014.

Addendum to the article

This section displays a battery of graphs that correspond to the indicators in figure 2.24 at system level (figure 2.25). They all represent in the x axis the percentage of prone area flooded, while the y axis measures the level of damage in terms of the potential benefit of the system. Such figures can be understood as the cumulative impacts caused by floods, in its progression along the prone area.

To avoid unnecessary repetitions of figures the display of the different results will be as follows: first, we will thoroughly analyze the `homogeneous` configuration, under the assumption that every flooded farm will employ `internal` as coping tactic. Then, we will compare the differential effects of using the `external` tactic. Subsequently, sizes and exposure levels will be compared with the `homogeneous` configuration for both coping tactics as well.

3.3 `Homogeneous` distribution, assuming every farm opts for the `internal` coping tactic

3.3.1 Damages in soils.

According to our damage functions, always plots are floods, tasks of soil reconditioning have to be done. Such task are assumed to be always the same, therefore damage in soils does not present any seasonal variation. Nonetheless, they present a positive slope, due to the increasing amount of plots flooded as floods grow in extent (see figure 3.2).

3.3.2 Damages in plants.

Damages in plants do display seasonal behavior. As we can see, they respond to the probabilities included in the plot's damage function (table 2.5).

Floods in spring registers the biggest impact, with estimated destruction higher than 1.5 times the system's YPGB. As the probability of destruction drops along summer and autumn, so does the amount of damage estimated in SFSs, with winter presenting no damage at all (see figure 3.3).

3.3.3 Damages in harvest.

Damages in harvest (see figure 3.4) include both direct impacts of floods over the harvest ($\sum_{i=1}^{n} q_{i_D}$), and harvest losses due to material damages in farms ($\sum_{i=1}^{n} q_{i_\beta}$).

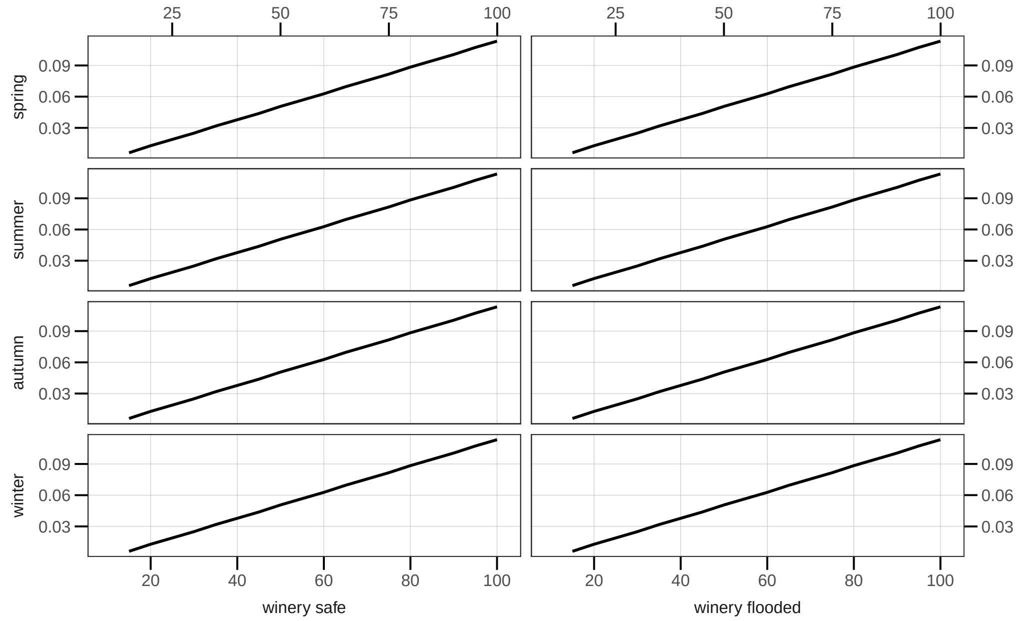


Figure 3.2 – Damages in soils. `Homogeneous` distribution. `Internal` coping tactic

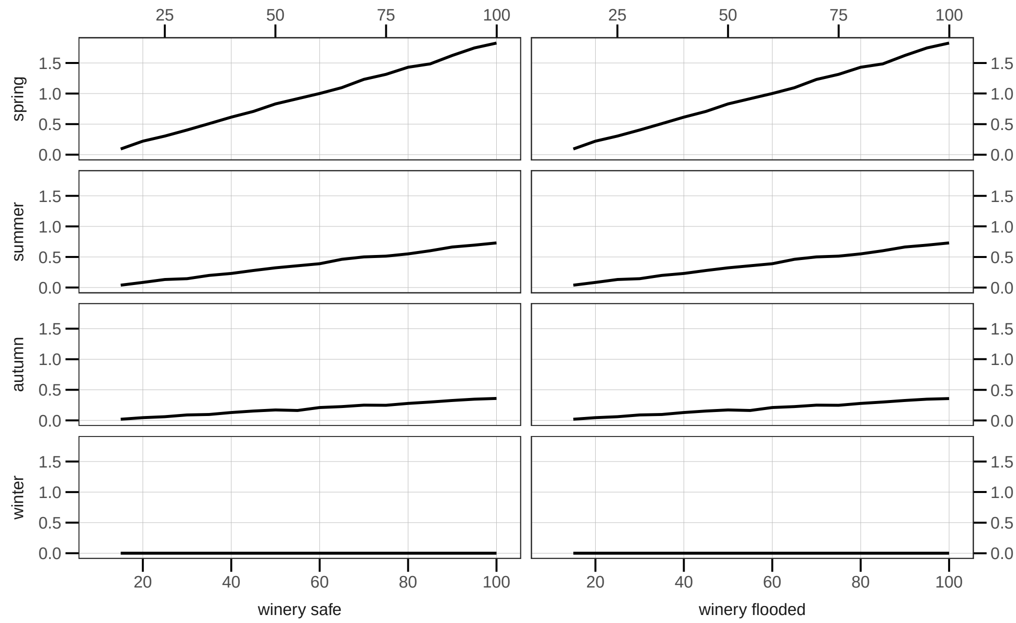


Figure 3.3 – Damages in plants. `Homogeneous` distribution. `Internal` coping tactic

Floods over the system in winter, since plot's damage function does not include plant damage nor harvest during the season, let us fully appreciate the effect of the coping tactic: in most extreme events, such damages can reach 25% of the system's YPGB.

Floods in spring, summer and autumn display a similar behavior, with growing damages as floods become larger and hit more productive plots. In the worst case scenario, the harvest losses are approximately equivalent to the system's YPGB.

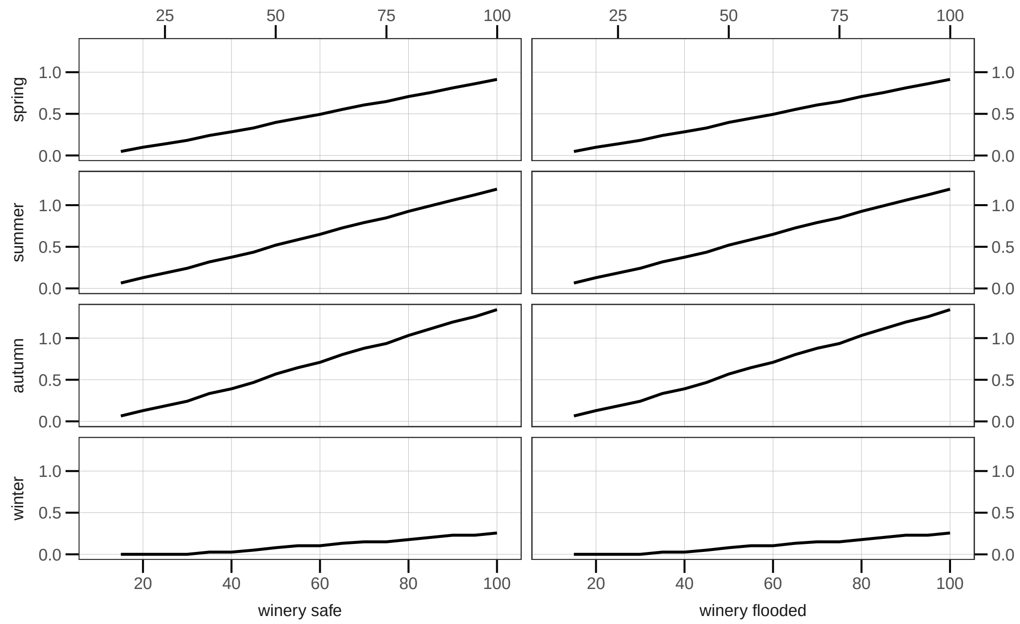


Figure 3.4 – Damages in harvest. `Homogeneous` distribution. `Internal` coping tactic

3.3.4 Variations in vine-growing cost. Short term.

As a consequence of damages in plants, harvest and the chosen coping tactic, vine-growing cost drops (see figure 3.5). Seasonal differences are richer than the ones seen until now: winter diminishes in an interval from 0 to 5% of the YPGB as a consequence of the vine-growing tasks not done by flooded farms.

Floods in spring add impacts over plots to the effects of the coping strategy, which naturally results in bigger variations of vine-growing costs. Contrary to what it could be thought, the fact that the probability of plant destruction is the highest of all seasons, does not provokes that floods have the highest impacts. Paradoxically, the actual combination of impacts behind the variations of vine-growing cost, make spring less harming than summer.

Precisely in summer, although probability of plant destruction descends more than half, all plots impacted will lose 100% of their production. This circumstance, linked to the, on one hand, harming effects, and, on the other hand, cost savings, consequence of the coping tactic, make summer the season where SFSs present the biggest vine-growing cost variations.

Autumn present exactly the same elements behind costs variations than spring and summer. It is even the season where the `internal` coping tactic in SFSs has the biggest impacts (see table 2.13). However, when floods hit the system in this season, most of the vine-growing cost of the year is already paid.

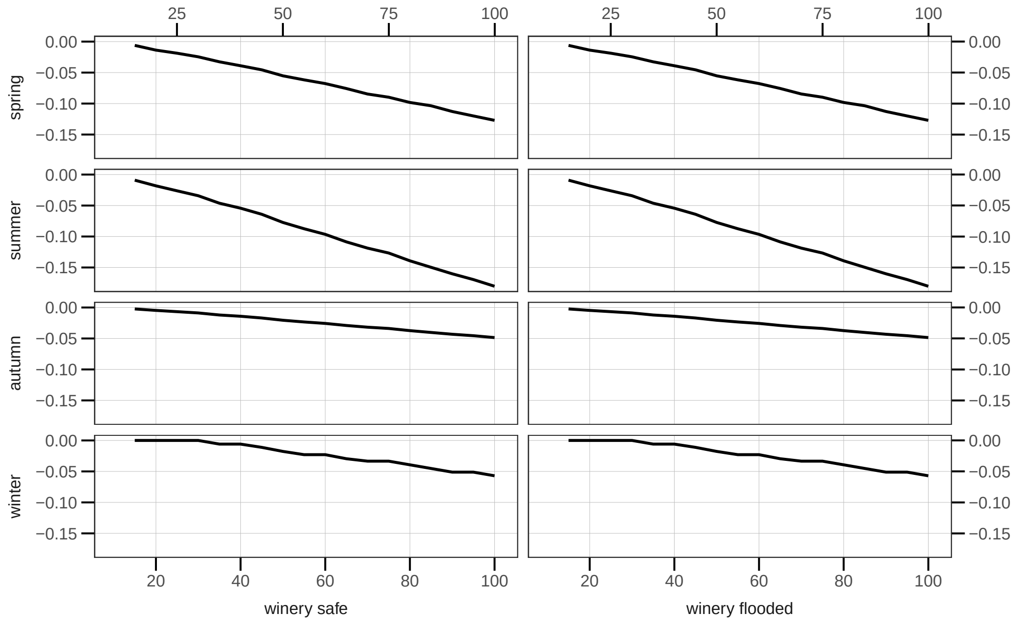


Figure 3.5 – Variations in short term vine-growing cost. `Homogeneous` distribution. `Internal` coping tactic

3.3.5 Damages in farms' buildings and materials.

This damages, as well as damages in soils, present no seasonal difference whatsoever (as expected). They do present an increasing trend and shifts along the curve, that come explained by the number of farm's buildings hit with each flood extent (see figure 3.6).

3.3.6 Variations in wine-making cost. Short term.

Variations in short term, or immediate, wine-making cost are null, except for winter season in case the winery is hit by a flood. In such situation, the production of year $t = 0$ is lost, and wine-making cost correspond only to the winery's structural cost (see figure 3.7).

3.3.7 Damages in winery's buildings and materials.

As it happened in the case of farms' buildings, when the cooperative is in the prone area, it gets hit by the flood. That situation reports important damages to the system in terms of material lost: more than 4 times the system's YPGB (see figure 3.8).

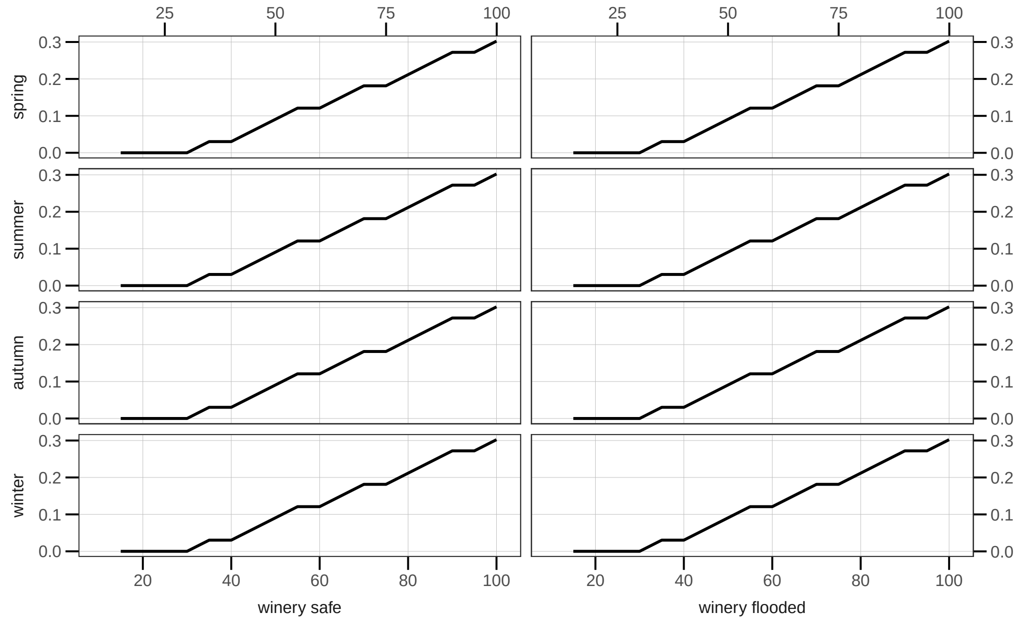


Figure 3.6 – Damages in farms' buildings and materials. `Homogeneous` distribution. `Internal` coping tactic

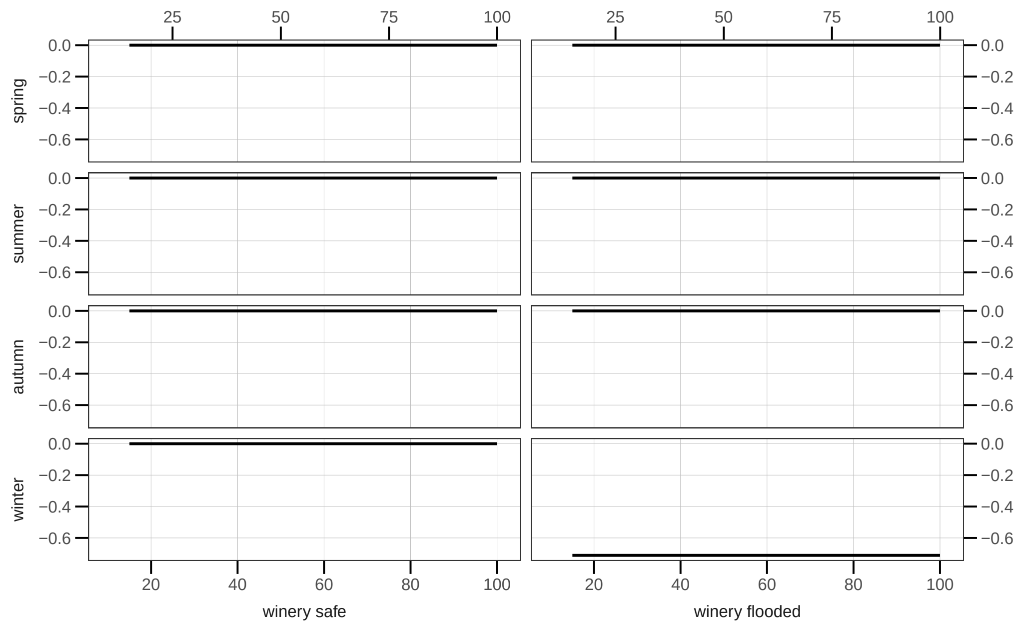


Figure 3.7 – Variations in short term vine-growing cost. `Homogeneous` distribution. `Internal` coping tactic

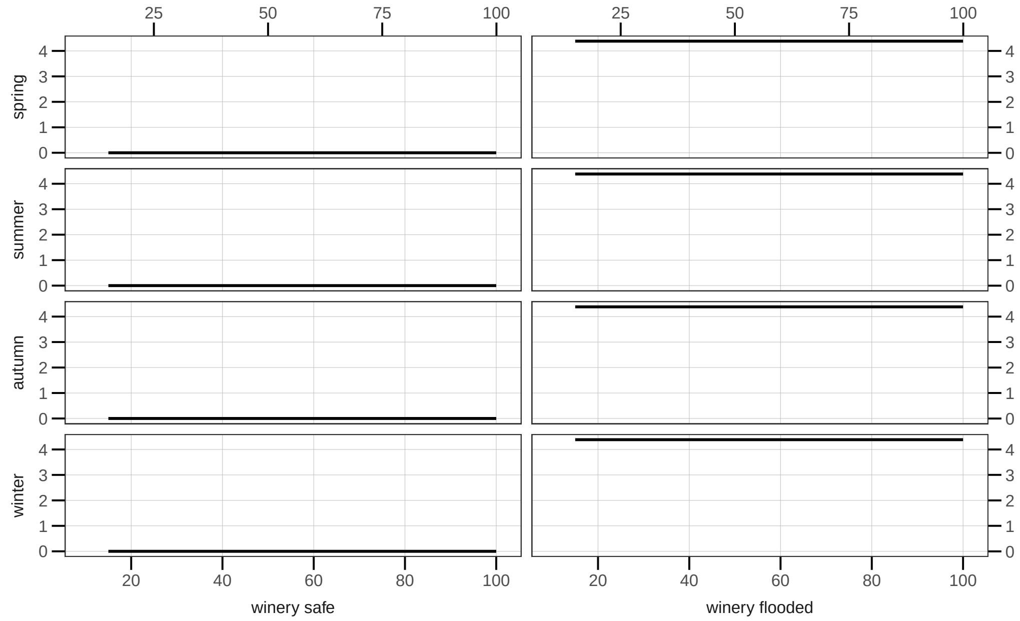


Figure 3.8 – Damages in winery's buildings and materials. `Homogeneous` distribution. `Internal` coping tactic

3.3.8 Damages in yield and production due to damages in winery.

When the cooperative winery is flooded, besides its material damages, there is an added loss of production (see figure 3.8). Seasonal differences can be observed in the figure though: i) in winter and spring, all production from the prior year (year $t = 0$), whether it has been transformed or not into the final product, is in the cooperative winery. Therefore, when the winery is flooded, such production is lost; ii) in summer, since no essential activity is performed in the winery, there are no effects over the production; and iii) In autumn, losses begin at the same level that winter or spring —when floods cover a really small extent there is no difference in the production of the system—, but they decrease at the same time the flood extent grows, reflecting the damages in yield.

3.3.9 Variations in wine-making cost (long term).

Long term (or induced) wine-making costs present one important, and essential, seasonal difference: when the cooperative winery is flooded in autumn, the harvest cannot be collected in $t = 1$, therefore there is no production in $t = 2$, hence the shift in the curve (see figure 3.10).

When the winery is not flooded, the graph reflects the effects of the floods over yield (either direct or indirect, immediate or induced). The rest of the seasons, whether the winery is flooded or not display similar behavior.

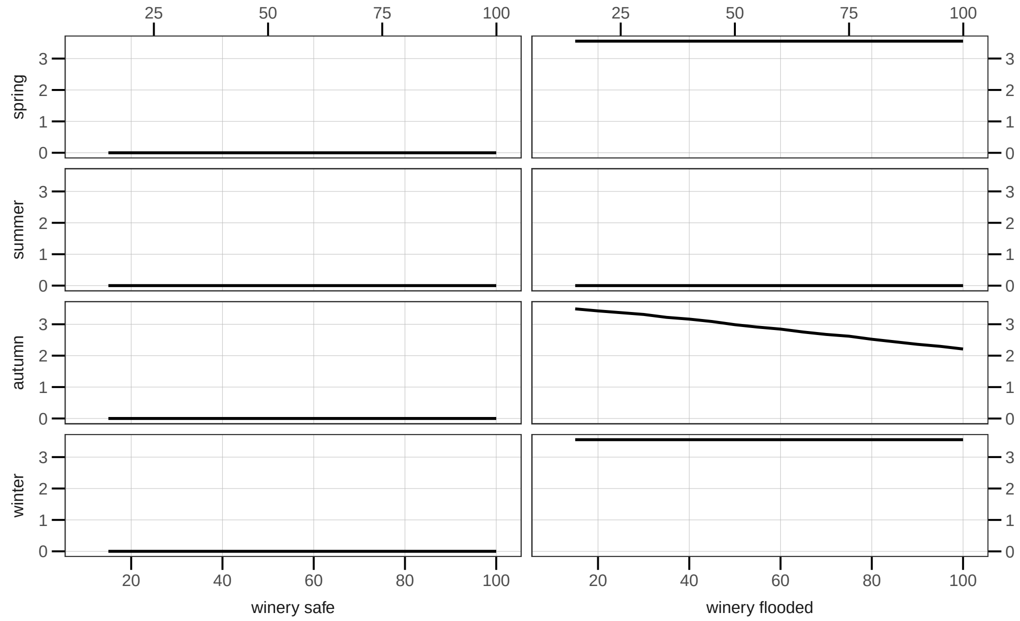


Figure 3.9 – Damages in harvest due to damages in winery's buildings and materials. `Homogeneous` distribution. `Internal` coping tactic

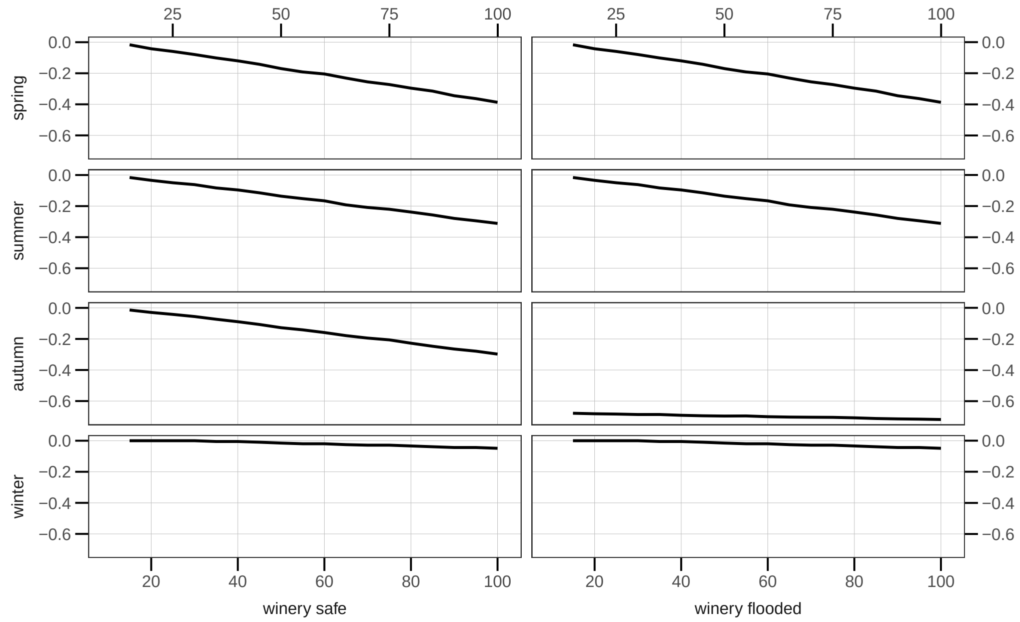


Figure 3.10 – Variations in long term wine-making cost. `Homogeneous` distribution. `Internal` coping tactic

3.3.10 Variations in harvest due to plant destruction.

These variations display the effects over yield caused by plant destruction in the aftermath of the flood during the time plants get replanted and they are productive again. Approximately, it displays the same behavior than the plant destruction indicator (see figure 3.11).

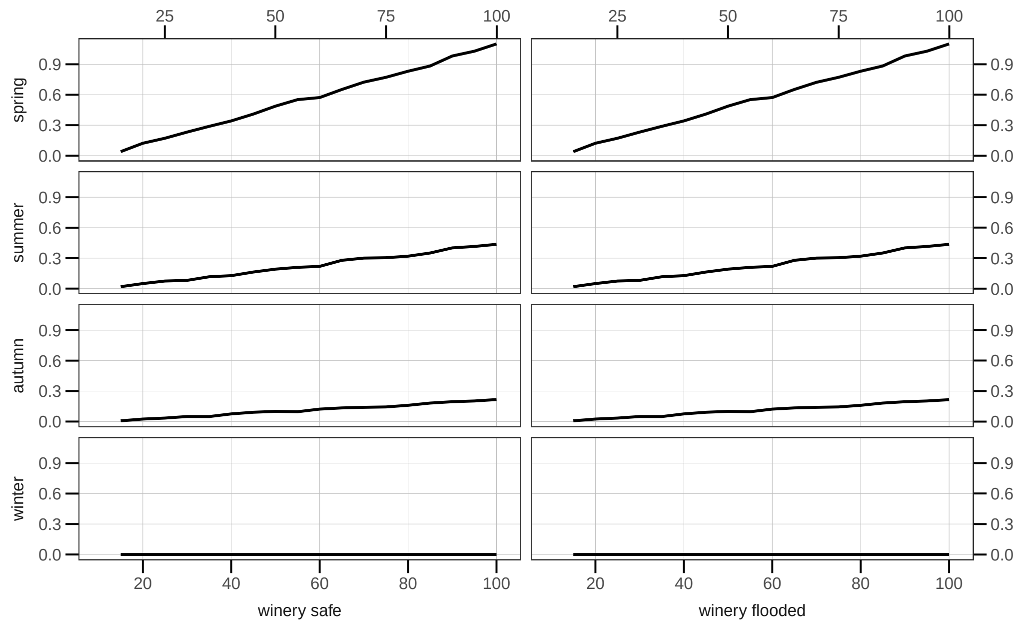


Figure 3.11 – Variations in harvest due to plant destruction. `Homogeneous` distribution. `Internal` coping tactic

3.3.11 Variations in vine-growing cost. Long term.

This indicator behaves like a mirror of the variations in harvest caused by plants. Compared with the indicator of short-term variations of vine-growing cost, in this indicator, since there is no presence of any other influence, spring reflects the bigger losses caused by the higher probability of plant destruction. Summer and autumn have the same behavior but in smaller magnitude, and variations are nonexistent in winter (see figure 3.12).

3.3.12 Total damages.

Aggregating all of the indicators reviewed, curves as the ones in figure 3.13 emerge (see figure 3.13). As we can see, the presence of the winery in the prone area has a significant effect, that we can observe, not only in terms of magnitude of damage, but also in seasonal behavior.

Beginning with the magnitude of damages, when the cooperative is not flooded, we reach a maximum of 2.5 times the system's YPGB. But as soon as it is flooded, damages multiply by five, at least, the system's YPGB; 10 in worst case scenarios.

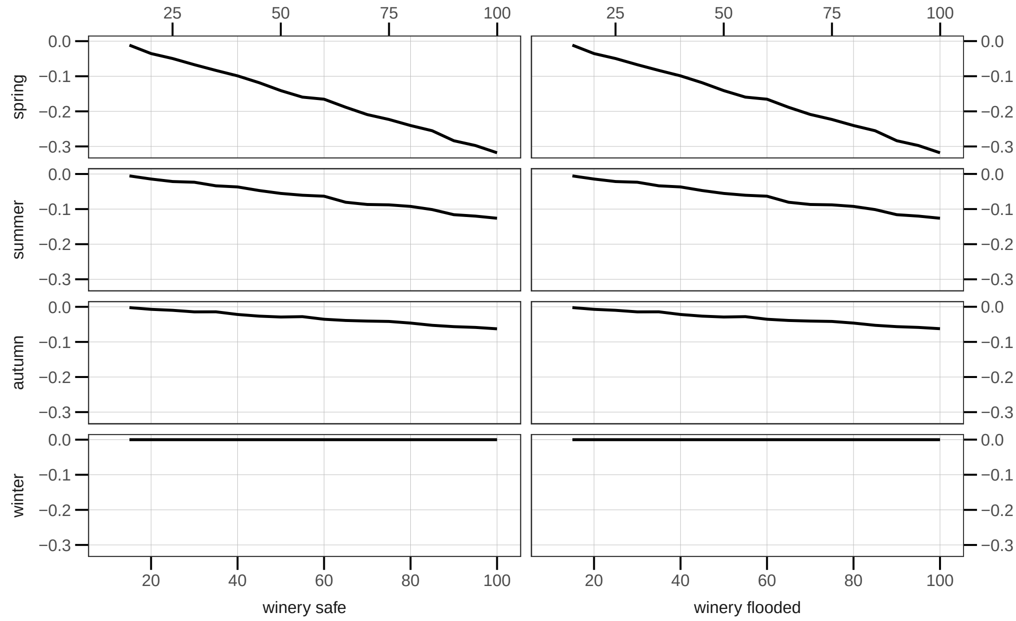


Figure 3.12 – Variations in long term vine-growing cost. `Homogeneous` distribution. `Internal` coping tactic

Regarding seasonal behavior, when the winery is not hit by the flood, damages are clearly influenced by damages at plots' level: damage curves display higher damages in spring, while summer and autumn are smaller in comparison, and winter is practically zero. However, when the winery is flooded, the apparition of the differential effects already described, make all curves shift upwards but in different scales. Such process, bring autumn and winter closer in level of damages, and above summer, while floods in spring continues to report the greatest damages.

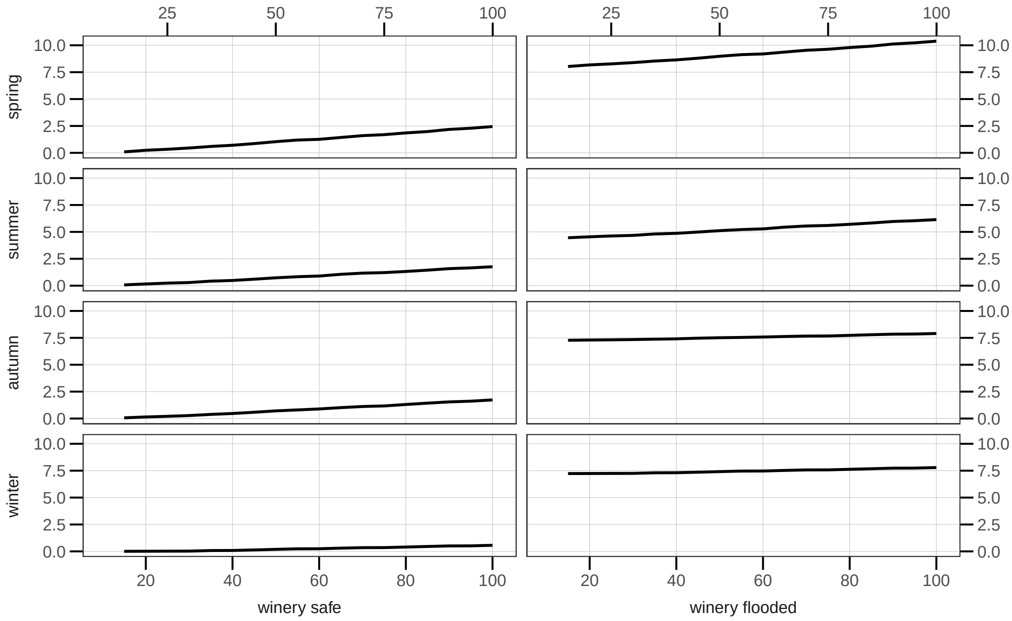


Figure 3.13 – Total damages. `Homogeneous` distribution. `Internal` coping tactic

3.4 `homogeneous` distribution, comparison of `internal` and `external` coping tactics

This section compares the scenario in which all farms opt for a `internal` coping tactic with its alternative: all farms opt for the `external` coping tactic. Differences can be observed along several indicators. Concretely in: Damages in harvest, variations in short term vine-growing costs, Damages in yield and production due to damages in winery, variations in long term (induced) wine-making cost and total damages.

Figures in this section represent the series of differences between the two tactics. Values above zero imply that the effects of the `external` tactic are bigger in magnitude than those of `internal` tactic.

3.4.1 Damages in harvest.

Damages in harvest are smaller when we use the `external` coping tactic. It is due to the absence of extra losses provoked by farms being unable to perform their tasks. Differences between the two coping tactics are important, estimated in a maximum of 20% of the YPGB (see figure 3.14).

3.4.2 Variations in vine-growing cost. Short term.

On the contrary, short term (immediate) vine-growing costs are now higher (see figure 3.15). They reflect two different phenomena: first, to outsource activities means extra cost at each flooded farm level. Second, when impacted agents choose the `internal` tactic, they save vine-growing cost in relation to the Business as Usual

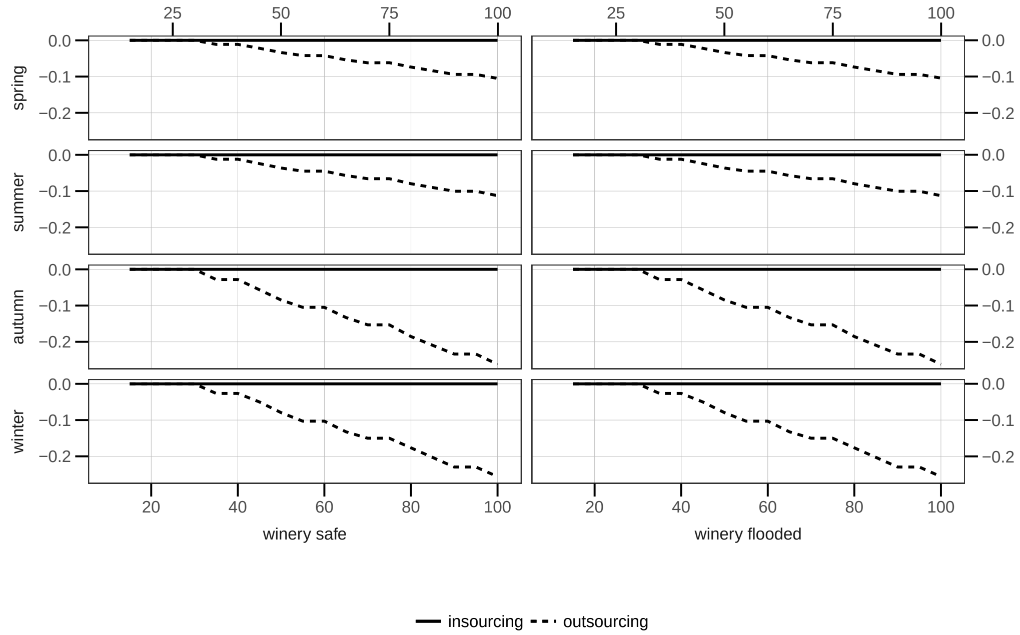


Figure 3.14 – Damages in harvest. `homogeneous` distribution. `Internal` vs. `external` coping tactic

scenario or Zero Flood Scenario (BAU) for all of those vine-growing task they cannot do.

Therefore, the differences between the two curves reflect i) outsourcing extra cost, and ii) absence of savings due to inability to perform. Once again the magnitude of the variation is not negligible: it rest in a interval from 0 to 15% of the YPGB.

3.4.3 Damages in yield and production due to damages in winery.

In this case, the only change comes when floods hit the system in autumn, and the cooperative winery is located in prone area. Using the `external` tactic farms do not add yield losses. Thus, losses of production due to material damages in winery's buildings are now higher since they involve higher yields from the farms (see figure 3.16).

3.4.4 Variations in wine-making cost. Long term.

Linked with the prior explanation, the same lack of yield loss causes higher amount of production in the system, which eventually reverts in smaller variations of long term (induced) wine-making cost (see figure 3.17).

3.4.5 Total damages.

Due to the adoption of the `external` coping tactic, the amount of total damage in the system can be, in general terms, reduced (see figure 3.18). The magnitude of

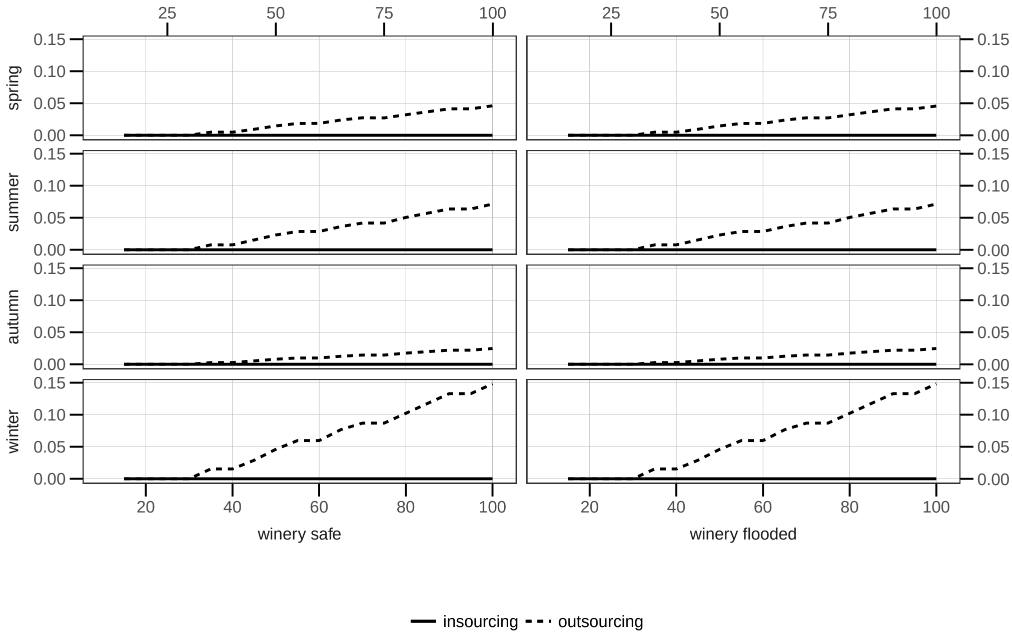


Figure 3.15 – Variations in short term vine-growing cost. `homogeneous` distribution. `Internal` vs. `external` coping tactic

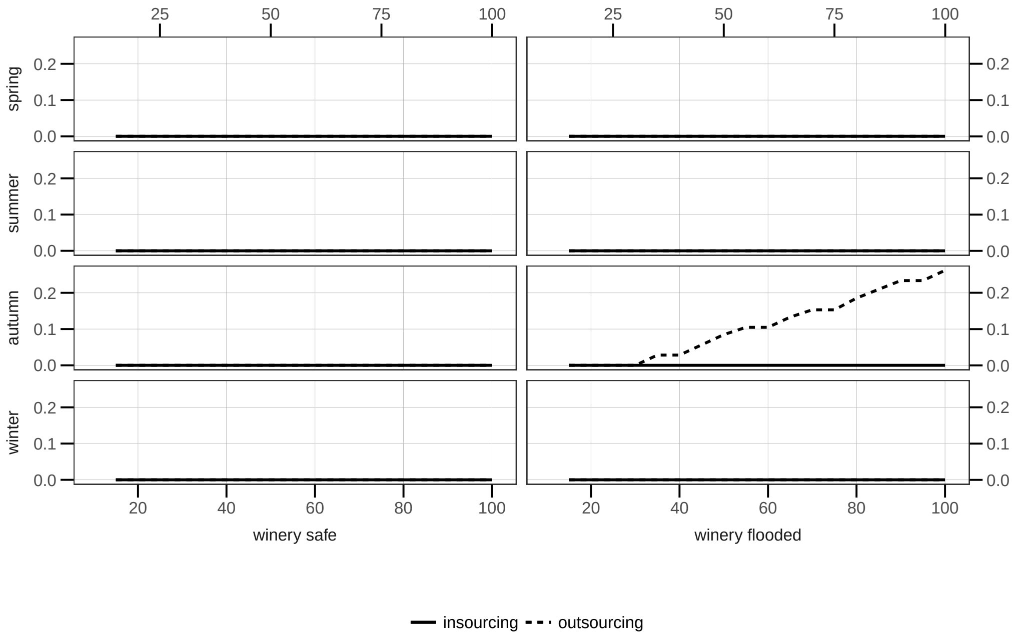


Figure 3.16 – Damages in harvest due to damages in winery's buildings and materials. `homogeneous` distribution. `Internal` vs. `external` coping tactic

that reduction, though, will depend on different components and parameters such

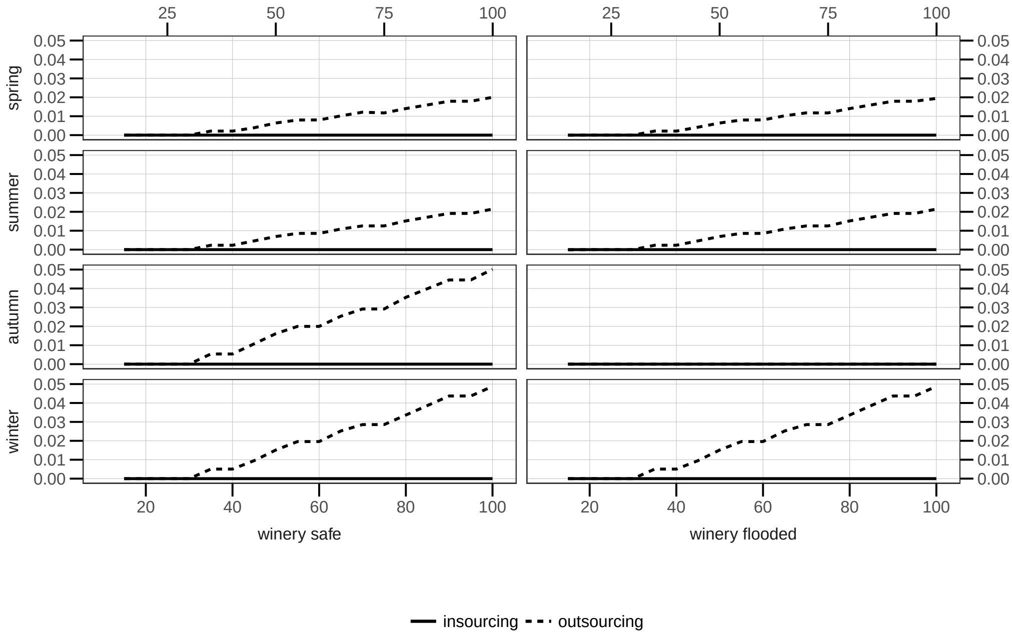


Figure 3.17 – Variations in long term wine-making cost. `homogeneous` distribution. `Internal` vs. `external` coping tactic

as the season the system is hit, the extent of the flood, the location of the entities (winery in our example) or the level of damage in each entity. In our system damage reduction ranges from 0 to more than 15% of the YPGB.

As exception to that general rule we enounced, we have the case of floods hitting the system in autumn when the cooperative winery is flooded, therefore unable to perform their assigned tasks. In such case, to use the `external` coping tactic, saves damages to the system in terms of harvest lost as a consequence of material damages in farms. However, that means that when the cooperative is hit, all that yield saved, is lost anyway. In other words, farms decide to invest extra money in saving their productions, just to find out that, further in the productive system, an essential link is broken and the production will be lost anyway, plus the extra expenses.

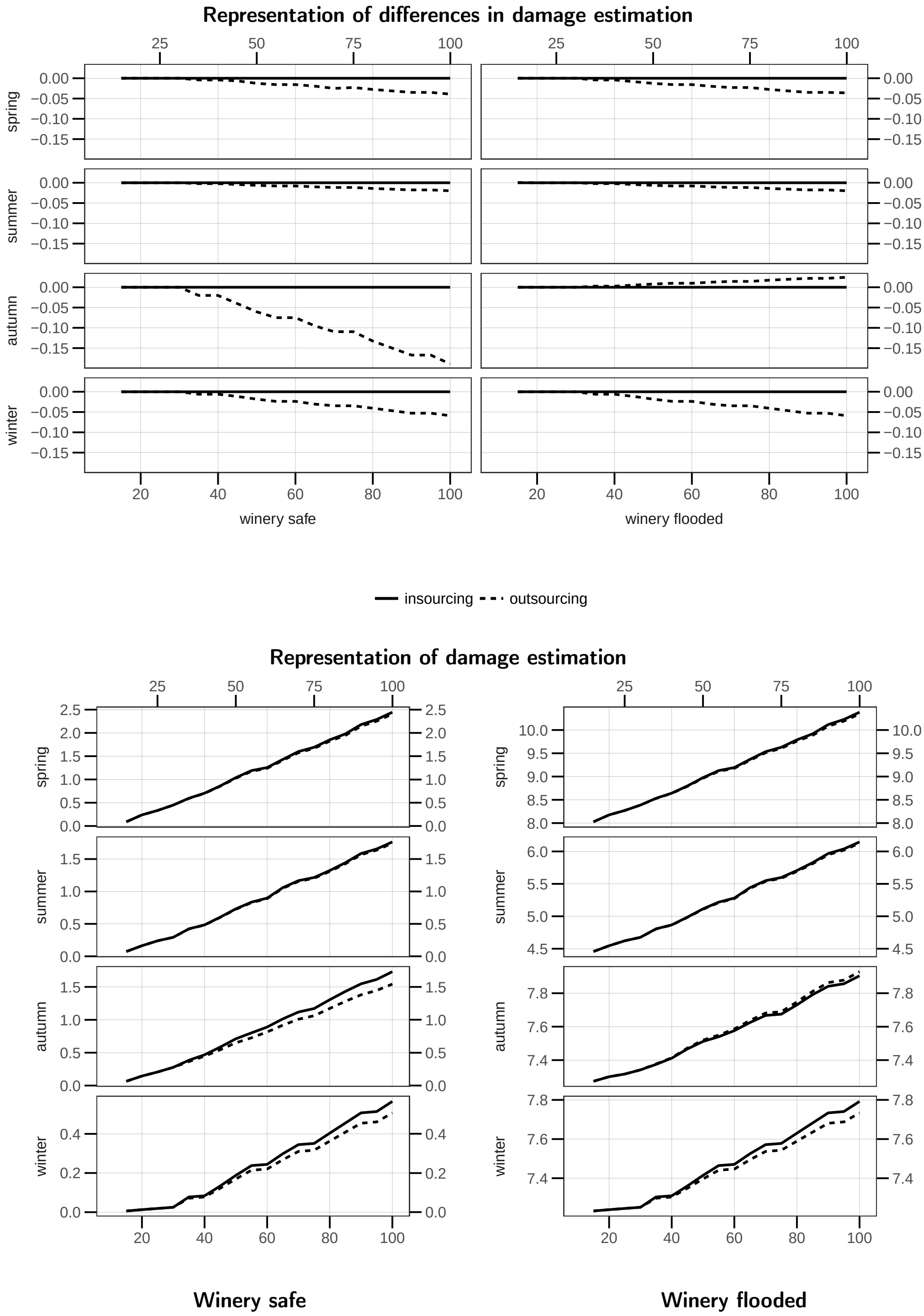


Figure 3.18 – Total damages. `homogeneous` distribution. `Internal` vs. `external` coping tactic

3.5 Internal coping tactic. Comparison of configurations of interactions

Assuming all vinegrowers opt for a internal tactic, the section compares the difference between the following configurations of interactions (their description is reproduced here for the reader's comfort):

homogeneous In this configuration all farms have the same number of plots (10). The proportion of plots in the flood-prone area is equivalent between each farm.

size In this configuration, 10 farms are big (30 plots), 40 farms are small (5 plots). The total number of farms and plots remains identical to the homogeneous configuration. The proportion of plots in the flood-prone area is equivalent between each farm.

exposure-best In this configuration, all farms have the same number of plots. The farms which building is in the flood-prone area have also all their plots in this area. The remaining plots in the flood-prone area are more or less equally distributed between the remaining farms.

exposure-worst In this configuration, all farms have the same number of plots. The farms which building is in the flood-prone have all their plots out of the flood-prone area. Plots in the flood-prone area are more or less equally distributed between the remaining farms.

size-exposure-worst In this configuration too, 10 farms are big (30 plots), 40 farms are small (5 plots). All the big farms have their building in the flood-prone area but no plots inside. Thus, all plots in the flood-prone area are associated to small farms, that contrary to big farms, do not have a building in the flood-prone area.

size-exposure-best In this configuration too, 10 farms are big (30 plots), 40 farms are small (5 plots). 10 small farms have their building and all their plots inside in the flood-prone area. The remaining plots located in the flood-prone are allocated between the remaining small farms. The 10 big farms are not exposed at all to flooding.

Figures represent the differences between the homogeneous configuration and the rest of them. Values above zero imply a bigger damage than in the homogeneous configuration.

As in the prior section, five indicators register differences: Damages in harvest, variations in short term vine-growing costs, Damages in yield and production due to damages in winery, variations in long term (induced) wine-making cost and total damages.

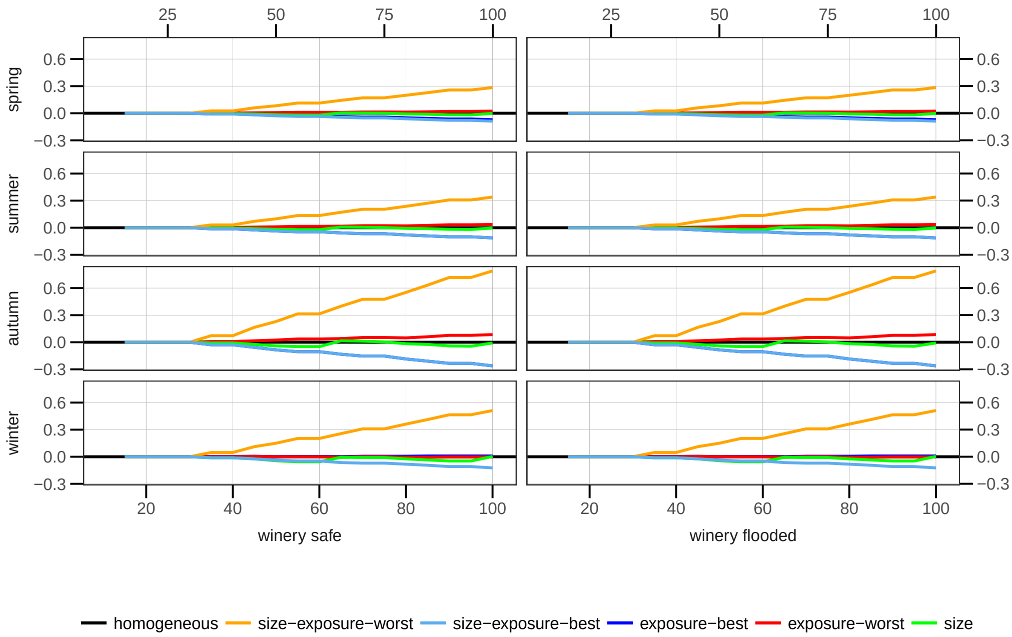
3.5.1 Damages in harvest.

See figure 3.19. The fact that the winery is flooded makes no difference regarding damage behavior. Among the different configuration we can find two clear groups: configurations size-exposure-worst with bigger impacts than our homogeneous, and size-exposure-best and exposure-best, that present smaller damages. Differences between homogeneous and size and exposure-worst are negligible.

Given the way the simulations have been conducted, in all configurations the amount of plots impacted, their productivity, age, probability of plant destruction, etc, are the same. As a consequence, what we observe in the behavior of the configuration `size-exposure-worst` is just the difference in harvest lost because of material damages in farms. In this configuration all large farms are present in the prone area. Therefore, the amount of plots that lose part of its harvest is much bigger than in the `homogeneous` configuration.

The opposite phenomenon happens for `size-exposure-best` and `exposure-best`. Those two overexpose farms whose buildings are located in the flood-prone area by assigning as well all plots in the flood-prone area. As a result impacts on harvest caused by material damages on farms are smaller than in the `homogeneous` configuration.

Seasonal differences come given by the seasonal component of the plot's damage function.



Remark: curves of configurations `size-exposure-best` and `exposure-best` are superposed

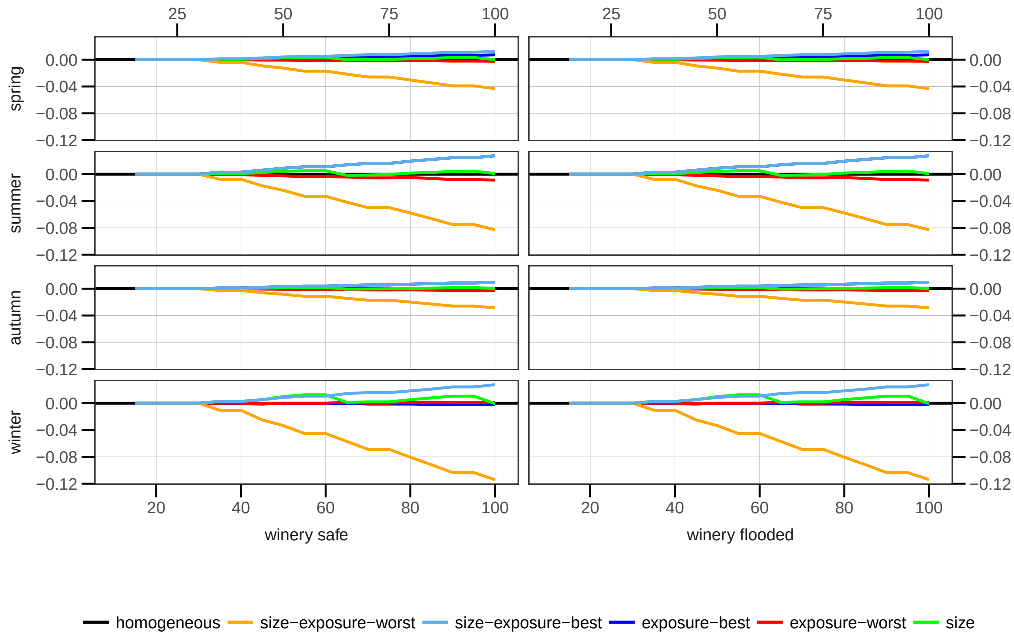
Figure 3.19 – Damages in harvest. Differences respect to `homogeneous` distribution. `Internal` coping tactic

3.5.2 Variations in vine-growing cost. Short term.

For the same reasons exposed above, variations in short term (immediate) vine-growing costs behave in opposite directions: in the case of `size-exposure-worst` the bigger loss of harvest makes the variation of vine-growing cost with respect to the BAU higher than in the case of `homogeneous` configuration (see figure 3.20).

For `size-exposure-best` and `exposure-best`, insofar their losses are smaller than in the `homogeneous` configuration, the variations of vine-growing cost with respect to the BAU are as well smaller than in the `homogeneous`, ergo the difference is positive.

Differences between `homogeneous` and `size` and `exposure-worst` are negligible.



Remark: curves of configurations `size-exposure-best` and `exposure-best` are superposed

Figure 3.20 – Variations in short term vine-growing cost. Differences respect to `homogeneous` distribution. `Internal` coping tactic

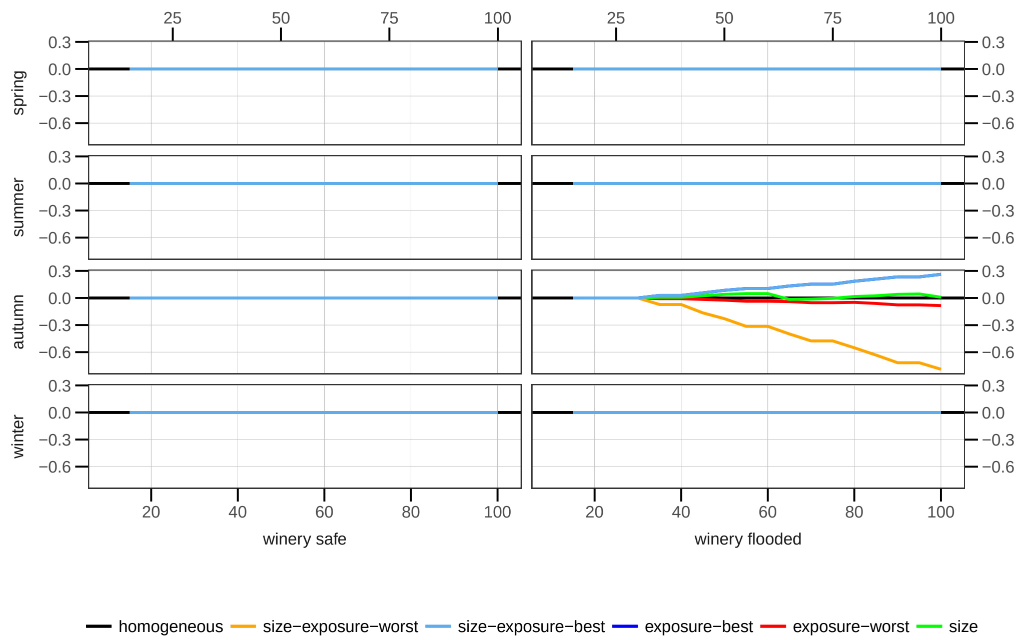
3.5.3 Damages in yield and production due to damages in winery.

As expected, the only differences happen in autumn when the cooperative winery is flooded (see figure 3.21). The reason lies in the fact that, it is in this season, when the winery is supposed to collect the yield from farms. Once again, losses due to the coping tactic, sizes and geographic disposition of elements are going to give us the key to understand the differences in the graph.

Loss of harvest due to damages in wineries is smaller in case of `size-exposure-worst` than in `homogeneous` due to the, already explained, bigger losses of harvest due to damages in farms' buildings. Inasmuch as a part of the yield has already been lost because of the misperformance of the vinegrowers, the yield loss attributable to damages in the winery is smaller (see hierarchy of damages. Chapter 2, section2.11.4).

On the contrary, for `size-exposure-best` and `exposure-best` yield losses due to damages in the winery are higher than in the `homogeneous` configuration. Since the losses due to the `internal` tactic are smaller than in the `homogeneous`, once the winery is flooded, the harvest destroyed will be bigger than in the `homogeneous`.

Differences between `homogeneous` and `size` and `exposure-worst` are negligible.



Remark: curves of configurations `size-exposure-best` and `exposure-best` are superposed

Figure 3.21 – Damages in harvest due to damages in winery's buildings and materials. Differences respect to `homogeneous` distribution. `Internal` coping tactic

3.5.4 Variations in wine-making cost. Long term.

Differences in this indicator follow the same line of reasoning than the prior one: once again, for `size-exposure-worst` the amount of harvest lost due to the `internal` coping tactic is bigger than in the `homogeneous` (see figure 3.22). It means that when in year $t = 2$, yield is processed in the winery, wine-making costs are smaller than in the `homogeneous`. Right the opposite in the case of `size-exposure-best` and `exposure-best`.

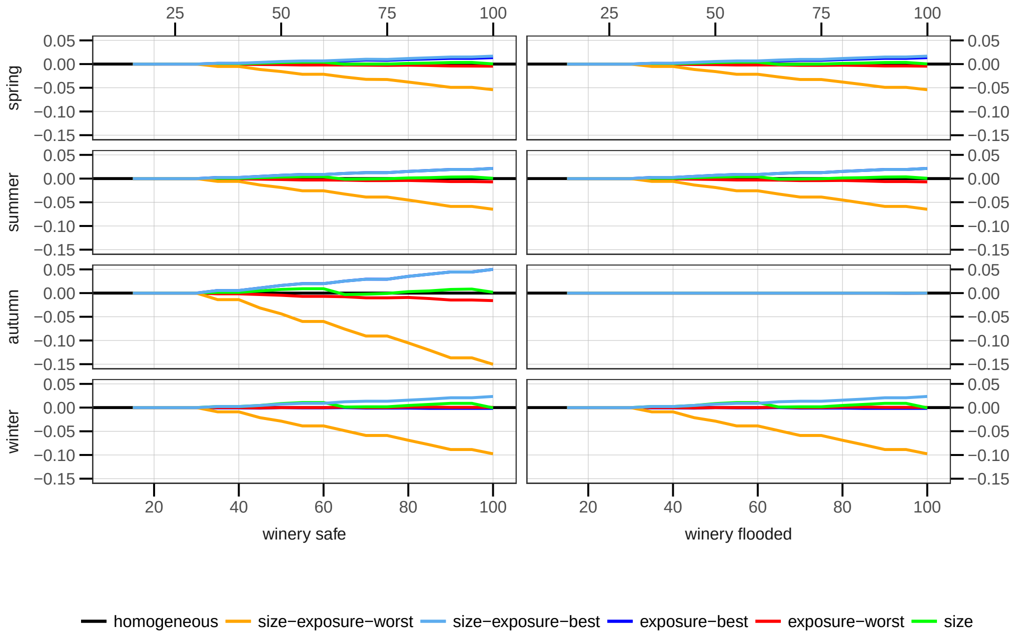
Differences between `homogeneous` and `size` and `exposure-worst` are negligible.

In autumn, when the winery is flooded all production is lost anyway so there exist no differences.

3.5.5 Total damages.

In the end, the greater destruction of harvest provoked by the coping tactic prevails and total damage is higher in the `size-exposure-worst` configuration (see figure 3.23). Configurations `size-exposure-best` and `exposure-best` present the smaller amount of total damages.

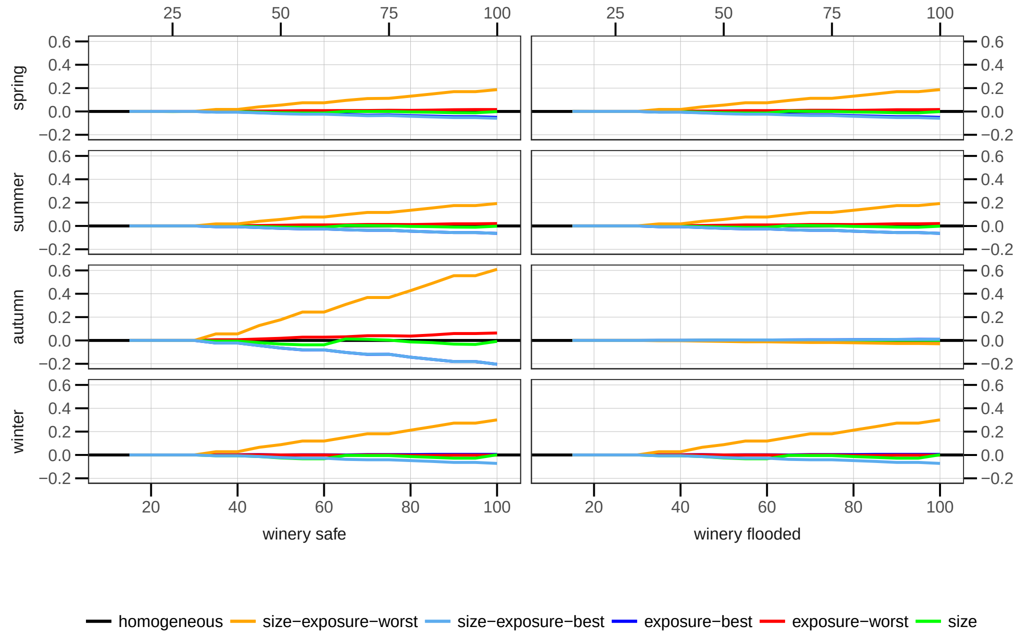
In autumn, due to the bigger effect of the `internal` coping tactic in terms of yield loss, differences between configurations are amplified when the winery is not flooded. On the contrary, when the winery is flooded, the differences in the damage estimation are null due to the consequences that impacts over wineries has for the CWS.



Remark: curves of configurations `size-exposure-best` and `exposure-best` are superposed

Figure 3.22 – Variations in long term wine-making cost. Differences respect to `homogeneous` distribution. `Internal` coping tactic

Differences between `homogeneous` and `size` and `exposure-worst` are negligible.



Remark: curves of configurations `size-exposure-best` and `exposure-best` are superposed

Figure 3.23 – Total damages. Differences respect to `homogeneous` distribution. `Internal` coping tactic

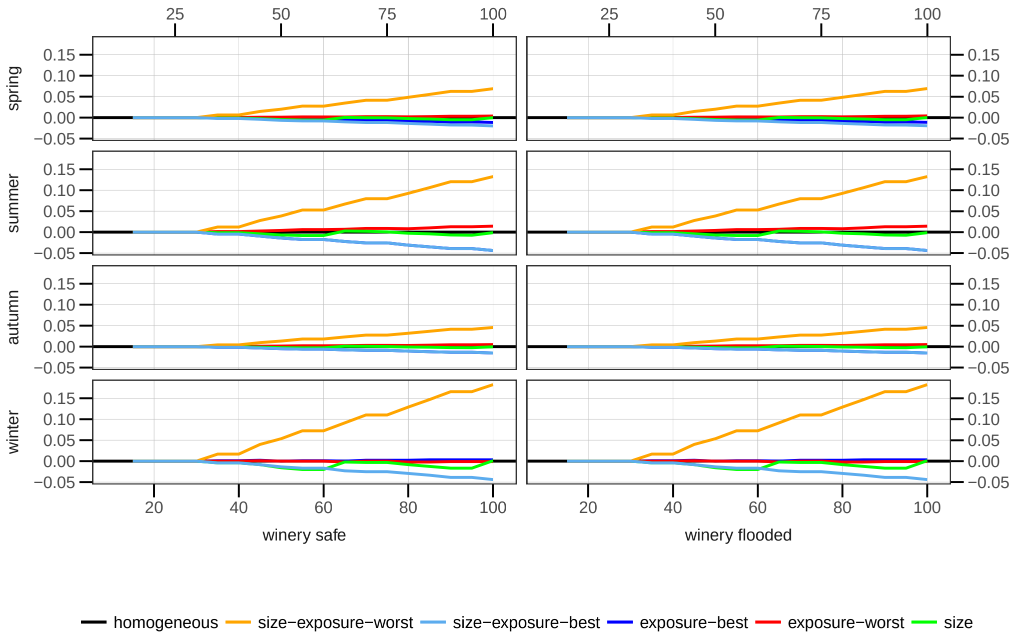
3.6 `External` coping tactic. Comparison of configurations of interactions

When the coping tactic used is `external` a small number of indicators present differences. Only the short term (immediate) vine-growing costs (figure 3.24) and the total damages (figure 3.25) display divergences among configurations.

The results obtained when vinegrowers use the `external` tactic mirror those obtained with the `internal` one. As we can see in figure 3.24, for the configuration `size-exposure-worst` now variations in vine-growing cost are higher than in the `homogeneous` configuration. Exactly the opposite that happens with `internal` tactic, yet motivated for the same reasons: insofar big farms have their buildings located in the flood-prone but not their plots and the extra fee to outsource activities is paid by productive plot, `size-exposure-worst` present a higher variation of vinegrowing cost than `homogeneous`.

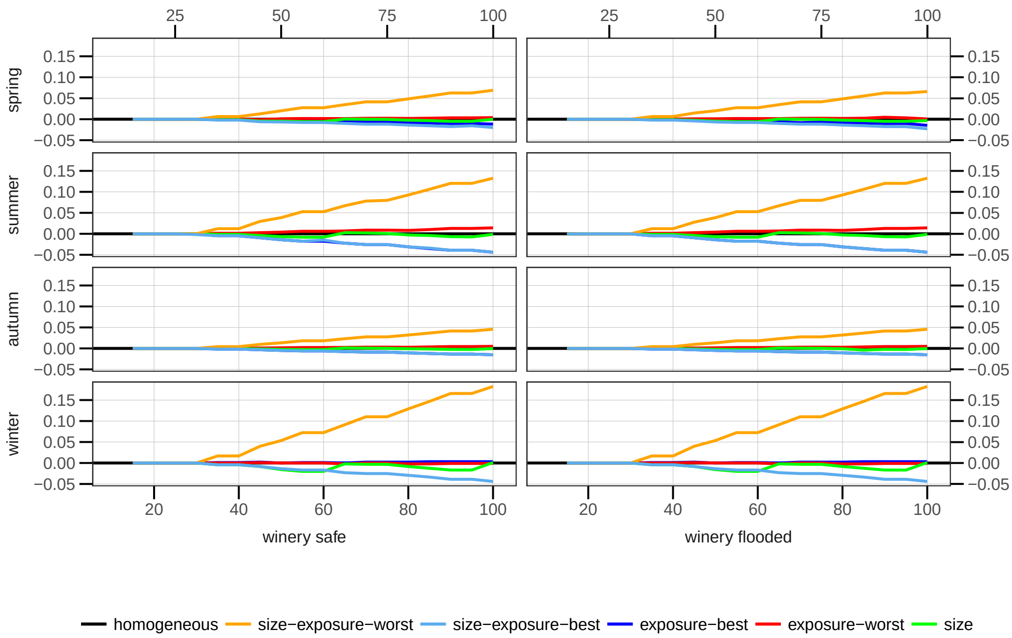
`size-exposure-best` and `exposure-best` experiment the same process, but with smaller magnitudes derived from the smaller size of the exposed farms. Hence, variations of vine-growing cost are smaller than in the `homogeneous` configuration.

Differences between `homogeneous` and `size` and `exposure-worst` are negligible.



Remark: curves of configurations `size-exposure-best` and `exposure-best` are superposed

Figure 3.24 – Variations in short term vine-growing cost. Differences respect to `homogeneous` distribution. `External` coping tactic



Remark: curves of configurations `size-exposure-best` and `exposure-best` are superposed

Figure 3.25 – Total damages. Differences respect to `homogeneous` distribution. `External` coping tactic

CHAPTER 4

Results II: from individual to system level

"An organization at any level is a distortion of the level below (10th Law of Levels)"

— Jame K. Feibleman

4.1 General discussion of the results obtained in the article *Floods, interactions and financial distress: testing the financial viability of individual farms in complex productive systems and its implications for the performance of the system* in relation to the dissertation's research goal

4.1.1 The article in the light of the dissertation

This chapter of results adopts a financial perspective to analyze the CWS in search for vulnerability factors. The magnitude of impacts in terms of Yearly Potential Gross Benefit (YPGB) of chapter 3 raises the question of the extent to which the system is capable of absorbing the impact from a financial point of view. Namely, we wonder if there is a threshold of harm above which the system is not profitable anymore. But, insofar in the CWS the results observable at collective level emerge from the dynamics at individual level, a compromised profitability at system level shall arise from financially troubled vinegrowers.

In this chapter we are going to focus our analysis on the factors that may be potentially driving the financial vulnerability of individuals in the aftermath of the flood: pre-flood conditions, interactions, etc. We are also stepping into the analysis of the inter-level interactions (individual–collective) in the aggregational scale to study in what measure the aforementioned factors also contribute to the vulnerability of the system as a whole.

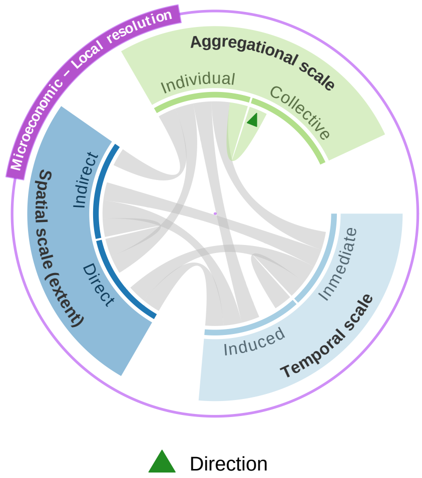


Figure 4.1 – Scales and levels taken into account in this chapter in relation to set of scales and levels considered in the dissertation. This chapter of results focuses mainly in the analysis of the influence of vulnerability drivers at individual level with impact over the whole Cooperative winemaking system (CWS)

To ensure the comparability of results between this chapter and the prior one (chapter 3), the article uses the so called `homogeneous` configuration (see chapter 4, article's section: simulation protocol). The potential effects of the alternative coping tactic or alternative configurations, insofar they are not included in the article, are provided in an addendum.

4.1.2 Summary of main results of the article

The article uses the COOPER model to explore to what extent the potential post-flood financial stress suffered by each individual vinegrower may drive the system to a restructuring point. Furthermore, accounting for the interactions of cooperative winery-vinegrowers, the article also analyzes to what extent characteristics of the cooperative winery (cost-revenue sharing rule and rigidity of cost-structure) may contribute to bring the system to the aforementioned restructuring point.

Agents present a reactive behavior: return as soon as possible to the *statu quo ante*. Vinegrowers also opt for an internal coping tactic to deal with the consequences in the immediate aftermath of flood: vinegrowers whose buildings are flooded do not count on external assistance to repair and perform their tasks. The misperformance due to impacts results in further yield losses (see chapter 2, section 2.11.2.2).

In the article we tests 6 key parameters to analyze the long term potential for financial distress in the CWS: i) individual business cessation criteria; ii) individual initial treasury; iii) winery's cost structure flexibility; iv) spatial location of the cooperative winery; v) season; and vi) flood extent

The effects of flood extent and season are similar than in chapter 3: on the one hand, longer floods impact more numerous elements so impacts and damages add up. On the other hand, damages over plants and yields display seasonal differences, thus they affect differently the flow of cash (inflows and outflows) generated by each vinegrower. Simulated Flood Scenarios (SFSs) in winter barely have negative impacts. In contrast, the higher probability of plant destruction in spring generates high impacts on cash flow both in the short and long term. Summer and autumn SFSs display more moderate impacts.

In relation to the other 4 parameters, the analysis performed highlights the higher sensitivity of the system to those parameters that belong to the central agent (winery) than to those that belong to the individual producers (vinegrowers). Furthermore, our results find that the return to a pre-disaster state may not be possible for either individual businesses or the system [1]. After floods hit the system, some vinegrowers may enter financially distressful situations that, eventually, may force the cessation of their activities. As a consequence, the whole system might need restructuring if it wants to survive.

Potential for damage spreading and intensity in such spreading, as well as explicit interactions and their configuration (what interacts with what) are key to explain the financial viability of both individual and collective (system) levels. To fail in taking into account those indirect effects might be leaving out of the design of risk prevention policies key factors to assure the economic and financial viability of businesses in flood-prone areas.

4.1.3 Discussion of results of the article in the light of the main question of this dissertation

4.1.3.1 Individual business cessation criteria

This parameter indicates the time between the moment in which the individual vinegrower incurs in a situation of payment default [2] and the moment in which said

1. This assumption of return to pre-disaster state is widely present in standard practices in Cost-Benefit analysis and business resilience studies.

2. Annual outflow larger than the combination of the annual inflow and the resources stocked in treasury

vinegrower ceases its activity (see article's section: Individual viability criteria).

The parameter is therefore an indicator of the time the vinegrower endures business losses before ceasing his activities. Insofar longer cessation horizons imply greater capacity of individual businesses to cope with the aftermath of the flood without ceasing their activities, the CWS will benefit as well of a greater capacity to cope and absorb the long term impacts of a given flood.

Plots destroyed by flood impacts reduce the owner's monetary inflow for several years. Those plots need replant, and newly replanted plots do not become fully productive until years later (5 in COOPER model). At the same time, the need for replant to make those plots productive as soon as possible (hypothesis of individual behavior) increases the monetary outflow for investments. But those investments are unplanned and may cause certain financial burden to the vinegrowers that need to do them. In those situation of potential financial distress or burden a greater degree of tolerance to payment default on the part of the financial sector (longer cessation horizons) increases the capacity of the individual vinegrowers to cope with the long term effects of the floods.

4.1.3.2 Individual initial treasury

The amount of monetary resources with which each individual vinegrower counts on before a given flood hits them also influences the vinegrower's capacity to cope with the consequences of the flood. As in the prior case, an improvement in the capacity of individual agents to cope with the long term impacts of the flood ameliorates the capacity of the whole system to cope and absorb the impacts of the flood. As we saw in the previous chapter, the effects of a given flood can reach an amount several times higher than what the system is capable of generating in full performance. In this sense, when the pre-disaster situation of the system includes large amounts of liquid assets, the system presents a lower degree of vulnerability to a given flood due to the improvement in the coping capacity.

4.1.3.3 Winery's cost structure flexibility

The degree of flexibility displayed by the structure of costs of the cooperative winery plays an important role in the susceptibility of both the system and the individual vinegrowers to floods. Indeed, the eventual sharing of costs and revenues of the winery between all associated vinegrowers under the rule with which the COOPER model works presents potential for impact spreading (see the mathematical demonstration in the annex of the article that follows)

Its influence is materialized through two different mechanisms, depending on whether we focus on the system or on the vinegrowers. In the former case, a more flexible cost structure (higher proportion of total costs linked to production) is directly linked with a greater coping capacity at system level, regardless business cessation horizons, seasonal behavior or initial treasury conditions. The presence of a part of the cost independent from the level of production structural cost prevents reductions of cost to be proportional to reductions in productions. The structural cost will, in fact, moderate the reduction of cost associated with a reduction of the production. On the other hand, the income generated in the system is proportional to the production, thus reductions of production will imply reductions of the same order of magnitude in the income generated by the system. The more rigid the cost structure is, the less reactive it will be to the reduction of production, and the faster we will reach a situation of zero profits in the system. It will reduce therefore the capacity of the system to cope with long term impacts of floods.

When we focus on vinegrowers, the presence of structural cost in the winery is going to also have redistributional effects (see article's mathematical annex). The magnitude of those redistributional effects depends on the rigidity of the structure of costs of the system. The more rigid the cost structure is, the more intense the redistributive effect and greater the potential for impact spreading along the system. This mechanism eventually increases the susceptibility of vinegrowers to suffer impacts from floods. At the same time more intense redistributive effects are linked to more intense reductions of profits given a reduction of production, which, as it happens at system level, reduces the coping capacity of the individual vinegrowers.

Given a seasonal SFS of certain extent, relatively flexible cost structures in the winery (majority of costs linked to production) show a lower degree of susceptibility and greater coping capacity than relatively rigid cost structures (majority of costs independent from production). Rigid structures are thus linked to more vulnerable individual agents and systems.

4.1.3.4 Spatial location of the cooperative winery

As in the prior chapter (chapter 3), the spatial location of the cooperative winery building(s) is key to the susceptibility of the system. The presence of the cooperative winery in the flood prone area increases significantly the susceptibility of the system to flood impacts.

4.1.3.5 Remarks on the effects of coping tactics and variations in the configurations of links between elements

Parameters like the use of an alternative coping tactic (external) or the variation of links between material components have not been include in the article that serves as core of this chapter. Their effects over the long term financial viability of the system have been tested though. The results are presented in the figures included in the Addendum to the article.

With regard to the coping tactic, the results obtained with the tactic `external` do not significantly differ from those of tactic `internal`, except in case of autumn SFSs, when differences between tactics are maximal (see figures 4.2 and 4.3). The observable differences in autumn, even though they do affect the amount of cessations among individual vinegrowers, do not alter the situations in which the system reaches the restructuring point. As well differences are attenuated by longer individual business cessation horizons (see figure 4.2).

Variations in the configuration of links among elements (see figures 4.5 and 4.6) influence the number of cessations of individual vinegrowers, and may have a significant effect in the capacity of the system to absorb the impact in the aftermath of the flood. Thus concrete configurations of links are going to influence the capacity of both individuals and system to deal with the consequences of the flood in the aftermath.

Floods, interactions and financial distress: testing the financial viability of individual farms in complex productive systems and its implications for the performance of the system

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Abstract

This paper analyzes the long-term financial viability of a cooperative winemaking system in presence of flood risk, as a result of the financial viability of the ensemble of participants in the system. To do so, we use a novel agent-based model (COOPER) that simulates the dynamics of production and cash flow of a cooperative winemaking system. We conduct experiments based on 6 key parameters: i) winery's cost structure flexibility, ii) winery's geographical position, iii) individual business cessation criteria, iv) individual initial treasury, v) flood extent and vi) season in which the flood takes part Accordingly, Analyses of financial viability are conducted both at individual level and at system's level, testing the capacity of both the individuals and the system to absorb the impact of the flood. The results obtained show that parameters related to the winery influence the aforementioned capacity of both system and individuals more than individual parameters. In addition, the post-disaster analysis of cash flow sustains the conclusion that after a disruption neither the system nor the individuals can always go back to pre-disaster conditions.

Keywords: Vulnerability, Indicator, flood, network, Agent-based model, Damage, Interaction, Cash-Flow, Agriculture

Acronyms

BAU: Business as usual aka no flood scenario | **SFS**: Simulated Flood Scenario | **GMV**: Guaranteed Minimum Wage | **CWS**: Cooperative winemaking system | **ABM**: Agent-Based Model | **SRT**: Systemic restructuring threshold |

1. Introduction

Pursuing improvement in risk prevention, damage reduction an economic sustainability, nowadays flood risk management practices include non-structural measures based on ecosystem services, like floodplains and water retention areas (Hooijer et al., 2004). These practices though prioritize the protection of urban and industrial areas in detriment of rural and agricultural spaces due to lower potential impacts (Barbut et al., 2004; Le Bourhis, 2007; Penning-Rowsell et al., 2013; Brémond et al., 2013; Decrop, 2014). Thus they are increasing the exposition to floods of rural and agricultural areas.

Besides impacts on infrastructures and disruptions in transport, floods can badly affect agricultural land in both short and long term. Floods can destroy crops and harvests, alter soil conditions (which ultimately affects crops and harvests) and impede critical field tasks, causing further repercussions in some crops (Bremond, 2011; Brémond et al., 2013; Penning-Rowsell et al., 2013). The viability of agricultural businesses located in those floodplain and water retention areas can get therefore severely compromised. Especially insofar the economic structure of the agricultural sector display singular patterns that make farming activities particularly vulnerable to income and cash flow shifts (see Barry and Robison, 2001, for a review of those patterns). Moreover, like a domino effect, supply chains can get impacted and local communities badly affected.

In nowadays world, local businesses are more and more interconnected in complex production networks and value chains. And, indeed, natural hazard-related disruptions in value chains and production networks seem to have increased during the last decades (Wenz and Levermann, 2016). The capacity of supply chains and production networks to withstand upheavals and return to pre-disturbance states has also been attracting the attention of both scholars and practitioners (for instance Kim et al., 2015; Brusset and Teller, 2017). Disruptive events in these supply chains and productive networks, due to the existing backward- and forward-linkages between their elements, enable the apparition of indirect impacts rippling through the networks and chains (Kim et al., 2015; Otto et al., 2017).

Works in this area have focused on the identification of vulnerability drivers and resilience/coping capacities of enterprises facing both man-made and natural hazard-related disruptions (e.g. Graveline and Grémont, 2017; Brusset and Teller, 2017). However, in general terms, farm-level studies are rare to find (Nicholas and Durham, 2012; Reidsma et al., 2018). So are studies on the economic and financial viability of small businesses operating in flood-prone —or more generally hazard-prone— areas (Marshall et al., 2015). The existing works have tended to focus on statistical studies on business demise (for an interesting discussion see Gosling and Hiles, 2010), or identifying relevant factors for business' lack of resilience (e.g. Tierney, 1993; Brown et al., 2015; Marshall et al., 2015; Graveline and Grémont, 2017). In addition, those works frequently focus on pre-disaster conditions instead of on post-disaster drivers, such as business interruptions, losses of capital, recovery strategy, or cash flow problems (Marshall and Schrank, 2014). As a consequence, the factors and mechanisms threatening the individual exploitations' financial viability and their potential consequences over production and value chains are not well understood yet (Bubeck and Kreibich, 2011; Penning-Rowsell et al., 2013).

1.1. Cooperative productive systems as supply chains

The viability of agrarian businesses is critically linked to the productivity of the land, which, in turn, is linked to the farming system and the type of land use (type of culture) (Posthumus et al., 2009; Penning-Rowsell et al., 2013). Thus, farm-type discrimination is recognized as essential in order to provide models capable of reliable assessments of impacts and vulnerabilities (Reidsma et al., 2018). In such regard, we will be focusing our work in this article on vinegrowing farms. Specifically on the study of what we call the Cooperative Winemaking System (CWS hereafter). This kind of productive system has been used by small-scale vinegrowers as a defense mechanism against market and institutional rigors (Chevet, 2004). Yet, according to the french confederation of wine cooperatives[1], 50% of the french wine production is conducted in cooperative wineries.

There seems to exist, indeed, an increasing interest on the effects that climate change can have in the wine sector (Sacchelli et al., 2016a,b; Mozell and Thach, 2014). Authors like Sacchelli et al. (2016b) highlight the need to widen the knowledge on climate change effects, vulnerability and adaptations on winegrowing and wine-producing activities. Battagliani et al. (2009), in their study on perceptions of vine-growers to climate change, already collect the awareness of french vine-growers to an increasing frequency of floods. Although not numerous, it is possible to find studies of vulnerability of individual vinegrowers to climate change in general (Nicholas and Durham, 2012), or more particularly to floods (Bremond, 2011). To date,

[1] Confédération des coopératives vinicoles de France, in the original French

however, research addressing specific matters related to vulnerability to floods (or climate change in general) in cooperative wineries seem to have been overlooked.

The CWS present a few features that make its study pertinent from both an individual business' and supply chain's point of view. The CWS can be conceptualized in fact as an encapsulated supply chain. In it, two different kinds of operators interact: a cooperative winery and a collection of vinegrowers associated to said winery. The basic commodity to the system/supply chain (grapes) is provided by the latter, whilst the former integrates under the same structure the rest of the stages in the supply chain (fermentation, bottling and commercialization) for their associated vinegrowers. Thus both vine-growers and cooperative winery depend on each other to ensure production and revenue. In addition, the CWS mutualizes costs, revenues and the propriety of the winery's assets between its associated vine-growers. Due to such circumstance the CWS as a supply chain i) has very limited potential for input substitution; ii) is highly dependable on the individual performance of their associates to ensure a final amount of product; and iii) relies on one entity (winery) to ensure the final economic success of the whole system. In addition, the rules for cost-revenue sharing among associates (see Touzard et al., 2001; Jarrige and Touzard, 2001; Biarnès and Touzard, 2003) have the potential to propagate any disturbance at individual level across the whole system (see annex for a formal demonstration)

Works like Lereboullet et al. (2013) or Bremond (2011) have pointed out that, due to their mutualizing practices and networked productive structure, cooperative winemaking processes are going to have different vulnerability drivers than those of *independent* vine-growers. Nonetheless, these factors seem to not have been explicitly investigated.

The present article pretends to start to fill this gap. We search to study the post-disaster long term financial viability of a CWS in presence of flooding risk. Works like Haraguchi and Lall (2015); Bode and Wagner (2015) or Green et al. (2011) have showed that the potential for disruption propagation, thus identification of indirect effects, relies on the characterization of the underlying topology of the system. This way, the recognition of the nature and location of nodes within the system, nexus between them and direction of relations (thus hubs can be identified) become key in the study of the potential for disruption and indirect impacts. Such an in-depth knowledge of the system is ultimately highly dependent on the available information for the given system. Only a few studies in the literature have established explicit system topologies to analyze the potential for disruption (Kim et al., 2015). More work is needed, especially at microeconomic levels, to narrow the existing knowledge gap on how economic systems would react to flood hazard (Meyer et al., 2013). Microeconomic studies can potentially improve i) the understanding of the direct–indirect impact connection; ii) the understanding of mutual influence of nodes, links and hubs, and their reactions to external shocks; and iii) the trajectories the system may follow after the shock.

1.2. Agent-based model as a tool for the study of supply chains

Supply networks can be recognized as complex systems (Choi et al., 2001; Otto et al., 2017). To adopt such a perspective enables us to approach the study of the system as an ensemble of heterogeneous units interacting with each other according a given topology. Thus we can analyze the direct impact of a disruption, its spreading along the topology in time and space (indirect impacts) and the potential for alternative trajectories. This perspective also demands for adapted modeling techniques. Agent-based modeling (ABM) is a computational tool for the description and dynamic simulation of systems in which both interactions and heterogeneity of entities are relevant. In ABMs the system's design starts from the base layer, identifying the entities (nodes) of interest, their interactions and the environment in which they take place (Smajgl and Barreteau, 2014). ABMs can be seen as *computational laboratories* to test the behavior of specific systems to controlled changes in key parameters (Macy and Willer, 2002; Dibble, 2006; Seppelt et al., 2009; Bruch and Atwell, 2015). ABMs are not necessarily equilibrium oriented. Rather they assist to explore the different trajectories that a system may follow in relation with the value of the parameters of the experiment. In this sense, ABMs provide us with a robust tool for ex ante evaluations of system's behavior. ABMs can also be spatially explicit (Gilbert, 2008; Dibble, 2006). Thus it is possible to take into account the effect of location in space when it is relevant for the study

Neither agriculture research nor the flood impact assessment research community count ABMs within their respective standard toolboxes. Nonetheless they present the potential to contribute to the better understanding of flood shock propagation (Meyer et al., 2013). As well as clear advantages when it comes to interaction representation and simulation of decision-making in agricultural systems (Jansen et al., 2016; Reidsma et al., 2018). Indeed, to date, several studies on flood impacts have been conducted with ABMs (e.g. Filatova, 2015; Tonn and Guikema, 2017; Erdlenbruch and Bonté, 2018; Dubbelboer et al., 2017). Reidsma et al. (2018) census 28 works(over 184 published between 2007 and 2015) based on ABMs, addressing impact assessments of policy measures over agricultural systems at European level. Supply networks disruptions have also been approached with ABM. The ACCLIMATE model (Bierkandt et al., 2014) has been used in several works to study global supply disruptions (e.g. Otto et al., 2017; Wenz and Levermann, 2016).

ABMs present yet another advantage for the goal we pretend to reach. ABMs enable us to track down the impacts that floods may have on individual flows of income and expenditure, insofar they are capable of account for heterogeneity among the system's composing entities. Monetary valuations of those flows over certain periods of time in combination with accounting conventions and methods is common practice in microeconomic approaches (Bubeck and Kreibich, 2011; Penning-Rowsell et al., 2013). Indeed cash flow analysis is a widely used accounting technique to foreseen potential corporate failure and financial distress (for a complete literature review, see Sharma, 2001). Its use is founded on the basis that i) it helps to avoid deficiencies of the accrual system; ii) business performance is intrinsically associated with the inflows and outflows of cash, thus signals of financial distress can be evident long before a crash (Aziz et al., 1988; Sharma, 2001; Arlov et al., 2015); and iii) the fundamentals of the approach recognize only transactions in which the cash actually changes hands.

We do not pretend to examine all the factors that may influence the financial vulnerability of each of the entities that may belong to the CWS. Instead we want to focus on the potential that the architecture of the system offers for the study of indirect effects that emerge from direct impacts. Concretely we are interested by the next two questions: To which degree financial distress due to flood impacts on individual vinegrowers might drive the CWS they belong to into a restructuring point? May the cooperative winery influence such a degree?

The rest of the paper is structured as follows: section 2 presents the data sources and our method, based on the COOPER model, an ABM we developed to represent how the CWS is impacted by floods. We also explain how we use it to perform the analysis of the financial viability of both individuals and system. Section 3 details the simulation protocol followed and the values considered for the parameters to test. In section 4 we present the results obtained according the different parameters tested. The article finishes with a discussion of those results in section 5. The article also includes a mathematical annex (Appendix A) with the demonstrations of the potential for impact propagation in the system and its intensity.

2. Materials and Method

We have build an agent-based model to simulate the dynamics of a CWS (the COOPER model). As we explained in the introduction, we use this model as a virtual laboratory for the ex ante evaluation of the behavior of the CWS to flooding phenomena. There has been observed a general lack of models adapted to our research goal. It has eventually demanded us to build our model from scratch. To do so, we have combined several data elicitation methods and relied on two study cases located in southern France.

2.1. Data

The model calibration and main hypotheses are based on the information extracted from *Aude* and *Var* regions.

2.1.1. Case Studies

Aude and Var are two counties located in southern France. In both areas, the wine sector represents a critical share of local economy and land occupation. Cooperative vinification is an institution rooted in both territories (Chevet, 2004; Touzard, 2011).

Aude an Var areas have endured flood related catastrophes of different intensity in recent years. In 1999, the Aude river basin suffered one of the major flood disasters of the past few years in France (European Environment Agency, 2010). The whole socioeconomic system of the area resulted impacted. Losses were estimated at €620 million. The damage in the agricultural sector was estimated at €33 million which amounts to 9% of the total damage and 70% of the damage to the businesses sector (Vinet, 2003). Viticulture was the main agricultural activity impacted in the county (Bauduceau, 2001).

The Var county was impacted several times by floods in the last years. The flood of June 2010 in the Argens river basin was specially dramatic: 23 casualties and €1.2 billion in material damage (Collombat, 2012). 250 farming businesses were impacted, leading to a damage estimated at €150 million (12.5% of the total). In average, farmers lost 57% of yields and 40% of perennial plants (Chambre d'agriculture Var, 2014).

2.1.2. Data sources

The level of detail of the COOPER model has required the combination of several data elicitation methods. In first place, individual *interviews* with both winegrowers and winery CEOs were conducted. They are a source of qualitative data on i) the system's general functioning; ii) the rules more generally applied; iii) the most common behaviors; and iv) the damages endured by the different agents. Interviews were also conducted with accounting experts to test the plausibility of financial hypotheses. Interviews with experts on flood damage assisted in the formulation of simplified damage functions

The use of GIS assists in the construction of plausible territorial configurations and terrain's productivity for our virtual world.

Individual financial structures are constructed by mixing several data sources: CER (2014), CER (2017), FADN, FranceAgriMer (2016), FranceAgriMer (2017), Mutualité Social Agricole (MSA), Direction de la communication - Service Presse (2017), INSEE (2016), Folwell and Castaldi (2004.).

Last, Touzard et al. (2001); Biarnès and Touzard (2003); Jarrige and Touzard (2001) provide concrete cost-revenue sharing rules for CWS. Bremond (2011) provide information on vinegrowing tasks and damages aassociated in case of inability to perform.

2.2. Model

The model description that follows is not exhaustive. It intends to offer an overview of the model that enables the reader to understand its key points without getting to deep into details or hypotheses. The complete documentation of the model is available at COOPER in CoMSES.

2.2.1. General overview

Our model is conceptualized as the interaction of a biophysical environment and a productive-economic environment (the CWS), where the latter transforms the inputs from the former into consumption goods.

The CWS is characterized as a tree-type topology (Wilhite, 2006): all elements in the system are connected one to each other through a central element (figure 1). This kind of topology represents accurately the organization of the CWS: the cooperative winery is linked and links all vinegrowers, mutualizing productive means, costs, risk and benefits. At the same time, each winegrower is also linked to its vineyards.

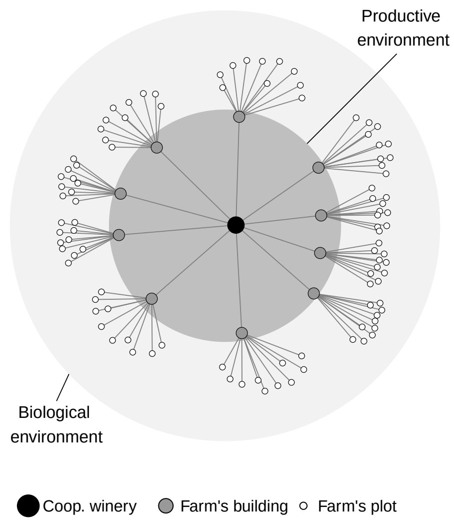


Figure 1: Resulting bio-productive environment, represented as a star-type network, based on a cooperative winery

Floods originated in the biophysical environment, covering different extents of a maximum flooding area, may hit the CWS. When that happens, the normal performance of the system, hence the expected flow of inputs and outputs in the system, gets impacted.

2.2.2. Brief description of the operational productive process

The productive process is actively conducted by both vinegrowers and cooperative wineries. Vinegrowers perform year-round grape-growing tasks on their owned plots. Such tasks are organized according a seasonal schedule, starting in winter. As well, vinegrowers should reinvest in their plots (replant) every certain time. It causes two different consequences for the productive process: first, replanted plots are assumed to be not immediately productive; vinegrowers have therefore heterogeneous and lower-than-the-potential productions. Secondly, there exist rotation between productive/unproductive lands.

Each vinegrower is associated with one, and only one, cooperative winery. Wineries are in charge of wine production with the input provided by vinegrowers, as well as its commercialization in markets. They also follow a seasonal schedule: in autumn they receive the grapes coming from their associated vinegrowers; That input is transformed in wine during winter, and sold in spring. The whole stock is assumed to be sold, therefore, there is no stock in summer.

The cooperative winery shares each year the revenues from the commercialization minus the wine-making cost incurred, proportionally to the amount of grape given by each vinegrower (Touzard et al., 2001; Biarnès and Touzard, 2003; Jarrige and Touzard, 2001). Additionally, each vinegrower should cover its own vine-growing costs.

2.2.3. Brief description of the investing-financing process

As it was stated, the model includes an investment cycle at plots' level. Each plot is assumed to be replanted every each 30 years; of them, the 5 first ones, the plot will remain unproductive, although it still will need tasks to be conducted over; the remaining 25, the plot is assumed to be productive, providing a constant, known amount of hectoliters.

To finance their investments, vinegrowers are assumed to borrow money from financial institutions. In such regard it is assumed that lenders always lend the money and, furthermore, they offer homogeneous conditions to all vinegrowers.

2.2.4. Brief description of others intervening variables

The analysis of each vinegrower's monetary inflows and outflows rests upon four key variables: production (Q_t), revenues (R_t), costs (C_{vg_t} —vine-growing— and C_{wm_t} —wine-making—) and investments and reinvestments (I_t). To them, the analysis of monetary inflows and outflows adds the following variables:

- Taxes (T_t): Amount paid each moment t to public treasury over the production of the prior year.
- Owner's remuneration (O_t): Amount assigned each moment t as remuneration of the owner. Expressed as a proportion of the Guaranteed Minimum Wage (GMW)
- Subventions to investments and reinvestments (Sb_t): injections of public money applied to specific investments done by farmers.
- Insurance compensations(IC_t): Public and private insurance schemes that offer monetary compensations to the impacted entities in the model.

2.2.5. Simulation procedure, flood procedure and impacts of floods

Simulation procedure. The model simulates the behavior of the cooperative system for 30 years at a seasonal timestep. Each season tasks are to be performed by the vinegrowers and the cooperative winery in order to conduct the production process. Each set of 4 season is considered a year, and each year the model register the state of the different monetary flows.

Flood procedure. Our elements are located in a virtual territory, divided in cells. Each of those cells can host only one element -either a plot, a vinegrower or a winery. Over the territory, two different areas can be distinguish: one subject to floods (flood-prone area), one not. The so-called flood-prone area is, at the same time, divided in 100 subareas, numbered from 1 to 100.

Floods come defined by two parameters: extent and season of occurrence. Thus when a flood of extent 50 hits the system in spring, all cells located between the subareas 0 to 50 in the flood-prone area the first spring after the simulation starts, are considered flooded and all the elements located in those cells impacted

Impacts of floods. Impacts of floods can affect simultaneously plots, vinegrowers and wineries, having, directly or indirectly, reflect on one or more of the four key variables in which we can summarize monetary flows in our model. Those impacts can have a twofold nature —material and non-material (those that imply disturbance of the normal process)— and have been given a hierarchical structure that prevent double accounting phenomena.

In the base of the hierarchy, we find the material damages on plots. These damages are threefold: i) damages on soils, considered independent of the season; ii) damages in yield, dependent on the season; and iii) damages in plants, dependent on the season as well and also stochastic.

When plants in plots get destroyed, all yield of that plot is lost. Moreover, to replant is needed, and replanted plots remain unproductive for 5 years (with the consequent effects that it will have over the different flows on the system).

One step higher we find damages on vinegrower's buildings and equipment. In our model buildings and equipment are considered as a unit and its damage function has been simplified to the maximum: when impacted, buildings and materials need to be repaired and the value of the damage is constant. Until such reparations are complete, they will lose some of their functionality. In the non material side, this loss in functionality is translated in a vinegrower unable to perform its task adequately during the flood season. The consequences of such inability will be translated either in cost raising or production fall

In this same level, we should locate as well savings in vine-growing costs coming from plots whose yield has been destroyed. Whether by plant destruction or by direct damage in yield, as soon as the plot loses all its yield, the owner stops performing vine-growing tasks in said plot and save the cost of the remaining tasks.

The top level in our hierarchy is occupied by material and not material damages on the winery's building. Approached identically to the vinegrower's building, impacts in this level add damages on wine/grape stock when the buildings are flooded: vinegrowers are not suppose to kept wine/grape stocks in their buildings; on the contrary, wineries are suppose to stock wine/grapes in their buildings from autumn to spring, being totally lost if the building gets flooded. Any other stock has not been considered separately, but part of the equipment.

Furthermore, when the winery's buildings are flooded, depending on the season it gets impacted, grape collection, production or commercialization may not be performed, therefore production as a whole may result lost.

2.3. Financial analysis

The COOPER model allows us to simulate the evolution of each vinegrower's individual cash flow. The study of cash flows we present is based on a simplified adaptation of the Lawson's identity (Foster and Ward, 1997), interpreted as in Lee (Sharma, 2001). This way, each individual agent in the model prioritize his cash inflows (+) and outflows (-) according the following scheme:

$$R - C_{vg} - C_{wm} - FO - T - OR + FI - I = \pm Tr \qquad (1)$$

Where: R = revenues from wine selling; C_{vg} = vinegrowing costs; C_{wm} = winemaking costs; FO = financial outflows (interest + loan/s annuity/ies); T = taxes; O = Owner's remuneration; FI = Financial inflows (loans + subventions); I = Replacement investments[2]; Tr = Treasury inflow(+)/outflow(-)

As we can see (figure 2) the operational net cash flow $(R - C_{vg} - C_{wm})$ permits the farm cover outflows due to financing activities (debt reimbursement), taxes, at the same time it ensures a minimum floor to owner's remuneration. Operational outflows, corresponding to the farm's reinvestment —replant— schedule are covered by financial inflows coming from subventions and loans for reinvestment.

In such scenario the evolution of the liquidity position —cumulative balance of treasury— is always increasing, con an stable accumulation throughout the periods of simulation

Both the evolution of the treasury and the evolution the cash flows does not indicate any kind of problem of viability for such given farm

2.3.1. Individual viability criteria

In the COOPER model, replacement investments are always covered by loans and subventions. Nonetheless the financial sector does not present an active role in the model. Each time an individual wants to make a replacement investment he would receive a loan under specific, constant conditions.

Individual agents use their operational net cash flows $(R - C_{vg} - C_{wm})$ to face paymentss in concept of interest and annuities, taxes and finally own remuneration. Depending thus on the respective magnitude of outflows and inflows, the agent will face three different outcomes:

[2]The current version of the COOPER model does not enable individual growth investments. Individual business size remains thus constant during simulations

- Inflows > outflows. The difference between inflows and outflows represents a treasury inflow, hence an increment in the firm's stock of monetary resources available (liquidity improvement)
- Inflows = outflows, which will have no effect over treasury flows nor firm's liquidity position
- Inflows < outflows. The difference between inflows and outflows represents a treasury outflow. The firm's stock of monetary resources will therefore decrease (liquidity worsening)

The capacity of any individual agent in our model to face the latter outcome is directly determined by the amount of monetary resources he could have stocked. When the monetary resources stocked in an agent's treasury are not enough to cover the difference between inflows and outflows said agent is considered to be overdrawing his monetary resources (figure 3). Overdrawing situations in our model are penalized. They will generate additional payments in concept of interest over the amount overdrawn.

There exist several different criteria to judge a firm's viability in the existing literature on cash flow analysis (Salfizan Fawzi et al., 2015, reviews those criteria). However, as Desbois (2008) points out some of those criteria are difficult to apply to the agricultural sector, notably due to lack of information. To build a reliable criterion we could use with the COOPER model we decided to mix two existing criteria. First, we use the general notion of financial default. This criterion considers that a firm is in a situation of financial distress when it is incapable of meeting payments and/or contractual obligations in time. Next, we include Desbois notion of farm's viability. According to this criterion no farm can be considered viable if it is not capable of generating an income for the owner equivalent to that of other professional activities (Desbois, 2008). This criterion remains slightly open to interpretation though, inasmuch as it is not explicit what is the level of income that satisfies the condition of equivalency with the other professional categories. Nonetheless, Over the basis of such premise, a farm cannot be considered viable if it is not capable to i) provide the owner with a minimum amount of money that ensures its subsistence, and ii) remunerate the rest of productive factors (work and capital), even if the farm is not in situation of default or negative cash flows. Our resulting criterion does not limit therefore *default* to loan payments and interest but also owner's remuneration. In other words, agents in situation of overdrawing are considered in situation of *default*, thus their activities are not viable.

How long can an agent endure a situation of default/non-viability? we consider three different temporal horizons:

1. *Default + 0* (or simply *default*). As soon as the vinegrower does not have enough resurces to back his outflows, the activity ceases.
2. *Default + 3* (based on Sharma, 2001). The vinegrower endures 3 years of losses before ceasing the activity. The implicit level of trust and solidarity from the financial sector as well as the agent's motivation are thus greater than in the first case
3. *Default + 5* (based on Sharma, 2001). The vinegrower endures 5 years of losses before stopping the activity. Financial sector's trust and solidarity and agent's motivation are the greatest of all three horizons.

2.3.2. Systemic restructuring threshold (SRT)

Due to the existence of structural cost in the cooperative winery and the cost-revenue sharing rules used in the CWS, individual business cessation is expected to have an impact over the whole system. Such impact is going to be driven by changes in the share of cost asummed by each individual vinegrower. Insofar individual revenue is proportional to individual production, business cessation does not affect the individual flow of income of the remaining businesses. Nor the cost associated to vinegrowing activities. At system level, individual business cessations are going to reduce both final production —thus revenues— and wine-making operational cost (winery's cost linked to production). However, the existence of wine-making structural cost (winery's cost not linked to production) is going to lessen the rate of decrement of cost in relation to

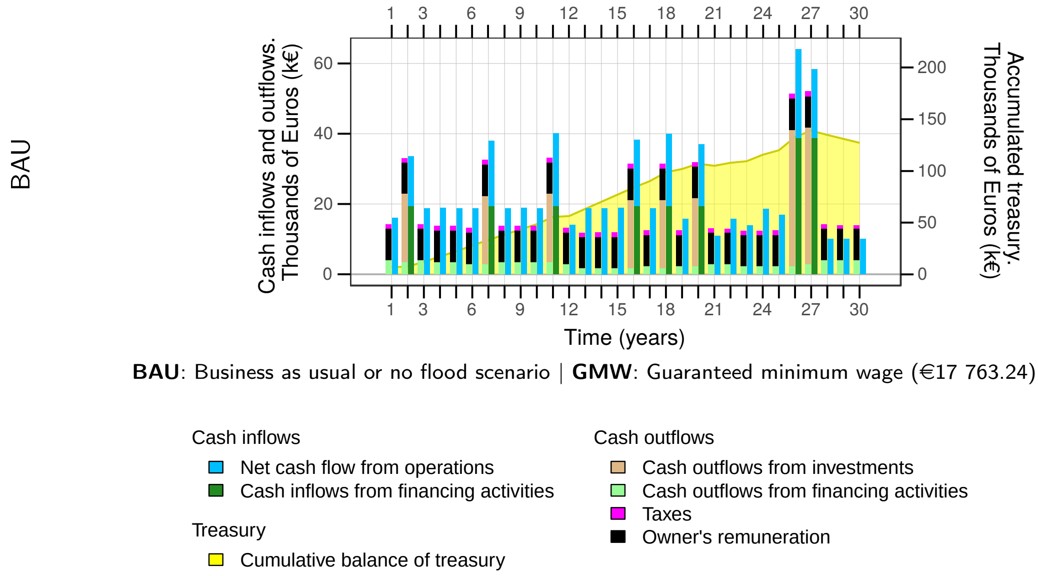


Figure 2: Cash inflows vs. cash outflows and evolution of the accumulated treasury of a given farm for the Business as usual or zero flood scenario, assuming accumulated treasury in year 1 is €5000 the owner's remuneration floor is 0.5 times the GMW

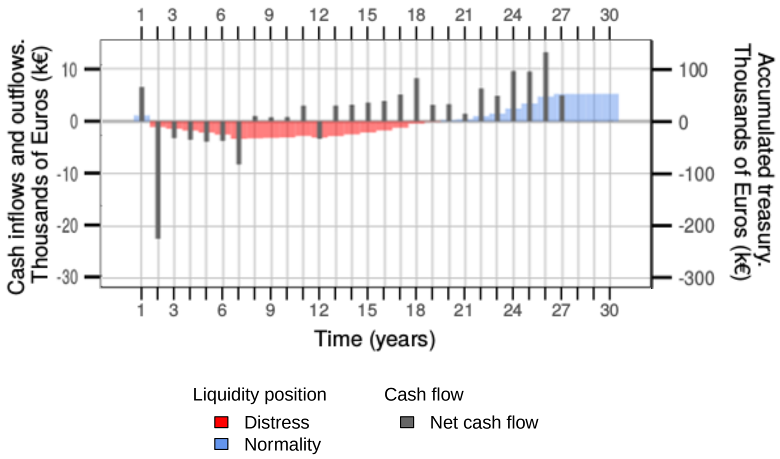


Figure 3: Example of monetary resources overdrawn between years t=2 and t=20 because of negative net cash flow between t=2 and t=7

production —thus revenues. In other words, in the CWS, individual businesses cessation is going to decrease production and revenue at system level at a faster rate than cost.

Individual business cessation is also going to reduce the number of associated vinegrowers in the CWS. Thus, insofar the wine-making structural cost does not vary, each of the remaining vinegrowers will have to pay a larger share of the aforementioned cost. As a consequence, *ceteris paribus*, each individual business cessation is going to reduce the individual profit rate of the remaining businesses in the system.

In view of such a phenomenon, we wonder to what extent the system is capable of generating benefits for its members if an increasing number of vinegrowers cease their activities. This idea lies behind what we will call *systemic restructuring threshold* (SRT hereafter). The SRT is defined as the minimum amount of vinegrowers that must cease their activity to cause a null profit to the remaining ones

To determine the SRT, first we run a set of simulations in absence of floods. These simulations enable us to characterize the defining values of both a hypothetical *average vinegrower* and *average system* in the COOPER model.

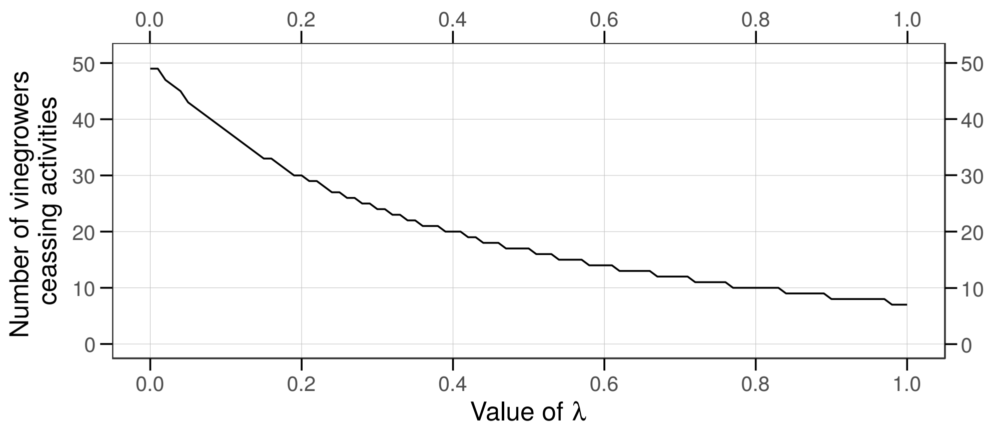
Once we have set the prior average values, we proceed to reduce the production in the system. In the COOPER model, each hectare of productive surface has a constant amount of production associated. By reducing one hectare of productive surface at a time, we ensure a sequential reduction of production at a fixed rate. With each reduction, we recalculate the overal wine-making costs associated to the new production.

Assuming the productive surface of our *average vinegrower* remains unchanged (hence production and revenues), we are able to evaluate the effect of the new wine-making cost over his profit. Whenever such profit gets reduced to zero, we identify the amount of productive surface lost as SRT. Inasmuch as the analysis we are presenting here is based on an homogeneous size of vinegrower, we can easily calculate the number of individual vinegrowers that must cease their activities before the system reaches the SRT.

The potential of individual businesses cessations to impact the system is linked to the existence of wine-making structural costs. Intuitively, CWSs characterized by wineries with rigid structures where most of the cost is not linked to production should present higher potential for impact spreading. Since most of the wine-making cost in those structures is not linked to production, the increment in the wine-making share of cost finally paid should be higher than in more flexible structures. The fall in the individual profits, *ceteris paribus*, should be therefore higher than in more flexible structures. Rigid structures present, thus, higher potential for domino effects.

To represent the flexibility of the winery's cost structure, we define the parameter $\lambda \in [0, 1]$, where higher values of λ indicate more rigid structures (see annex). Figure 4 displays the different SRT calculated for different values of lambda. As we can see, higher values of λ (winery characterized by more rigid cost structure) are associated with lower SRT. For instance, in a system with 50 vinegrowers, when the cost structure in the winery is relatively flexible ($\lambda = 0.2$), 30 vinegrowers must cease their activity to cause that the remaining 20 cannot get positive benefits. On the contrary, when the cost structure is relatively rigid ($\lambda = 0.8$) the number of vinegrowers that must cease their activities to impede the remaining vinegrowers get positive benefits drops to 10.

In other words, the capacity of the system to absorb individual problems is inversely linked to the flexibility of the structure of cost of the cooperative winery.



Mean financial outflow: €2 942.6 | **Number of hectares individually owned**: 10
Owner's remuneration floor: 0.5 times GMW | **Number of productive hectares individually owned**: 8.4
GMW: Guaranteed minimum wage (€17 763.24)

Figure 4: Minimum number of business cessations necessary to cause null profits for the remaining business operating in the system, according to the level of flexibility in the winery's cost structure (λ)
Calculations based on the system's average vinegrower values

3. Simulation protocol

3.1. Spatial repartition of material entities

All simulations we present in this article share the following characteristics (see table 1):

- One winery cooperative is present in the system;
- 50 vinegrowers are linked to the winery cooperative, 20% of which have building located in the flood prone area;
- 500 plots are exploited by the vinegrowers, 30% of which are located in the flood prone area. Their assumed size is 1ha each

The number of elements as well as their proportions in flood prone area rely on information gathered from our case studies

Within the floodprone area (see figure 5), 150 plots (30% of 500) are randomly distributed in cells within the band [10–100]. As for vinegrowers' buildings, 10 are distributed within the band [30–100]. As it is shown in the figure, the number of vinegrowers' buildings and plots in the flood prone area increases linearly.

Table 1: Common characteristics for location of material components in simulations

Element	Number of elements in		**Total**
	Flood area	Safe area	
Winery	depends	depends	**1**
Farm	10	40	**50**
Plot	150	350	**500**

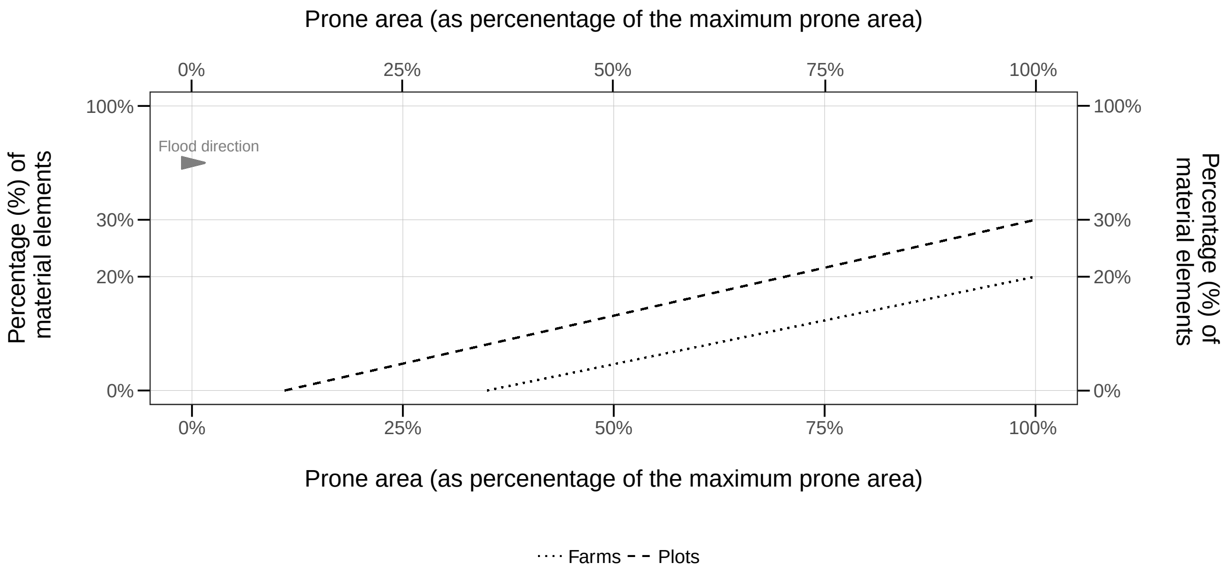


Figure 5: Distribution of elements on the flood-prone area

3.2. Size

Vinegrowers are assumed to have an homogeneous size of 10 plots (10 ha) each display an homogeneus

3.3. System's topology and exposure

Spatial location is key in the assessment of flood impacts and their spreading along a system. To ensure the absence of noise from variation in locations in our simulations, both the spatial location of nodes and links between them in the underlying topology of the system is kept constant. Namely, once a concrete element (vineyard, vinegrower or winery) is set, it keeps its position and links to other elements all along the different simulations conducted. This way direct impacts always occur upon the same elements, and the potential observed differences from one simulation to another can be traced back to the changes in the parameters.

The topology used ensure that around 30% of plots owned by each individual vinegrower is located in flood-prone area. The location of those plots is however randomly attributed. Namely, each individual vinegrower present an homogeneous percentage of 30% of his plots in flood-prone area but it cannot be assure that they are uniformly distributed along the flood-prone area.

The position of the cooperative winery is used as a parameter of simulation. Two positions have been then considered: inside the flood-prone area and outside the flood-prone area

Table 2 sums up the main characteristics of size, spatial distribution and flood exposure.

Table 2: Main spatial distribution characteristics of explored configuration

size	exposure	n_{farms}	building	n_{plots}	exposed
homogenous	random	10	exposed	10	32%
homogenous	random	40	safe	10	30%

3.3.1. Vinegrower remuneration and initial treasury resources

To fix the level of a plausible minimum remuneration of each winegrower, we have taken into account the information provided by Mutualité Social Agricole (MSA), Direction de la communication - Service Presse (2017) and CER (2014). Accordingly, the remuneration's floor is established in 5% of the Guaranteed minimum wage (GMW) per ha owned. Thus in our simulations we will set the minimum owners remuneration at a 50% of the Guaranteed minimum wage (GMW)

3.3.2. Initial treasury resources

In like manner as with minimum remunerations, based on data available in the European Farm Accountancy Data Network (FADN) we have fixed an average amount of €500 per ha. Nonetheless, in the simulations conducted, the sensitivity to the initial liquidity of farms has been tested. Thus the values have been established in the interval [0, 1000] per ha owned

3.3.3. Cost structure rigidity: value of λ

To test the influence that the rigidity of the structure of costs in the cooperative winery may have over the system, we establish the following values for λ:

Relatively flexible structure: $\lambda = 0.2$ (Folwell and Castaldi, 2004.)

Relatively rigid structure: $\lambda = 0.8$ (CER, 2017)

3.3.4. Simulations

As stated in section 2.2.5, our model presents stochastic processes to determine the impacts of floods over plots.

Each flood scenario is simulated 50 times. Most and least impacting repetitions in terms of vineyards (plots) destroyed are kept as worst and best case scenarios. The difference between both stands as a measure of the model's uncertainty.

4. Results

Our analysis present all potential cases between two different outcomes: best case scenario (less destructive one at system's level) and the worst case scenario (most destructive one). In both outcomes we analyze the potential for each individual vinegrower to enter in a situation of potential distress.

4.1. Influence of season

The results obtained display different behavior according the season in which the flood scenario is simulated (figure 6). Plant cycles and the different damages assumed for each stage of he cycle are going to have therefore an influence on the capacity to absorb the impact of each individual. Thus on the system itself.

Simulated flood scenarios (SFSs hereafter) in winter barely have negative impacts over plants or yield. Flooded vinegrowers face material reparations but not losses of plants or yield at all. In contrast, the higher vulnerability of plants in spring (growing season) adds important damages and losses to individual vinegrowers whose lands are flooded. Damages and losses over lands impact present and future cash flows: production losses affect revenues while non planned plot replant force investments that may become a financial burden.

Observable differences between SFSs in spring and winter, at any level of initial treasury, come therefore explained by the effects both immediate and belated that floods have on lands and yields.

Summer and autumn SFSs present lower probabilities of plot destruction than spring SFSs in the COOPER model. It also implies lower probability of failing investments and associated loss of revenues. Thus comparatively summer and autumn present levels of business cessation more moderate than spring.

4.2. Analysis of indirect impacts: winery's cost structure

The weight of the structural cost in the structure of costs of the cooperative winery plays an important role in the capacity of the system to absorb the impact (figures 6 and 8). Its influence is materialized in two different phenomenons. First it affects the SRT. Concretely, the SRT shows an inverse relation with the rigidity of thestructure of costs in the winery: the more rigid the structure (the higher the value of the parameter λ) the lower the SRT is located, therefore the smaller the capacity of the system to absorb the impact. At the same time, at any flood extent and initial treasury, more rigid structures of cost in the winery increase the number of businesses cessations. The higher potential for domino effects in the system derived from more rigid cost structures in the cooperative winery that we ventured in section 2.3.1 (see mathematical formalization in annex) does exist. Exact initial conditions, perturbations and direct impacts/damages lead to higher number of individual vinegrowers ceasing their activities when the cooperative winery presents a cost structure less sensitive to changes in production.

Both the effect over the SRT and over individual vinegrowers reduce the capacity of the system to absorb the impacts of floods, regardless seasonal behavior or initial treasury conditions. Indeed, simulations with wineries that present a relatively flexible cost structure (λ=0.2) barely get close to the SRT. The cases in which these simulations trespass the threshold are reduced to large flood worst case scenarios with small intial treasuries under the assumption that activities cease as soon as the default occurs.

In contrast, when the winery presents a rigid cost structure (λ=0.8), the system needs relatively small flood extents (between 20 and 50% of the flood-prone area), except for the most optimistic cases of initial treasury conditions and less exigent cessation criteria (default+5 and default+3) in summer and autumn.

4.3. Analysis of indirect impacts: winery's geographical situation

Such a situation, plausible in real life according the available information, will trigger several effects (figures 7 and 9). First of all, despite the season in which the flood occurs, the reparations not covered by insurance will materialized in a credit that all associates to the winery will have to pay. Given the loan maturity commonly used in this cases (up to 30 years), annuities can be considered as a rise in the structural costs. Such a rise will consequently increase the operational outflows of each vinegrower in the CWS. In addition, SFSs in winter, spring and autumn are going to render the winery incapable of performing production, commercialization and recollection respectively. Insofar in the COOPER model this inability to perform provokes the loss of the whole year's production (although part is covered by insurance), the entire system collapses. I.e. as soon as the winery is impacted by a flood all individual vinegrowers in the system are taken automatically to a situation of default. Spring SFSs are particularly violent due to the fact that the production is lost but the the whole productive process is done, therefore, wine-making costs are already charged.

Summer SFSs do not affect any essential task in the winery. Therefore there are no effects on the production derived from impacts over the winery. Notwithstanding, the reparations to be done, as stated before, are going to increase the share of cost of each individual vinegrower in the system. Thus reducing the net cash flow from operations. As a consequence, the number of individual business cessations increases. The system needs even smaller extent of terrain flooded to trespass the SRT

4.4. Influence of initial treasury and cessation criteria

Comparatively speaking, the level of initial treasure presents a small influence over the capacity of the system to absorb the impact of a given flood before reaching the SRT. Yet, a close observation of trajectories permits to identify a regular difference of 30% in the flood extent needed to bring the system to the SRT between the minimum and the maximum level of treasury considered.

The influence that the different criteria used to delimit the temporal horizon to ceases the businesses' activities shows a less regular pattern. It seems to be influenced by the season and the level of initial treasury. Yet patterns seem to be random. For instance, if in figure 8 we compare spring, summer and autumn SFSs for a level of initial treasury of €7 500, we can appreciate how the trajectories of the system show complete different behaviors. Notwithstanding, as it was expected longer horizons give the system a higher potential to absorb the impact of floods before reaching the SRT.

Although intuitively both parameters may seem the most important in individual terms to deal with the effects of floods, the way the whole system works make indirect impacts much more relevant in the explanation of the potential collapse of the system.

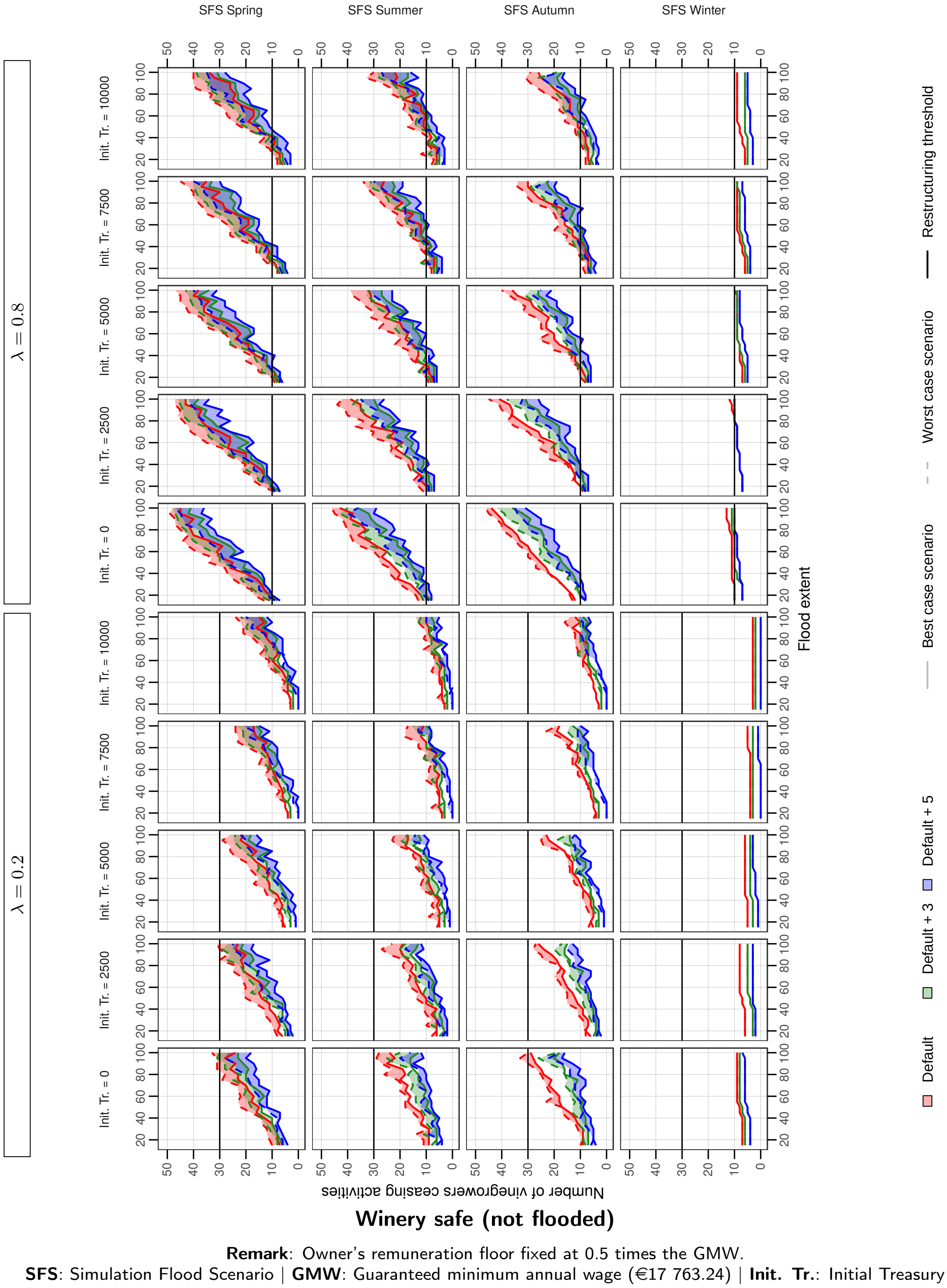
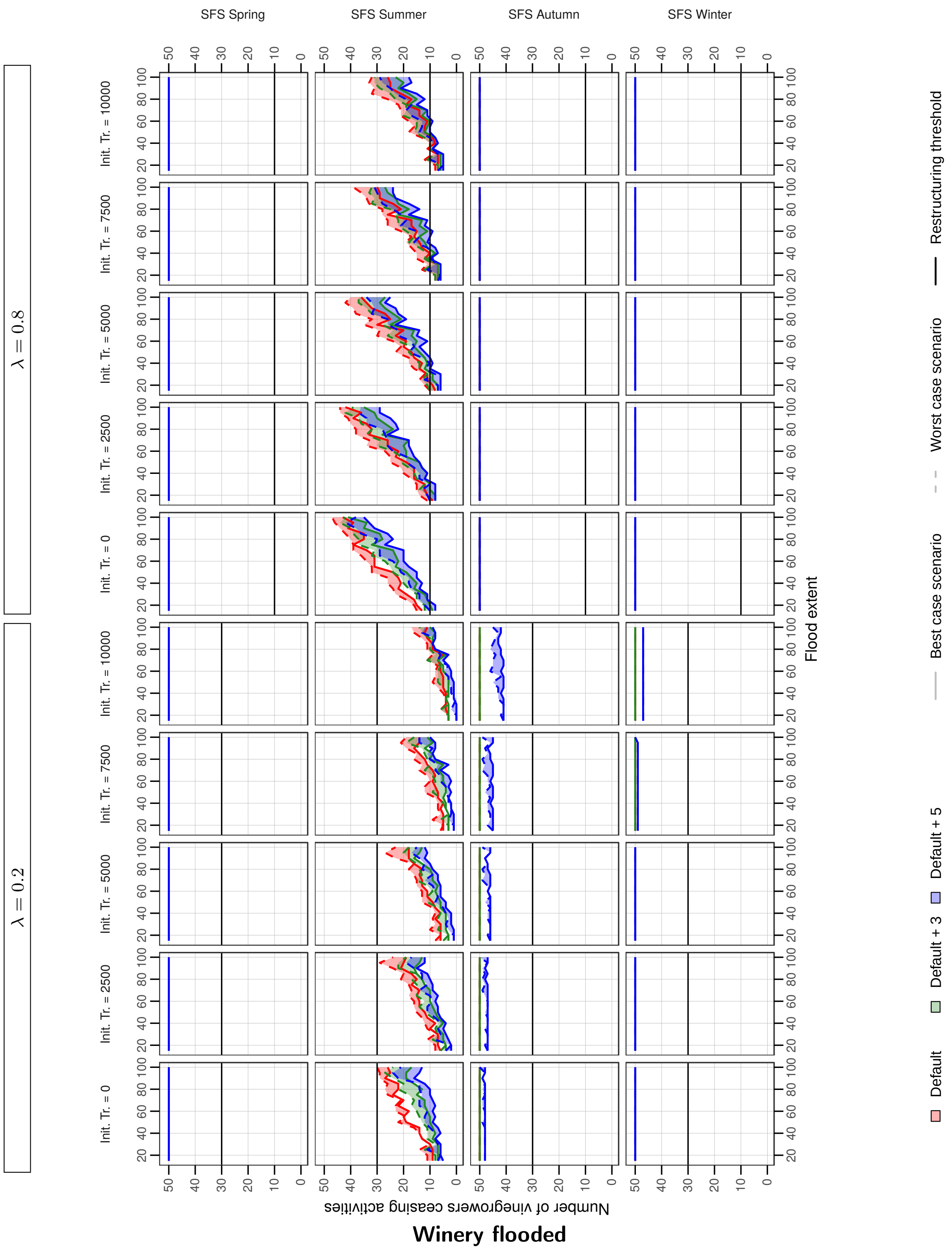
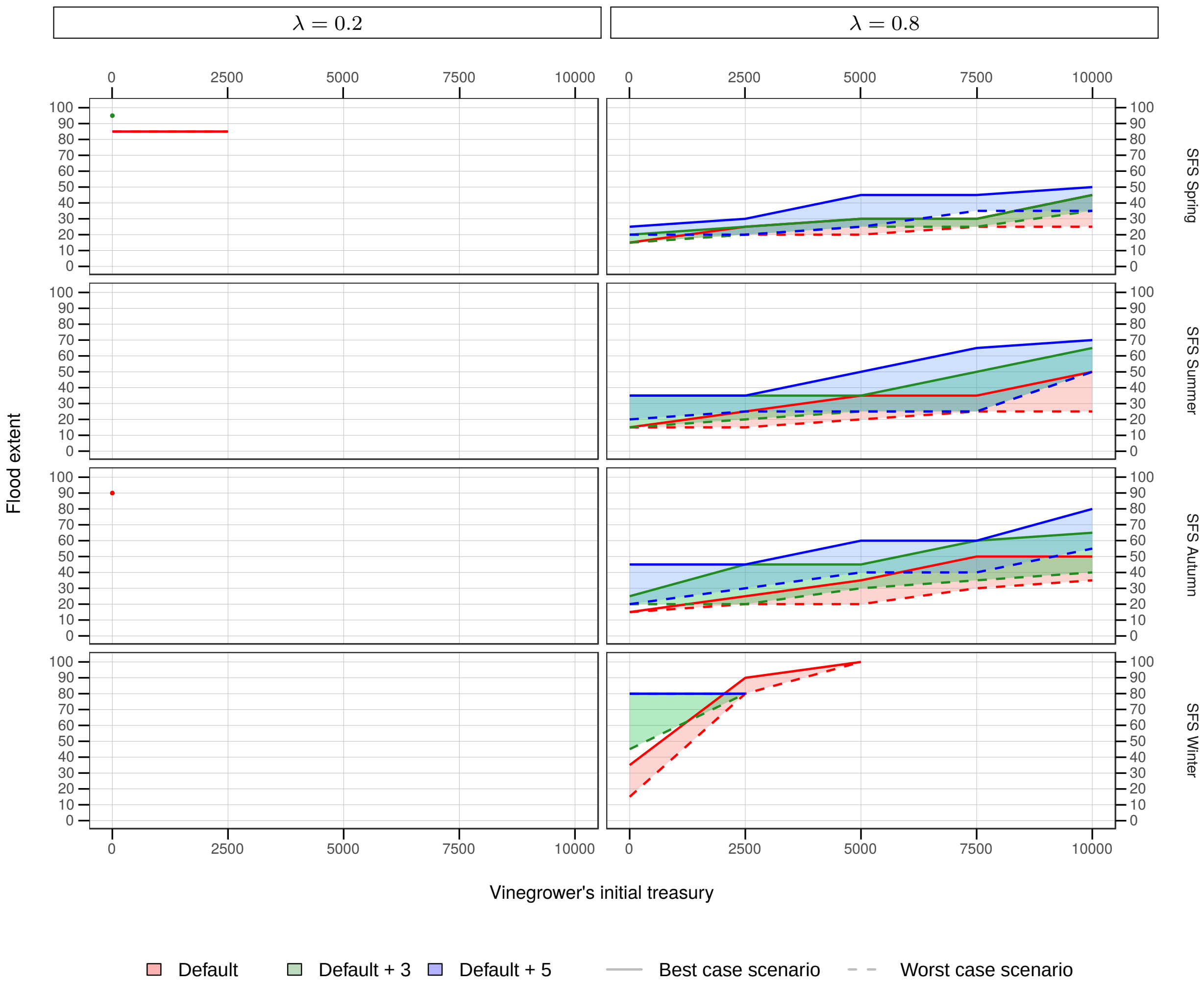


Figure 6: Number of business cessations.
Representation of uncertainty interval between best and worst case SFS by flood extent, initial treasury and value of lambda. Individual cessation time horizon considered: Default to default+5.



Remark: Owner's remuneration floor fixed at 0.5 times the GMW.
SFS: Simulation Flood Scenario | **GMW**: Guaranteed minimum annual wage (€17 763.24) | **Init. Tr.**: Initial Treasury

Figure 7: Number of business cessations.
Representation of uncertainty interval between best and worst case SFS by flood extent, vinegrowers' initial treasury and value of lambda. Individual cessation time horizon considered: Default to default+5.

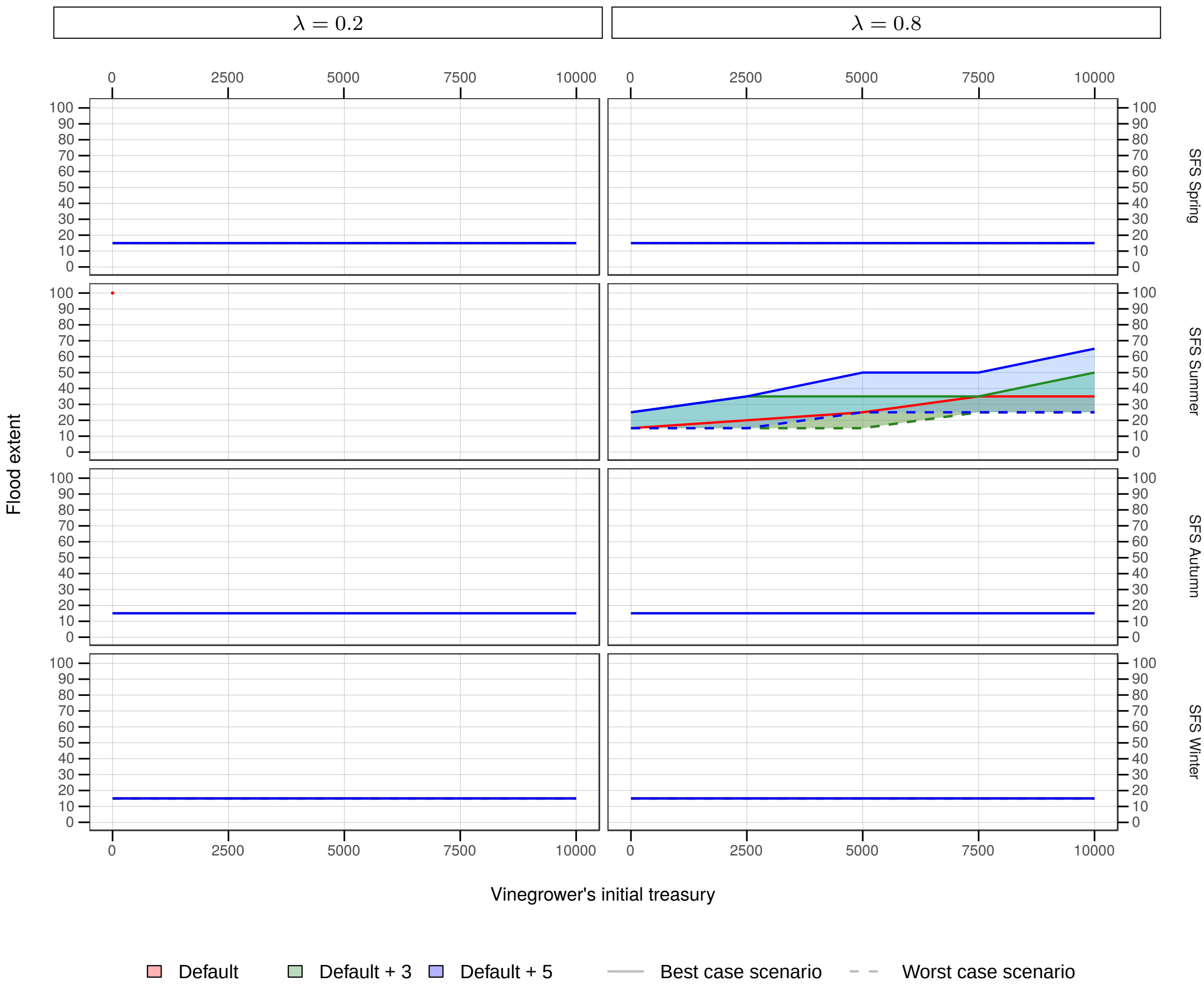


Winery safe (not flooded)

Remark I: Empty graphs imply that the system does not reach the restructuring threshold in any Individual cessation time horizon considered. Likewise, the absence of representation of any particular cessation horizon should be understood as a scenario in which the system does not reach the restructuring threshold. Points correspond to cases in which the threshold is reached in isolated flood extents.
Remark II: Owner's remuneration floor fixed at 0.5 times the GMW.

SFS: Simulation Flood Scenario | **GMW**: Guaranteed minimum annual wage (€17 763.24)

Figure 8: Minimum flood extent necessary to reach the restructuring threshold.
Representation of uncertainty interval between best and worst case SFS by vinegrowers' initial treasury and value of lambda.
Individual cessation time horizon considered: Default to default+5.



Winery flooded

Remark I: Empty graphs imply that the system does not reach the restructuring threshold in any Individual cessation time horizon considered. Likewise, the absence of representation of any particular cessation horizon should be understood as a scenario in which the system does not reach the restructuring threshold. Points correspond to cases in which the threshold is reached in isolated flood extents.
Remark II: Owner's remuneration floor fixed at 0.5 times the GMW.

SFS: Simulation Flood Scenario | **GMW**: Guaranteed minimum annual wage (€17 763.24)

Figure 9: Minimum flood extent necessary to reach the restructuring threshold.
Representation of uncertainty interval between best and worst case SFS by vinegrowers' initial treasury and value of lambda. Individual cessation time horizon considered: Default to default+5.

5. Discussion and conclusion

This paper presents findings based on the potential of Agent-based models (ABM) for the study of flood impact spreading within a productive system/production chain. To do so, we have built a novel model for the dynamic simulation of a cooperative production system, where we can test the disturbance in the economic realm caused by natural phenomena. While the focus of the paper is on the wine sector, our model is may be adapted to other types of kinds of crops and agricultural systems that might be characterized under the same organizational approach. This analysis we are presenting is innovative due to its dynamic nature, its dual focus (individual farmer/productive chain) and last, the explicit representation of individual characteristics of each entity, organizational rules in the system and its topology.

5.1. Results of the simulations

The use of ABM inevitability turns the modeling and analysis more complex. The model has been subject to careful development and verification, over a set of hypotheses and rules formulated according the available evidence from the study cases. These assumptions, rules and simplifications made are well documented in COOPER in CoMSES. Their presence though may introduce uncertainties in the result that should be addressed and results must be interpreted carefully according those underlying assumptions. Simulations are thus carried out repeatedly to provide an assessment of model uncertainty.

The article shows how the ABM captures the diffusion of flood impacts along a productive system in which a central agent acts like a hub. While the existence of those impacts can be demonstrated throughout mathematical analysis, what draws attention in our results is the magnitude of the indirect effects in the system. Indeed, existing studies on individual businesses highlight the importance of several factors like age or gender (see Marshall et al., 2015). However, the sensitivity analysis over the parameters tested highlights that the system is more sensitive to those parameters that belong to the central agent than to those that belong to the individual producers.

From this point of view, the lack of studies on indirect effects over might be leaving out of the design of risk prevention policies key factors to assure eco-financial viability of businesses in areas that may become flood plain areas

Standard practices in Cost-Benefit analysis and business resilience studies assume that there is a return to a pre-disaster state. The actual analysis of long term post-disaster cash flows we conducted shows otherwise: our results demonstrated that such return to a pre-disaster state might not be reachable for neither individual businesses nor the system. Furthermore, some units might be vanished from the system as a consequence of the disaster and the very system might be put in need of a restructuring if it wants to survive. Supply or production chains that show characteristics in common with our system might be facing their demise if the flood trends are confirmed and the role of indirect impacts is not study more intensively and extensively.

5.2. Limitations and hard hypotheses

Our study present some limitations though that should be taken into account to analyze the results obtained. First, our hypothesis on the complete destruction of production when the winery's building is touched is a hard hypothesis. The evidence gathered in our case study terrains supports their plausibility. As a matter of fact, wineries in the area reported to have lost full vats during floods. Nonetheless such scenario should be taken as a worst case scenario in case the winery is flooded. Real situations are expected to be between both flooded and not flooded winery.

Second, the presence of the indirect effects is due to the cost-revenue sharing rule used in the system. Systems with sharing rules different from the one we used, i.e. based on surface, might present result different from ours. Their use has not been reported in the literature though though (see Touzard et al., 2001; Jarrige and Touzard, 2001; Biarnès and Touzard, 2003).

Third, our agents are reactive. Such behavior may cause agents to put themselves in financial situations that might be avoidable if agents displayed a more optimizing-oriented behavior. Nonetheless this choice of behavior is supported by the evidence gathered through interviews in our case study territories. Information on the plausible behavior displayed by the agents in the supply chain in case of disruption becomes crucial for the fine tuning of the model and the analysis of impacts.

Fourth, In our model we have assumed as well that there were both subventions to replant and free access to credit. Both hypotheses may be softening the post-disaster scenario. The disappearance of such subventions will or more realistic conditions for credit access (age, gender, solvency, business prospective, etc) may actually harden the conditions that individual vinegrowers endure.

Fifth, our systems has been treated as isolated from other networks and markets. The results obtained are thus limited by the boundaries set. To take into account, for instance, price variations or long term contracts lost because of the effects of the flood may influence the results obtained. More research is therefore needed to continue understanding the effects of the different economic and financial variables.

Last, insofar our analysis is context-dependent (based on an specific topology and system), the results obtained can not be extrapolate but to systems with the same internal organization and underlying topology.

5.3. Methodology and technique

Studies based on ABMs are highly resource-demanding. Yet their potential to serve as spatialized laboratories for the ex-ante study of the consequences of disruptions in supply chains caused by natural hazards is enormous.

Indeed, both the construction and posterior utilization of the ABM enable the analyst to track down triggers, causes, and drivers of impacts in their spread along the system's topology. The utilization of ABMs represents therefore a worthy opportunity to understand the relevancy of the factors that mostly influence the system object of study. In such manner, their potential to contribute to the formulation and study of risk management policies should be taken into account.

References

0. Arlov, S. Rankov, and S. Kotlica. Cash flow in predicting financial distress and bankruptcy. In *Advances in environmental science and energy planning. Proceedings of the 3rd International Conference on Management, Marketing, Tourism, Retail, Finance and Computer Applications*, 2015.

A. Aziz, D.C. Emanuel, and G.H. Lawson. Bankruptcy prediction - an investigation of cash flow based models. *Journal of Management Studies*, 1988.

L. Barbut, N. Bauduceau, and C. Devaux Ros. Vers une evaluation de la vulnérabilité des activités agricoles aux inondations. *Ingénieries - E A T, IRSTEA*, pages 29 – 41, 2004.

Peter J. Barry and Lindon J. Robison. Agricultural finance: Credit, credit constraints, and consequences. In *Agricultural Production*, volume 1 of *Handbook of Agricultural Economics*, chapter 10, pages 513 – 571. Elsevier, 2001. doi: https://doi.org/10.1016/S1574-0072(01)10013-7.

Antonella Battagliani, Gerard Barbeau, Marco Bindi, and Franz W. Badeck. European winegrowers' perceptions of climate change impact and options for adaptation. *Regional Environmental Change*, 9:61–63, 2009. doi: 1.

N. Bauduceau. Elèments d'analyse des répercussions des inondations de novembre 1999 sur les activités agricoles des départements de l'aude, des pyrénées orientales et du tarn. Technical report, 2001.

Anne Biarnès and Jean-Marc Touzard. La rémunération différenciée du raisin dans les coopératives du Languedoc. In Draperi J.F. and Touzard J.M., editors, *Les coopératives entre territoires et mondialisation.* L'harmattan–IES, 2003.

Robert Bierkandt, Leonie Wenz, Sven Norman Willner, and Anders Levermann. Acclimate—a model for economic damage propagation. part 1: basic formulation of damage transfer within a global supply network and damage conserving dynamics. *Environment Systems and Decisions*, 34(4):507–524, Dec 2014. ISSN 2194-5411. doi: 10.1007/s10669-014-9523-4.

Christoph Bode and Stephan M. Wagner. Structural drivers of upstream supply chain complexity and the frequency of supply chain disruptions. *Journal of Operations Management*, 36:215 – 228, 2015. doi: https://doi.org/10.1016/j.jom.2014.12.004.

P. Bremond. *Caractérisation et Évaluation Économique de la vulnérabilité des exploitations agricoles aux inondations.* PhD thesis, École Doctorale Économie et Gestion de Montpellier, 2011.

P. Brémond, F. Grelot, and A.L. Agenais. Review article: economic evaluation of flood damage to agriculture - review and analysis of existing methods. *Natural Hazards and Earth System Sciences*, 13:p. 2493 – p. 2512, 2013. doi: 10.5194/nhess-13-2493-2013.

Charlotte Brown, Joanne Stevenson, Sonia Giovinazzi, Erica Seville, and John Vargo. Factors influencing impacts on and recovery trends of organisations: evidence from the 2010/2011 canterbury earthquakes. *International Journal of Disaster Risk Reduction*, 14:56–72, 2015.

Elizabeth Bruch and Jon Atwell. Agent-based models in empirical social research. *Sociological Methods & Research*, 44(2):186–221, 2015. doi: 10.1177/0049124113506405. PMID: 25983351.

Xavier Brusset and Christoph Teller. Supply chain capabilities, risks, and resilience. *International Journal of Production Economics*, 184:59 – 68, 2017. doi: https://doi.org/10.1016/j.ijpe.2016.09.008.

P. Bubeck and H Kreibich. Natural hazards: direct costs and losses due to the disruption of production processes. CONHAZ project WP1 Final Report, Helmholtz Centre Postdam, September 2011.

Références technico-économiques d'une vigne palissée en Languedoc Roussillon. CER France, 2014 edition, 2014.

Références technico-économiques d'une vigne palissée en Languedoc Roussillon. CER France, 2017 edition, 2017.

Chambre d'agriculture Var. *Action 25 du PAPI d'intention de l'Argens. Réalisation de diagnostics de vulnérabilité d'installations agricoles en zone inondable*, 2014. URL http://www.viva2010.org/telechargements/2014-05-06_PAPI-Argens-intention_Diapos-ChAgri.pdf.

Jean-Michel Chevet. Le rôle des caves coopératives dans le regroupement de l'offre en france au xxème siècle. Technical Report 2004-12, INRA-CORELA working papers, 2004. URL https://www6.versailles-grignon.inra.fr/aliss/content/download/3348/35635/file/WP04-12.pdf.

Thomas Y Choi, Kevin J Dooley, and Manus Rungtusanatham. Supply networks and complex adaptive systems: control versus emergence. *Journal of Operations Management*, 19(3):351 – 366, 2001. doi: https://doi.org/10.1016/S0272-6963(00)00068-1.

P.-Y. Collombat. *Rapport d'information fait au nom de la mission commune d'information sur les inondations qui se sont produites dans le Var, et plus largement, dans le sud-est de la France au mois de novembre 2011*, 2012.

Geneviève Decrop. L'expertise en question dans la gestion des risques naturels. le cas des ruines de séchilienne. *Vertigo*, 14(1), 2014.

D. Desbois. Introduction to scoring methods: financial problems of farm holding. *Case Studies in Business Industry and Gouvernment Statistics*, 2008.

Catherine Dibble. Computational laboratories for spatial agent-based models. In Leigh Tesfatsion and Kenneth L. Judd, editors, *Handbook of Computational Economics*, volume 2, chapter 31. Elsevier B.V., 2006. doi: 10.1016/S1574-0021(05)02031-9.

J Dubbelboer, I. Nikolic, K. Jenkins, and J. Hall. An agent-based model of flood risk and insurance. *Journal of Artificial Societies and Social Simulation*, 20(1)(6), 2017.

Katrin Erdlenbruch and Bruno Bonté. Simulating the dynamics of individual adaptation to floods. *Environmental Science & Policy*, 84:134 – 148, 2018. doi: https://doi.org/10.1016/j.envsci.2018.03.005.

European Environment Agency. Mapping the impacts of natural hazards and technological accidents in Europe. Technical report, European Environment Agency (EEA), 2010.

FADN. *Farm Accountancy Data Network.* European Comission. URL http://ec.europa.eu/agriculture/rica/.

Tatiana Filatova. Empirical agent-based land market: Integrating adaptive economic behavior in urban land-use models. *Computers, Environment and Urban Systems*, 54:397 – 413, 2015. doi: https://doi.org/10.1016/j.compenvurbsys.2014.06.007.

R. J. Folwell and M. A. Castaldi. Bulk winery investment and operating costs. *Agricultural Research Center, College of Agricultural, Human, and Natural Resources Sciences, Washington State University, Pullman, Washington*, 2004.

B.P. Foster and T.J. Ward. Using cash flow trends to identify risks of bankruptcy. *The CPA journal*, 60, 1997.

FranceAgriMer. *Constatation nationale des prix moyens d'achat de vin en vrac. Campagne vitivinicole 2015-2016*, April/Mars 2016.

FranceAgriMer. Les chiffres de la filière viti-vinicole 2006/2016. Technical report, 2017.

Nigel Gilbert. *Agent-Based Models*. SAGE publications, 2008.

M. Gosling and A. Hiles. *Business continuity statistics: where myth meets fact*. Continuity Central, 2010. URL http://www.continuitycentral.com/feature0660.html.

Nina Graveline and Marine Grémont. Measuring and understanding the microeconomic resilience of businesses to lifeline service interruptions due to natural disasters. *International Journal of Disaster Risk Reduction*, 24:526 – 538, 2017. doi: https://doi.org/10.1016/j.ijdrr.2017.05.012.

C. Green, C. Viavattene, and P. Thompson. Guidance for assessing flood losses. CONHAZ WP6 Final Report, Flood Hazard Research Center - Middlesex University, September 2011.

Masahiko Haraguchi and Upmanu Lall. Flood risks and impacts: A case study of thailand's floods in 2011 and research questions for supply chain decision making. *International Journal of Disaster Risk Reduction*, 14(Part 3):256–272, 2015. doi: http://dx.doi.org/10.1016/j.ijdrr.2014.09.005. Risking Disaster – the role of private investment and public regulation in disaster risk management.

Aljosja Hooijer, Frans Klijn, G. Bas M. Pedroli, and Ad G. Van Os. Towards sustainable flood risk management in the rhine and meuse river basins: synopsis of the findings of irma-sponge. *River Research and Applications*, 20(3):343–357, 2004. doi: 10.1002/rra.781.

INSEE. *Structure de l'emploi total par grand secteur d'activité en 2016*. Institut national de la statstique et des études économiques, 2016. URL https://www.insee.fr/fr/statistiques/2012798#titre-bloc-1.

J. Jansen, M. van Ittersum, S. Janssen, and P. Reidsma. *Integrated Assessment of Agricultural Systems at the European Level*. Policy Brief LIAISE, 2016.

F. Jarrige and J.M. Touzard. Les mutations de l'organisation coopérative à travers l'évolution de ses règles: La rémunération de la vendange dans les caves coopératives du Midi. *Revue International de L'Économie Sociale (RECMA)*, (280), 2001.

Yusoon Kim, Yi-Su Chen, and Kevin Linderman. Supply network disruption and resilience: A network structural perspective. *Journal of Operations Management*, 33-34:43 – 59, 2015. doi: https://doi.org/10.1016/j.jom.2014.10.006.

Jean-Pierre Le Bourhis. Du savoir cartographique au pouvoir bureaucratique. les cartes des zones inondables dans la politique des risques (1970-2000). *Genéses*, 3(68):75–96, 2007.

Anne-Laure Lereboullet, Douglas Bardsley, and Gérard Beltrando. Assessing vulnerability and framing adaptive options of two mediterranean wine growing regions facing climate change: Roussillon (france) and mclaren vale (australia). *EchoGéo*, 23, 2013. doi: 10.4000/echogeo.13384Hautdepage.

Michael W. Macy and Robert Willer. From factors to actors: Computational sociology and agent-based modeling. *Annual Review of Sociology*, 28:143–166, 2002.

Maria I. Marshall and Holly L. Schrank. Small business disaster recovery: a research framework. *Nat Hazards*, 72:597–616, 2014. doi: DOI10.1007/s11069-013-1025-z.

M.I. Marshall, L.S. Niehm, S.B. Sydnor, and H.L. Schrank. Predicting small business demise after a natural disaster: an analysis of pre-existing conditions. *Nat Hazards*, 2015.

V. Meyer, N. Becker, V. Markantonis, R. Schwarze, J. C. J. M. van den Bergh, L. M. Bouwer, P. Bubeck, P. Ciavola, E. Genovese, C. Green, S. Hallegatte, H. Kreibich, Q. Lequeux, I. Logar, E. Papyrakis, C. Pfurtscheller, J. Poussin, V. Przyluski, A. H. Thieken, and C. Viavattene. Review article: Assessing the costs of natural hazards - state of the art and knowledge gaps. *Natural Hazards and Earth System Sciences*, 13(5):1351–1373, 2013.

Michelle Renée Mozell and Liz Thach. The impact of climate change on the global wine industry: Challenges & solutions. *Wine Economics and Policy*, 3(2):81 – 89, 2014. doi: https://doi.org/10.1016/j.wep.2014.08.001.

Mutualité Social Agricole (MSA), Direction de la communication - Service Presse. Conférence de presse de rentrée de la CCMSA. [Online press release], oct 2017. Last access: January 2018.

Kimberly A. Nicholas and William H. Durham. Farm-scale adaptation and vulnerability to environmental stresses: Insights from winegrowing in northern california. *Global Environmental Change*, 22, 2012. doi: 10.1016/j.gloenvcha.2012.01.001.

C. Otto, S.N. Willner, L. Wenz, K. Frieler, and A. Levermann. Modeling loss-propagation in the global supply network: The dynamic agent-based model acclimate. *Journal of Economic Dynamics and Control*, 83:232 – 269, 2017. doi: https://doi.org/10.1016/j.jedc.2017.08.001.

Edmund Penning-Rowsell, Sally Priest, Dennis Parker, Joe Morris, Sylvia Tunstall, Christophe Viavattene, John Chatterton, and Damon Owen. *Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal*. Routledge, 2013.

H. Posthumus, J. Morris, T.M. Hess, D. Neville, E. Phillips, and A. Baylis. Impacts of the summer 2007 floods on agriculture in england. *Journal of Flood Risk Management*, 2(3), 2009.

Pytrik Reidsma, Sander Janssen, Jacques Jansen, and Martin K. van Ittersum. On the development and use of farm models for policy impact assessment in the European Union – A review. *Agricultural Systems*, 159:111 – 125, 2018.

Sandro Sacchelli, Sara Fabbrizzi, and Silvio Menghini. Climate change effects and adaptation strategies in the wine sector: a quantitative literature review. *Wine Economics and Policy*, 5(2):114 – 126, 2016a. doi: https://doi.org/10.1016/j.wep.2016.08.001.

Sandro Sacchelli, Sara Fabbrizzi, and Silvio Menghini. Climate change, wine and sustainability: A quantitative discourse analysis of the international scientific literature. *Agriculture and Agricultural Science Procedia*, 8:167 – 175, 2016b. doi: https://doi.org/10.1016/j.aaspro.2016.02.090. Florence "Sustainability of Well-Being International Forum". 2015: Food for

Sustainability and not just food, FlorenceSWIF2015.
N. Salfizan Fawzi, A. Kamaluddin, and Z. Mohd SAnusi. Monitoring distressed companies through cash flow analysis. *Procedia Economics and Finance*, 28(Supplement C):136 – 144, 2015. 7th INTERNATIONAL CONFERENCE ON FINANCIAL CRIMINOLOGY 2015, 7th ICFC 2015, 13-14 April 2015,Wadham College, Oxford University, United Kingdom.
Ralf Seppelt, Felix Müller, Boris Schröder, and Martin Volk. Challenges of simulating complex environmental systems at the landscape scale: A controversial dialogue between two cups of espresso. *Ecological Modelling*, 220(24):3481–3489, 2009.
D.S. Sharma. The role of cash flow information in predicting corporate failure: The state of the literature. *Managerial finance*, 27(4), 2001.
Alex Smajgl and Olivier Barreteau. Empiricism and agent-based modelling. In Alexander Smajgl and Olivier Barreteau, editors, *Empirical Agent-Based Modelling - Challenges and Solutions*, volume 1, The Characterisation and Parameterisation of Empirical Agent-Based Models, chapter 1. Springer-Verlag New York, 2014. doi: 10.1007/978-1-4614-6134-0.
Kathleen J. Tierney. Business vulnerability and disruption: Data from the 1993 midwest floods. DRC Preliminary Papers 213, Disaster Research Center, 1993. URL http://udspace.udel.edu/handle/19716/596.
Gina L. Tonn and Seth D. Guikema. An Agent-Based Model of Evolving Community Flood Risk. *Risk Analysis*, 2017. doi: https://doi.org/10.1111/risa.12939.
J.M. Touzard. Les caves coopératives dans la trasnformation du vignoble languedocien. *Etudes Héraultaises*, hors série "Vingt siècles de viticulture...":101–112, 2011.
J.M. Touzard, C. Gaullier, and F. Jarrige. Qualité du vin et prix du raisin. Trois lectures du changement dans les coopératives du Languedoc. *Etudes et Recherches sur les Systèmes Agraires et le Développement*, 32:19–36, 2001.
F Vinet. *Crues et inondations dans la France méditerranéenne. Les crues torrentielles des 12 et 13 novembre 1999 (Aude, Tarn, Pyrénées Orientales et Hérault).* Editions du Temps, 2003.
Leonie Wenz and Anders Levermann. Enhanced economic connectivity to foster heat stress–related losses. *Science Advances*, 2(6), 2016. doi: 10.1126/sciadv.1501026. URL http://advances.sciencemag.org/content/2/6/e1501026.
Allen Wilhite. Economic activity on fixed networks. In Leigh Tesfatsion and Kenneth L. Judd, editors, *Handbook of Computational Economics*, volume 2, chapter 20. Elsevier B.V., 2006. doi: 10.1016/S1574-0021(05)02020-4.

Appendix A. Mathematical Annex

Appendix A.1. Winery's cost sharing rule

In our model we use the simplest version of the sharing formulas reviewed by Touzard et al. (2001); Jarrige and Touzard (2001); Biarnès and Touzard (2003). The cooperative winery shares each year the revenues from the commercialization minus the wine-making cost incurred, proportionally to the amount of grape given by each vinegrower, without keeping any amount in concept of reserve (equation A.1).

$$S_{i_t} = pq_{i_t} - \left(\frac{C_{wm_t}}{Q_t}\right) q_{i_t} \quad (i = 1, 2...n) \tag{A.1}$$

Where:

- S_{i_t} is the share of the benefit in the winery for the vinegrower i in moment t
- p is the price of the wine (let's assume in euros -€. Considered constant
- q_{i_t} is the production of the vinegrower i in moment t.
- pq_{i_t} is the share of revenue of the vinegrower i in moment t.
- $\frac{C_{wm_t}}{Q_t} q_{i_t}$ is the share of wine-making cost for vinegrower i in moment t.

  Wine-making costs are not proportional to the quantity transformed; rather they can be expressed through a linear function with a non zero constant, identifying the amount of fixed cost in the winery's cost structure:
  $$C_{wm_t}(Q) = F_{wm} + v_{wm} Q_t, \tag{A.2}$$
  where F_{wm} is the fixed or structural cost, and v_{wm} is the variable cost per hectoliter.
- $Q_t = \sum_{i=1}^{n} q_{i_t}$ is the total production in the cooperative winery in moment t, that can be expressed as sum of the individual productions of the associated vinegrowers in moment t.

Additionally, each vinegrower should cover its own vine-growing costs, C_{vg_t}. In the same way that it happened with wine-making costs, Vine-growing costs are not proportional to the amount of production, but a linear function with positive constant value representing the fixed cost in each vinegrower's cost structure:

$$C_{vg_t}(q) = F_{vg} + v_{vg} q_t, \tag{A.3}$$

where F_{vg} is the fixed or structural cost, and v_{vg} is the variable cost per hectoliter.

In consequence, the final balance of flows derived from the operational productive process each moment t (ONF_t) can be expressed as in equation A.4:

$$ONF_{i_t} = \left(p - \frac{C_{wm_t}}{Q_t} - v_{vg}\right) q_{i_t} - F_{vg} \quad (i = 1, 2...n) \tag{A.4}$$

Where, as we can see, the term F_{vg} prevents the equation from being proportional to q_{i_t}, whilst the term $\frac{C_{wm_t}}{Q_t}$ introduces non-linearity and links each vinegrower i with the evolutions of the system as a whole, thus with the evolutions of any other single vinegrower.

Appendix A.2. Potential for impact propagation

According such a rule, being S our system, individually paid wine-making cost by vinegrower i, $i \in S$ in equation A.4 can be expressed as in equation A.5:

$$C_{wm_{it}} = \left(\frac{C_{wm_t}}{Q_t}\right) q_{i_t} = \left(\frac{F_{wm} + V_{wm}}{\sum_{i=1}^{n} q_{i_t}}\right) q_{i_t} = v_{wm} q_{i_t} + F_{wm} \frac{q_{i_t}}{\sum_{i=1}^{n} q_{i_t}} \tag{A.5}$$

Where:

1. F_{wm} is the fixed wine-making cost
2. V_{wm_t} is the variable wine-making costs in moment t.
   $V = v_{wm} \sum_{i=1}^{n} q_{i_t}$, where the unitary variable cost, v_{mn}, is known a priori
3. $\sum_{i=1}^{n} q_{i_t}$ is the total production in the cooperative winery in moment t, as a sum of the individual productions of the associated vinegrowers.
4. q_{i_t} is the production of the vinegrower i in moment t.

Essentially this rule takes all cost in the winery — fixed, that is due to the existence of the structure, and variable, that is dependable on production— divides it by the whole production and assigns it to vinegrower i proportionally to its production q_{i_t}. We can clearly see that the wine-making cost imputed to vinegrower i depends not only on its absolute production, q_{i_t}, but also on the proportion that such production represents over the total production of the system; in other words, the relative production of the farmer i, $\frac{q_{i_t}}{\sum_{i=1}^{n} q_{i_t}}$.

Vinegrowers' relative production will be the factor determining the amount of fixed wine-making cost that farmer i is effectively supporting. That means that, *ceteris paribus*, a reduction of q_{i_t} in vinegrower i decreases not only the absolute production of farmer i, but also the total input for the cooperative winery, $\sum_{i=1}^{n} q_{i_t}$, which will, eventually, decrease the value of relative production of vinegrower i and increase the value of relative productions of every other farmer in the system. As a consequence, farmer i will pay a smaller proportion of the fixed cost in the cooperative, while the rest of farmers $j \neq i$ will support a bigger proportion.

To approximate such variations in costs due to individual, independent variations of productions, we approached the problem using method of marginal costs. In our system S, $\frac{\partial C_i}{\partial q_{i_t}}$ represents the marginal change in the cost effectively paid by vinegrower $i \in S$ when the production of vinegrower i changes, while $\frac{\partial C_i}{\partial q_{j(-i)}}$ represents the marginal change in the cost effectively paid by vinegrower i when the production of any vinegrower $j \in S, j \neq i$ changes. Results are expressed in equations A.6 and A.7

$$\frac{\partial C_{it}}{\partial q_{i_t}} = v + \frac{F_{wm}}{\sum_{i=1}^{n} q_{i_t}} - \frac{F_{wm} q_{i_t}}{\left(\sum_{i=1}^{n} q_{i_t}\right)^2} \tag{A.6}$$

$$\frac{\partial C_{it}}{\partial q_{j(-i)}} = -\frac{F_{wm} q_{i_t}}{\left(\sum_{i=1}^{n} q_{i_t}\right)^2} \tag{A.7}$$

So in equation A.6, assuming q_{i_t} decreases —that is $\delta q_{i_t} < 0$—, the variation in costs imputed will i) decrease by the action (sign) of the unitary variable wine-making cost: v; ii) decrease by the action (sign) of the term $\frac{F}{\sum_{i=1}^{n} q_{i_t}}$; and iii) increase by the action (sign) of the term $\frac{F q_{i_t}}{\left(\sum_{i=1}^{n} q_{i_t}\right)^2}$.

We know that the third term $\frac{F q_{i_t}}{\left(\sum_{i=1}^{n} q_{i_t}\right)^2}$ is always less or equal than the second one[3] $\frac{F}{\sum_{i=1}^{n} q_{i_t}}$ Therefore, the presence of the third term, will lessen the effect of the two first ones, thus, making the decrease in cost corresponding to the decrease in q_{i_t} less intense.

Regarding equation A.7, any variation of q_j will provoke an effect of opposite direction on the share of cost paid by i. Let's assume that certain q_j has decreased ($\bigtriangledown q_j$). Given the sign of our equation, for vinegrower i it will mean an increment in the share of cost equal to $\frac{F q_{i_t}}{\left(\sum_{i=1}^{n} q_{i_t}\right)^2} \bigtriangledown q_j$

Such result might perfectly be interpreted as the mathematical proof of the existence of indirect effects in the bosom of the cooperative winery when i) the rule used to impute costs targets production and ii) fixed costs are not null, $F \neq 0$.

Appendix A.3. Intensity

As we can see in the prior subsection the potential for impact propagation is linked to the presence of fixed cost in the cooperative winery. We venture to hypothesize that more rigid structure of costs (prevalence of structural cost, F_{wm}, in detriment of operational costs) may favor the potential for impact distribution. On the contrary, when structural costs are reduced, the cooperative winery prevents the impact spreading.

To check out such hypothesis we are going to express the average value of wine-making cost per hectoliter in the model's initialization (CER, 2014) as:

[3] Due to:

$$\frac{F q_{i_t}}{\left(\sum_{i=1}^{n} q_{i_t}\right)^2} = \frac{F}{\sum_{i=1}^{n} q_{i_t}} \frac{q_{i_t}}{\sum_{i=1}^{n} q_{i_t}}; \; \frac{q_{i_t}}{\sum_{i=1}^{n} q_{i_t}} \leq 1 \Rightarrow \frac{F q_{i_t}}{\left(\sum_{i=1}^{n} q_{i_t}\right)^2} \leq \frac{F}{\sum_{i=1}^{n} q_{i_t}}$$

$$\overline{C}_{wm_{t=0}} = \frac{F_{wm}}{\sum_{i=1}^{n} q_{i_{t=0}}} + v_{wm} = f_{wm} + v_{wm} \tag{A.8}$$

Dividing by $\overline{C}_{wm_{t=0}}$ and reorganizing terms, we can express the different components of the average cost as a linear combination of the average initial cost:

$$\overline{C}_{wm_{t=0}} = \lambda f_{wm} + (1 - \lambda) v_{wm} \tag{A.9}$$

Where the value of λ express the specific weight of the structural cost in the average cost paid per hectoliter. Thus it can be used as indicator of flexibility in the winery's cost structure. F_{wm} can be then expressed as:

$$F_{wm} = \lambda \overline{C}_{wm_{t=0}} Q_p \tag{A.10}$$

Where Q_p is the potential of production in the winery.

Insofar $\overline{C}_{wm_{t=0}}$ is expected to remain constant during the simulations, to substitute the prior result in equation A.7 enables us to conclude that:

$$\frac{\partial C_{it}}{\partial q_{j(-i)}} = \lambda \frac{-\overline{C}_{wm_{t=0}} Q_p}{\left(\sum_{i=1}^{n} q_{i_t}\right)^2} q_{i_t} \tag{A.11}$$

The intensity with which variations of production of any vinegrower $j \in S$ affect the wine-making cost paid by vinegrower i, $j \neq i$ depends on the value of λ. Such formulation is coherent with our hypothesis: high values of λ imply high structural costs (thus more rigid winery's cost structure), which increases the magnitude of cost variation for vinegrower i due to other vinegrower's affairs.

Addendum to the article

The following figures display the effects that i) coping tactics (figures 4.2 and 4.3); and ii) variations in the configuration of links between elements within the system (figures 4.5 and 4.6), may have over the long term financial viability of both individual vinegrowers and system as a whole.

The results in this addendum do not display as much cases as in the article *Floods, interactions and financial distress: testing the financial viability of individual farms in complex productive systems and its implications for the performance of the system.* This choice is motivated by the systematic behavior of the results before parameters like initial treasury or individual business cessation criteria. Sequentially larger initial treasuries improve the capacity of individual vinegrowers and system to respond to flood impacts. Likewise, sequentially longer temporal horizons for business cessations contribute to increase the capacity of vinegrowers and system to endure the flood impact. We consider the effect of the aforementioned parameters in figures 4.2 to 4.6 easy to extrapolate.

On the other hand, variations in the configuration of links within the system have been limited to those cases in which the vinegrower's size is homogeneous and equal to 10. This limitation is motivated by the way in which the system's restructuring threshold is calculated. Such threshold is calibrated to vinegrowers of size 10. We must therefore limit the study to those configurations characterized by vinegrowers of the same size in order to ensure the comparability of results with the ones in the article. Otherwise, the system's restructuring threshold should be recalculated and the comparability of results will be compromised.

4.3 Coping tactic

In figures 4.2 and 4.3 we compared the effects that the two coping tactics implemented in the COOPER model (internal and external)[3] have over the long term financial viability of the CWS

The results are calculated with i) the `homogeneous` configuration; ii) an homogeneous amount of individual initial treasury of €5 000 (see chapter 2, section 2.19); and iii) *Default + 0* as individual cessation criteria.

3. See chapter 2, section 2.11.2.2

To opt for one or another coping tactic does not imply any difference in terms of number of individual businesses ceasing their activities in the aftermath of any given flood, except in case autumn's SFSs when the cooperative winery is out of the flood-prone area (figure 4.2).

The difference in terms of loss of harvest between both tactics reaches its maximum precisely in autumn. This circumstance is the most plausible explanation for the divergent behavior in the dynamics of cessations of individual businesses observable in autumn's SFSs. Thus, although the implementation of our coping tactics focuses on immediate effects over yield, if the magnitude of such an effect is sufficiently large it can reverberate through time causing significant induced effects.

Observable divergences grow with the extent of the flood. At the same time, appreciable differences between tactics start to appear at different points depending on the rigidity of the winery's structure of costs. When the winery's cost structure is relatively flexible, differences between coping tactics begin to appear when the extent cover by the floods corresponds to a 40% of the maximum prone area. When the structure of cost is relatively rigid, differences do not appear until 60% of the maximum prone area is flooded.

The appreciated divergences between coping tactics depend on the temporal horizon considered to cease the business activities. As we can see comparing figures 4.2 and 4.4, longer time horizons attenuate the divergences between both tactics.

4.4 Variations in the configurations of links between elements within the system

Figures 4.5 and 4.6 display the number of cessations of individual businesses in the aftermath of any given flood, according the next three configurations:

`homogeneous` In this configuration all farms have the same number of plots. The proportion of plots in flood-prone area is equivalent between each farm. This is the configuration we have presented in the last two sections.

`exposure-best` In this configuration, all farms have the same number of plots. Farms with buildings in flood-prone area have also all their plots in this area. Remaining plots in flood prone are more or less equally distributed between remaining farms.

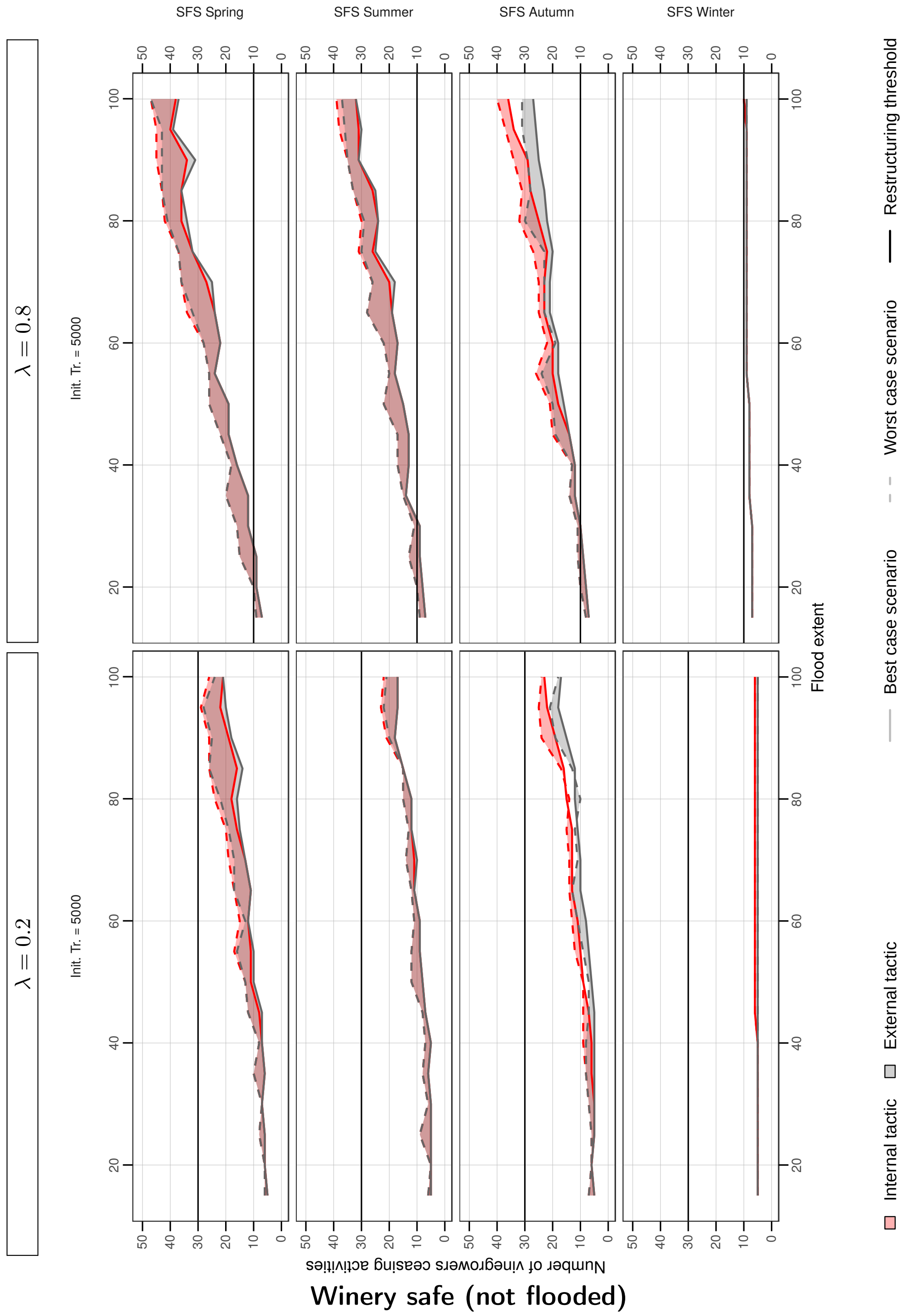
`exposure-worst` In this configuration, all farms have the same number of plots. Farms with buildings in flood-prone area have all their plots out the flood-prone area. Plots in the flood prone area are more or less equally distributed between remaining farms.

The results are calculated with i) all vinegrowers opting for coping tactic internal; ii) an homogeneous amount of individual initial treasury of €5 000 (see chapter 2, section 2.19); and iii) *Default + 0* as individual cessation criteria.

Except in the SFSs in which floods over the cooperative winery fundamentally affect the production of the system (winter, spring and autumn SFSs in figure 4.6), there exist differences between configurations. Both alternative configurations (`exposure-best` and `exposure-worst`) lower the amount of individuals out of business (curves of cessations of individual businesses shift down) for any given flood. Differences between configurations are more evident in spring SFSs. Also with relatively rigid structures of cost in the cooperative winery ($\lambda = 0.8$)

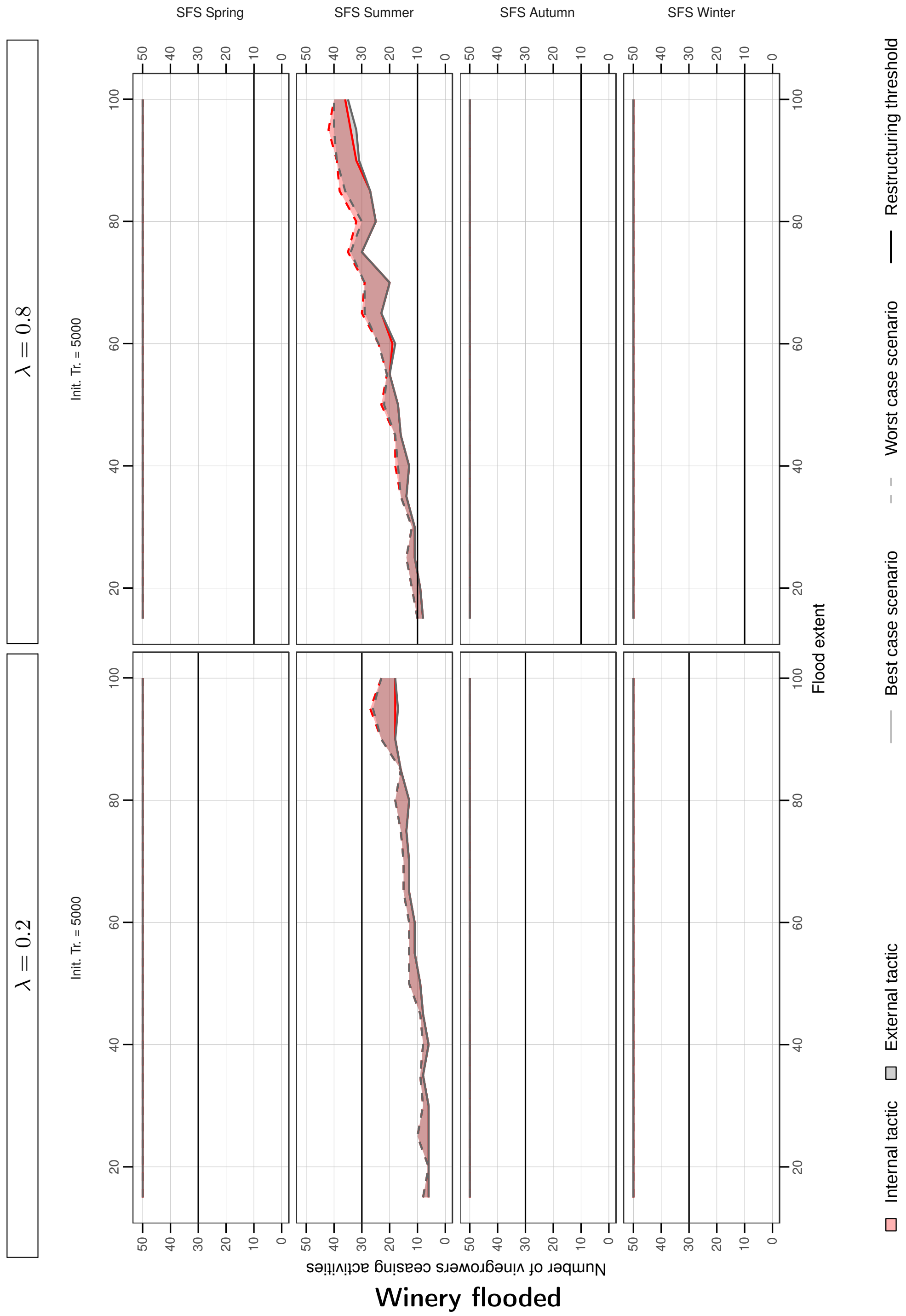
A plausible explanation for the observed effects could lay over the final distribution of impacts across configurations. In `exposure-best` vinegrowers in flood-prone areas are overexposed: both buildings and plots are in flood-prone area. Impacts in the system are going to be mostly endured by those vinegrowers. So will be the financial burden of the recovery. Nonetheless, such overexposure of a handful of vinegrowers protects the rest of vinegrowers in the CWS, shifting down the curve of businesses cessations for any flood.

Regarding `exposure-worst`, a plausible reason to explain the observed shift in comparison with `homogeneous` rests upon the of multiplicity of impacts at individual level: Vinegrowers with buildings in flood-prone area do not own plots in flood-prone area. Thus, when a flood impacts the system, vinegrowers will have either plot replant or building reparation, but never both at the same time. In this configuration impacts spread further along the system than in `exposure-best`, but not as much as in `homogeneous`.



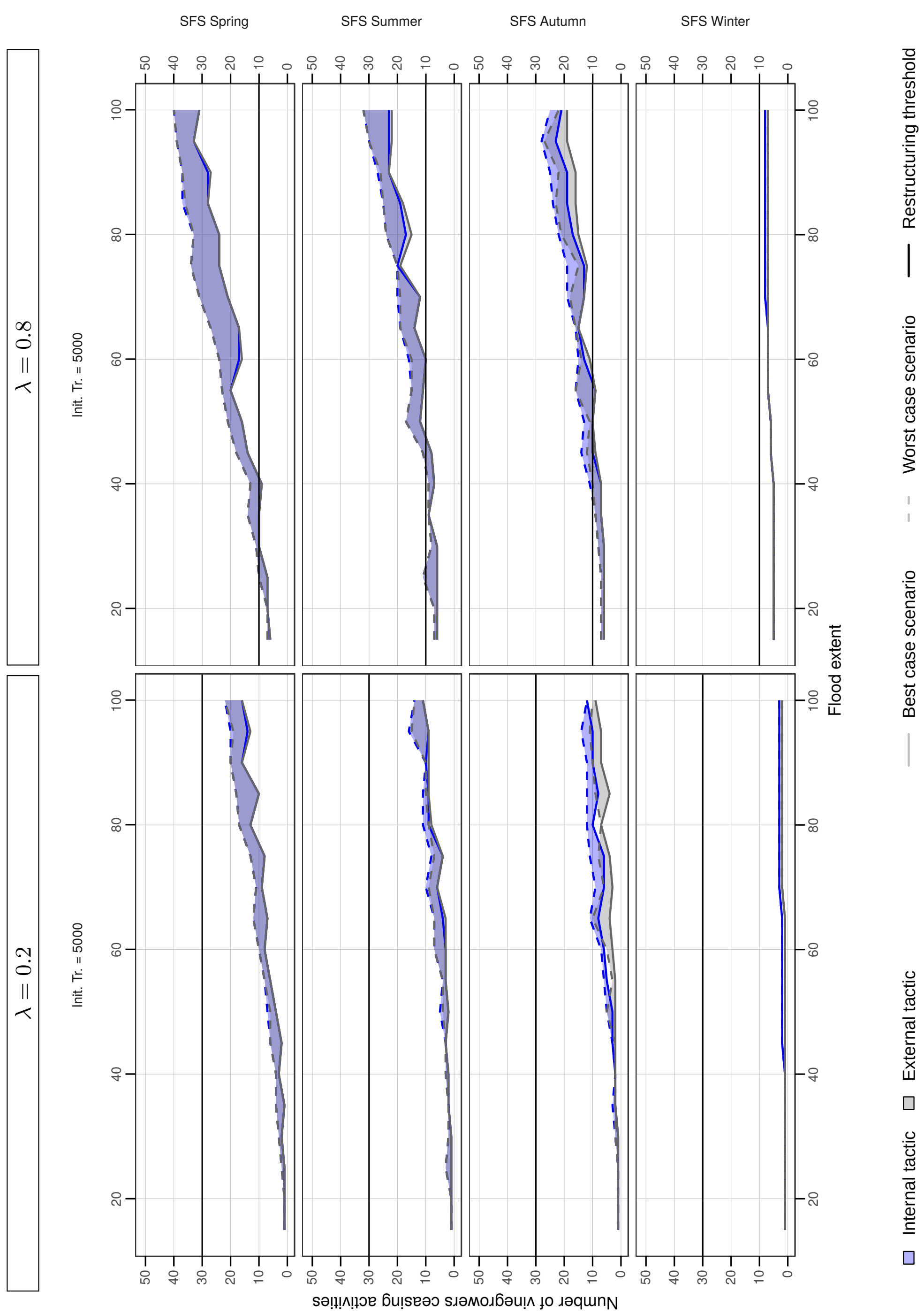
Remark: Owner's remuneration floor fixed at 0.5 times the GMW | Initial treasury: €5 000
SFS: Simulation Flood Scenario | **GMW**: Guaranteed minimum annual wage (€17 763.24) | **Init. Tr.**: Initial Treasury

Figure 4.2 – Number of business cessations. Individual cessation time horizon considered: *Default* Representation of uncertainty interval between best and worst case SFS by flood extent, coping tactic and value of lambda



Remark: Owner's remuneration floor fixed at 0.5 times the GMW | Initial treasury: €5 000
SFS: Simulation Flood Scenario | **GMW**: Guaranteed minimum annual wage (€17 763.24) | **Init. Tr.**: Initial Treasury

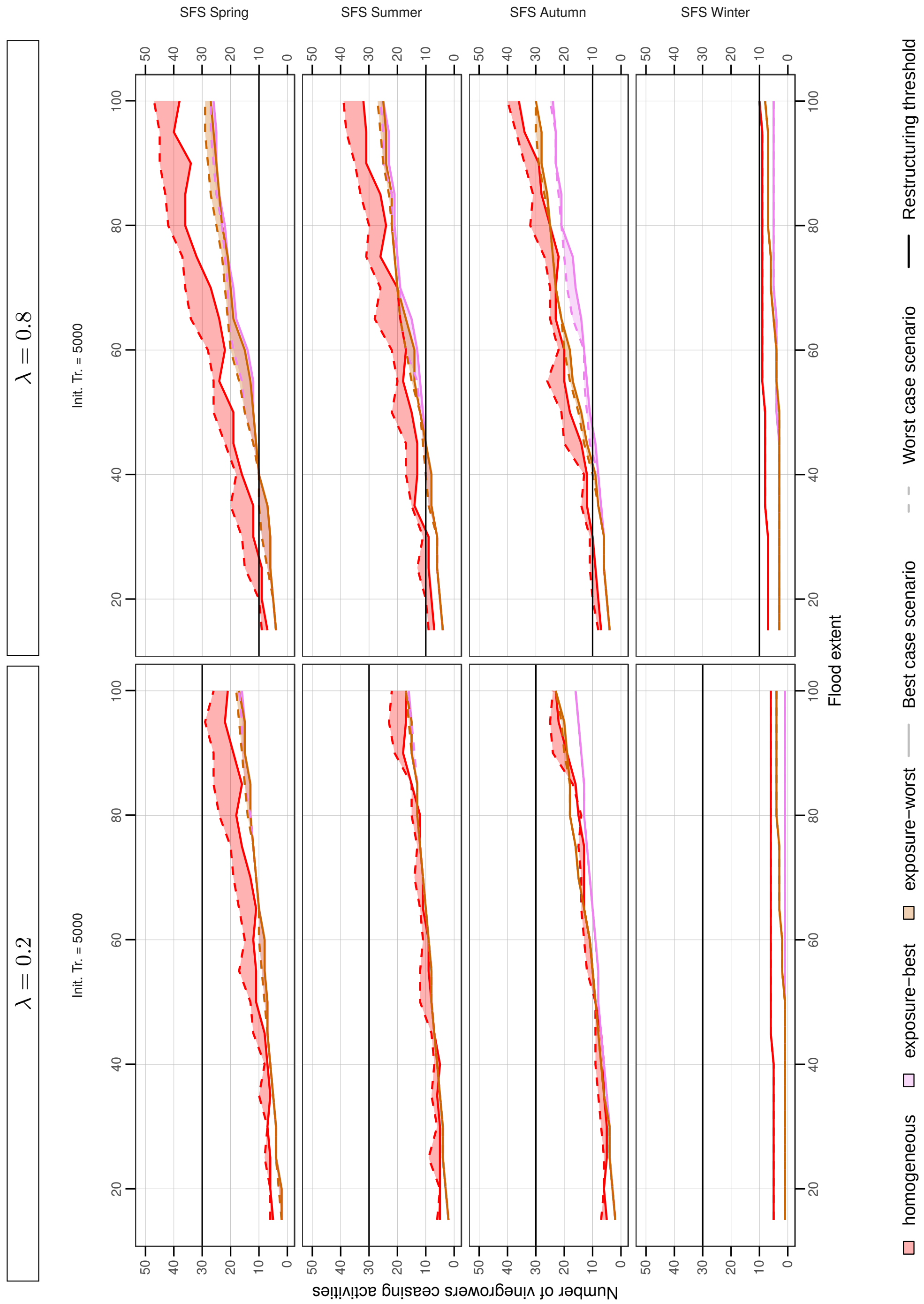
Figure 4.3 – Number of business cessations. Individual cessation time horizon considered: *Default* Representation of uncertainty interval between best and worst case SFS by flood extent, coping tactic and value of lambda



Winery safe (not flooded)

Remark: Owner's remuneration floor fixed at 0.5 times the GMW | Initial treasury: €5 000
SFS: Simulation Flood Scenario | **GMW**: Guaranteed minimum annual wage (€17 763.24) | **Init. Tr.**: Initial Treasury

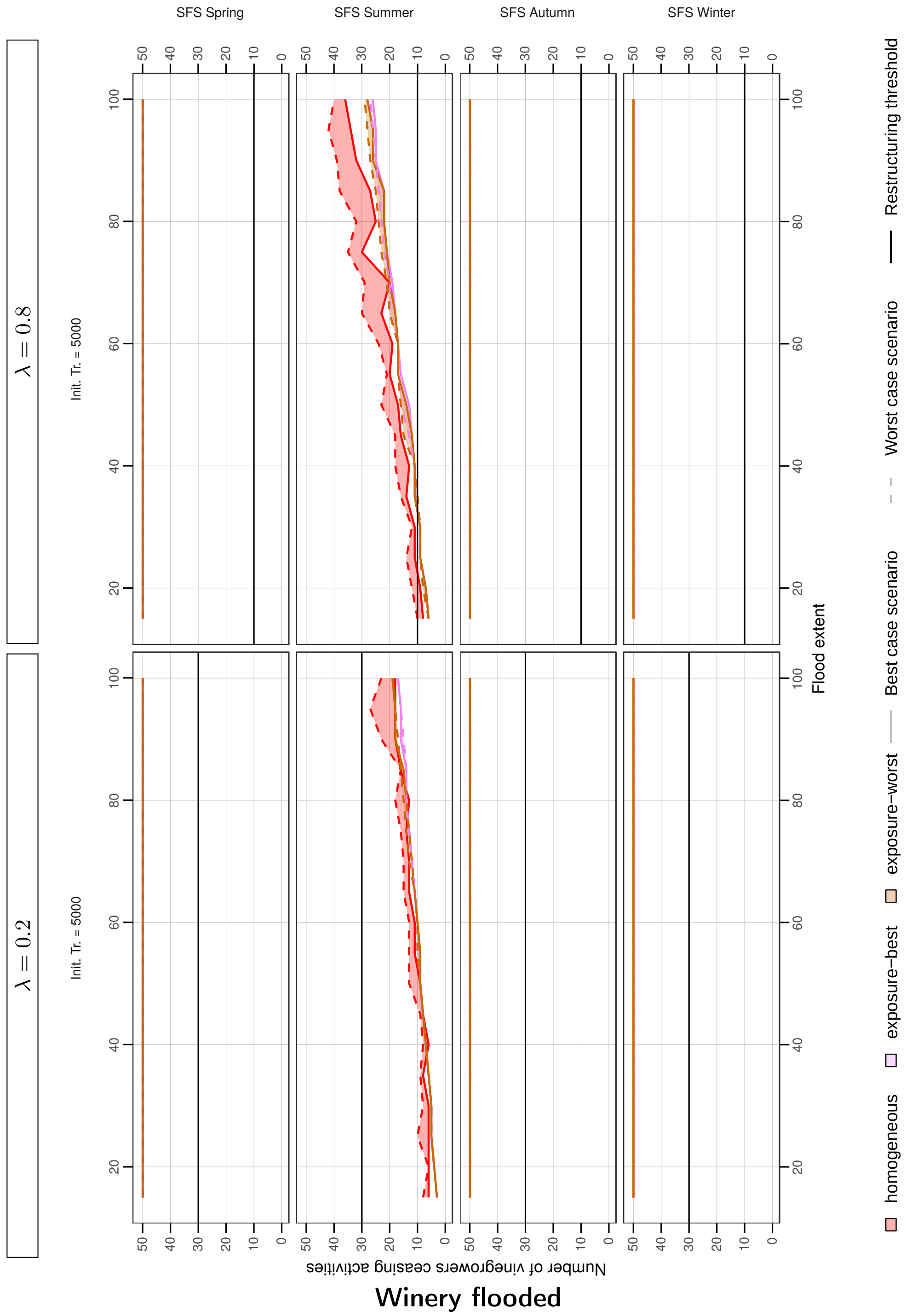
Figure 4.4 – Number of business cessations. Individual cessation time horizon considered: *Default+5*. Representation of uncertainty interval between best and worst case SFS by flood extent, coping tactic and value of lambda



Winery safe (not flooded)

Remark: Owner's remuneration floor fixed at 0.5 times the GMW | Initial treasury: €5 000
SFS: Simulation Flood Scenario | **GMW**: Guaranteed minimum annual wage (€17 763.24) | **Init. Tr.**: Initial Treasury

Figure 4.5 – Number of business cessations. Representation of uncertainty interval between best and worst case SFS by flood extent, configuration and value of lambda. Individual cessation time horizon considered: Default



Remark: Owner's remuneration floor fixed at 0.5 times the GMW | Initial treasury: €5 000
SFS: Simulation Flood Scenario | **GMW**: Guaranteed minimum annual wage (€17 763.24) | **Init. Tr.**: Initial Treasury

Figure 4.6 – Number of business cessations. Representation of uncertainty interval between best and worst case SFS by flood extent, configuration and value of lambda. Individual cessation time horizon considered: Default

CHAPTER 5

Discussion, conclusion and perspectives

"The only way to know how a complex system will behave —after you modify it— is to modify it and see how it behaves."

— George E. P. Box

5.1 Summary and conclusions

The work presented in this dissertation aims to test to what extent the integration of several scales of analysis contribute to the detection and understanding of factors and drivers of vulnerability of a Cooperative winemaking system (CWS) to floods.

The choice of such a system has been driven by i) the role that agricultural and rural lands play in nowadays risk prevention policies; ii) the importance and scarcity of microeconomic analysis of business viability and economic vulnerability of farming activities; iii) the proclivity of the networked system's structure to give raise to the occurrence of indirect impacts; iv) its complex and hierarchic structure, that enables the analysis according to different scales and levels; v) the specific weight that the CWS has in the productive and agricultural structure in our case studies; vi) its specific weight in the wine sector in France (50% of french wine is produced in cooperative wineries); and vii) the need expressed by some authors to widen the knowledge on vulnerability, climate change effects and adaptations on winegrowing and wine-producing activities.

The study applies a definition of vulnerability as a susceptibility of an element or system to be affected by a disturbance. Thence we approach the exploration of vulnerability drivers upon the premise that vulnerability factors can be surfaced through the study of damages and impacts over the entity/system. The study of those damages is undertook with a novel Agent-Based Model (ABM) —the COOPER model— we design and build «from scratch». The potential of ABMs is recognized by research communities in vulnerability, agriculture or flood damage assessment, although it is not among their standard tools. In our particular case, to choose a modeling technique such as ABMs is motivated by i) the issues pointed out by the specialized literature on flood damage assessment when more standard modeling options (Computer General Equilibrium Model (CGEM) and Input-Output analysis (I-O)) are applied to microeconomic analyses; ii) the potential of ABMs to represent explicit topologies, spatialized virtual terrains and both interactions between entities and between entities and the environment; iii) the capacity of ABMs to represent complex, hierarchical systems and their dynamics, enabling the analyst to accomplish analysis according to several scales and levels; iv) linked to the latter, the capacity of ABMs to show the influence that interactions between entities have at both individual and collective levels; and v) the potential of ABMs as computational laboratories where to conduct ex-ante analysis of flood impacts and damages.

The COOPER model reproduces the dynamics of production of a generic CWS, based on the information available in/elicited from our two chosen study cases. The impacts of floods over the dynamics and performance of the CWS are then observable and analyzed according to 3 different scales (temporal, spatial and aggregational) in each of which we distinguish 2 different levels: immediate and induced (belated) in the temporal scale; direct and indirect in the spatial scale; and individual and collective in the aggregational scale

Overall, from the results obtained we can draw the following general conclusions:

The system's topology, specifically the way material elements

are linked to each other (what is linked to what), influences the susceptibility of the system

Studies analyzing vulnerability in systems with explicit topologies are rare to find. Yet, according to the results included in chapter 3, only by varying the map of links binding binds entities together in our system, the magnitude with which the system is impacted varies considerably.

This finding is not only important for the vulnerability assessment but for the flood damage assessment itself. It shows the specific importance that a good characterization of the relations between elements has in the assessment of the magnitude of damages, thus in the evaluation of the susceptibility of the system. Indirectly, it also reinforces the point of view that flood damage assessments and vulnerability valuations are case-dependent. Indeed, according to our results the difference between two maps of links can be as big as the whole Yearly Potential Gross Benefit (YPGB) in case of large flood extents.

In parallel to those implications, the fact that, in a fixed spatial distribution of elements, *what-is-linked-to-what* matters in terms of vulnerability challenges the very definition of vulnerability and whether the notion of exposure should be taken into account. In other words, inasmuch as the results obtained do not sustain the neutrality of the configuration of links between elements within the system as a factor of vulnerability of the system, it is possible to also conclude the following:

The role of the exposure, thus the inclusion of its notion as both factor and part of the definition of vulnerability, is more complex than the available literature shows

When we set our working definition of vulnerability we rejected the idea that exposure should be part of the elements included in such definition. The idea behind is that an element is not vulnerable because it is exposed but because it has certain intrinsic features that are going to make it more or less susceptible to disruptions. Therefore, said susceptibility is an intrinsic property of the system that exists despite its exposure.

In light of our results, the inclusion of the notion of exposure in the definition and analysis of vulnerability does not seem to be optional anymore. Rather it is conditional to the level at which the analysis of vulnerability pretends to be accomplished: exposure is not needed to explain the susceptibility of our material components. Their susceptibility is linked to their physical characteristics. When we move up in the level of aggregation, in three of the configurations of links tested, agent «vinegrower» is homogeneous, and so is its susceptibility to floods. Variations in damage come explained by variations in exposure. But another level up in the aggregation scale demands to take into account the degree of exposure of the entities in the level below: the observable susceptibility at system levels is driven by the links that bind together the entities at inferior levels, and those links define the degree of exposure of each entity.

It is therefore plausible that, as far as the analysis of systems is concerned, several definitions of vulnerability may coexist in a given study, depending on the levels in which we want to focus on.

The influence of individual coping tactics over the final system's susceptibility cannot be anticipated. Furthermore, said influence can be counterintuitive in some instances

As explained in chapter 3, the coping tactics implemented in the COOPER model ultimately affect the plots' yield and with it the whole system's production. According to the results obtained in the COOPER model, differences between the two coping tactics implemented can be significant, especially in case of floods of certain importance in terms of extent. Flood extent becomes important insofar the strength with which the coping tactics influence the final susceptibility of the system is linked to the number of vinegrowers affected by the flood and the amount of productive plots they own.

Consequently, the influence of the coping tactic is more remarkable in systems with vinegrowers of heterogeneous size where large vinegrowing farms have their buildings and other materials overexposed since the inability to perform provokes larger losses of yield. In systems characterized by such topologies the possibility to outsource certain activities in case of emergency, assuring the amount of yield, is therefore going to make the system less susceptible to harm.

That being said, we have been able to detect at least one counterintuitive case thanks to the possibility offered by ABMs to account for explicit interactions. In such a case (figure 3.18. Chapter 3's addendum), due to the inability of the cooperative winery to receive the yield from plots, the initiative of the flooded vinegrowers to reduce yield losses through the employment of external resources increases the susceptibility of the system. Total damages are higher in that case.

The presence of such a case advises for prudence regarding general recipes in the implementation of coping tactics. It also demonstrates that due to the fact that agents are not isolated, emergency measures to reduce impacts that may make sense at individual level could eventually increase the collective damage that the system must endure.

Coping tactics may be irrelevant in terms of long term financial viability in the aftermath of a flood

The differences between coping tactics remarked in chapter 3 do not alter significantly the results obtained in relation to the long term viability of the system in case of flood. When the coping tactic used focuses on avoiding immediate effects (i.e. yield losses) but has limited effects over impacts reverberating in the system for longer periods of time (i.e. plant losses), its influence over the long term viability of both individual vinegrowers and the system is very limited. Furthermore, there exist cases where differences are not observable at all.

Under the cost-revenue sharing rules assumed to govern the CWS, the financial management of the winery influences the

long term vulnerability of both vinegrowers and the whole CWS in greater degree than the vinegrowers' individual financial factors

The analysis presented in chapter 4 highlights how the presence of structural cost is the key driver to the redistribution of impacts, whilst the proportion that those structural cost represent in the winery's cost structure determines the intensity of the redistribution.

In consequence, cooperative wineries characterized by high proportions of structural cost are going to, on the one hand, reduce the capacity of the system to cope with the financial long term consequences of the floods, while, on the other, they enable a higher degree of redistribution of impacts among vinegrowers. A cooperative winery with a cost structure relatively rigid makes the CWS more vulnerable than a cooperative winery with a relatively flexible structure of cost.

The analysis presented in chapter 4 also highlights the importance of taking into account interactions within systems and the way in which those interactions occur. Factors that, intuitively, can make a difference in the the long term coping capacity of the individual vinegrower (i.e. the vinegrower's initial treasury), although relevant, play a less influencing role than factors that escape their control (i.e. winery's cost structure). Indeed, although all parameters tested in the study of long term financial viability influence the capacity of the vinegrowers and the system to cope with the long term consequences of floods, the structure of costs of the cooperative winery is the most influencing one for both vinegrowers and the system.

These results depend however on the rule applied by the cooperative winery to share costs and revenues. In our concrete case, the cost-revenue sharing rule of the system is essential for the creation and transmission of indirect impacts, thus for the existence of domino effects. Rules based on, for instance, surface owned instead of yield delivered are expected to display different results. Thus the correct identification of the rules and mechanisms that shape the interactions between entities is key to the study of the of disruptions in systems.

The ABM method has proven very useful to understand how the ensemble of units get disrupted in case of flood, and how the way entities interact in the system shapes impacts and impact spreading along the system

ABMs offer indeed a powerful modeling approach for the ex-ante evaluation of the effects of disruptions in hierarchic systems, such as flood impacts in the CWS. So far, the model designed and built as part of the results of this research has shown the potential of ABMs to contribute to the understanding of the mutual influence that entities have on each other depending on the links established. As well, in a model like the COOPER it is actually possible to trace the connections between direct and indirect impacts. Furthermore, thanks to the possibility of including actual explicit rules that govern the relations between agents (productive relations in our case), we are even able to understand how certain mechanisms enable the spreading of impacts among the receptors of different orders in Green's jargon (Green et al., 2011).

5.2 Perspectives and further research

The work accomplished in this dissertation presents further research opportunities both in terms characterization of potential drivers of vulnerability and damage assessment. Furthermore, the current state of technical development of the COOPER model also presents room for further improvement in terms of performance and user friendliness.

Several elements from the evidence gathered from the study cases not taken into account in this work, may represent opportunities to deepen the knowledge of drivers of vulnerability of the CWS and systems alike.

5.2.1 Agents' behavior

Behavior of agents in ABM may play a significant role in the outcome of the simulations. Moreover, such behavior can be characterized in many different ways and degrees of complexity (see Balke and Gilbert, 2014). As stated, although we have opted for a reactive behavior sustained upon the evidence gathered, more reflective behaviors were also reported. For instance, vinegrowers give priority to investments in plot replanting but they distribute these investments along several years. In other cases, vinegrowers whose lands have been impacted prefer to prepare their soils. Such recondition of soil may take one year, which means that plot replanting is delayed on purpose. Behaviors like the two last ones, delay the replant of vineyard and keep plots unproductive for longer periods than our reactive behavior. Eventually the amount of induced damages should rise and decisions taken by agents can become factors/drivers of vulnerability.

There is therefore room to consider in what extent the behavioral hypotheses used influence the observability of vulnerability factors. Furthermore, would the factors of vulnerability already identified as relevant would remain as such if behavioral hypotheses vary? Assuming that vinegrowers do distribute large investment projects along several years, may such a behavior prevent financial distress? Or, on the contrary, may it provoke that the vinegrower gets into vicious "poverty loops" (i.e. the lack of resources hampers the reinvestment and this impedes the availability of new resources)?.

5.2.2 Solidarity

Every interviewed highlights the wide presence of solidarity. Such solidarity is expressed in different ways depending on the actors that participate and the time span we refer to: in the case of the immediate aftermath of the flood, both emergency units and volunteers begin to help people cleaning their properties. It is interesting to point out that while large-scale vinegrowers tend to count on their own resources to face cleaning and reparations, small ones depend more on direct action from volunteers to avoid suffering further damage or save reparation cost.

We did not consider any explicit solidarity in the COOPER model. Both our choice of temporal span of reference (season) and the simplifications of vinegrowing tasks prevented us from being able to study the potential of solidarity as driver of vulnerability. Hence, to accomplish such an analysis, the COOPER model should be recoded with a smaller temporal span of reference (a week or even a day) and more detailed tasks and damage functions. Furthermore, these modifications in the model would most likely need further characterization of the type and amount of help that floods can mobilize.

A model as such could be further integrated with the COOPER model to calibrate the COOPER's damage functions or to provide it with initial values of simulation.

An implicit mechanism of solidarity that we did include in the COOPER model is its current rule of cost-revenue sharing in the cooperative winery. As long as the redistributional effects explained exist, solidarity among vinegrowers motivated by financial incentives may exist. Eventually the share of structural costs that each vinegrower pays depends on the relative production of the vinegrower in relation to the total of the system. If helping the neighbor prevent losses of production, it also prevents big changes in the relative production. Solidarity in the bosom of the cooperative may therefore be perfectly driven by individual profit maximization, especially in the case of those farmers less impacted by the flood. The existence and effects of those incentives in the vulnerability of the system are worthy of further research.

5.2.3 Role of authorities

Our work has not considered any interaction with an explicit authority (either local or regional). However,the evidence gathered indicates that the perception that vinegrowers have of the role of institutions and authorities is mostly negative. Institutions and authorities are seen as a limitation to the vinegrowers' autonomy to prevent flood damages. Such perception rests upon the institutional stipulation that every reconstruction should be done in the exact same way it was done before the flood. In this sense, ABMs coupled with hydrological models can be developed and used to acknowledge the downstream consequences over lands, productions and, ultimately, economic performance of uncoordinated individual adaptations for flood protection.

Furthermore, to involve vinegrowers and authorities in the process of development of such models (stakeholder participation), may give give all actors some perspective on each other's challenges and needs. This sort of participatory process may eventually result in reductions of long term transactional costs, lower degree of conflict and more efficient risk management practices (see the works on participation of stakeholders and policy development of, for example Brouwer et al., 2007; Nicholas and Durham, 2012; Papathoma-Köhle et al., 2014; Tanner and Árvai, 2018, among others).

The evidence gathered also suggests that, when reasonable doubt on the legality of infrastructures rebuilt exists, public insurance compensations may get blocked (not denied) until the case is solved. The financial impact of such measures is not negligible, especially in the case of highly impacted vinegrowers.

5.2.4 Financial sector: banking and insurance institutions

The role of the financial sector in the COOPER model is passive. Such simplification is compatible with post-catastrophe situations, in which, according to the evidence gathered banks prepare special credit lines for those affected by the catastrophe. However this is not the normal functioning of financial sectors. A more proactive financial sector, capable of denying loans based on lack of solvency or payment capacity, can change the results displayed in chapter 4 and become one driver of vulnerability of the CWS.

In a similar way, the COOPER model does not consider any delay or uncertainty regarding insurance compensations. But interviews show that both delays and incertitude do exist. In normal conditions, vinegrowers report to wait up to a year to receive their compensations. More so if the vinegrower might be investigated because of unauthorized modifications/installations to protect himself from future floods. This delay/absence of compensations can have a big impact in the result obtained, mostly by worsening the situation of the vinegrowers that do not receive the compensation on time. It can generate cash flow problems, delay in reparations, thus the vinegrowing performance can suffer further impacts and, with it, his production and the production of the whole system.

5.2.5 Markets and large distribution

The year the flood occurs, the system loses production to a greater or lesser extent and, except for the potential damages over plants, there is no other source of induced impact. However the evidence gathered suggests that, for instance, large distribution chains if not served the amount expected may revise and cancel contracts. Such a situation may provoke further damages to the system that has not been taken into account in our model.

5.2.6 Adaptation

Although the objectives of our work included the identification of vulnerability factors within the system, their potential evolution over time due to various potential adaptations has been left out of the dissertation. Such a decision is based on two main arguments: first, our research goal was to find and describe the factors driving the susceptibility of the system, and not to offer and test solutions to modify the influence of such factors; and second, in the context of a system adaptations are eventually no more than vulnerability transfers between parts of the same system.

Nonetheless, when we set the working definition of vulnerability for this thesis we developed the arguments to undertake exposure out of the components of vulnerability as well. Yet, our findings have shown that the inclusion of exposure in the working definition of vulnerability might not be a conceptual choice but a need depending on the level/s in which we want to analyze the system. That premise can bring us as far as to use different vulnerability definitions depending on the level we are trying to analyze.

If more complex agent behaviors are to be implemented in the COOPER model (for instance, learning processes or adaptive behavior), the vulnerability of the system (either the susceptibility or the coping capacity) can be modified through local adaptations and interactions. In such regard, the evidence gathered suggests two profiles of agents: i) those that show complete resignation and do not see opportunities of action; and ii) those more proactive regarding adaptation that try to improve their emergency response, coping capacity and even susceptibility of material elements of their own. Furthermore, some agents have even taken advantages of the catastrophes and modernize their installations, processes, etc.

Further research would be needed to analyze the influence and eventual net effect of adaptations over the susceptibility of the CWS to floods. The evidence gathered in our study cases towards adaptation suggests that, to be able to evaluate some of the effects of the potential adaptations, the level of detail in aspects such as damage functions or vinegrowing tasks represented in the system should be increased though.

Appendices

APPENDIX A

Resilience: Where does it fit?

The introduction of the system's ability to cope in the analysis of the vulnerability is, as well, the Trojan horse with which resilience "sneaks into" the vulnerability analysis. Resilience should not be reduced to coping capacity though. Rather, coping capacities should be understood as encompassed by resilience.

Originally defined by Holling (1973) [1], the study of resilience, similarly to vulnerability, has been approached by different disciplines. As it happened with the latter, such circumstance has provoked the coexistence of the same mishmash of resilience-related definitions nowadays (Miller et al., 2010; Thywissen, 2006).

Within this plethora of definitions, Joakim et al. (2015) underlines 3 main different approaches/understandings of resilience. A first research line keeps the original meaning of the concept, and understands resilience as a property of the system which gives a measure of its resistance. Or, in other words, of the amount of disturbance a system can absorb before changing its state. Persistence or probability of extinction is the result.

A second research line understands resilience as a capacity to recover or *bounce back* in the aftermath of experiencing climate extremes or disasters. Over the assumption that an stable and original state (or trajectory) exists, this approach assumes that systems could recover and return to such original state/trajectory. Nonetheless, recent works (see, for example, Tierney, 2014) have challenged such implicit hypothesis over the basis of the observation that communities rarely return to a pre-disaster state, for a disaster changes the physical, economic, social and psychological reality of societal life. Thus, human and natural systems are more accurately seen as chaotic and non-equilibrating.

As a result, a research subline within resilience as capacity to recover, distinguishes between inherent and adaptive resilience (see, for example Graveline and Grémont, 2017). Inherent resilience refers to the pre-existing capacities that individuals and communities possess, and that can be implemented in the post-disaster or post-crisis situation. On the other hand, the so-called *adaptive resilience* refers to *"the ability in crisis situations to maintain function on the basis of ingenuity or extra effort"*.

The last research line approaches resilience as creative transformation. This way, resilience is understood as the process of *"adapting to new circumstances and learning from the disaster experience"* to create communities that have achieved greater resiliency and functionality. This approach, integrates *change* as an inevitable process, rather than a stressor from which a systems has to recover, and puts the accent on the adaptive and transformational capacity of individuals, groups and communities.

The analysis of Joakim et al. (2015) allows us to point out yet another research line (even when they do not include it explicitly): a conceptualization that uses all

1. As a system's characteristic that *determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist.* Later on, Walker, Holling, Carpenter, and Kinzig revise the concept in the context of Socio-ecological systems (SESs), and redefine resilience as the *capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity and feedback* (Walker et al., 2004)

three of the lines aforementioned. Such "holistic" understanding advocates for a concept/framework of resilience that integrates adaptation thinking, planning and implementation. Notwithstanding, Cannon and Muller-Mahn (2010) warn that a shift toward wider definitions of resilience, pretending to encompass concepts as adaptation or vulnerability itself, is dangerous. Under their point of view, such widening attempts remove or dilute the inherent connotations of the merged concepts, which may eventually result in the overlook of theorizations on how socio-economic structures produce unequal risk.

No need to be thorougher to conclude that, as vulnerability, resilience is a puzzle itself. The fuzziness of both concepts does not help to establish in a general, categorical way in what measure they are linked. Indeed, authors like Gallopin (2006) or Joakim et al. (2015) recognize that the relationship between these two concepts in the literature is neither trivial nor obvious. Joakim et al. goes even further, and states that the relationship is, in fact, highly complex and depends on place, time and context since attributes of vulnerability and resilience can have both positive and negative feedback on aspects of each other.

Yet, arguments in favor of integrating both concepts into the same framework can be found in the literature. For instance, Turner et al. (2003a) points out that precisely resilience is one of the major concepts vulnerability analysis draws on; Miller et al. (2010) state that fundamental links exist between the two concepts but they have been keep apart artificially; and Joakim et al. (2015) consider that it stresses the ability of a system to deal with a hazard —absorbing the disturbance or adapting to it—, helping to i) assess hazards holistically in coupled human-environment systems, and ii) explore policy options for dealing with uncertainty and future change.

Such integration has been materialized in 3 different approaches, according to Joakim et al.. Roughly described, the first conceptualization (as a continuum) understands resilience as the flip side of the coin of vulnerability: an increase in resilience would reduce vulnerability and vice versa.

The second one (See as well Schneiderbauer and Ehrlich, 2004, p. 20) establishes a temporal dimension in the relationship between both: vulnerability represents the pre-disaster conditions whereas resilience represents the post-disaster response. This way, vulnerability is a pre-existing or background condition —depending mostly on physical susceptibility—, and resistance and recovery —linked to socio-economic features— are related to resilience. As Joakim et al. (2015) points out, to relegate vulnerability to a 'background condition' in such terms, de-emphasizes the multidimensional processes that contribute to the generation and perpetuation of the vulnerability.

The third conceptualization simply considers vulnerability and resilience as different and separate, yet interrelated, concepts. Such scope recognizes the inherent complexities and potential unanticipated feedback likely to occur within SESs, and allow researchers to explain the relationship between vulnerability and resilience in more numerous contexts than the other two alternatives (e.g. when insurance schemes ensure communities facing impacts of natural hazards but fail to provide the correct incentives to adapt; in such situations, the initial susceptibility to the stressor is diminished by the action of the resilience mechanisms in place. Nonetheless, the presence of those resilience mechanisms can distort the perceived risk and induce communities to behave reckless, which eventually can turn out to be a source of increment in vulnerability)

The present work is ascribed to this last conceptualization. It is considered that to treat them as a different, interrelated concepts keeps their inherent connotations and complexities, yet offers a powerful working approach to frame complex phenomena, and the study of independent, evolutionary processes that may feed each other.

APPENDIX B

Case dependency in vulnerability and damage assessment. Analytical example

B.1 Case dependency of vulnerability assessments in hierarchical complex systems

Comprehensive vulnerability analyses in systems should include the system in its totality to fully and unequivocally describe how each factor and/or combination of factors drive the vulnerability of every entity and the whole system. However, such an endeavor is rather unrealistic in hierarchical complex systems (Turner et al., 2003a). Several reasons can be adduced. For instance, lack of available data, lack of knowledge of the systems themselves, lack of computational capacity and the need to prevent models becoming black boxes useless to isolate, explain and describe the effect of factors.

Hence, vulnerability analyses are performed on subsystems whose boundaries are artificially, and arbitrary, set according to the actors, interactions, outcomes and rules considered relevant a priori (McGinnis and Ostrom, 2014), and enabled by the property of *near-decomposability.* The resulting subsystem is then a simplified painting of the subjacent system in which variables and levels out of bounds will be treated either as constrains or noises that affect the system but are not affected by it.

What are the consequences for vulnerability analyses we might be facing? to illustrate it, let's recur to an analytical example: Let's assume that a system S is defined by the 5-tuple of variables $\{U, W, X, Y, Z\}$, which we presume fully interrelated.

Now, as we know, *near-decomposability* allows us to define subsystems within larger systems by the establishment of clear boundaries. Variables and levels out of bounds will be treated as constrains and noises that affect the system but are not affected by it. Let's assume that we define the subsystem S' using the sub 2-tuple $\{X, Y\}$ as variables and the sub 3-tuple $\{\bar{U}, \bar{W}, \bar{Z}\}$ as constrains. Confronting S' with an stressor we will get a vulnerability assessment, Vl', that depends on the behavior of $\{X, Y\}$, their functional relation, the potential feedback of one to another, and the values assumed for $\{\bar{U}, \bar{W}, \bar{Z}\}$.

If we define S'', using the sub 3-tuple $\{X, Y, Z\}$ as variables and the sub 2-tuple $\{\bar{U}, \bar{W}\}$ as constrains, the inclusion of Z as variable might alter the behavior of $\{X, Y\}$. Therefore the resulting vulnerability assessment, Vl'', may be different than Vl'. Alternatively, if we delimit S''' with the sub 3-tuple $\{X, Y, W\}$ as variables and the sub 2-tuple $\{\bar{U}, \bar{Z}\}$, we will get a third vulnerability assessment, Vl'''. Given the different relation and influence that W may have over the behavior of $\{X, Y\}$ in relation to that one of Z, this new assessment will be, most likely, different than the prior two.

Thus, inasmuch as the effects of the evolution of all variables are not present in any of the subsystem we can build, vulnerability analyses, ergo assessments, are incomplete. As well, assessments are going to be heavily dependent of the binomial *research goal – data availability.* This binomial drives the identification of the sub n-tuple to consider, the relations among the elements in tuple and, further, their initial values. Insofar the variables out of the retained sub n-tuple are integrated as constrains not subject to evolution, their initial values are going to tie the evolution of the sub n-tuple. Small changes in those initial conditions can provoke major changes in the outcome given the potential non-linear relations between elements in SES.

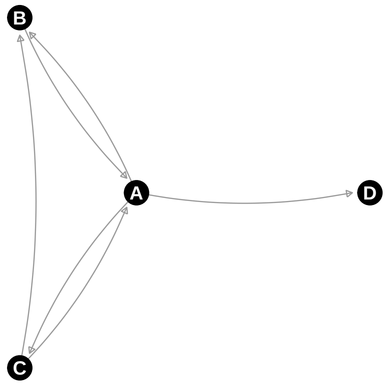
B.2 Case dependency and influence of topology in flood impact assessment

In our work, the valuation of the vulnerability of the system rests upon the assessment of flood impacts. The correct assessment of those flood impacts, especially in what respects to indirect impacts, is linked to both the topology of the system and the time horizon considered (section 5).

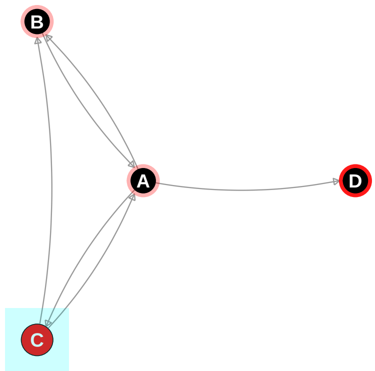
Precisely topologies and time horizon are part of the boundaries to seal off upon the demands of the property of *near-decomposability* of hierarchical systems (section 1, p 6). To see how these boundaries may affects the damage estimation, let us use again our analytical example of the beginning of the section. Let us, as well, assume that our subsystem S' is composed by the entities A, B, C and D (figure B.1a). We are not redefining S', just adding a layer of description: S' is a subsystem of S, composed by entities A, B, C and D, in which we are interested in studying the behavior of the sub 2-tuple of variables $\{X, Y\}$ in presence of the sub 3-tuple $\{\bar{U}, \bar{W}, \bar{Z}\}$ working as constrains.

To illustrate the relations that exist in the topology, let's assume that C produces certain commodity (e.g. steel) that is used by A and B as primary input. A will use B's production (e.g. preformed steel pieces) as intermediary inputs for their own productive processes (e.g design and assembly of certain types of machinery and pieces). A's production is at the same time used by B, C and D.

In such situation, direct impacts over C will spread (immediately and/or belatedly) to entities A and B. The production of steel is reduced, which causes lack in the production of machinery parts and machinery itself, interrupting the whole production chain. Our diagram (figure B.1b) illustrates a situation in which the direct impact over C is partially mitigated in its arrival to B and A. In the case of D, the shortage in steel and



(a) Example of topology in a system



(b) Example of impact spreading and intensity along system's topology

Legend: Arrows indicate the directionality of the relations between elements (they should not be understood as the direction of the indirect effect). A red point in a blue square indicates the area of direct impact. Red crown around black points indicated indirect impact. Color strength of red crown indicates intensity of indirect impact

Figure B.1 – Influence of topology in impact spreading the production problems in A provoke an amplification of the impact. The total damage, $dam_{S'}$, provoked by a flood over C should, therefore, include the direct impacts over C and the indirect ones upon A, B, and D ($dam_{S'} = C + A + B + D$).

Let us assume now that we drop D from the study. There exist a handful of reasons for which it may happen. E.g. it is plausible that the apparition of the indirect damages over D may be out of the temporal boundaries of the study; it is also possible that that the spatial definition of S' leaves D out; alternatively, insofar the topology established depends on the knowledge the analyst can gather, the exclusion of entities may be driven by misinformation. Anyhow, to drop D from our study would identify S' as a composition of the entities A, B and C. This redefinition would result as well in a new, and smaller, total damage ($dam_{S'} = C + A + B$). Let us assume now that we drop D from the study. There exist a handful of reasons for which it may happen. E.g. it is plausible that the apparition of the indirect damages over D may be out of the temporal boundaries of the study; it is also possible that that the spatial definition of S' leaves D out; alternatively, insofar the topology established depends on the knowledge the analyst can gather, the exclusion of entities may be driven by misinformation. Anyhow, to drop D from our study would identify S' as a composition of the entities A, B and C. This redefinition would result as well in a new, and smaller, total damage ($dam_{S'} = C + A + B$).

The identification of elements at risk is therefore a non trivial task that depends on i) the boundaries (spatial and temporal) with which the analyst choose to define its subsystem object of study; and ii) the degree of detail with which both entities and their relations are established in the subsystem. Consequently, damage assessments will be case- and context-dependent.

APPENDIX C

French wine classification and quality

C.1 Before 2009

Wines in France are primarily classified according two big groups: *IG*, that stands for *vin avec indication géographique* and *VSIG*, standing for *vin sans indication géographique.*

Withing the first group, *IG*, we can identify three different kinds:

1. *AOC, Appellation d'Origine Contrôlée*: The most strict category in terms of production methods and legislation. Theoretically (just theoretically) it is also the best quality.
2. *OVDQS, Appellation d'origine vin délimité de qualité supérieure*: Intermediate category for wines with lower reputation than AOC's
3. *Vins de pays*: category with more flexible legislation and freedom in choosing grapes and production methods

As for the *VSIG* wines, they have been known as *vins de table.* Their legislation is the most liberal one among wines.

C.2 After 2009

After the year 2009 the classification of wines has changed:

1. Wines under the *AOC, Appellation d'Origine Contrôlée* became wines under the denomination *AOP, Appellation d'Origine Protégée.*
2. The label *IGP, Indication Géographique Protégée* was implemented for the *Vins de pays*
3. *OVDQS*, Appellation d'origine vin délimité de qualité supérieure has disappeared and its wines are now in *AOP* or in *IGP*
4. *VSIG* wines, also known as *vins de table*, wee relabeled as *Vin de France*

APPENDIX D

Complete list of stylized facts about the cooperative winemaking system and its functioning, based on the information obtained in the interviews conducted in the case studies

D.1 The Cooperative winemaking system (CWS)

From the interviews conducted in the frame of the Résilience des territoires face à l'inondation. Pour une approche préventive par l'adaptation post-événement (RETINA) project (RETINA, 2014-2016) we can state the following stylized facts:

1. The Cooperative winemaking system (CWS) is composed by three fundamental entities: vineyards (also called plots), vinegrowing farms (also known as vinegrowers) and wineries
2. Young vineyards need a time window of 3 to 5 years to be productive.
3. Vinegrowers (thus their plots) are associated with one, and only one, cooperative winery. They provide the main production input (grapes) and leave in hands of the managerial team of the cooperative winery the rest of the wine-making process.
4. Cooperative wineries split the difference between revenues (from wine sales) and wine-making cost (benefits hereafter) among vinegrowers associated [1]. Delays of, at least, one year from the harvest date to split the benefits are common.
5. Remuneration policies can include some kind of policy of incentives [2], that favors some varieties over others [3]. Notwithstanding, they, essentially, remunerate associates in relation to the input delivered
6. Wine making cost are split proportionally to each vinegrower amount of input (grape) provided.

   Corollary: When a vinegrower does not transfer any input to the cooperative winery, he is not charged with wine-making cost nor receives revenues.

   Exception: It is foreseen the possibility of charging wine-costs to a vinegrower that has not supply any grapes to the cooperative. Such situation takes place when the said vinegrower does not deliver due to negligence of his activities. This mechanism is never used when floods hit the system, though.
7. Wine-making cost can include debt cost and amortization of loans. The structure of cost of a cooperative winery presents both structural (fixed) and operational (variable) costs.
8. Cooperative wineries do not stock financial reserves. Although a common operation in the past, it has been abandoned nowadays.
9. Contractual relations with members are officially revised each 5 years. It is admitted that if an associated vinegrower wishes to leave [4] the cooperative winery it can be done in any moment (they should not wait until the revision).

1. Consistent with literature. See Biarnès and Touzard (2003); Touzard et al. (2001) and Jarrige and Touzard (2001)
2. Idem
3. Systems of quotas can be found as well
4. Two situations are cited as more common reasons:

a) Vinegrowers that wish to grow their businesses and organized wine production and commercial strategies on their own. Some of them can come back to the cooperative if things do not go as expected.

b) Vinegrowers that sell their activities to private, big, professional wine-producers.

10. Due to the crises in the wine sector, there has been an apparent evolution to the professionalization of farming businesses. Along with it, the commercialization policies have turned more proactive, with sales focused on bottled wine, big brands and big bottlers.

D.2 The CWS in face of flood hazards

In the following subsections we are going to summarize the empirical evidence gathered through the different interviews conducted. It has been chosen to be presented as stylized facts to enhance the key points that allow the reader to get a complete picture of the way the CWS works when facing flood hazards

D.2.1 Winery

1. Cooperative wineries directly impacted by floods did not have action plans in case of flood hazard.
2. The nature and amount of damages is highly heterogeneous and may include production losses and structural impacts. The monetary valuation of the reparations can rise above the yearly turnover [5]
3. The behavior can be characterized as reactive: the main objective is either keep the activities ongoing or restart them as soon as possible.
4. The existence of damages in the transport network plays a negative role in the restart of the production activities
5. Impacts of flood hazards during grape collecting season from associated vinegrowers could be really problematic due to business losses. Same thing if they get hit around June, when they begin to sell
6. Part of the insurance compensations can be used to compensate vinegrowers for production losses
7. Flood hazards do not entail impact on sales. There seems to do not exist rejection of the final product driven by consumers psychological factors
8. Flood hazards do not entail any behavioral variation of big distribution channels. To not be able to deliver the final product jeopardizes the winery's business and activity (thus its associated vinegrowers)
9. Flood hazards can trigger the revision of contractual relations with service and material providers.
10. Insurance payments are usually split in several times. In addition they do not normally cover all damage registered. Insurance statements can take several months of preparation as well as additional expert staff to act as intermediary between the winery and the insurance companies/institutions.
11. Financial resources for reconstruction are highly homogeneous. They include compensations from insurance, loans (in some cases banks offer special, favorable conditions post-disaster —0 to 1% of interest rate), subventions and solidarity funds (marginal role)

5. chiffre d'affaires

D.2.1.1 Behavior displayed regarding adaptation

12. The evidence gathered suggests that both the attitude towards the winery's capacity to adapt and the adaptations adopted are quite heterogeneous. They range from complete resignation ("What could it be done?") to proactivity in flood prevention
13. Either due to merging or reconstruction processes there is evidence of location change for the winery's building(s).

    Remark: The evidence gathered also suggests that the buildings in flood prone areas continue to be used though. The evidence on reconstruction points out that new locations are close to the old ones. In case of repetition of the same phenomenon buildings are safe, but it does not mean that the winery is actually moved out of the flood prone area.
14. Winery reconstruction might be used as an opportunity to improve the winemaking process and the winery's performance. E.g. machinery update, capacity enlargement...
15. Investment projects prior to floods are often suspended to prioritize reconstruction and reparation
16. When relocation is not contemplated (or not an option), adaptation measures may include the installation of flood contention infrastructures (e.g. slot-in flood barriers), displacement of concrete infrastructures (e.g. bottling chain), and the setting of both cleaning and emergency respond plans.
17. Lack of prevention and awareness, together with rush to restart activities as soon as possible, and limited budget prevent in depth adaptations. Reconstructions and reparations are most likely done according to the corresponding legal framework.

D.2.2 Vinegrowers

As in the case of the wineries, we can establish the following stylized facts:

1. Damages over individual vinegrowers are widely heterogeneous, affecting from just small portions of surface to buildings. The responses given in the aftermath of the flood are, however, more homogeneous.
2. When floods hit the vineyards, behavior among vinegrowers is homogeneous and reactive. Cleaning and reconditioning begin as soon as possible to avoid further damages. In case the plants are damaged and cannot be saved, vinegrowers replant immediately, trying to return to their initial states.
3. If floods sweep the plots, dragging the soil downstream, vinegrowers should replenish the lost soil, which increases their reparation budget [6] and risks to affect soil productivity. In lands qualified as *AOC* (Appellation d'Origine Contrôlée [7]) the situation worsens as soil can only be replenish with material from the same AOC. Nonetheless, the majority of vinegrowers declared to have

6. €400 000 for 7ha is declared in one of the interviews
7. Controlled designation of origin

lost the no AOC lands, since AOC lands are commonly located farther away from the rivers.

4. Priority is always given to vineyard surfaces in relation to other investment projects: if hit by floods, investment projects are stopped or re-planned to meet the vineyard's financial needs. In case that all vineyards cannot be replanted at the same time because of financial constraints, the surface the replant process is split among several years, but keeps its priority over other investments.

   Four types of different motivations drive their actions in this case:

   a) The plots are the core of their activities and the base of their economic activities.

   b) Even if some of them consider that it is better to let the soil recover from the impact —using the land for alternative cultures and balancing the nutrients— there is a limit in the time span allowed to replant a vineyard (4-5 years). Once such time span reaches its limit, the land's legal status changes and cannot be used as vineyard anymore. In other words, if the vinegrower does not replant, they can lose their rights to use the surface as vineyard.[8].

      Yet, some vinegrowers prefer to prepare their soils. In such cases, even when the replant is delayed, they should begin as soon as possible since only the recondition of soil takes one year.

      Even if the vinegrower do not wish to continue with the activity —some of the vinegrowers are aged people whose heirs are not interested in keeping the activity— they prefer to keep the vineyards active, well aware that their value is higher as active vineyards[9].

   c) It is not uncommon that cleaning and reconditioning work result more expensive than replant.

5. There are four reported situations in which plots are most likely not replanted, especially where the surface is repeatedly flooded.:

   a) When the surface flooded is small in relation to the owned extent,

   b) When the vinegrower is an aged person, the activity is not the main activity and the investment is so big

   c) When the flood rebuilds the river banks and plots closely placed to the river become part of those banks.

   d) When victims corpses are found in those plots or near them. At least one of the people interviewed declares to have lost his will to go to work over those concrete plots.

      In cases a) and b) certain vinegrowers choose to either do not use such surface, or to reconvert it to other uses. In case c), to replant with perennial

8. According one vinegrower, planting rights can be demanded again. The time between the moment the vinegrower initiates the process until the rights are granted again is unknown, as well as the probability with which such rights are granted again. Competition between housing and agricultural activities is told to be there

9. one of the vinegrowers in la Londe-lès-Maures inform us that the price per ha is at least €10 000

crops (any kind, not only vineyards) is forbidden by the authorities. In any case, the potential production of the exploitation is impacted, and investment/adaptation projects have to be revisited.

6. Damages may also include infrastructures (e.g. bridges, tracks...) that grant vinegrowers access to their lands. Often such infrastructures are not of public ownership; in some cases they might be common property of different, independent farming businesses. The latter situation force impacted vie-growers to either negotiate with their neighbors the way reparations should be performed and financed, or to begin, and finance, reparations on their own (which can lead to potential conflicting situations).
7. High frequency floods might be specially problematic regarding vinegrowers' financial situation. Given a flood hazard, to the damages and activity losses derived from it, we should add the budget spent in reparations (to restart the activity as soon as possible) and the damages and activity losses due to a second flood (and following ones).
8. When floods provoke losses of human lives and corpses are missing, search and find works can delay reparation tasks.
9. Vinegrowers with experience in different floods tell that damages and the way they happen are different each time. That transmits certain feeling of uncertainty and impotence regarding adaptation and emergency response plans.

D.2.2.1 Behavior displayed regarding adaptation

10. Vinegrowers' adaptation is limited by legal frames. No intervention in the riverbanks is allowed by the authorities, therefore the construction of flood barriers, dikes and any other infrastructure, without the corresponding authorization, is out of reach for the individual farms. Moreover, all infrastructures for flood contention not declared (even if they were "historically" placed) and destroyed cannot be rebuilt [10].
11. Those vinegrowers wishing to make certain adaptations and to build retention infrastructures, like gabions or floodwalls, report that administrative processes regarding construction authorizations can take a year. In those cases with high flood frequency, such delay in authorizations is seen as a source of damage: the impossibility to build/rebuild such infrastructures together with empty plots —or recently replanted— increases the probability of soil removing, which increases the amount of damage and the long term impact on soils [11].
12. Adaptations in vineyards can be summarized in three kinds of measures:
    a) Planting direction of vineyards. The direction in which plants and trellising structures are placed influence the amount of damages: when planted in

10. According to the declarations, in the 90s decade of the last century, the French government allowed owners to declare such infrastructures and "legalize" them. Afterward all non-declared contention infrastructures are considered illegal, no matter how long they have been there

11. The impact of floods in soils is controversial: in some cases, it helps to recharge with new nutrients, which eventually, impacts positively over the production. In other cases, especially when important volumes of soil are dragged by the flood, vinegrowers report long term impacts on soil productivity, that, can force them to change their commercial strategies

the same sense than the water current they offer less resistance, thus the probability of damage decreases.

b) Construction of evacuation structures (e.g. ditches) so the water finds an exit from the plot. Especially valuable in those surfaces where the water tends to be retained and form ponds.

c) Maintenance and cleaning of ditches and evacuation infrastructures. In those cases where ditches already exist, floods either reactive maintenance activities, or reinforce their importance.

13. When vinegrowers should replant a plot, they usually choose to replant with those varieties that represent the best fit for their commercial strategies. For the associated to the cooperative winery, such commercial strategy is decided at the winery's level.

14. As it happens in the case of cooperative wineries, vinegrowers display attitudes towards adaptation that can be classified in two different profiles:

    a) Those that accept that there is not much they can do to adapt, even when they are aware of the risk in case of repetition of the flood.

    b) Those that try to place all the measures they can think of to prevent damages in case the floods hit again.

D.2.3 Role of existing insurance schemes

1. The evidence gathered suggest that no specific private insurance for floods is available.

2. Compensations after floods come mainly from the public french insurance systems: *Calamité Agricole* and/or *Cat-Nat*[12].

3. The access to the compensation funds coming from *Calamité Agricole* and/or *Cat-Nat* is costly in terms of time and paperwork. It is common practice to hire the services of intermediaries to assist in the process. The empirical evidence suggest two different alternatives in the way those external services are hired:

    a) Individually: each vinegrower searches and hires its own insurance expert.

    b) Collectively: cooperative wineries can adopt the role of intermediaries between the insurance and their associates, reducing, this way, transaction costs and, most likely, accelerating administrative processes. Such behavior allows associated vinegrowers to focus on reparations, at the same time the insurance's staff can have quick answers from people that knows how to translate information from the the terrain into paperwork.

4. Despite the presence of those intermediaries, errors, mistakes or simple lack of thoroughness in the compensation demands may result in lower level of compensations. There exist thus certain level of incertitude regarding compensations. In addition, they are not immediately received. Reparations, reconstruction

12. *Calamité Agricoles* are uninsurable damages of exceptional importance due to natural hazards of abnormal intensity, and that cannot be either prevented or remedied with the technical means usually used in agriculture.
Cat-Nat is an specific insurance scheme created by the french government for natural hazards like floods, earthquakes or droughts, considered uninsurable in private terms.

and restart of activities rest upon vinegrowers/winery own resources. Delays up to one year are not uncommon [13].

5. Although not a majority, the evidence gathered also show cases in which compensations are not demanded. This behavior is based on the belief that vinegrowing farms should be financially autonomous, thus not dependent on public sector's money.

D.2.4 Role of public institutions and legal frameworks

1. Institutions and authorities play a double role in the aftermath of the flood. On the one hand, they are in charge of both crisis management and to revert key infrastructures to their original state or, at least, offer plausible alternatives that help people do their emergency management. On the other hand, they exert a strict control to avoid the proliferation of uncontrolled flood contention infrastructures, based on the precept that not well planned and coordinated flood control infrastructures can cause more harm than benefit.
2. The perception of the role of institutions and authorities is mostly negative. They are seen as a limitation to the vinegrowers' autonomy to prevent flood damages. Such perception rest upon the institutional stipulation that every reconstruction should be done in the exact same way it was done before the flood.
3. Reasonable doubt on the legality of infrastructures rebuilt may block public compensations. The financial impact of such measures is not negligible, especially in the case of highly impacted vinegrowers.
4. Evidence suggest some sort of lack of either coordination or dialogue between local authorities and the managerial organisms of river basins regarding maintenance of river banks. We are informed of cases in which the initiative of local authorities to start maintenance works in the river banks are eventually stopped by river basin authorities. The perception is that floods are not a driver to coordination improvement.

D.2.5 Role of solidarity

1. Every interviewed enhances the wide presence of solidarity. Such solidarity is expressed in different ways depending on the actors that participate and the time span we refer to: in the case of the immediate aftermath of the flood, both emergency units and volunteers begin to help people cleaning their properties. It is interesting to point out that while big vinegrowers tend to count on their own resources to face cleaning and reparations, small ones depend more on direct action from volunteers to do not suffer further damage and or save reparation cost.
2. Solidarity behavior does not come only from people linked to each other in the region (neighbors' solidarity). Inter-regional solidarity is reported as well, with multiple materializations: manual work, expertise, lends of material...

13. In any case, some people interviewed state that no insurance inspector went to check out the level of damages they had.

3. When not impacted, cooperative wineries can act as neuralgic centers that organize meetings with authorities, serve as intermediaries for administrative processes, and even delay tasks (without neglecting the production process) to go help people in the area (especially their associates). On the contrary, when flooded, not impacted associated vinegrowers give priority to cleaning tasks in the the cooperative winery.
4. It is reported that some providers made "commercial efforts", like discounts, price contention, etc, trying to help both wineries and individual enterprises to restart.

APPENDIX E

Model implementation: flow diagrams, code structure and main processes

We remind the readers that in section E.2 they have available cheat sheet of symbols. We also remind them that the we have established the following convention :

— Variables, processes, functions and code in general, when part of the text, will be written in `teletypefont`. When summary tables of variables are shown, such variables are written in standard font.

— As a special case, when R is written as R, it refers to the programming language in a general way, while when written as `R`, it refers to the environment in which procedures, variables, functions or processes exist. Likewise for Netlogo.

E.1 Model implementation

The model is implemented combining Netlogo 5.3.1 (Wilensky, 1999) and R 3.4.1 (R Core Team, 2017), through the RNetLogo package (Thiele et al., 2012) in its version 1.0.2. [1]

E.1.1 Overall structure and processes

The model's code structure —outlined in figure E.1— can be split into two different big blocks that will interact, feeding information one to each other, all along the process. Such blocks also correspond to the different languages used to code the model.

Roughly speaking, on one side we have the `R` block, that contains:

— `Input generator` (top left of figure E.1)

— `Simulation launcher/iterator` (left side of figure E.1)

— `Impact calculator` (left side of figure E.1)
These two last procedures are thoroughly explained and outlined in section E.1.3 and figure E.4

On the other hand, the `Netlogo`'s one is constituted by the model's core, and so-called `flood simulator` (right side of figure E.1. More detailed in section E.1.2 and figures E.2 and E.3).

The very first step in the simulation process pass through the input generator. Its mission is to provide values to the `flood simulator`. To do that, it equips the user with a way to translate the values of the simulation parameters —the so-called `scenario's conf. data` in figures E.1 to E.4, whose content is summarized in table E.1— into information readable by the `flood simulator`. Once prompted (or facilitated by user's scripts) in the `R` terminal and processed, such information is stored with the proper format/order for `Netlogo` in standard `txt` files on the hard disk. This procedure obeys to different objectives:

— Time saving: all simulation parameters and values of a plan of experiments can be created, and stored, prior to the simulation launching.

1. Although available, higher versions of Netlogo have included major changes regarding language, and the model has not been yet adapted

— Replicability: all simulation parameters and values of a plan of experiments can be replicated numerous times, just by calling the proper file in the `flood simulator`

— Feedback: the stored files grant access to the simulation parameters, so the configuration of a particular simulation or plan of simulations is always accessible for the user.

— Reuse: new simulation parameters files can be done, reusing the ones already done without having to build entire new ones.

— Task sharing and information exchange: configurations of scenario parameters can be shared directly between users.

Although essential for the whole simulation process, the `input generator` is not part of the simulation procedure. It means that when the `simulation launcher/iterator` begins, the `input generator` will not be called at any moment. Only the stored `scenario's conf. data` files generated by it will be.

The `simulation launcher/iterator` starts the simulation procedure. As well as the `input generator`, it will provide simulation parameters to the initialization of the `flood simulator`. Such parameters are the ones whose values are expected to be modified by the `simulation launcher/iterator` in order to complete the experiment plan. An example is provided in table E.2.

As it can be seen, values in table E.2 are already included in table E.1. The information provided by the `input generator` and the `simulation launcher/iterator` is complementary. It means that parameter values whose effect we wish to test, are expected to be provided through the `simulation launcher/iterator`, whereas values stable values should be passed through the `input generator`.

The `simulation launcher/iterator` should set, additionally, values for two more variables (table E.3):

1. `dam_byR`: special boolean variable passed to the `flood simulator`, setting up whether we wish to use the Random Number Generator (RNG) of `Netlogo`, or to provide the damages over plants in plots through the RNG of `R` (the difference between both methods will be explained in section E.1.2)
2. Number of iterations of each simulation to be done, due, precisely, to the presence of random effects in the simulations.

When all values are set, the `simulation launcher/iterator` calls the `flood simulator` once per simulation[2], passing the control of the process to `netlogo`. When each simulation is finished, the `flood simulator`, returns control of the process to `R` along with the Business as Usual scenario or Zero Flood Scenarios (BAUs)[3]/Simulated Flood Scenarios (SFSs), to be processed by the `simulation launcher/iterator`. At this stage three different sequential tasks take place:

2. Assuming the simulation parameters in table E.2, we call simulation to the performance of one system set up by parameters in table E.1, with one specific `configuration of links`, during n `periods to simulate`, that uses one `coping tactic` when a flood —defined by one `flood extent` shorter or equal to the system's `extent of the prone area`— hits the system during one of the 4 first periods —set by `season`

3. By default BAUs are not iterated.

Global variables	Age at which the plot is considered productive
	Age at which the plot is replanted
	Number of farmers in the cooperative winery
	Number of cooperative wineries
	Amount of money to spend in soil set up after the flood
	Price per ha to replace the plants in the plots
	Amount of money to spend setting up again the farm after the flood
	Amount of money to spend setting up again the winery after the flood
	Average productivity by ha
	Average wine price by hl
	Periods to simulate (one period = one season)
	Configuration of links between plots and farms
	Extent of the prone area (by default = 100)
	Extent of the flood
	Season to simulate the flood
	Global coping tactic in the system
Plot	Internal `Netlogo ID`
	Position over terrain
	Owner
	Productivity
	State (planted/unplanted)
	extent
	Age
	Operational vine-growing cost associated
Farm	Internal `Netlogo ID`
	Position over terrain
	Initial amount of cumulated balance
	Proportion of structural costs over total vine-growing costs
	Winery's Internal `Netlogo ID` to be associated to
Winery	Internal `Netlogo ID`
	Position over terrain
	Fixed vinification costs proportion
	Average wine-making cost per hl
	Proportion of structural cost over total cost
	Efficiency

Table E.1 – Summary of parameters that conform the `scenario's conf. data` of the `flood simulator`, whose values need to be provided to the `input generator`. Classification by entity

1. Raw data from SFSs/BAUs is stored in the hard disk in R native format file *.rds*[4];
2. Data from SFSs/BAUs is classified into the different time spans considered (see

4. Such format, directly readable by R allows us to store the file already compressed, saving a significant amount of space when compared to *.csv* or *.txt*

Parameters	Periods to simulate (one period = one season)
	Configuration of links between plots and farms
	Extent of the prone area (by default = 100)
	Extent of the flood
	Season to simulate the flood
	Global coping tactic in the system

Table E.2 – Example of parameters whose values are provided by the simulator launcher/iterator

Special parameters
`dam_byR`
Iterations

Table E.3 – Special parameters to be provided to the simulator launcher/iterator

section 2.12) and stored in auxiliary files associated to each SFSs/BAUs

3. Forward the auxiliary files associated to SFSs/BAUs to the `impact calculator`

Over the those auxiliary files, the `impact calculator` determines the impact of the flood over the SFSs by comparison with BAUs. Impacts are then stored in the hard disk in R native format file *.rds* for further analysis [5]. When all simulations are done, the analyst has two possibilities over the stored results:

— To conduct the automated pre-coded statistical and graphical analysis, and/or

— To conduct their own statistical and graphical analysis

5. It is possible, though, to convert them to more standard formats, readable by other software

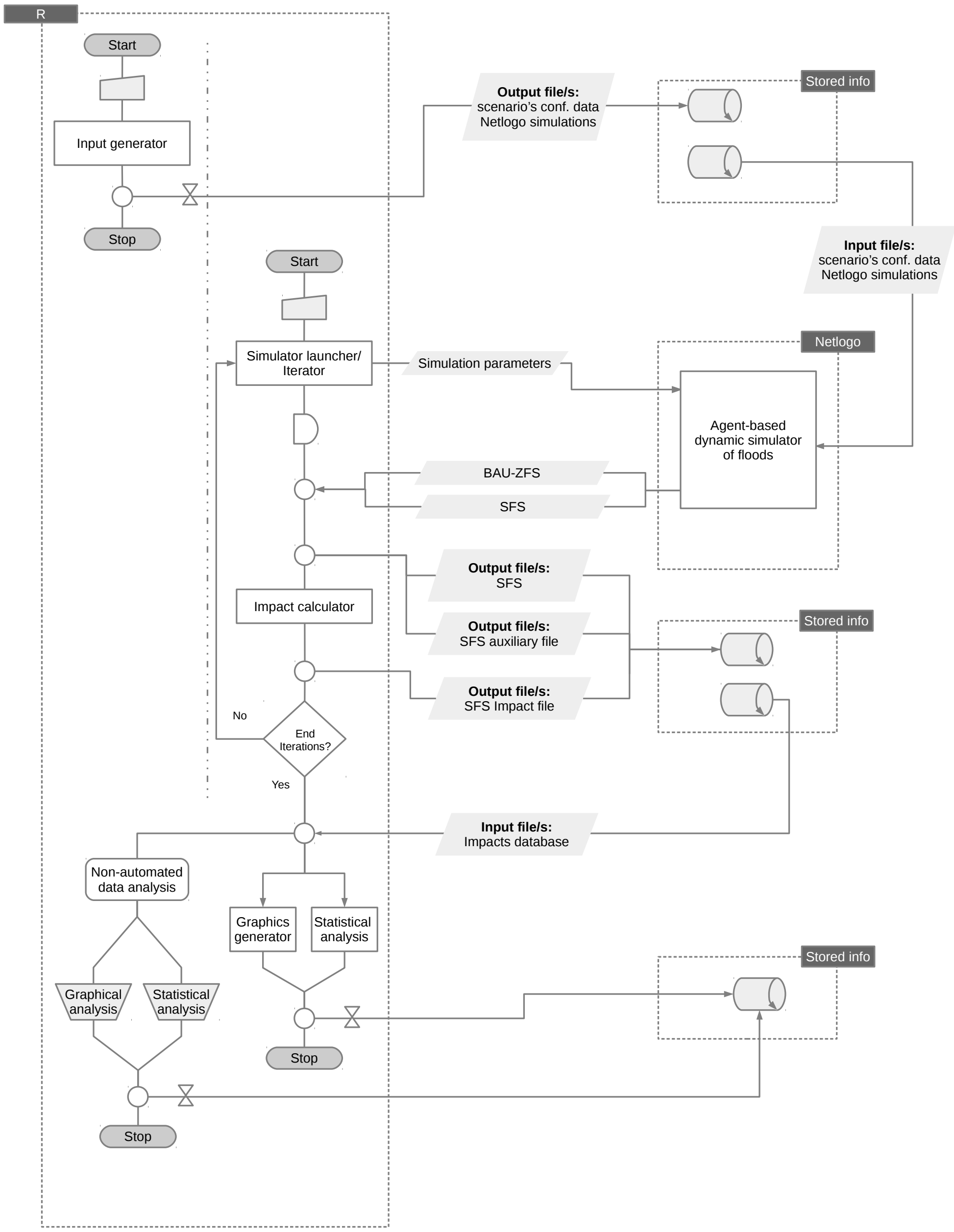


Figure E.1 – Model's general flowchart

E.1.2 Flood simulator

As it has been said, the `flood simulator` is the core of the simulation process. It is built as an agent-based model (fully written in Netlogo 5.3.1 (Wilensky, 1999)), and developed to be able to work i) as part of the simulation procedure when called by `R` —headless mode in our architecture— , or ii) independently –trough its own GUI [6]—, always the input files with the parameters in table E.1 exist, and `dam_byR` is set to `FALSE`.

Either way, the procedure remains the same (figure E.2). It starts setting up the simulation information coming from the `scenario's conf. data` files, and the `simulation launcher/iterator` in `R` when in headless mode. In other words, it displays entities over the terrain, assigns links between them, provides values to the key variables of the system and start the `season sequence` (`winter-spring-summer-autumn`).

The simulation sequence starts first season of the year (usually winter). It then checks if any flood is programmed to happen in such season; assuming no flood will take place, the procedure perform the operations scheduled during such season and advances one position on the `season sequence`.

This new season is compared with the first one in the sequence. When different, the procedure returns to the beginning (checking for programmed floods, etc). When equal, the value of the variables used to calculate the impacts are stored in memory as result of the year (`yearly result`). The procedure starts then a new year and the `season sequence` restarts.

When the procedure arrives to the end of the simulation (indicated by `periods to simulate` in table E.1) it returns the collection of values stored in memory. If the model is used in headless mode the values, and the control of the process, are passed directly to the `simulation launcher/iterator`. Otherwise, the user should extract the values and store them himself.

The behavior of the procedure in each season is a little bit more complex and needs a more thorough description. Seasons and years are not independent in our model (see section 2.10). Instead, they should feed each other with information that ensures the correct performance of the procedure. Assuming the procedure is in year n, the season to simulate is `winter`, and no flood has hit the system, nor will it during n, the procedure's seasonal component can be described as follows:

1. The procedure updates the number of productive plots and other variables such as the vine-growing costs.
2. Plots are replanted (`investment` task)
3. The vine-growing costs of the season are calculated and stored in memory (access 0.1)
4. The wine-making task is done, with the `available amount of input` stored in memory by the `winery's yield collection` task in `autumn` of $n-1$ (access 4)

6. It exists an alpha version of GUI in `R shiny` that pretends to serve as front end for the whole simulation process, making the model more user-friendly. In development

5. The wine-making task stores in memory `amount to sale` (access 2) and `cost data` (access 3)
6. The procedure advances one season. Now we are in `spring` of year n
7. The vine-growing costs of the season are calculated, added to those stored in access 0.1 and updated in memory (access 0.2)
8. The sales task is done, with the `amount to sale` stored in memory (access 2) from the `wine-making` task in `winter` of n
9. The sales task provides the `revenues data` to the procedure.
10. With the information in 9 and the `cost data` stored in memory (access 3), the cooperative winery splits its cost and revenue among its associates
11. The `financial balance` task adds the `vine-growing cost of the year` of $n-1$ (stored in `autumn`; access 1) to the result of 10 to calculate the final financial balance.
12. The procedure advances one season. Now we are simulating `summer`
13. The vine-growing costs of the season are calculated, added to those stored in access 0.2 and updated in memory (access 0.3)
14. The procedure advances one season. Now we are simulating `autumn`
15. The vine-growing costs of the season are calculated, added to those stored in access 0.3 and updated in memory as `vine-growing cost of the year` of n (access 1)
16. The `harvest` task is done and provides `yield data` to the `winery's yield collection` task
17. The `winery's yield collection` task updates the `available amount of input` (access 4)
18. The procedure advances one season. Now, year n is over and `winter` of $n+1$ will be simulated

The presence of the floods adds a layer of complexity. When a flood is scheduled to hit the system, the target season follows a parallel procedure, outlined in figure E.3. Known the value of the `flood extent`, each entity will check its status, reporting `flooded` when its coordinate in the x axis is smaller or equal to the `flood extent`. Together with its status, each entity will report as well the level of individual damages and the consequences over its performance. The algorithm incorporates all the information, updating whichever values are needed (harvest lost per plot, destruction of plants, tactic to follow by flooded farms, etc), and proceeds to calculate.

For instance, let's assume that the flood takes place in `summer` of year n ; let's assume as well that a few of the farms have been hit, and they only count on their own resources to face the aftermath. Steps 1 to 12 will remain the same, whereas from 13 it will be as follows:

13. The task `update values` introduces in the system information about harvest lost and plant destruction on plots, and material impacts on farms along with their coping tactic.

    The vine-growing costs of the season are calculated taken into account the new information: i) those plots destroyed will not pay the vine-growing cost from now on until they are replanted. ii) impacted farms, since they do not have extra support, will not perform all their task, thus vine-growing costs will be smaller this season.

The final seasonal amount of vine-growing costs is added to those stored in access 0.2 and updated in memory (access 0.3)

14. The procedure advances one season. Now we are simulating `autumn`
15. The vine-growing costs of the season are calculated over not destroyed plots, added to those stored in access 0.3 and updated in memory as `vine-growing cost of the year` of n (access 1)
16. The `harvest` task is done and provides `yield data` to the `winery's yield collection` task

    Since some vine-growing tasks could not be performed by the few farms hit in `autumn`, the consequences over the harvest of the not destroyed plots they own, are taken into account (reducing the final amount)
17. The `winery's yield collection` task updates the `available amount of input` (access 4)
18. The procedure advances one season. Now, year n is over and `winter` of $n+1$ will be simulated

As stated in section E.1.1, to determine whether plants in a plot are destroyed, thus the plot, we recur to RNGs. The `flood simulator` is capable to use two different ones depending on the value passed to `dam_byR`. Such feature responds to a need imposed by the replicability of iterations that could not be satisfied by Netlogo: using the netlogo's RNG we get different plots destroyed each iteration, and all of the iterations are independent. If we simulate an interval of m values for a given parameter p, repeating each value n iterations, we get mxn independent simulations for the parameter p.

That procedure impedes users to be sure in what proportion changes during the iteration n are due to variation of p and not to the RNG's behavior. To solve such contingency we make use of the R's RNG to generate the series of destroyed plots in each iteration. Then they are passed to the `flood simulator` as data lists. When `dam_byR` is set to `TRUE`, the `flood simulator` uses the data lists passed by the `simulation launcher/iterator` instead of Netlogo's RNG.

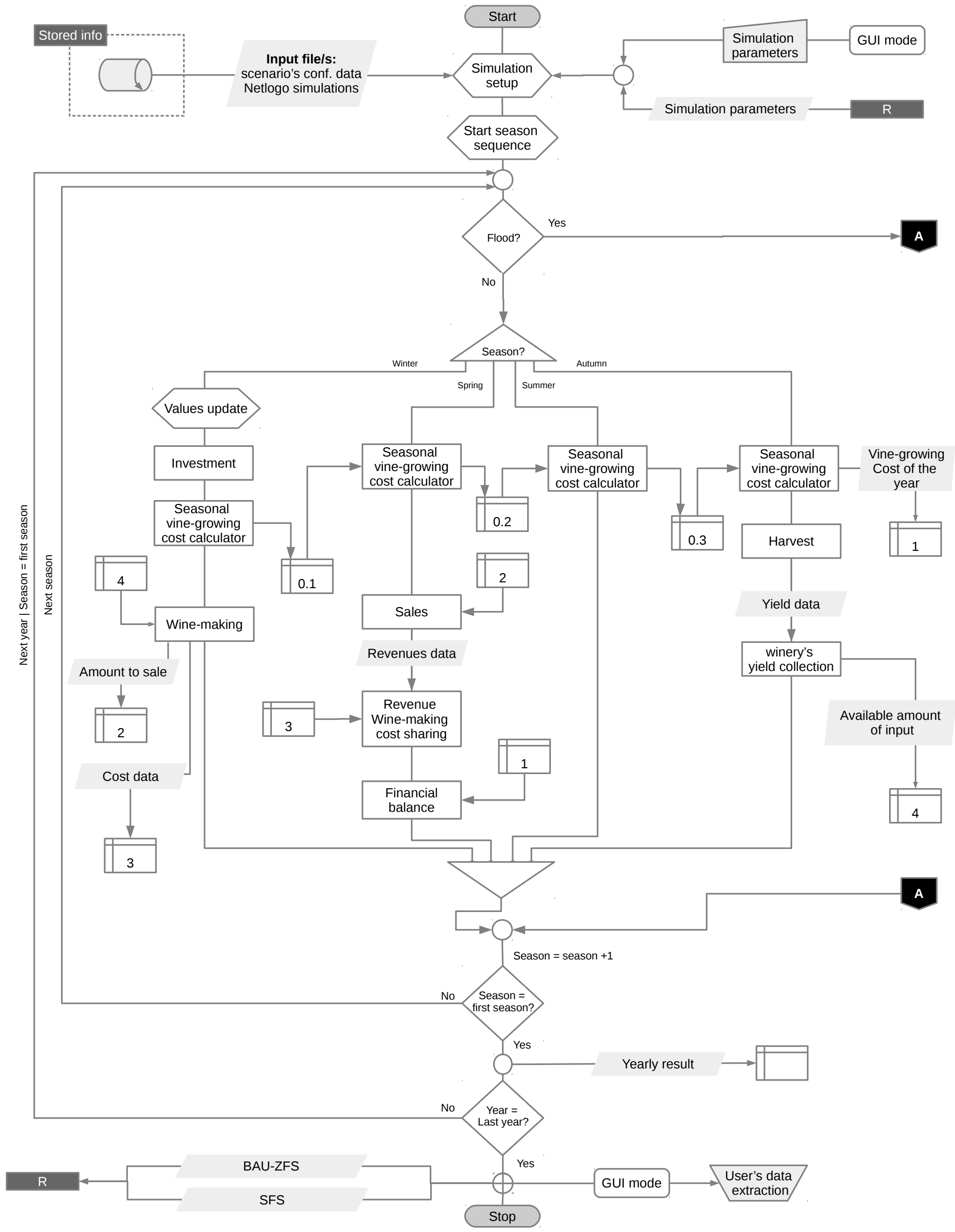


Figure E.2 – Model's core flood simulator flowchart

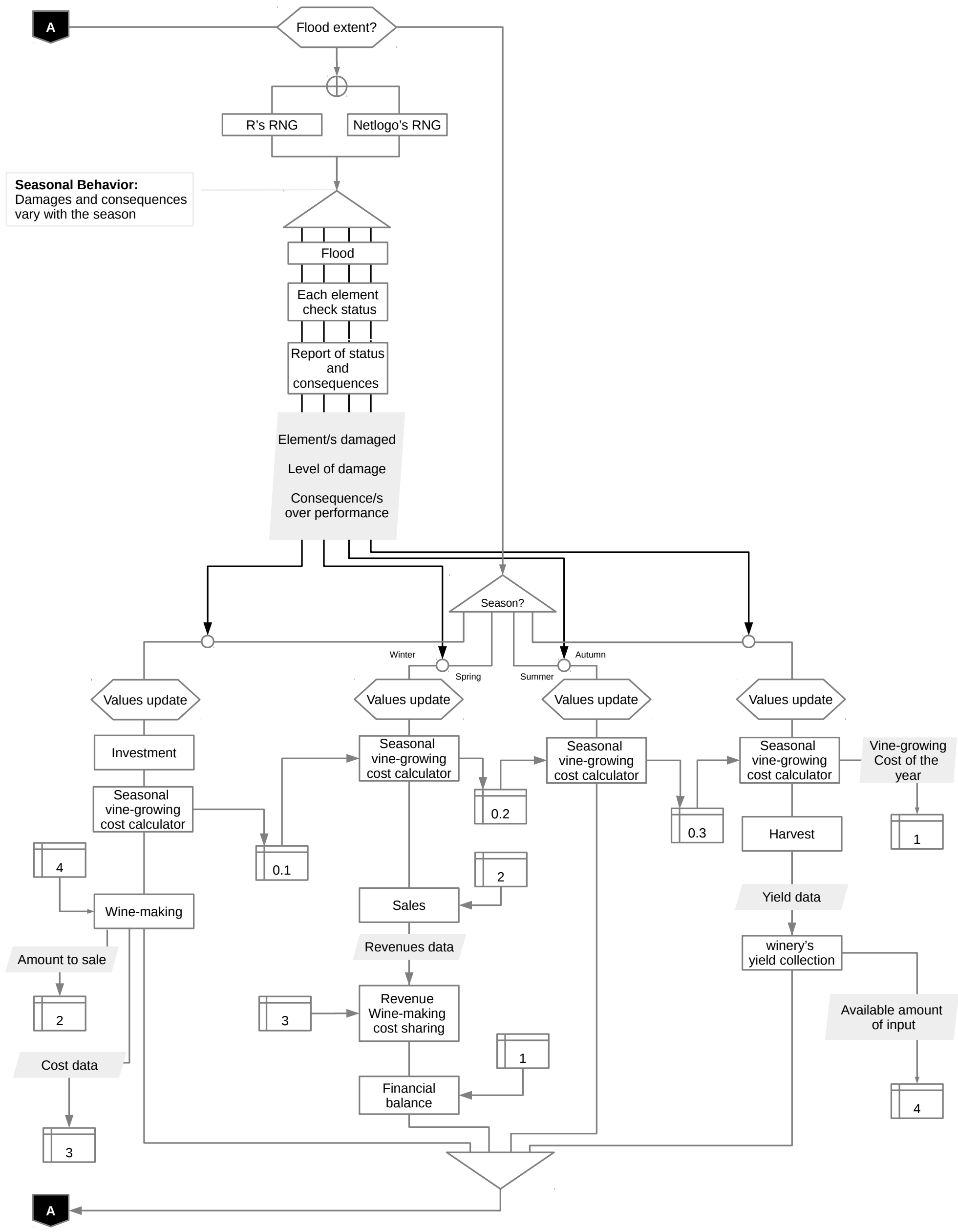


Figure E.3 – Model's core flood simulator outline

E.1.3 Simulator launcher and impact calculator

The `simulation launcher/iterator` presents an structure more complex than the one offered to describe the general structure of the simulation process. A more detailed outline is offered in figure E.4.

The process starts with the user introducing the values of the parameters to simulate (see section E.1.1), which are stored in memory for further usage.

The procedure is parallel-ready. Therefore, once the `simulation launcher/iterator` is launched, the number of available CPU cores is detected and used to set up a cluster. Over the cluster, the `flood simulator` is called as many times as CPU cores available in the cluster, which reduces significantly the simulation time.

At this point, it is worth mention that Netlogo needs an specific ID for each of the `flood simulators` called in parallel through RNetLogo —thus tasks can be sent to an specific `flood simulator`. Such IDs should be set up beforehand to avoid unwanted crashes. In our model, is up to users to decide the best strategy to approach such matter. Although possible, it is strongly unadvised to open/close a `flood simulator` each time a new simulation [7] is launched. It reduces considerably the advantages of the parallelization, overcharging the system with unnecessary operations that a good ID strategy can avoid [8]

When the `flood simulator` returns the control and the simulation results to the `simulation launcher/iterator`, this last one executes the processes already described in section E.1.1:

1. Storage of the raw SFS data in the hard disk
2. Classification of the raw data according the predefined time scale spans (see section 2.12), and storage into auxiliary files associated with the simulation in the hard disk.
3. Computation of impacts by comparison of SFSs against BAUs (`sweeper` task), and storage in the hard disk.

Before the procedure initiates the following iteration, all auxiliary objects created during the iteration are erased from the virtual memory. Tests have revealed a considerable usage of RAM memory during each iteration, thus the procedure has been equipped with an "eraser" to prevent crashes and overdemand of resources.

7. see footnote 2

8. For instance, assuming we have available 4 CPU cores and we want to simulate floods in each season, we can ID each of the `flood simulators` with one of the seasons. This way, each CPU will open one `flood simulator` with the given ID. All simulations with the same ID (season) will be sent to the same `flood simulator`, over the same core. Once all those simulations are done, the `flood simulator` with that specific ID(season) is closed.

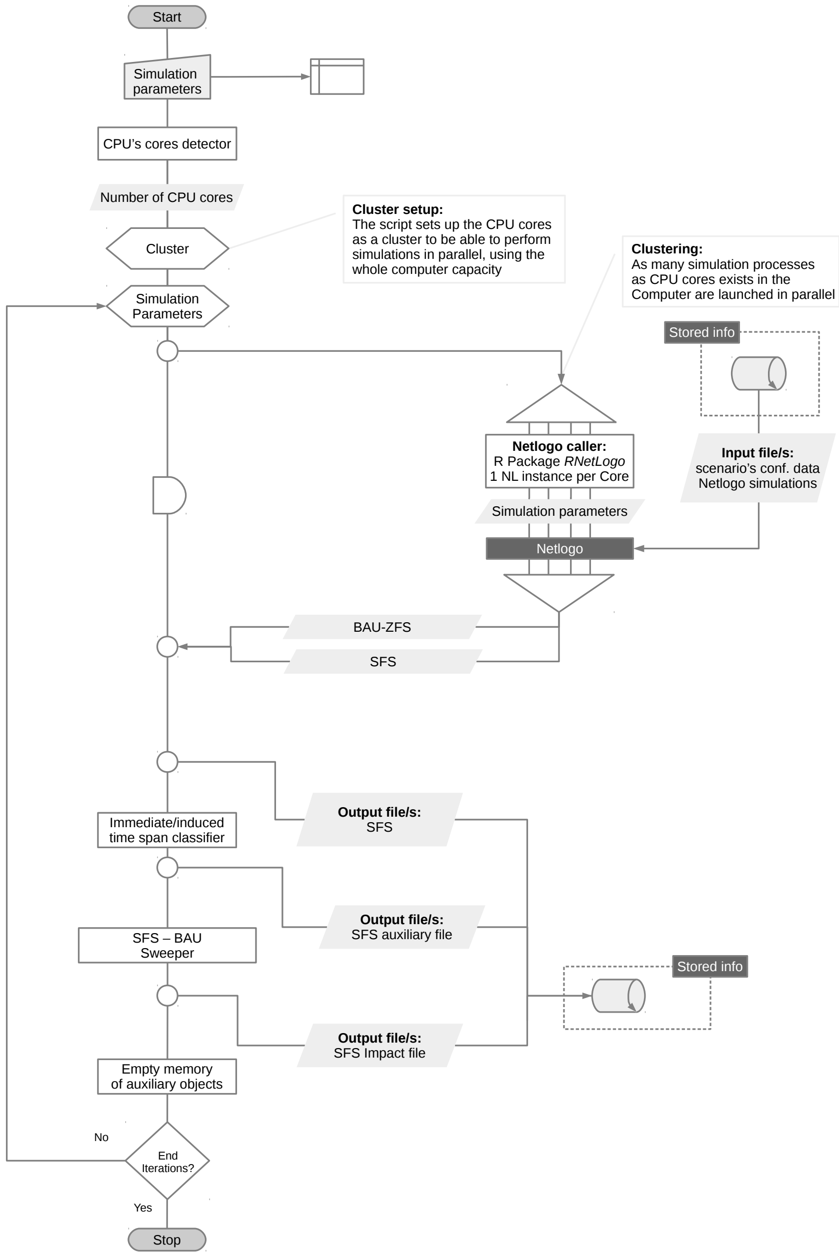
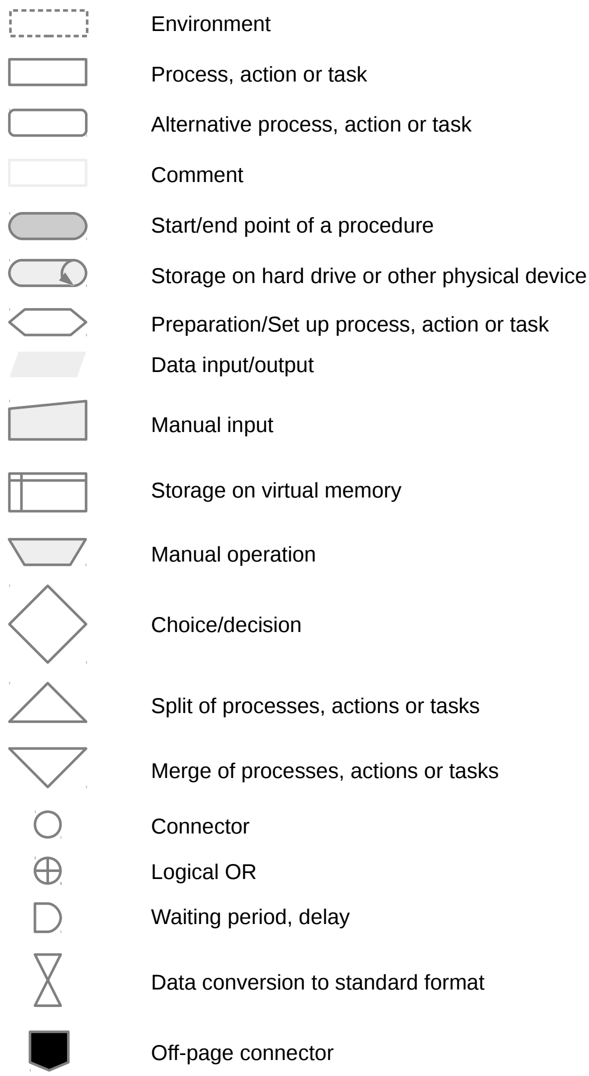


Figure E.4 – Model's core flood simulator flowchart

E.2 Flowchart symbols cheat sheet



APPENDIX F

Flood impacts. Technical cards

F.1 Brief explanation of the contents of the annex

This annex offers a characterization of the damages and impacts included in figure 2.24 (chapter 2, section 2.12). This characterization rests upon the seven key features (figure F.1) that we consider essential to delimit our understanding, management and capture of each of the aforementioned damages/impacts. The information exposed in each of those technical cards seeks to tackle the questions included in figure F.1 under each of the key features considered.

DAMAGE

What is the name given to the impact according figure 2.24?

ENTITY AFFECTED

What is the entity(ies) affected?

DESCRIPTION

Brief explanation of the impact

NATURE

Classification as direct/indirect–immediate/induced and for whom

ESTIMATION METHOD

How do we actually measure the damage? i.e. how do we calculate a monetary value?

What variable measures it in the COOPER model?

At what level its monetary value is available?

SOURCE

Primary source of the damage

POTENTIAL TRANSFERABILITY

Is it possible to transfer the damage between entities?

Figure F.1 – Example of damage card. Detail of questions to be answered under each of the key features included to characterize

F.2 Damages in soils

DAMAGE

Soils damaged

ENTITY AFFECTED

Plot

DESCRIPTION

Every time a plot is flooded, it is assume that the soil should be treated in some way

NATURE

Classified as direct damage for the plot owners (vinegrowers)

Classified as immediate impact for plot owners (vinegrowers)

ESTIMATION METHOD

Monetary value of reparations made

Directly measured in the model

Model variable(s) involved:

```
number of plots impacted
soil-reparation
reparations
```

Available at plot level, vinegrower level and system's level

SOURCE

Exposure to flood

POTENTIAL TRANSFERABILITY

No potential transferability

F.3 Damages in plants

DAMAGE

Plants damaged

ENTITY AFFECTED

Plots

DESCRIPTION

Every time a plot is flooded, the plants can be damaged

NATURE

Classified as direct damage for the plot owners (vinegrowers)

Classified as immediate impact for plot owners (vinegrowers)

ESTIMATION METHOD

Monetary value of reparations made

Directly measured in the model

Model variable(s) involved:

`croplands-impacted`
`croplands-unproductive-due-destruction`
`plant-reparation`
`reposition-cost`
`reparations`.

Available at plot level, vinegrower level and system's level

SOURCE

Exposure to flood

POTENTIAL TRANSFERABILITY

No potential transferability

F.4 Damages in harvest due to floods

DAMAGE

Damages on harvest because of floods over plots

ENTITY AFFECTED

Plots

DESCRIPTION

Depending on the season, flooded plots suffer losses in their respective yield.

NATURE

Considered direct impact for vinegrowers

Classified as indirect impact for wineries. As long as the revenue-cost sharing rule enables the diffusion of impacts in the bosom of the cooperative winery, this damage also classifies as indirect impact for those vinegrowers whose buildings have not been impacted.

Classified as immediate impact for those vinegrowers whose buildings are directly impacted/damaged. Classified as induced impact for winery and those vinegrowers whose buildings are not directly impacted/damaged. The effects on production and winemaking cost surface in year t+1

ESTIMATION METHOD

Value of the production lost (in hl) and monetary value of the production lost (at market price)

Directly measured in the model

Model variable(s) involved:
`harvest-damaged`
`croplands-impacted`
`croplands-unproductive-due-destruction`

Available at plot level, vinegrower level, winery level and system's level

SOURCE

Exposure to flood

POTENTIAL TRANSFERABILITY

Transferable throughout the entire CWS

F.5 Damages in harvest due to plant destruction

DAMAGE

Losses of harvest because of plants damaged (plots destroyed))

ENTITY AFFECTED

Plots

DESCRIPTION

When plants in a plot are destroyed, the plot needs a number of periods to be productive again. Therefore the production of the plot, of the vinegrower, of the cooperative winery and of the whole system is altered

NATURE

Classified as direct impact for vinegrowers whose plots have been destroyed

Classified as indirect impact for wineries. As long as the revenue-cost sharing rule enables the diffusion of impacts in the bosom of the cooperative winery, this damage also classifies as indirect impact for those vinegrowers whose plots have not been impacted.

Classified as induced impact for vinegrowers, winery and those vinegrowers whose plots have not been destroyed.

ESTIMATION METHOD

Value of the production lost (in hl) and monetary value of the production lost (at market price)

Directly measured in the model

Model variable(s) involved:

```
croplands-unproductive
harvest-damaged-bcplants
potential-harvest-damaged-bcplants
croplands-impacted
croplands-unproductive-due-destruction
total-harvested
```

Available at plot level, vinegrower level, winery level and system's level

SOURCE

Exposure to flood

POTENTIAL TRANSFERABILITY

Transferable throughout the entire CWS

F.6 Damages in farm buildings and materials

DAMAGE

Damages on vinegrower's building, machinery and other physical capital

ENTITY AFFECTED

Vinegrowers

DESCRIPTION

Every time a vinegrower's building is physically flooded, the model assumes damages in the building and physical capital stored/present within

NATURE

Classified as direct damage for vinegrowers

Classified as immediate damage: its effects are felt only in the immediate aftermath of the flood

ESTIMATION METHOD

Monetary value of reparations made

Directly measured in the model

Model variable(s) involved:
`reparations`

Available at individual (vinegrower) and system levels

SOURCE

Exposure to flood

POTENTIAL TRANSFERABILITY

no transferability

F.7 Damages in harvest due to damages in farms

DAMAGE

Impacts because of floods over vinegrower's building and machinery

ENTITY AFFECTED

Plots, vinegrowers and cooperative wineries

DESCRIPTION

When a vinegrower's building is flooded the vinegrower is unable to perform efficiently vinegrowing tasks over plots harvest the grapes. Thus a variable amount of yield is lost depending on the season.

It affects the vinegrower's production, and subsequently the cooperative winery's production and the system's production.

NATURE

Classified as direct impact for vinegrowers whose buildings are directly impacted/damaged

Classified as indirect impact for wineries. As long as the revenue-cost sharing rule enables the diffusion of impacts in the bosom of the cooperative winery, this damage also classifies as indirect impact for those vinegrowers whose buildings have not been impacted.

Classified as immediate impact for those vinegrowers whose buildings are directly impacted/damaged. Classified as induced impact for winery and those vinegrowers whose buildings are not directly impacted/damaged. The effects on production and winemaking cost surface in year t+1

ESTIMATION METHOD

Value of the production lost (in hl) and monetary value of the production lost (at market price).

Directly measured in the model

Model variable(s) involved:

```
able-to-harvest
harvest-if-not-flooded
total-harvested
TacticalBehavior
```

Available at plot level, vinegrower level, winery level and system's level

SOURCE

Exposure to flood

POTENTIAL TRANSFERABILITY

Transferable throughout the entire CWS

F.8 Impacts on vinegrowing cost

DAMAGE

Variations vinegrowing cost.

ENTITY AFFECTED

Vinegrowers

DESCRIPTION

Plots destroyed, complete losses of yield and the outsourcing (external) tactic (when vinegrowers' buildings are flooded) cause variations in the vinegrowing costs

NATURE

Classified as direct impact for vinegrowers

Classified as both immediate and induced depending on whether plant destruction is involved

ESTIMATION METHOD

Monetary value of the variable cost associated with lost harvest (real, for the year of the flood, and potential, for the years following the flood when plants are destroyed)

Directly measured in the model

Model variable(s) involved:
`production cost`

Available at plot level, vinegrower level and system's level

SOURCE

Production changes and exposure to flood

POTENTIAL TRANSFERABILITY

No potential transfer

F.9 Damages in winery's buildings and materials

DAMAGE

Damages on cooperative wineries' building, machinery and other physical capital

ENTITY AFFECTED

Cooperative wineries

DESCRIPTION

Every time a cooperative winery is physically flooded, the model assumes damages in the building and physical capital stored/present within

NATURE

Classified as direct impact for cooperative wineryess

Classified as indirect impact for vinegrowers

Classified as immediate impact

ESTIMATION METHOD

Monetary value of reparations made

Directly measured in the model

Model variable(s) involved:
`reparation-cost-from-cooperative`
`reparations`

Available at winery's level and system's level

SOURCE

Exposure to flood

POTENTIAL TRANSFERABILITY

Impact transferable to vinegrowers

F.10 Damages in harvest due to damages in winery

DAMAGE

Damages because of floods over cooperative wineries' building, machinery and other physical capital

ENTITY AFFECTED

Plots, vinegrowers and cooperative wineries

DESCRIPTION

When a cooperative winery's building is flooded in autumn, winter and/or spring, the winery is unable to collect (autumn), process (winter) or sell (spring) the production.

NATURE

Classified as direct impact for wineries

Classified as indirect impact for vinegrowers and plots

Classified as immediate impact

ESTIMATION METHOD

Value of the production lost (in hl) and monetary value of the production lost (at market price)

Directly measured in the model

Model variable(s) involved:
`harvest-lost-bcwinery`

Available at plot level, vinegrower level, winery level and system's level

SOURCE

Exposure to flood

POTENTIAL TRANSFERABILITY

Damage transferable to vinegrowers

F.11 Impacts on winemaking cost

DAMAGE

Variations in winemaking cost in the cooperative winery

ENTITY AFFECTED

Vinegrowers

DESCRIPTION

Yield losses originated in flooded plots decrease the resulting production of wine in the cooperative winery. Less production means less winemaking cost (the degree of reduction is also linked to the flexibility of the structure of cost of the winery). In addition, when plots are destroyed the reduction in winemaking cost can be sustained for long period in the aftermath of the flood. Last, if impacts over the cooperative winery impede the normal evolution of the winemaking process, they can carry reductions in winemaking costs (once again depending on the flexibility of the structure of costs of the cooperative winery).

NATURE

Classified as direct impact for winery

Classified as both immediate and induced insofar it can be caused by yield losses due to floods (immediate) or plot destruction (induced)

ESTIMATION METHOD

Monetary value of winemaking cost

Measured in the model. Model variable(s) involved: `vinification-cost`

Available at winery and vinegrower levels

SOURCE

Variations of productions and flood exposure

POTENTIAL TRANSFERABILITY

Insofar winemaking costs in the cooperative winery are paid by the ensemble of its associated vinegrowers, variations in winemaking cost are transferred to vinegrowers[1].

[1] Variations in winemaking costs and the way they are shared between vinegrowers may cause redistributional effects linked to changes in relative production of each vinegrower due to flood impacts. See annex of article *Floods, interactions and financial distress: testing the financial viability of individual farms in complex productive systems and its implications for the performance of the system* in chapter 4. Also see section 2.12 in chapter 2

APPENDIX G

Model data sources. Disclosure

		Cooperative winery							Farm						Plot		World			
		Size	Main Stages production	Cost structure	Financial data	Damage function	Sharing rules	Behavior when impact	Size	Tasks	Cost structure	Financial data	Damage function	Behavior when impact	Productivity	Damage function	Number of plots	Number of farms	In/out flood prone area proportions	Market price
GIS	Corine Land Cover																		✓	
GIS	Ins																		✓	
GIS	Atlas des Zones Inondables																		✓	
Statistics	FranceAgriMer (2012)	✓													✓					✓
Statistics	Agreste (2011)								✓											
Statistics	FADN										✓	✓								
Reports	INSEE (2016)											✓								
Reports	CCMSA (2017)											✓								
Reports	CER France (2017)			✓																
Reports	CER France (2014)										✓					✓				
Literature	Chevet (2004)		✓		✓															
Literature	Folwell and Castaldi (2004.)			✓																
Literature	Battagliani et al. (2009)								✓											
Literature	Brémond (2011)									✓										
Literature	Biarnès and Touzard (2003)						✓													
Literature	Jarrige and Touzard (2001)						✓													
Literature	Touzard et al. (2001)						✓													
Interviews	Experts				✓	✓		✓				✓	✓			✓				
Interviews	Winery CEOs	✓	✓				✓	✓									✓	✓		
Interviews	Vinegrowers		✓											✓						

Table G.1 – Sources of information organized by element feature

ANNEXE H

Resumé de la thèse en français

Introduction

Les conséquences néfastes des inondations sur les systèmes de société peuvent être comprises comme un problème de durabilité dans les stratégies de développement économique des sociétés (Green et al., 2011; Villagrán de León, 2006). En effet, les études disponibles au niveau européen ne trouvent pas de preuves concluantes établissant un lien entre les tendances des inondations liées au climat et les tendances des pertes dues aux inondations en Europe (European Environment Agency, 2010). Les données suggèrent plutôt que la croissance démographique et les actifs économiques croissants dans les zones exposées sont les principaux facteurs des pertes économiques croissantes dues aux inondations au cours des dernières décennies (European Environment Agency, 2010, 2012a). Plutôt que les conséquences inévitables liées aux caprices de la nature, l'existence des inondations dommageables est donc la conséquence probable de facteurs socio-économiques. La compréhension correcte de la manière dont ces facteurs génèrent les risques d'inondation devient donc fondamentale pour la conception efficace de politiques orientées vers la durabilité économique, la prévention des risques et la réduction des dommages.

C'est précisément dans l'étude des risques d'inondations et de catastrophes naturelles en général que l'analyse de la vulnérabilité est devenu un outil central (Adger, 2006; Birkmann et al., 2014b). En fait, dans la littérature scientifique actuelle sur l'évaluation des risques, le risque est perçu comme une combinaison de l'aléa, l'exposition et de la vulnérabilité (Birkmann, 2007; Hiete and Merz, 2009). Selon cette combinaison, la probabilité de subir des pertes (le risque) existera dans la mesure où les éléments exposés —directement ou indirectement— à un aléa sont sensibles à un tel aléa. En conséquence, le risque ne peut être entièrement compris ni évalué sans une compréhension profonde de la vulnérabilité (sensibilité ou susceptibilité) de chaque élément.

Les zones urbaines et industrielles sont supposées être plus susceptibles aux dommages que les zones rurales et agricoles (Förster et al., 2008). C'est pourquoi les nouvelles pratiques en matière de protection et de prévention des risques d'inondation se tournent vers le recours à des mesures non structurelles, telles que la création de plaines inondables. Ces mesures augmentent l'exposition des zones rurales et agricoles aux inondations (Barbut et al., 2004; Brémond et al., 2013; Decrop, 2014; Erdlenbruch et al., 2009; Hartmann and Driessen, 2013; Hooijer et al., 2004; Kreibich et al., 2009; Le Bourhis, 2007; Penning-Rowsell et al., 2013). Cependant, les secteurs agricoles ont des caractéristiques qui les rendent particulièrement vulnérables aux changements de revenus et de flux de trésorerie (Barry and Robison, 2001). Ainsi, ces tendances en matière d'élaboration de politiques de prévention des risques bénéficient d'une connaissance approfondie des facteurs de vulnérabilité des entreprises opérant dans des zones exposées aux inondations. Toutefois, les études micro-économiques sur l'évolution de la viabilité économique/financière de ces entreprises ne sont pas nombreux (Marshall et al., 2015). Encore moins s'ils se concentrent sur des activités agricoles (Nicholas and Durham, 2012; Reidsma et al., 2018). Il est donc nécessaire de poursuivre les recherches sur l'identification des facteurs de vulnérabilité économique des exploitations agricoles face aux inondations (Johnson et al., 2007; Morris et al., 2008; Posthumus et al., 2009).

L'agriculture, en plus, peut être considérée comme un système socio-écologique (SES) complexe, formé de l'ensemble des activités agricoles, du territoire, de l'environnement et des relations établies entre ces trois éléments (Benoit et al., 1997; Brémond, 2011; Rivera-Ferre et al., 2013). De cette façon, il peut exister des facteurs qui, agissant sur plusieurs échelles, jouent un rôle fondamental dans la détermination de la vulnérabilité du système agricole (Anderies et al., 2004; Michel-Kerjan, 2000; Redman et al., 2004; Turner et al., 2003a).

La présente thèse, concentré sur un niveau microéconomique, cherchera à comprendre et à caractériser la vulnérabilité des activités agricoles aux risques d'inondation. Néanmoins, la discrimination entre les types d'exploitations est essentielle pour fournir des évaluations des impacts et des vulnérabilités fiables (Reidsma et al., 2018). À cet égard, la viticulture joue un rôle important dans l'économie locale, l'orientation agricole et l'occupation des sols dans nos études de cas. Il en va de même pour le système de vinification coopératif. Ce système est également important au niveau national français : selon le Confédération des Coopératives Vinicoles de France (CCVF), 50% du vin français est produit dans le cadre de régimes coopératifs. Par conséquent, nous proposons nous concentrer sur les activités viticoles organisées dans un système coopératif de vinification (SCV).

Des auteurs tels que Sacchelli et al. (2016b) ont récemment souligné la nécessité d'élargir les connaissances sur la vulnérabilité, les effets du changement climatique et les adaptations apportées aux activités viticoles. Bien que peu nombreux, il est possible de trouver des études sur la vulnérabilité des viticulteurs individuels au changement climatique en général (Nicholas and Durham, 2012) ou, plus particulièrement, aux inondations (Brémond, 2011). À ce jour, néanmoins, les recherches portant sur des questions spécifiques liées à la vulnérabilité aux inondations (ou au changement climatique en général) dans des établissements viticoles coopératifs semblent avoir été négligées. Des travaux comme Lereboullet et al. (2013) ou Brémond (2011) ont remarqué, en fait, que, en raison de leurs pratiques de mutualisation et de leur structure de production en réseau, les processus de vinification coopératifs auront des facteurs de vulnérabilité différents de ceux des vignerons indépendants. Pourtant, ces facteurs n'ont pas été explicitement étudiés. En fait, nous n'avons pas trouvé des travaux publiés sur la vulnérabilité des établissements vinicoles coopératifs aux inondations ou au changement climatique en général.

Cette thèse cherchera ainsi à étudier en quoi l'intégration de plusieurs échelles d'analyse contribue à la compréhension et à la caractérisation de la vulnérabilité d'un SCV aux risques d'inondation. À savoir : Quels sont les facteurs qui rendent la vulnérabilité aux inondations d'un SCV ? Dans quelle mesure l'intégration de plusieurs échelles d'analyse contribue-t-elle à la détection, à la compréhension et à l'analyse de tels facteurs ?

Il convient de noter cependant que ce travail ne prétend pas modéliser et analyser une étude de cas particulière. En ce sens, il ne s'agit pas d'une étude ex-post d'un événement d'inondation concret. Au contraire, il cherche à reproduire le fonctionnement d'un SCV, en alimentant une phase de modélisation et une phase ultérieure de simulation avec des données qualitatives et quantitatives issues des études de cas. De cette manière, le modèle résultant peut être utilisé comme laboratoire pour l'analyse ex-ante de l'exposition d'un SCV à divers scénarios d'inondations.

H.1 La notion de système dans ce travail : systèmes hiérarchiques, système socio-écologique (SES) et système coopératif de vinification (SCV)

H.1.1 Comprendre le fondement : systèmes hiérarchiques

Le type de système avec lequel nous allons travailler dans cette thèse peut être classé dans le paradigme hiérarchique. Les systèmes hiérarchiques présentent certaines caractéristiques distinctes qui vont influencer/limiter la façon dont le système peut être conceptualisé, analysé et/ou modélisé. Nous condensons les propriétés principales qui caractérisent les systèmes hiérarchiques, sur la base des travaux de Costanza et al. (1993); Feibleman (1954); Giampietro (1994); Liu et al. (2007); Potochnik and McGill (2012) et Simon (1962).

Ces caractéristiques comprennent l'interconnexion complète des entités au sein du système, la composition et analyse à plusieurs niveaux dans plusieurs échelles, les interactions inter et intra-niveaux et les phénomènes émergents.

Les sous-systèmes au sein de systèmes hiérarchiques complexes peuvent être étudiés et analysés à l'aide de la propriété de *quasi-décomposabilité*. Afin d'étudier un sous-système, ses limites doivent être clairement et explicitement isolées : variables à prendre en compte, entités, niveaux et échelles. Les variables hors limites agiront comme des contraintes ou des "bruits", selon leur niveau d'origine, dans l'étude (par convention, les "bruits" proviennent des niveaux inférieurs, alors que les restrictions proviennent des niveaux supérieurs).

H.1.2 Le système socio-écologique (SES)

Les SES ont été définies de plusieurs manières. Probablement, la définition la plus complète à ce jour a été fournie par Redman, Grove, and Kuby, qui définit SES comme i) un système cohérent de facteurs biophysiques et sociaux qui interagissent régulièrement de manière résiliente et durable ; ii) un système défini à plusieurs échelles spatiales, temporelles et organisationnelles, pouvant être liées hiérarchiquement ; iii) un ensemble de ressources critiques (naturelles, socio-économiques et culturelles) dont le débit et l'utilisation sont régis par une combinaison de systèmes écologiques et sociaux ; et iv) un système complexe et perpétuellement dynamique avec une adaptation continue (Redman et al., 2004).

Le cadre SES repose sur plusieurs postulats de la théorie des systèmes hiérarchiques. Dans sa formulation la plus large, nous pouvons distinguer, pour un niveau donné, 4 entités différentes mais interdépendantes Ostrom (2007) : un système de ressources (RS), les unités de ressources émises par ledit système (RU), ses utilisateurs et autres acteurs (A) et le système de gouvernance (GS).

Les systèmes de ressources fournissent des unités de ressources, qui sont récoltées/extraites/utilisées et gérées par les utilisateurs des ressources conformément à l'ensemble de règles émanant du système de gouvernance. Les unités de ressources sont ensuite transformées en résultats par d'autres acteurs multiples, en fonction de leur ensemble de règles (données par le système de gouvernance), dans l'espace de *Action-Situations*. Une action-situation est, dans la définition de (McGinnis, 2010, p. 9) de McGinnis, une situation dans laquelle des individus *"observent des informations, sélectionnent actions, s'engagent dans des modèles d'interaction et réalisent les résultats de leur interaction"*. Les entités considérées (toutes ou une partie d'entre elles) reçoivent un retour d'informations du domaine action-situation, ce qui finira par influer sur leurs propres évolutions, et donc sur celles du système.

Le cadre SES de Ostrom est complété par les ensembles de paramètres social économique et politique (S) et écologique (ECO). Ils sont tous deux supposés influencer de manière exogène la dynamique au niveau d'analyse choisi (comme contraintes).

Le besoin de coupler des systèmes écologiques et humains a été reconnu par toutes les disciplines qui nous intéressent dans ce travail : Recherche sur la durabilité économique, sur les systèmes agricoles et sur la vulnérabilité.

H.1.3 Le système de vinification coopérative

Le cadre SES n'est encore que timidement appliquée aux sujets liés au vin (Lereboullet et al., 2013). Néanmoins, le SCV affiche tous les éléments nécessaires pour entrer dans la catégorie de systèmes que nous avons examinés.

Premièrement, le SCV résulte d'un domaine biophysique (terres, cultures, etc.) en interaction avec une activité socio-économique organisée (viticulture et production de vin). Dans ce système, il y a deux acteurs principaux : les viticulteurs et la cave coopérative. Les viticulteurs effectuent des tâches viticoles sur leurs terres (système de ressources) et récoltent les raisins (unités de ressources) qui y poussent. La quantité récoltée chaque année dépend de l'interaction de plusieurs éléments biophysiques différents : conditions du sol, conditions météorologiques, performances du vigneron... Les raisins récoltés sont fournis à la cave coopérative comme intrant de base pour la production de vin.

Les viticulteurs et les caves coopératives dépendent donc les uns des autres pour assurer leur production et leurs revenus. Les relations entre les viticulteurs et les caves coopératives sont encadrées par un ensemble de règles concrètes (système de gouvernance) : le SCV mutualise les actifs, les coûts et les revenus des caves entre ses viticulteurs associés, en les reliant entre eux.

Il existe donc un potentiel de *réverbération* de perturbations dans le système. Brémond (2011, p.277) souligne la nécessité de poursuivre l'étude des interactions le long des opérateurs de la chaîne d'approvisionnement pour la caractérisation des effets indirects des inondations.

H.2 Vulnérabilité. Définition utilisé

La vulnérabilité est un concept polysémique et les définitions disponibles sont multiples. Alignant notre travail sur ce qui a été suggéré, entre autres, par ADR (2005); Felbruegge and von Braun (2002); Gallopin (2006); Pelling et al. (2004); Rashed and Weeks (2003); Reveau (2004) ou Balica et al. (2013), notre étude examinera la définition suivante de la vulnérabilité : le degré auquel le système est modifié ou affecté par une perturbation interne ou externe (sensibilité). Pour évaluer un tel degré, nous incluons *la capacité du système à s'adapter à une perturbation, à limiter les dommages potentiels, à tirer parti des opportunités et à faire face aux conséquences d'une transformation en cours* (capacité de réaction ou de coping)

L'inclusion de la capacité du système à faire face à la catastrophe (capacité de réaction ou de coping) repose sur la prémisse que le comportement affiché par chaque entité au lendemain de la catastrophe peut potentiellement amplifier ou réduire le choc initial (Birkmann, 2007; Okuyama, 2003; Wisner, 2002).

Il y a définitions de la vulnérabilité qui considèrent l'exposition comme facteur de vulnerabilite (voir Birkmann et al., 2013, 2014a; Turner et al., 2003b). Nous ne considérons pas l'exposition dans notre définition. Comme des auteurs comme Alexander (2000), nous considérons que l'exposition est une composante du risque et non de la vulnérabilité. Abandonner l'exposition en tant que facteur de vulnérabilité implique que la vulnérabilité ne soit pas une propriété de l'interaction entre le système et son environnement, mais une caractéristique intrinsèque du système, que l'exposition existe ou non.

La notion d'adaptation n'est pas non plus présente dans notre définition (voir Birkmann et al., 2013, 2014a). La raison réside dans la nature même du travail proposé. Notre objectif est de caractériser et de décrire la vulnérabilité du système. Notamment rechercher et décrire les facteurs déterminant la susceptibilité du système, ne pas proposer et tester des solutions pour atténuer l'influence de tels facteurs.

Parallèlement à sa polysémie, la vulnérabilité est également un concept multidimensionnel (Müller et al., 2011). Notre étude examinera les quatre dimensions suivantes dans sa phase de modélisation / simulation : physique, économique, institutionnelle et environnementale.

H.3 Vulnérabilité, systèmes et échelles

H.3.1 Vulnérabilité dans les systèmes hiérarchiques et SES

L'analyse de la vulnérabilité dans les systèmes révèle une grande utilité lorsqu'elle est capable d'identifier i) la vulnérabilité d'entités particulières, ii) la vulnérabilité aux niveaux imbriqués sur une échelle, et enfin iii) les facteurs et mécanismes déterminant cette dernière dans relation avec le premier (Adger, 2006; Birkmann, 2005; Hiete and Merz, 2009; Turner et al., 2003a; Vogel and O'Brien, 2004).

En effet, la totale interconnexion des entités dans les systèmes hiérarchiques implique qu'une *"perturbation introduite dans une organisation à un niveau quelconque se répercute à tous les niveaux qu'elle couvre"* (Feibleman, 1954, 6ème loi des niveaux, p. 61). L'analyse de la vulnérabilité dans ce type de système devrait donc inclure la notion de ce qu'on appelle le *effet domino* (Michel-Kerjan, 2000; Turner et al., 2003a) : lorsqu'un événement —e.g. une inondation— se produit, affectant une ou plus entités dans un système donné, le choc initial devrait se répercuter sur le système en une série d'effets enchaînés.

En outre, compte tenu du fait que les propriétés des entités d'un niveau donné émergent des niveaux inférieurs, les entités et les sous-entités peuvent être différemment sensibles aux effets de l'aléa. En conséquence, certains effets pourraient ne pas être observables mais que à certains niveaux spécifiques, alors que les facteurs qui les expliquent (ou les génèrent) devraient être recherchés aux niveaux inférieurs du système.

Les interactions peuvent aussi atténuer ou amplifier l'ampleur du choc initial lors de sa propagation le long de la topologie du système. C'est-à-dire la disposition des entités composant le système, le modèle d'interconnexion entre elles et la forme fonctionnelle adoptée par ces connexions peuvent avoir un effet sur l'intensité avec laquelle le choc initial se propage (Dekker, 2007).

H.3.2 Échelles d'analyse dans le présent travail

L'analyse économique peu se concentrer sur le comportement des producteurs/consommateurs (niveau micro), la dynamique sectorielle (niveau méso) ou l'évolution de gros agrégats économiques (niveau macro). Dans la mesure où notre travail se concentre sur une cave coopérative et ses viticulteurs associés, il reposera au niveau microéconomique.

Dans la mesure où, dans l'étude des impacts des inondations, la distribution géographique des entités joue un rôle fondamental dans la dynamique des impacts observables dans le système, le présent travail inclut une échelle spatiale permettant de mesurer l'étendue du territoire. Deux niveaux principaux seront définis : le territoire correspondant à la zone inondée (conséquences directes des travaux actuels) et le territoire situé en dehors de la zone inondée (conséquences indirectes).

Également, les conséquences d'une perturbation concrète (une inondation) ne sont pas toutes observables dans le même laps de temps (Brémond et al., 2013; Merz et al., 2010). L'échelle de temps doit être ainsi présente dans notre analyse. Par conséquent, en ce qui concerne les niveaux de notre échelle de temps, nous aborderons notre étude en utilisant deux niveaux différents : effets immédiats et tardifs.

Enfin, lorsque nous travaillons avec des systèmes dans lesquels différents niveaux d'agrégation peuvent être établis entre leurs entités, nous devons inclure une échelle d'agrégation. Les analyses de vulnérabilité disponibles dans la littérature ont été réalisées à différents niveaux dans ce que les géographes appellent les échelles de résolution spatiale. Dans le contexte de SES, une telle échelle fait référence au degré de détail avec lequel le système est représenté. Les niveaux communs de cette échelle sont global, national, régional, local, voire même sous-local (par exemple, les communautés). Les niveaux d'analyse locaux étant donné le degré de détail plus élevé dans la description du système, présentent des avantages pour la compréhension des racines de la vulnérabilité et de ses facteurs déterminants (Birkmann, 2007; Fekete et al., 2010; Villagrán de León, 2006).

Donc notre étude examinera les échelles et niveaux suivants

— Échelle d'agrégation ; seulement niveau local retenu. Dans ce niveau, il y aura deux sous-niveaux : collectif et individuel
— Échelle spatiale ; niveaux : zone directement inonde (donc effets directs) et zone non inondé (donc effets indirectes).
— Échelle temporelle ; niveaux : effets immédiats et tardifs.

H.4 Approche de l'évaluation de la vulnérabilité dans ce travail

Intuitivement, la vulnérabilité provient de la confrontation d'une entité/système avec une perturbation. Si l'entité/système est vulnérable à cette perturbation, une telle confrontation nuira, endommagera ou, plus généralement, aura un impact sur l'entité/système (Wolf, 2012). Les évaluations des dommages/impacts sont donc sous-jacentes à toute évaluation de la vulnérabilité (Aven, 2016, p. 4).

Dans notre travail, nous allons fonder notre approche sur l'interprétation du risque de, entre autres, Birkmann (2007) ou Hiete and Merz (2009). Ces auteurs suggèrent que le risque, c'est-à-dire la valeur escomptée des pertes, peut être considéré comme une fonction de l'aléa, de l'exposition à l'aléa et de la vulnérabilité. En acceptant une telle prémisse, il est conceptuellement plausible d'évaluer la vulnérabilité d'un système, et de dégager ses facteurs déterminants, en évaluant la valeur des pertes en supposant que l'aléa et l'exposition restent inchangés. C'est à dire, si pour un aléa et une exposition donnés, la variation d'une caractéristique d'une entité/système entraîne une variation de la valeur des pertes, cette caractéristique doit être considérée comme un facteur influant sur la vulnérabilité de l'entité/du système.

Cette notion peut en effet être trouvée dans plusieurs approches pratiques existantes en matière d'évaluation de la vulnérabilité (voir Luers et al., 2003; Oliveira Tavares et al., 2015; Sendhil et al., 2018).

H.4.1 Limitations de l'évaluation de la vulnérabilité dans les systèmes

Pour décrire et mesurer la manière dont chaque facteur et ses combinaisons potentielles génèrent la vulnérabilité de chaque entité et de l'ensemble du système, des analyses de vulnérabilité complètes doivent englober le système dans sa totalité. Néanmoins, dans le type de système que nous essayons d'analyser —des systèmes complexes hiérarchiques combinant des domaines environnemental et humain—, un tel degré d'exhaustivité reste irréaliste Turner et al. (2003a). Les raisons de cet irréalisme sont très pratiques : le manque de données disponibles, le manque de connaissance des systèmes eux-mêmes, le manque de capacité de calcul et le besoin d'empêcher les modèles de devenir des "black boxes" inutilisables pour isoler, expliquer et décrire la façon dans laquelle différents facteurs influencent la vulnérabilité du système.

Les évaluations de la vulnérabilité dépendent donc fortement du cas. Ils sont également soumis à un degré d'incertitude élevé, provenant de trois sources différentes : i) le caractère incomplet, dérivé de l'existence de limites arbitraires, mais nécessaires, à l'étude ; ii) l'arbitraire lié aux choix de l'analyste et aux valeurs initiales ; et iii) qualité et disponibilité des données (voir annexe B, section B.1).

H.5 De l'évaluation de la vulnérabilité à l'évaluation des dommages causés par les inondations

H.5.1 Nature des dommages inclus dans ce travail

L'évaluation de l'impact des inondations est essentielle à l'évaluation de la vulnérabilité. Les deux sont basés sur la susceptibilité d'éléments à des facteurs de stress. Cependant, l'analyse de vulnérabilité recherche les facteurs qui déterminent la susceptibilité Vogel and O'Brien (2004). Considérées comme telles, les évaluations d'impact sont des outils indirects qui permettent à l'analyse de vulnérabilité de révéler où, et dans quelle mesure, les systèmes sont sensibles aux facteurs de stress.

Les inondations ont une incidence sur les systèmes économiques de nombreuses manières. Pour cette raison, la littérature existante discute et établit différentes typologies d'impacts d'inondations (voir, par exemple, Brémond et al., 2013; Bubeck and Kreibich, 2011; Green et al., 2011; Hallegate and Przyluski, 2010; Merz et al., 2010; Meyer et al., 2013; Penning-Rowsell et al., 2013; Penning-Rowsell and Green, 2000, entre autres) Toutefois, les travaux présentés dans cette thèse ne traitent pas le spectre complet des typologies d'impact existants. Les dommages dits intangible (ceux qui ne sont pas facilement identifiables en termes monétaires) ne sont pas pris en compte dans notre étude. Non plus seront pris en compte les dommages dits actuels (ceux définis comme des impacts estimé ex-post d'une inondation réelle) (Gissing and Blong, 2004; Merz et al., 2010)

Notre travail se concentrera donc sur les impacts tangibles (ceux-ci facilement spécifiés en termes monétaires) et potentiels (définie comme l'estimation ex ante des impacts qui pourraient avoir lieu dans un système compte tenu de son état). Dans ce groupe de dommages tangibles et potentiels, nous distinguerons, selon le classement proposé par Brémond et al. (2013), entre :

- Impacts immédiat directs : impacts dus à une exposition directe aux inondations, et qui se sont manifestés pendant ou juste après les inondations
- Impact Immédiat indirect : l'impact est survenu en dehors de la zone inondée et s'est manifesté pendant ou juste après l'inondation
- Impacts directs induits : impacts dus à une exposition directe aux inondations, se manifestant plus tard dans le temps
- Impacts indirectes induites : les impacts se sont produites en dehors de la zone inondée et se sont manifestées plus tard dans le temps.

H.5.2 Méthodes d'évaluation des impacts pris en compte. Techniques principales et problèmes associés

D'une manière générale, l'évaluation de l'impact des inondations considérés dans ce travail peut être réalisée selon une méthode assez simple, reposant sur 3 étapes successives : i) l'identification des éléments en risque ; ii) l'évaluation de la valeur des actifs en risque ; et iii) l'analyse de la vulnérabilité aux inondations (Bubeck and Kreibich, 2011; Green et al., 2011; Merz et al., 2010; Penning-Rowsell et al., 2013).

Définir clairement quelle entité est en risque de inondation n'est pas toujours clair. L'identification des entités risquant d'être physiquement affectées par l'inondation est aujourd'hui facile, grâce au développement des systèmes d'information géographique (SIG) et à l'existence de cartes des risques d'inondation. Cependant, l'identification des entités qui subissent des impacts dus aux perturbations causées par les inondations dans le système (que ce soit dans le temps ou dans l'espace) et non par un contact direct avec elles, est beaucoup plus compliquée. Leur identification dépend i) des limites du système considéré ; ii) du degré de détail considéré ; et iii) de la caractérisation de la topologie du système.

Une fois les entités à risque identifiées, la deuxième étape de l'évaluation des dommages causés par les inondations consiste à déterminer la valeur économique des actifs en risque. Pour cela, la pratique habituelle d'estimation des dommages regroupe les différentes entités en clusters. La détermination de la valeur économique des actifs est ensuite effectuée en supposant l'homogénéité intra-cluster et l'hétérogénéité inter-cluster. La composition de ces groupes est toutefois liée aux éléments suivants : i) le niveau de détail de l'étude et ii) la disponibilité des informations.

La troisième et dernière étape consiste à déterminer la susceptibilité des entités exposées au risque d'inondation. Cette étape est, précisément, le lien entre l'analyse de la vulnérabilité et l'estimation des dommages. Cependant, étant donné la nature différente des dommages pris en compte, différentes méthodes doivent être prises en compte pour une estimation correcte des dommages.

Les impacts directs des inondations ont suscité le plus d'attention dans la littérature. Son évaluation se fait à travers les fonctions de dommage. De telles fonctions lient les paramètres d'inondation (vitesse, hauteur) au degré d'endommagement des éléments exposés. Dans notre travail, nous intégrons des fonctions de dommages synthétiques (c'est-à-dire construites selon des opinions d'experts) basées soit sur des valeurs absolues (évaluation monétaire du dommage), soit sur des valeurs relatives (dommages en tant que pourcentage de la valeur de l'actif). Green et al. (Voir 2011); Merz et al. (Voir 2010)

Contrairement aux impacts directs, les impacts indirects ont moins retenu l'attention de la communauté des chercheurs (Brémond et al., 2013; Green et al., 2011; Merz et al., 2010; Meyer et al., 2013). Les impacts indirects sont plus difficiles à saisir étant donné que (i) les sources de données sont plus rares que dans le cas des impacts directs ; et ii) ils dépendent des limites définies pour le système et de la connaissance de la topologie sous-jacente dudit système. Cette dépendance rend également nécessaire l'utilisation de modèles. Cependant, les techniques de modélisation les plus utilisées dans l'estimation des dommages ne s'adaptent pas bien au niveau dans lequel nous voulons concentré notre étude (Niveau locale). À cet égard, voir Green et al. (2011). En fait, à ce niveau, il est reconnu la nécessité d'entreprendre des travaux supplémentaires pour améliorer la compréhension de la réaction globale des systèmes économiques aux inondations (Meyer et al., 2013). En outre, la recherche existante sur l'évaluation de l'impact des inondations reconnaît que les études au niveau local/sublocal ont le potentiel d'améliorer i) la compréhension des liens entre les impacts directs et indirects ; ii) la "cartographie" de la topologie des systèmes économiques, la détection de la nature et l'emplacement des nœuds, des liens et des "hubs" dans le système ; et iii) la compréhension de l'influence mutuelle des nœuds, des liens et des "hubs", ainsi que de leurs réactions aux chocs externes, tels que les inondations (Green et al., 2011; Merz et al., 2010; Meyer et al., 2013)..

Notre travail sera donc directement mis au défi par ce manque de connaissances (et nous espérons donc contribuer également à son amélioration avec nos résultats).

H.6 Méthode de modélisation

Les dynamiques locales/sublocales sont mieux ajustées par des approches ascendantes ou méthodes "bottom-up" (Crespi et al., 2008; Sabatier, 1986). Ces approches sont caractérisées en commençant la conception du modèle à partir d'une couche de base, en identifiant les entités d'intérêt, leurs interactions et l'environnement dans lequel elles se déroulent. La trajectoire suivie par le système se pose après ces interactions.

Les modèles multiagents (ABM) sont des techniques de modélisation et de simulation qui permettent de mettre en œuvre des approches "bottom-up" dans des systèmes hiérarchiques complexes (Balbi and Giupponi, 2009; Bonabeau, 2002; DeAngelis and Grimm, 2014; Jenkins et al., 2017; Loomis et al., 2008; Macy and Willer, 2002; Smajgl and Barreteau, 2017; Tesfatsion, 2002; Zheng et al., 2013, entre autres). Ils ont été utilisés, entre autres disciplines, dans l'étude du systèmes socio-écologiques, des systèmes agricoles ou de l'économie. Pourtant, ni la recherche agricole, ni l'analyse de la vulnérabilité, ni l'évaluation de l'impact des inondations n'incluent des modèles ABM dans leurs outils communs.

Dans le cadre de la recherche sur les impacts des inondations, nous avons suivi 13 travaux publiés. Malgré son petit nombre, il est déjà possible de distinguer 4 tendances de recherche différentes. La première de ces tendances engloberait les travaux de Filatova (2015); Filatova et al. (2009, 2011) et Putra et al. (2015). Son objectif principal est basé sur les effets des inondations sur les marchés fonciers et immobiliers. Un autre bloc de littérature regroupe les travaux de Haer et al. (2016a,b); Tonn and Guikema (2017) et Erdlenbruch and Bonté (2018). L'accent est mis sur l'adaptation des ménages pour la réduction des dommages causes par les inondations. Une troisième tendance, formée par les travaux de Brouwers and Boman (2010); Jenkins et al. (2017) et Dubbelboer et al. (2017), concerne les problèmes liés à l'assurance en présence de risque d'inondation. Enfin, la dernière tendance identifiée concerne l'étude des interventions d'urgence en cas d'inondations (Dawson et al., 2011)

Aucun des documents présentés dans ces quatre tendances ne mentionne explicitement l'agriculture ou la propagation des impacts. Dans un article récent, Otto et al. (2017) propose un ABM pour analyser la propagation des pertes économiques. Cependant, son modèle ne se concentre pas sur les inondations. Au lieu de cela, ils traitent des interruptions des catastrophes naturelles (en général) pour les producteurs et les consommateurs le long d'une chaîne d'approvisionnement. Son modèle n'est ni spatialement explicite ni défini pour un niveau de résolution plus détaillé que les agrégations régionales.

Bien que les ABM soient de plus en plus connus et utilisés, leur présence comme outil est encore marginal, surtout en ce qui nous concerne. Les études combinant modèles ABM, inondation, vulnérabilité et systèmes de production n'existent pas à notre connaissance. Néanmoins, au sein de la communauté agricole, des auteurs tels que Jansen et al. (2016) et Reidsma et al. (2018) soulignent l'avantage des ABM pour la représentation et la simulation des interactions dans les systèmes agricoles. De même, dans la recherche sur l'évaluation des dommages des inondations, Meyer et al. (2013) reconnaît le potentiel des modèles ABM à contribuer à une meilleure compréhension de la propagation des chocs d'inondation.

H.7 Plan de thèse

Cette thèse cherche à étudier :

> *Quels facteurs déterminent ou influencent la vulnérabilité d'un Système coopératif viticole (SCV) aux inondations ? Dans quelle mesure l'intégration de plusieurs échelles d'analyse contribue-t-elle à la détection, à la compréhension et à l'analyse de tels facteurs ?*

Pour atteindre notre objectif de recherche et apporter une réponse à notre question, nous construisons un modèle multiagent (ABM) d'un SCV. Cet ABM est codé «à partir de zéro», basé sur l'abstraction d'un SCV que nous faisons à partir des informations extraites de deux études de cas. Les informations sont recueillies grâce à la combinaison de plusieurs méthodes de extraction des données : SIG, recensements, statistiques et des entretiens. Le chapitre 2 offre au lecteur une description détaillée à la fois du SCV et du modèle ABM.

La thèse vise à contribuer à plusieurs communautés de recherche. Premièrement, à notre connaissance, il n'existe aucun travail sur la vulnérabilité du SCV aux inondations ou à d'autres catastrophes naturelles. Notre étude sur les inondations est donc une nouveauté en soi. Deuxièmement, notre approche se trouve sur la modélisation ABM, qui a été utilisé timidement dans la recherche sur la vulnérabilité. Ces deux points font de cette thèse un travail totalement novateur dans la recherche sur la vulnérabilité. En outre, aucun modèle similaire permettant d'analyser les effets des inondations sur les SCV n'a été trouvé dans la littérature. En ce sens, le modèle lui-même est une nouveauté. De plus, nous l'avons construit avec suffisamment de flexibilité pour étudier les impacts d'autres risques naturels avec un minimum de modifications/transformations.

Troisièmement, nous avons déjà indiqué que cet outil (ABM) peut prendre en compte des topologies de système explicites ainsi que plusieurs échelles et niveaux d'analyse. Il offre une nouvelle perspective à l'évaluation de l'impact des inondations au niveau local, déjà citée dans la littérature comme digne d'être explorée.

La quatrième contribution de la thèse concerne l'économie des entreprises et des systèmes agricoles. Les modèles d'entreprises agricoles individuelles sont encore rares ; beaucoup plus ceux qui peuvent offrir des analyses des fermes individuelles et de leurs interactions dans un système fermé.

À terme, la thèse vise à sensibiliser les agents et les décideurs du SCV à leur propre vulnérabilité. Ainsi, les pratiques de gestion des risques d'inondation peuvent être améliorées, mis à jour ou mis en œuvre. Dans le même temps, nos conclusions peuvent contribuer à la conception de mécanismes de compensation, d'aides et de fonds financiers, ainsi qu'à l'élaboration des politiques de prévention et de gestion des risques en général.

La thèse est structurée comme suit : elle est divisée en 5 chapitres. La première présente au lecteur la méthodologie ABM, en passant en revue les points clés autour du concept de modèle ABM et les avantages que présente la méthodologie ainsi que leurs principales faiblesses. Le chapitre se termine par un examen de la procédure permettant de créer un modèle ABM «à partir de zero» sur la base d'études de cas.

Le deuxième chapitre est consacré à montrer le premier produit/résultat de notre recherche. Il est divisé en trois parties. La première partie résume les informations pertinentes sur lesquelles reposent les hypothèses qui orientent et soutiennent notre modèle (phase de construction du métamodèle). Les deuxième et troisième parties du chapitre sont consacrées à une description détaillée du modèle ABM résultant : le modèle COOPER.

Notre troisième chapitre s'articule autour d'un premier article intitulé *Are interactions between economic entities determinant for the estimation of flood damage of complex productive systems ? Insights from a micro modelling approach applied to wine cooperative system.* Il porte sur le sous-niveau **collectif** de l'échelle d'aggregation. C'est à dire, nous étudierons l'ensemble des entités, et non aucune entité individuelle. Ce chapitre peut être considéré comme un double objectif. D'une part, l'article aborde la question suivante : la prise en compte de topologies d'interactions explicites a-t-elle un effet sur l'évaluation des dommages d'impact par rapport aux pratiques actuelles ? Si oui, comment influence-t-il l'évaluation ? Il vise donc à contribuer à l'utilisation des modèles ABM dans l'évaluation des dommages causés par les inondations. Point déjà marqué pertinent pour la communauté de recherche d'évaluation d'impact sur les inondations.

Par ailleurs, les expériences et les résultats réalisés nous offrent l'occasion de réfléchir à certains facteurs de vulnérabilité. De cette manière, dans le contexte de la thèse, nous pourrons examiner les effets que des facteurs tels que la topologie ou la tactique de coping peuvent avoir sur la vulnérabilité du SCV. Sans les limites imposées par les articles, nous pourrons également procéder à un examen approfondi des indicateurs à la recherche de déclencheurs et de mécanismes de vulnérabilité.

Notre quatrième chapitre s'appuie sur le potentiel des règles de partage au sein de la cave coopérative pour redistribuer les impacts financiers au sein du réseau des coopérants. Il va se concentrer davantage sur le sous-niveau **individuel** de l'échelle d'agrégation. De plus, l'analyse des facteurs de vulnérabilité passera dans une perspective plus financière.

Le chapitre s'articule autour de l'article *Floods, interactions and financial distress : testing the financial viability of individual farms in complex productive systems and its implications for the performance of the system.* Cet article cherche à étudier la viabilité à long terme des exploitations agricoles individuelles intégrées dans un SCV et du SCV lui-même en présence de risques d'inondation. C'est à dire, Quelle est l'influence que le SCV, en tant qu'environnement productif spécifique, peut avoir dans les difficultés financières de ses exploitations associées ? Parallèlement, mais à l'inverse, lorsque des exploitations individuelles se trouvent dans une situation financière difficile, leur faillite potentielle pourrait-elle avoir des conséquences importantes sur l'ensemble du SCV ?

Les réflexions sur les facteurs de vulnérabilité financière et les facteurs que nous pouvons trouver dans ce chapitre seront guidées par les questions suivantes :

— Les exploitations agricoles peuvent-elles se retrouver dans une situation de détresse financière dans un SCV ? Pourquoi ?
— Quels sont les éléments clés des règles de partage qui permettent d'étendre l'impact le long de la topologie du système ? Si certains de ces éléments subissent des variations, comment ces variations se traduisent-elles par la propagation des impacts ?
— Si oui, combien de fermes se retrouvent dans des positions de detresse financièr ? Ce nombre pourrait-il affecter la stabilité du système ?
— Le système a-t-il un seuil de dommages/impacts au-dessus duquel le système s'effondre ?
— Dans un cas affirmatif, dans quelle mesure les inondations peuvent-elles amener le système à un tel point ? Pourquoi ?

Pour clôturer la thèse, nous incluons un court chapitre résumant brièvement notre travail, discutant des résultats obtenus et tirant les principales conclusions. Ce court chapitre comprend également une réflexion sur les perspectives des recherches futures ouvertes.

Description du modèle

La construction de notre modèle repose sur les informations recueillies auprès des départements de l'Aude et du Var. Pour rassembler toutes les informations, nous avons utilisé plusieurs méthodes de collecte de données : SIG, informations statistiques, publications, entretiens, recensement, etc.

H.1 Aperçu général

Notre modèle est conceptualisé comme l'interaction d'un environnement biophysique et d'un environnement productif-économique. Ce dernier transforme les données d'entrée du premier en biens de consommation.

Le SCV est caractérisé comme une topologie de type arbre : tous les éléments du système sont connectés les uns aux autres par le biais d'un élément central. Ce type de topologie représente avec précision l'organisation du SCV : la cave coopérative est lié et relie tous les vignerons, en mutualisant les moyens de production, les coûts, les risques et les bénéfices. Dans le même temps, chaque viticulteur est également lié à ses vignobles.

Les inondations provenant de l'environnement biophysique et couvrant différentes étendues d'une zone d'inondation maximale, peuvent toucher le SP. Lorsque cela se produit, les performances normales du système, et donc le flux prévu d'entrées et de sorties dans le système, sont affectés.

H.2 Brève description du processus de production opérationnel

Le processus de production est activement mené à la fois par les viticulteurs et les caves coopératives. Les vignerons effectuent toute l'année des tâches de viticulture sur leurs parcelles. Ces tâches sont organisées selon un calendrier saisonnier, commençant en hiver. De plus, les viticulteurs devraient réinvestir périodiquement dans leurs parcelles (replantation).

Cela a deux conséquences différentes sur le processus de production : premièrement, les pieds de vigne replantés ne sont pas immédiatement productif ; les vignerons ont donc des productions hétérogènes et inférieures au potentiel. Deuxièmement, il existe une rotation entre les terres productives/non productives.

Chaque viticulteur est associé à un et une seule cave coopérative. Les établissements vinicoles sont chargés de la production de vin avec les intrants fournis par les vignerons, ainsi que de sa commercialisation sur les marchés. Ils suivent également un calendrier saisonnier. En automne, ils reçoivent les raisins provenant des viticulteurs associés. Cette entrée est transformée en vin en hiver et vendue au printemps. L'ensemble du stock étant censé être vendu, il n'y a pas de stock en été.

La coopérative viticole partage chaque année les revenus de la commercialisation moins les coûts de vinification (profit de commercialisation) proportionnellement à la quantité de raisin fournie par chaque vigneron. De plus, chaque viticulteur doit couvrir ses propres coûts de culture de la vigne.

H.3 Brève description du processus d'investissement-financement

Comme il a été indiqué, le modèle comprend un cycle d'investissement au niveau des parcelles. Chaque parcelle est supposée être replantée tous les 30 ans. Les 5 premières années, la parcelle restera improductive même si elle engendre des coûts. Les 25 autres années, elle sera productive fournissant une constante, quantité connue d'hectolitres.

Pour financer leurs investissements, les viticulteurs sont supposés emprunter de l'argent auprès d'institutions financières. À cet égard, il est supposé que les prêteurs prêtent toujours l'argent et offrent en outre des conditions homogènes à tous les viticulteurs.

H.4 Brève description des autres variables intervenantes

L'analyse des entrées et des sorties monétaires de chaque viticulteur repose sur quatre variables clés : la production (Q_t), les revenus (R_t), les coûts (C_{vg_t} — viticoles — et C_{wm_t} — vinification —) et investissements et réinvestissements (I_t). Pour eux, l'analyse des entrées et des sorties de monnaie ajoute les variables suivantes :

— Taxes (T_t) : Montant versé chaque instant t au trésor public sur la production de l'exercice précédent.

— Rémunération du propriétaire (O_t) : montant affecté à chaque instant t à titre de rémunération du propriétaire. Exprimé en proportion du salaire minimum garanti (GMW)

— Subventions aux investissements et réinvestissements (Sb_t) : injections de fonds publics appliquées à des investissements spécifiques réalisés par des agriculteurs.

— Compensations d'assurance (IC_t) : Régimes d'assurance publics et privés offrant des compensations monétaires aux entités concernées du modèle.

H.5 Procédure de simulation, procédure d'inondation et impacts des inondations

H.5.1 Procédure de simulation

Le modèle simule le comportement du système coopératif pendant 30 ans à un moment saisonnier. Chaque saison, les tâches doivent être effectuées par les viticulteurs et la cave coopérative afin de mener à bien le processus de production. Chaque série de 4 saisons est considérée comme une année. De plus, le modèle enregistre l'état des différents flux monétaires au cours de l'année.

H.5.2 procédure d'inondation

Nos éléments sont situés sur un territoire virtuel, divisé en cellules. Chacune de ces cellules ne peut héberger qu'un seul élément : une parcelle, un vigneron ou une cave. Sur le territoire, deux zones différentes peuvent être distinguées : l'une sujette aux inondations (zone sujette aux inondations), l'autre non. La zone dite inondable est en même temps divisée en 100 sous-zones numérotées de 1 à 100.

Les inondations sont définies par deux paramètres : l'étendue et la saison d'occurrence. Ainsi, quand une inondation d'étendue 50 frappe le système au printemps, le premier printemps suivant le début de la simulation, toutes les cellules situées entre les sous-zones 0 à 50 dans la zone inondable sont considérées comme inondées et tous les éléments situés dans ces cellules impactées.

H.5.3 Impacts des inondations

Les impacts des inondations peuvent affecter simultanément les parcelles, les viticulteurs et les établissements vinicoles, en ayant, directement ou indirectement, une incidence sur une ou plusieurs des quatre variables clés dans lesquelles nous pouvons résumer les flux monétaires dans notre modèle. Ces impacts peuvent revêtir un double caractère —matériel et non matériel (ceux qui impliquent une perturbation du processus normal)— et ils ont été donné une structure hiérarchique qui empêchent les phénomènes de double comptabilité.

Dans la base de la hiérarchie, on trouve les dégâts matériels sur les parcelles. Ces dommages sont triples : i) dommages sur les sols, considérés comme indépendants de la saison ; ii) des dommages en rendement, dépendant de la saison ; et iii) dommages causés aux plantes, en fonction de la saison et également stochastiques.

Lorsque les plantes des parcelles sont détruites, tout le rendement de cette parcelle est perdu. De plus, il est nécessaire de replanter, et les parcelles replantées restent non productives pendant 5 ans (avec les conséquences que cela aura sur les différents flux sur le système).

Un peu plus haut, nous constatons des dégâts sur les bâtiments et les équipements du viticulteur. Dans notre modèle, les bâtiments et les équipements sont considérés comme une unité et leur fonction de dommage a été simplifiée au maximum : en cas de choc, les bâtiments et les matériaux doivent être réparés et la valeur des dommages est constante. Tant que ces réparations ne seront pas terminées, ils perdront certaines de leurs fonctionnalités. Du côté non matériel, cette perte de fonctionnalité est traduite en un viticulteur incapable de s'acquitter correctement de sa tâche pendant la saison des crues. Les conséquences de cette incapacité se traduiront soit par une augmentation des coûts, soit par une baisse de la production.

À ce même niveau, il faut également prendre en compte les économies de coûts de viticulture provenant des parcelles dont le rendement a été détruit. Que ce soit par destruction de la plante ou par dommage direct sur le rendement, dès que la parcelle perd tout son rendement, le propriétaire cesse de réaliser des tâches de culture de la vigne sur ladite parcelle et économise le coût des tâches restantes.

Le niveau supérieur de notre hiérarchie est occupé par des dégâts matériels et non matériels sur le bâtiment de la cave. Abordés à l'identique du bâtiment du vigneron, les impacts à ce niveau ajoutent des dommages au stock de vin / raisin lorsque les bâtiments sont inondés : les viticulteurs ne sont pas censés conserver des stocks de vin / raisin dans leurs bâtiments ; au contraire, les établissements vinicoles sont supposés stocker du vin / raisin dans leurs bâtiments de l'automne au printemps et sont totalement perdus si le bâtiment est inondé. Tout autre stock n'a pas été considéré séparément, mais fait partie de l'équipement.

En outre, lorsque les bâtiments de la cave sont inondés, il est possible que la récolte, la production ou la commercialisation du raisin ne soit pas effectuées, de sorte que la production dans son ensemble peut être perdue.

H.6 Analyse financière

Le modèle COOPER nous permet de simuler l'évolution des flux de trésorerie individuels de chaque viticulteur. L'étude des flux de trésorerie que nous présentons est basée sur une adaptation simplifiée de l'identité de Lawson (Foster and Ward, 1997), interprétée comme dans Lee (Sharma, 2001). De cette manière, chaque agent du modèle priorise ses entrées de fonds (+) et ses sorties (-) selon le schéma suivant :

$$R - C_{vg} - C_{wm} - FO - T - OU + FI - I = \pm Tr \tag{H.1}$$

Où : R = revenus de la vente de vin ; C_{vg} = coûts de culture ; C_{wm} = coûts de vinification ; FO = sorties financières (intérêts + prêt / rente (s)) ; T = taxes ; O = rémunération du propriétaire ; FI = entrées financières (prêts + subventions) ; I = investissements de remplacement note La version actuelle du modèle COOPER ne permet pas d'investissement de croissance individuels. La taille des entreprises individuelles reste ainsi constante pendant les simulations ; Tr = entrée (+) / sortie (-) du Trésor

Le cash-flow net opérationnel ($R - C_{vg} - C_{wm}$) permet aux exploitations agricoles faire face aux sorties de cash dus aux activités de financement (remboursement de la dette), les taxes, tout en garantissant un plancher minimum à la rémunération du propriétaire. Les sorties opérationnelles, correspondant au réinvestissement de l'exploitation - la replantation - sont planifiées par des entrées de fonds provenant de subventions et de prêts pour réinvestir.

Resultats I

H.1 Discussion générale sur les résultats obtenus dans l'article *Are interactions between economic entities determinant for the estimation of flood damage of complex productive systems ? Insights from a micro modelling approach applied to wine cooperative system* en relation avec l'objectif de recherche de la thèse

H.1.1 L'article à la lumière de la thèse

L'article sur lequel nous construisons ce chapitre analyse dans quelle mesure la prise en compte des interactions explicites entre les entités du système coopératif viticole (SCV) améliorent l'estimation des dommages liés aux inondations par rapport aux méthodes actuelles. En outre, l'article analyse également comment, sur une distribution spatiale constante des éléments, les variations des liens entre dites éléments influent sur la magnitude des dommages dans le système.

Dans la mesure où notre hypothèse est que le montant des dommages est un indicateur de la susceptibilité du système à subir des dommages, la caractérisation de la vulnérabilité dépend, premièrement, de la prise en compte des interactions et, ensuite, de la manière dont ces interactions sont établies (qu'est-ce qui est lié à quoi). De plus, lorsque l'aléa et l'exposition restent inchangés, toute variation d'une caractéristique d'une entité/d'un système conduisant à une variation de la valeur des pertes doit être considérée comme un facteur de vulnérabilité.

L'indicateur de dommages est construit conformément aux spécifications du chapitre 2, section 2.12. L'analyse du SCV présentée dans ce chapitre est axée sur le niveau collectif dans notre échelle d'agrégation.

L'article est complété par une addenda de figures indiquant la décomposition des dommages totaux utilisés dans l'article. Cet addenda est inclus pour détailler les effets que les différentes étendues d'inondations simulées et la saison au cours de laquelle elles sont simulées ont sur l'ensemble des indicateurs construits dans le modèle COOPER (voir chapitre 2, section 2.12, figure 2.25). L'addenda aide à identifier les facteurs sous-jacents qui pourraient conduire à la vulnérabilité du système.

H.1.2 Résumé des principaux résultats de l'article

Comme nous l'avons dit avant, l'article aborde la question de savoir dans quelle mesure la modélisation des interactions entre entités peut améliorer l'estimation des dommages causés par les inondations, par rapport aux approches actuelles qui ne prennent en compte aucune de ces interactions.

À l'aide du modèle COOPER, l'article teste les 7 paramètres suivants, sur une distribution spatiale fixe de composants matériels, pour analyser l'impact des interactions dans l'estimation des dommages causés par les inondations : i) présence d'interaction explicite ; ii) tactique de coping du viticulteur ; iii) configuration des interactions entre les composants matériels ; iv) hétérogénéité de taille ; v) localisation spatiale de la cave coopérative ; vi) saison ; et vii) étendue de l'inondation

L'article constate que la prise en compte des interactions a un effet sur l'estimation des dommages. En effet, par rapport aux pratiques actuelles, les interactions mal représentées peuvent conduire soit à une sous-estimation, soit à une surestimation des dommages au niveau du système, selon que l'information absente (par absence de l'interaction) induit une erreur d'identification ou une double comptabilisation des dommages.

De plus, la manière dont ces interactions sont établies entre les composants matériels a également des effets sur l'estimation des dommages. Ainsi, la configuration des liens (qu'est-ce qui est lié à quoi) entre les composants matériels, *ceteris paribus*, est également pertinente. En d'autres termes, si les interactions doivent être prises en compte, leur spécification doit être faite de manière complète.

H.1.3 Discussion des résultats de l'article à la lumière de la question principale de cette thèse

H.1.3.1 tactique de coping

Selon les résultats obtenus dans le modèle COOPER, les différences entre les deux tactiques de coping choisies sont importantes. En raison de l'adoption de la tactique de coping `external`, le montant total des dommages causés au système peut, en général, être réduit . En limitant d'abord notre analyse aux différences observables entre les deux tactiques de la configuration `homogenous`, nous pouvons comprendre que l'ampleur de cette réduction dépend de l'interaction des différents composants et paramètres du modèle (voir addenda, section 3.4, figures 3.14 à 3.18). Ces paramètres incluent la saison au cours de laquelle le système est touché, l'étendue de l'inondation et l'emplacement de la cave.

Comme expliqué au chapitre 2, section 2.11.2.2, la tactique `external` permet aux viticulteurs d'éviter de nouvelles pertes de rendement provoquées par la mauvaise exécution des tâches qui leur sont assignées lorsque leurs bâtiments sont physiquement touchés par l'inondation. Cela implique également une réduction de la variation du coût de la vigne immédiat et des coûts de vinification immédiats (à court terme) et induits (à long terme). Les effets cumulatifs générés par la tactique `external` dans le système réduisent, en termes généraux, la susceptibilité finale du système à subir des dommages.

Il existe cependant une exception notable (voir addenda, section 3.4, figures 3.16 et 3.18). Lorsque des inondations frappent le système à l'automne et que la cave coopérative est affectée, la cave est incapable de collecter la récolte des parcelles pour effectuer la production postérieure. En conséquence, même si la tactique de coping `external` réduit les dommages causés au système en termes de perte de rendement, tout le rendement du système est finalement perdu en raison de dommages subis par la cave. Dans un tel scénario, une tactique de coping telle que `external` n'entraînerait qu'un coût financier supplémentaire pour les viticulteurs, dans la mesure où d'autres activités de la chaîne de production ne pourraient être réalisées et que tout rendement serait perdu de toute façon.

H.1.3.2 Configuration des interaction

La caractérisation des interactions pertinentes entre les éléments matériels au sein du système est importante pour évaluer le degré de vulnérabilité du dit système et pour identifier ses facteurs. En effet, les résultats affichés dans la figure 6 de l'article montrent comment, sur une distribution spatiale fixe de composants matériels, la prise en compte des interactions entre ces composants, *ceteris paribus*, influe sur les dommages totaux causés par une inondation.

De plus, en supposant que i) toutes les interactions pertinentes ont été prises en compte (modalité *full interaction* de l'article) et ii) que la distribution spatiale des composants matériels ne varie pas, les variations de la carte des liens qui relient les composants matériels entraînent des variations de l'ampleur des dégâts. Par conséquent, la susceptibilité du système à subir des dommages, *ceteris paribus*, dépend de la carte de liens susmentionnée (également appelée configuration des interactions).

Les interactions sont donc un facteur de vulnérabilité dans les systèmes, à la fois par sa présence et par la manière dont elles lient des éléments.

Ce résultat est intéressant, non seulement dans la mesure où il confirme que la comptabilisation des interactions explicites et ses configurations améliore l'évaluation des dommages et des vulnérabilités dans les systèmes économiques, mais dans la mesure où il a des implications dans la définition même de la vulnérabilité avec laquelle les systèmes doivent être analysés.

En effet, le résultat autour du rôle des interactions dans l'analyse de vulnérabilité implique que, lorsque différents éléments sont conformes à un système, avec des liens entre eux, la susceptibilité montrée par le système à un niveau donné peut dépendre du degré éventuel d'exposition au niveau inférieur. Par exemple, dans le modèle COOPER, la vulnérabilité des composants matériels est une propriété intrinsèque indépendante de l'exposition. Lorsque nous analysons le système au niveau collectif, le degré d'exposition des composants matériels ne change pas (la localisation spatiale des éléments est constante d'une simulation à l'autre). Toutefois, avec chaque configuration de liens différente, le degré d'exposition de l'agent «vinegrower» [1], dans la mesure où l'emplacement spatial de ses composants matériels change. Ainsi, la sensibilité avec laquelle le SCV réagit aux inondations dépend du degré d'exposition

1. L'agent «vinegrower» est considéré comme l'ensemble d'un nombre donné de parcelles et d'un bâtiment (composants matériels). Voir le chapitre 2, section 2.9

de chaque viticulteur, bien que dans aucun cas le degré d'exposition du système change.

À la lumière de ces résultats, l'inclusion de l'exposition cesse d'être une discussion purement conceptuelle et devient un facteur de vulnérabilité, mais seulement à un certain niveau d'agrégation au sein du système.

H.1.3.3 Localisation spatiale de la cave coopérative

Dans le même ordre d'idées que la dernière section, mais de façon plus spécifique, la position spatiale de la cave coopérative joue un rôle central dans la susceptibilité du système. Comme nous l'avons montré dans la figure 2.4 (voir le chapitre 2, section 2.3), la présence de bâtiments vinicoles dans des zones inondables est plausible.

L'inclusion de l'établissement vinicole coopératif dans la zone exposée aux inondations a un effet significatif sur la vulnérabilité du système aux impacts des inondations (voir addenda, section 3.4 figure 3.13). Lorsque la coopérative est située hors de la zone exposée, les dommages maximaux sont équivalents à 2,5-3 fois le YPGB [2] du système (voir le chapitre 2, section 2.12). Dès que la cave est située dans la zone exposée (donc inondée), les dommages se multiplient et atteignent 10 fois le YPGB du système dans les cas les plus défavorables.

L'inclusion de l'établissement vinicole dans la zone sujette aux inondations modifie également le comportement saisonnier. Lorsque la coopérative se trouve en dehors de la zone inondable, les dommages sont causés par l'évolution des dommages au niveau des parcelles : le printemps présente les dommages les plus importants malgré l'étendue de l'inondation, suivi de l'été et de l'automne alors que les dommages l'hiver sont pratiquement nuls. Lorsque le vignoble est inondé, les inondations printanières montrent toujours les dommages les plus importants, tandis que les inondations d'automne et d'hiver présentent des dégâts similaires, et que l'été devient la saison la moins dommageable.

H.1.3.4 Taille du vigneron

L'hétérogénéité de la taille des exploitations viticoles ne provoque pas d'effets significatifs sur l'ampleur des dommages causés au système. Les configurations des interactions `homogenous` et `size` présentent des dommages de magnitude similaire (voir la figure 7 de l'article et les figures de l'addenda 3.19 à 3.25). Par conséquent, il n'est pas considéré comme un facteur de vulnérabilité du SCV.

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Resultats II

H.1 Discussion générale sur les résultats obtenus dans l'article *Floods, interactions and financial distress : testing the financial viability of individual farms in complex productive systems and its implications for the performance of the system* en relation avec l'objectif de recherche de la thèse

H.1.1 L'article à la lumière de la thèse

Ce chapitre de résultats adopte une perspective financière pour analyser le système coopératif viticole (SCV) à la recherche de facteurs de vulnérabilité. L'ampleur des impacts en termes de YPGB [3] du chapitre 3 soulève la question de la mesure dans laquelle le système est capable d'absorber l'impact d'un point de vue financier. Nous nous demandons notamment s'il existe un seuil de préjudice au-delà duquel le système n'est plus rentable. Mais, dans la mesure où, dans le SCV, les résultats observables au niveau collectif résultent de la dynamique au niveau individuel, une rentabilité compromise au niveau du système doit provenir des viticulteurs en difficulté financière.

Dans ce chapitre, nous allons centrer notre analyse sur les facteurs susceptibles d'exacerber la vulnérabilité financière des viticulteurs coopératifs à la suite des inondations : conditions préalables aux inondations, interactions, etc. Nous nous intéressons également à l'analyse des interactions entre niveaux (individuelles - collectives) à l'échelle d'agrégation pour déterminer dans quelle mesure les facteurs susmentionnés contribuent également à la vulnérabilité du système dans son ensemble.

Pour assurer la comparabilité des résultats entre ce chapitre et le précédent (chapitre 3), l'article utilise la configuration dite `homogeneous` (voir chapitre 4, section de l'article : simulation protocol). Les effets potentiels de la tactique de coping alternative ou des configurations alternatives, dans la mesure où ils ne sont pas inclus dans l'article, sont fournis dans un addenda.

H.1.2 Résumé des principaux résultats de l'article

L'article utilise le modèle COOPER pour explorer dans quelle mesure le stress financier potentiel subi par chaque viticulteur après une inondation peut conduire le

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système à un point de restructuration. En outre, en tenant compte des interactions entre la cave coopérative et ses viticulteurs, l'article analyse également dans quelle mesure les caractéristiques de la cave coopérative (règle de partage coûts-revenus et rigidité de la structure des coûts) peuvent contribuer à amener le système au point de restructuration susmentionné.

Les agents présentent un comportement réactif : retournez dès que possible à le *statu quo ante*. Les viticulteurs optent également pour une tactique d'adaptation interne pour faire face aux conséquences immédiates des inondations : les viticulteurs dont les bâtiments sont inondés ne comptent pas sur une aide extérieure pour les réparer et les mener à bien. La mauvaise performance due aux impacts entraîne de nouvelles pertes de rendement (voir chapitre 2, section 2.11.2.2).

Dans cet article, nous testons 6 paramètres clés pour analyser le potentiel de détresse financière à long terme dans le SCV : i) critères individuels de cessation d'activité ; ii) trésorerie initiale individuelle ; iii) la flexibilité de la structure de coûts de la cave ; iv) localisation spatiale de la cave coopérative ; v) saison ; et vi) étendue de l'inondation

Les effets de l'étendue et de la saison des inondations sont similaires à ceux du chapitre 3 : D'un côté, des inondations plus longues affectent des éléments plus nombreux, ce qui entraîne l'addition des impacts et des dommages. En revanche, les dommages sur les plantes et les rendements présentent des différences saisonnières, ils affectent donc différemment les flux de trésorerie (entrées et sorties) générés par chaque viticulteur. Les inondations en hiver ont à peine des impacts négatifs. En revanche, la probabilité plus élevée de destruction des plantes au printemps génère des impacts importants sur les flux de trésorerie, à court et à long terme. Les inondations en été et en automne ont des impacts plus modérés.

En ce qui concerne les 4 autres paramètres, l'analyse effectuée met en évidence la plus grande sensibilité du système aux paramètres appartenant à l'agent central (cave coopérative) plutôt qu'à ceux appartenant aux producteurs individuels (viticulteurs). De plus, nos résultats montrent que le retour à un état antérieur à la catastrophe peut ne pas être possible pour les entreprises individuelles ou pour le système [4]. Après que des inondations se soient abattues sur le système, certains viticulteurs risquent de tomber dans des difficultés financières qui pourraient éventuellement les contraindre à cesser leurs activités. En conséquence, tout le système pourrait nécessiter une restructuration s'il veut survivre.

Le potentiel de propagation des dommages et leur intensité, ainsi que les interactions et leur configuration, sont essentiels pour expliquer la viabilité financière des niveaux individuel et collectif (système). Ne pas tenir compte de ces effets indirects pourrait exclure de la conception des politiques de prévention des risques facteurs clés pour garantir la viabilité économique et financière des entreprises dans les zones exposées aux inondations.

4. Cette hypothèse de retour à l'état antérieur à la catastrophe est largement présente dans les pratiques standard d'analyse coûts-bénéfice et d'études de résilience des entreprises.

H.1.3 Discussion des résultats de l'article à la lumière de la question principale de cette thèse

H.1.3.1 Critères individuels de cessation d'activité

Ce paramètre indique le temps écoulé entre le moment où le vigneron encourt un défaut de paiement [5] et le moment où ledit viticulteur cesse son activité (voir section de l'article : Individual viability criteria).

Ce paramètre est donc un indicateur de la période pendant laquelle le viticulteur subit des pertes commerciales avant de cesser ses activités. Dans la mesure où des horizons de cessation plus longs impliquent une plus grande capacité des entreprises individuelles à faire face aux conséquences de l'inondation sans cesser leurs activités, le SCV bénéficiera également d'une plus grande capacité à faire face et à absorber les impacts à long terme d'une inondation donnée.

Les parcelles détruites par les inondations réduisent les entrées monétaires du propriétaire pendant plusieurs années. Ces parcelles doivent être replantées et les parcelles nouvellement replantées ne deviennent pleinement productives que des années plus tard (5 dans le modèle COOPER). Au même temps, la nécessité de replanter pour rendre ces parcelles productives dès que possible (hypothèse de comportement individuel) accroît les sorties de fonds pour les investissements. Mais ces investissements ne sont pas planifiés et peuvent entraîner un certain "fardeau" financier pour les viticulteurs qui doivent le faire. En cas de difficultés financières, une plus grande tolérance au défaut de paiement de la part du secteur financier (horizon de cessation plus long) augmente la capacité de chaque viticulteur à faire face aux effets à long terme des inondations.

H.1.3.2 Trésor initial individuel

La quantité de ressources monétaires sur laquelle chaque viticulteur compte avant l'inondation influe également sur la capacité à faire face aux conséquences de l'inondation. Comme dans le cas précédent, l'amélioration de la capacité de chaque agent à faire face aux impacts à long terme de l'inondation améliore la capacité de l'ensemble du système à faire face et à absorber les impacts de l'inondation. Comme nous l'avons vu dans le chapitre précédent, les effets d'une inondation peuvent atteindre un montant plusieurs fois supérieur à ce que le système est capable de générer en pleine performance. En ce sens, lorsque la situation du système avant une catastrophe inclut de grandes quantités de trésorerie, le système présente un degré de vulnérabilité plus faible face à une inondation donnée en raison de l'amélioration de la capacité de réaction.

H.1.3.3 Flexibilité de la structure de coûts de la cave

Le degré de flexibilité affiché par la structure des coûts de la cave coopérative joue un rôle important dans la vulnérabilité du système et des viticulteurs individuels aux inondations. En effet, le partage des coûts et des revenus de la coopérative entre tous ses viticulteurs associés conformément à la règle selon laquelle le modèle COOPER

5. Sortie annuelle supérieure à la combinaison des entrées annuelles et des ressources stockées dans la trésorerie

fonctionne présente un potentiel de propagation d'impact (voir la démonstration mathématique dans l'annexe de l'article qui suit)

Son influence se matérialise à travers deux mécanismes différents, selon que l'analyse se concentre sur le système ou sur les viticulteurs. Dans le premier cas, une structure de coûts plus flexible (proportion plus élevée des coûts totaux liés à la production) est directement liée à une plus grande capacité d'adaptation au niveau du système, quels que soient l'horizon de cessation d'activité, le comportement saisonnier ou les conditions de trésorerie initiales. La présence d'une partie du coût indépendante du niveau de la production (coût structurel) empêche que les réductions de coûts soient proportionnelles aux réductions de productions. En fait, le coût structurel atténuera la réduction du coût associée à la réduction de la production. D'autre part, les revenus générés dans le système étant proportionnels à la production, donc une réduction de la production impliquera des réductions du même ordre de grandeur des revenus générés par le système. Plus la structure de coûts est rigide, moins elle sera réactive à la réduction de la production et plus vite nous atteindrons une situation de profit nul dans le système. Cela réduira donc la capacité du système à faire face aux impacts à long terme des inondations.

Lorsque nous nous concentrons sur les viticulteurs, la présence de coûts structurels dans la cave aura également des effets redistributifs (voir annexe mathématique de l'article). L'ampleur de ces effets de redistribution dépend de la rigidité de la structure des coûts du système. Plus la structure de coûts est rigide, plus l'effet de redistribution est intense et plus le potentiel de propagation des impacts sur le système est important. Ce mécanisme augmente éventuellement la vulnérabilité des viticulteurs à subir les effets des inondations. Dans le même temps, des effets redistributifs plus intenses sont liés à des réductions plus importantes des profits, compte tenu d'une réduction de la production, ce qui, comme c'est le cas au niveau du système, réduit la capacité d'adaptation des viticulteurs.

Compte tenu d'une inondation saisonnière d'une certaine ampleur, les structures de coûts relativement flexibles dans la coopérative (la majorité des coûts liés à la production) présentent un degré de vulnérabilité plus faible et une plus grande capacité de réaction que des structures de coûts relativement rigides (la majorité des coûts est indépendante de la production). Les structures rigides sont donc liées à des agents et systèmes individuels plus vulnérables.

H.1.3.4 Localisation spatiale de la cave coopérative

Comme dans le chapitre précédent (chapitre 3), l'emplacement géographique du ou des bâtiments de la cave coopérative est clé pour la susceptibilité du système. La présence de la cave coopérative dans la zone exposée aux inondations augmente considérablement la sensibilité du système aux impacts des inondations.

H.1.3.5 Remarques sur les effets des tactiques de coping et de la variation de la topologie

Des paramètres tels que l'utilisation d'une tactique de coping alternative (external) ou la variation des liens entre les composants matériels n'ont pas été inclus dans l'article qui constitue le cœur de ce chapitre. Leurs effets sur la viabilité financière à long terme du système ont cependant été testés. Les résultats sont présentés dans les figures inclus dans l'Addendum to the article.

En ce qui concerne la tactique de coping, les résultats obtenus avec la tactique `external` ne diffèrent pas significativement de ceux de la tactique `internal`, sauf en cas d'inondations d'automne, où les différences tactiques sont maximales (voir figures 4.2 et 4.3). Les différences observables en automne, même si elles affectent le nombre de cessations parmi les viticulteurs individuels, ne modifient pas les situations dans lesquelles le système atteint le point de restructuration. Aussi, les différences sont atténuées par les horizons de cessation de l'activité des entreprises individuelles plus longues (voir la figure 4.2).

Les variations de configurations de liens (voir figures 4.5 et 4.6) influent sur le nombre de cessations d'exploitation de vignerons individuels. Elles peuvent avoir un effet significatif sur la capacité du système à absorber l'impact au lendemain de l'inondation. Ainsi, la configuration de liens concrète va influencer la capacité des individus et du système à faire face aux conséquences de l'inondation qui suivra.

Discussion et conclusion

H.1 Résumé et conclusions

A partir des résultats obtenus dans cette thèse, nous pouvons tirer les conclusions générales suivantes :

> **La topologie du système, en particulier la manière dont les éléments matériels sont liés les uns aux autres (ce qui est lié à quoi), influence la susceptibilité du système**

Les variations non seulement de la présence du lien (le lien entre deux éléments est explicite) mais aussi dans les éléments liés entre eux ont un effet sur l'estimation des dommages et donc sur l'évaluation de la vulnérabilité. Il est donc important de bien caractériser les relations entre les éléments pour évaluer l'ampleur des dommages et de la vulnérabilité. Ce résultat remet également en cause la définition même de la vulnérabilité et si la notion d'exposition doit être prise en compte.

> **Le rôle de l'exposition, ainsi l'inclusion de sa notion à la fois comme facteur et élément de la définition de la vulnérabilité, est plus complexe que le montre la littérature disponible**

À la lumière de nos résultats, l'inclusion de la notion d'exposition dans la définition et l'analyse de la vulnérabilité ne semble plus être optionnel. Il dépend plutôt du niveau auquel l'analyse de la vulnérabilité prétend avoir été accomplie. Il est donc plausible que, concernant l'analyse des systèmes, plusieurs définitions de la vulnérabilité puissent coexister dans une étude donnée, selon le niveau dans lequel nous voulons nous concentrer.

> **L'influence des tactiques de coping individuelles sur la susceptibilité du système final ne peut être anticipée. En outre, ladite influence peut être contre-intuitive dans certains cas**

Les différences de mises en œuvre entre les deux tactiques de coping peuvent être importantes, notamment en cas d'inondation d'une certaine importance. De manière générale, dans des systèmes comme le nôtre, la possibilité de sous-traiter certaines activités en cas d'urgence rend le système moins vulnérable. Cependant, il existe au moins un cas contre-intuitif dans nos résultats. Dans tel cas, en raison des impacts sur la cave coopératif, la tactique `external` augmente le montant des dégâts totaux.

Les tactiques de coping peuvent ne pas être pertinentes en termes de viabilité financière à long terme à la suite d'une inondation

Les différences entre les tactiques de coping mentionnées au chapitre 3 ne modifient pas de manière significative les résultats obtenus concernant la viabilité à long terme du système en cas d'inondation.

Selon les règles de partage des coûts et des revenus qui régissent le système cooperative viticole (SCV), la gestion financière de la cave coopérative influence la vulnérabilité à long terme des coopérativistes et du système entier de manière plus importante que les facteurs financiers individuels des coopérativistes

La présence de coûts structurels dans la structure de coûts de la coopérative est le facteur clé de la redistribution des impacts, tandis que la proportion de ces coûts structurels dans la structure de coûts détermine l'intensité de la redistribution. Les établissements vinicoles coopératifs avec des structures de coûts rigides (forte proportion de coûts structurels) rendent les SCV plus vulnérables : ils réduisent, d'une part, la capacité du système à faire face aux conséquences financières à long terme des inondations. D'autre part, ils permettent une plus grande redistribution des impacts entre les viticulteurs. La rigidité susmentionnée joue un rôle plus influent que les facteurs qui, intuitivement, peuvent faire une différence dans la capacité de coping à long terme de chaque viticulteur (par exemple, la trésorerie initiale du viticulteur). L'identification correcte des règles et des mécanismes qui façonnent les interactions entre les entités est donc essentielle pour l'étude des perturbations dans les systèmes.

La méthode multiagent s'est révélée très utile pour comprendre comment l'ensemble des unités est perturbé en cas d'inondation, et comment la manière dont les entités interagissent dans le système façonne les impacts et sa propagation dans le système

Les modèles multiagents offrent une approche de modélisation puissante pour l'évaluation ex ante des effets des perturbations dans les systèmes hiérarchiques, tels que les impacts des inondations sur le SCV. Le modèle conçu et construit dans le cadre de cette recherche a démontré le potentiel des modèles multiagents pour contribuer à la compréhension de l'influence mutuelle que les entités ont entre elles, en fonction des liens établis par rapport a l'estimation de dommages' des inondations. En outre, dans un modèle tel que COOPER, il est possible de tracer les liens entre les impacts directs et indirects. De plus, grâce à la possibilité d'inclure des règles explicites régissant les relations entre agents (relations productives dans notre cas), nous pouvons même comprendre comment certains mécanismes permettent la diffusion des impacts entre les entités du système

H.2 Perspectives de recherche

Dans l'information recueillie des cas d'études , plusieurs éléments n'ont pas été pris en compte dans ce travail et peuvent représenter des opportunités pour approfondir la connaissance des facteurs de vulnérabilité des SCV.

H.2.1 Comportement

Le comportement des agents dans les modèles multiagents peut jouer un rôle important dans le résultat des simulations. Comme indiqué, bien que nous ayons opté pour un comportement réactif soutenu par les preuves rassemblées, des comportements plus réflexifs ont également été rapportés. Il est donc possible d'examiner dans quelle mesure les hypothèses comportementales utilisées influencent non seulement la vulnérabilité du système, mais aussi l'observabilité de certains facteurs de vulnérabilité.

H.2.2 Solidarité

Nous n'avons envisagé aucune solidarité explicite dans le modèle COOPER, même si toutes les personnes interrogées ont souligné sa large présence. Notre choix d'envergure temporelle de référence (saison) et les simplifications de tâches viticoles nous ont empêchées d'étudier le potentiel de solidarité en tant que facteur de vulnérabilité.

Pour réaliser une telle analyse, le modèle COOPER doit être recodé avec i) une période de référence temporelle plus petite (une semaine ou même un jour) ; ii) des tâches plus détaillées et fonctions de dommage ; et iii) une caractérisation plus poussée du type et du montant de l'aide que les inondations peuvent mobiliser.

D'autre part, compte tenu du fonctionnement de la règle de partage coûts-revenus, il peut exister une solidarité entre les viticulteurs motivés par des incitations financières. La solidarité au sein de la coopérative peut être parfaitement motivée par la maximisation du profit individuel, en particulier dans le cas des agriculteurs moins touchés par les inondations. L'existence et les effets de ces incitations sur la vulnérabilité du système méritent d'être approfondis.

H.2.3 Rôle des autorités

Notre travail n'a pas envisagé d'interaction avec une autorité explicite (locale ou régionale). Leur rôle est perçu comme négatif : limiter l'autonomie des vignerons pour prévenir les dégâts causés par les inondations.

En ce sens, des modèles multiagents associé à des modèles hydrologiques peuvent être développé et utilisé pour prendre en compte les conséquences en aval sur les terres, les productions et, à la fin, les performances économiques d'adaptations individuelles non coordonnées pour la protection contre les inondations. Impliquer les viticulteurs et les autorités dans le processus de développement de ces modèles peut donner à tous les acteurs un aperçu des défis et des besoins de chacun.

Les éléments de preuve réunis suggèrent également que, lorsqu'il existe un doute raisonnable sur la légalité des infrastructures reconstruites, les compensations de l'assurance publique peuvent être bloquées (non refusées) jusqu'à ce que l'affaire soit résolue. L'impact financier de telles mesures n'est pas négligeable, en particulier dans le cas des viticulteurs fortement touchés.

H.2.4 Secteur financier : établissements bancaires et d'assurances

Le rôle du secteur financier dans le modèle COOPER est passif. Cependant, ce n'est pas son fonctionnement normal. Un secteur financier plus proactif peut complètement changer les résultats affichés dans le chapitre **??** et devenir un facteur de vulnérabilité du SCV.

De la même manière, le modèle COOPER ne prend en compte aucun retard ni aucune incertitude en ce qui concerne les compensations d'assurance, bien que les deux existent. Les retards et les incertitudes peuvent générer des problèmes de trésorerie et des retards dans les réparations, ils peuvent donc causer des dommages plus importants que ceux envisagés dans cette version du modèle COOPER.

H.2.5 Marchés et grande distribution

L'information rassemblée suggère que, par exemple, les grandes chaînes de distribution, si elles ne reçoivent pas le montant attendu, peuvent réviser et annuler des contrats. Une telle situation peut provoquer des dommages supplémentaires au système qui n'a pas été pris en compte dans notre modèle.

H.2.6 Adaptation

Si des comportements d'agent plus complexes doivent être implémentés dans le modèle COOPER, la vulnérabilité du système peut être modifiée par le biais d'adaptations et d'interactions locales. Des recherches plus poussées seraient nécessaires pour analyser l'influence et l'effet final des adaptations sur la susceptibilité du SCV aux inondations. Les données recueillies dans nos études sur l'adaptation suggèrent que, pour pouvoir évaluer certains des effets des adaptations potentielles, le niveau de détail d'aspects tels que les fonctions d'endommagement ou les tâches viticoles représentées dans le système devrait cependant être augmenté.

Bibliography

General references

Total Disaster Risk Management - Good Practices.
Technical report, Asian Disaster Reduction Centre (ADRC), 2005.

L. Acosta-Michlik and V. Espaldon.
Assessing vulnerability of selected farming communities in the philippines based on a behavioural model of agent's adaptation to global environmental change.
Global Environmental Change, 18(4):554 – 563, 2008.
doi:https://doi.org/10.1016/j.gloenvcha.2008.08.006.

W. Adger.
Vulnerability.
Global Environmental Change, 16, 2006.

A. Aguilera-Ontiveros and J. C. Contreras-Manrique.
The role of emotions in environmental decision making: A formal modeling framework.
In A. López Paredes and C. Hernández Iglesias, editors, *Agent Based Modelling in Natural Resource Management*, chapter 9. INSISOC. Madrid, Mar. 2008.
ISBN 978-84-205-4560-8.

D. Alexander.
Confronting Catastrophe - New Perspectives on Natural Disasters.
Oxford University Press, 2000.

L. Alfieri, P. Burek, L. Feyen, and G. Forzieri.
Global warming increases the frequency of river floods in europe.
Global Environmental Change, 35, 2015a.

L. Alfieri, L. Feyen, F. Dottori, and A. Bianchi.
Ensemble flood risk assessment in europe under high end climate scenarios.
Hydrology and Earth System Sciences Discussions, 12, 2015b.

L. An, M. Linderman, J. Qi, A. Shortridge, and J. Liu.
Exploring complexity in a human–environment system: An agent-based spatial model for multidisciplinary and multiscale integration.
Annals of the Association of American Geographers, 95(1):54–79, 2005.

J. M. Anderies, M. A. Janssen, and E. Ostrom.
A framework to analyze the robustness of social-ecological systems from an institutional perspective.
Ecology and Society, 9(1), 2004.

L. Arroyo Abad and K. Khalifa.
What are stylized facts?
Journal of Economic Methodology, 22(2):143–156, 2015.
doi:10.1080/1350178X.2015.1024878.

W. B. Arthur.
Complexity Economics: A Different Framework for Economic Thought.
Working paper 2013-04-012, Santa Fe Institute, 2013.

I. Arto, V. Andreoni, and J. M. R. Cantuche.
Global impacts of the automotive supply chain disruption following the japanese earthquake of 2011.
Economic Systems Research, 27(3):306–323, 2015.
doi:10.1080/09535314.2015.1034657.

A. Atteridge and E. Remling.
Is adaptation reducing vulnerability or redistributing it?
Wiley Interdisciplinary Reviews: Climate Change, 9(1), 2 2018.
doi:10.1002/wcc.500.

T. Aven.
Risk assessment and risk management: Review of recent advances on their foundation.
European Journal of Operational Research, (253), 2016.

S. Balbi and C. Giupponi.
Reviewing agent-based modelling of socio-ecosystems: a methodology for the analysis of climate change adaptation and sustainability.
Working Papers 2009-15, Department of Economics, University of Venice "Ca' Foscari", 2009.

S. Balica, I. Popescu, L. Beevers, and N. Wright.
Parametric and physically based modelling techniques for flood risk and vulnerability assessment: A comparison.
Environmental Modelling & Software, 41, 2013.

T. Balke and N. Gilbert.
How do agents make decisions? a survey.
Journal of Artificial Societies and Social Simulation, 17(4):13, 2014.
doi:10.18564/jasss.2687.

L. Barbut, N. Bauduceau, and C. Devaux Ros.
Vers une evaluation de la vulnérabilité des activités agricoles aux inondations.
Ingénieries - E A T, IRSTEA, pages 29 – 41, 2004.

O. Barreteau, F. Bousquet, C. Millier, and J. Weber.
Suitability of multi-agent simulations to study irrigated system viability: Application to case studies in the senegal river valley.
80:255–275, 06 2004.

P. J. Barry and L. J. Robison.
Agricultural finance: Credit, credit constraints, and consequences.
In *Agricultural Production*, volume 1 of *Handbook of Agricultural Economics*, chapter 10, pages 513 – 571. Elsevier, 2001.
doi:https://doi.org/10.1016/S1574-0072(01)10013-7.
URL http://www.sciencedirect.com/science/article/pii/S1574007201100137.

A. Battagliani, G. Barbeau, M. Bindi, and F. W. Badeck.
European winegrowers' perceptions of climate change impact and options for adaptation.
Regional Environmental Change, 9:61–63, 2009.
doi:1.

N. Bauduceau.
Elèments d'analyse des répercussions des inondations de novembre 1999 sur les activités agricoles des départements de l'aude, des pyrénées orientales et du tarn.
Technical report, 2001.

M. Benoit, J.-P. Deffontaines, F. Gras, E. Bienaimé, and R. Riela-Cosserat.
Agriculture et qualité de l'eau une approche interdisciplinaire de la pollution par les nitrates d'un bassin d'alimentation.
Cahiers Agricultures, 1997.

T. Berger and C. Troost.
Agent-based modelling of climate adaptation and mitigation options in agriculture.
Journal of Agricultural Economics, 65(2):323–348, 2014.
doi:10.1111/1477-9552.12045.

A. Biarnès and J.-M. Touzard.
La rémunération différenciée du raisin dans les coopératives du Languedoc.
In D. J.F. and T. J.M., editors, *Les coopératives entre territoires et mondialisation*.
L'harmattan–IES, 2003.

M. B. Biggs and J. A. Papin.
Novel Multiscale Modeling Tool Applied to Pseudomonas aeruginosa Biofilm Formation.
PLOS ONE, 8(10), 2013.

C. R. Binder, J. Hinkel, P. W. Bots, and C. Pahl-Wostl.
Comparison of frameworks for analyzing social-ecological systems.
Ecology and Society, 18(4), 2013.

J. Birkmann.
Danger need not spell disaster but how vulnerable are we?
In *United Nations University Research brief*, number 1, 2005.

J. Birkmann.
Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications.
Environmental Hazards, 7, 2007.

J. Birkmann and K. von Teichman.
Integrating disaster risk reduction and climate change adaptation: key challenges - scales, knowledge, and norms.
Integrated Research System for Sustainability Science, (5), 2010.

J. Birkmann, O. D. Cardona, M. L. Carreño, A. H. Barbat, M. Pelling, S. Schneiderbauer, S. Kienberger, M. Keiler, D. E. Alexander, P. Zeil, and T. Welle.
Framing vulnerability, risk and societal responses: the MOVE framework.
Natural Hazards, 67(2):193–211, Jun 2013.

J. Birkmann, O. D. Cardona, M. L. Carreño, A. H. Barbat, M. Pelling, S. Schneiderbauer, S. Kienberger, M. Keiler, D. E. Alexander, P. Zeil, and T. Welle.
Theoretical and conceptual framework for the assessment of vulnerability to natural hazards and climate change in europe: The MOVE framework.
In J. Birkmann, S. Kienberger, and D. E. Alexander, editors, *Assessment of Vulnerability to Natural Hazards. A European Perspective*, chapter 1. Elsevier, 2014a.

J. Birkmann, S. Kienberger, and D. E. Alexander.
Vulnerability: a key determinant of risk and its importance for risk management and sustainability.
In J. Birkmann, S. Kienberger, and D. E. Alexander, editors, *Assessment of Vulnerability to Natural Hazards. A European Perspective*, chapter Introduction. Elsevier, 2014b.

E. Bonabeau.
Agent-based modeling: Methods and techniques for simulating human systems.
Proceedings of the National Academy of Sciences, 99(suppl 3):7280–7287, 2002.
doi:www.pnas.org/cgi/doi/10.1073/pnas.082080899.

T. S. Bontkes and H. van Keulen.
Modelling the dynamics of agricultural development at farm and regional level.
Agricultural Systems, 76(1):379 – 396, 2003.
doi:https://doi.org/10.1016/S0308-521X(02)00128-2.

F. Bousquet and C. Le Page.
Multi-agent simulations and ecosystem management: a review.
Ecological Modelling, 176(3):313 – 332, 2004.
doi:https://doi.org/10.1016/j.ecolmodel.2004.01.011.

P. Brémond.
Caractérisation et Évaluation Économique de la vulnérabilité des exploitations agricoles aux inondations.
PhD thesis, École Doctorale Économie et Gestion de Montpellier, 2011.

P. Brémond, F. Grelot, and A. Agenais.
Review article: economic evaluation of flood damage to agriculture - review and analysis of existing methods.
Natural Hazards and Earth System Sciences, 13:p. 2493 – p. 2512, 2013.
doi:10.5194/nhess-13-2493-2013.

T. Brener.
Agent learning representation: Advice on modelling economic learning.
In L. Tesfatsion and K. L. Judd, editors, *Handbook of Computational Economics*, volume 2, chapter 18. Elsevier B.V., 2006.
doi:10.1016/S1574-0021(05)02018-6.

L. Briguglio, G. Cordina, N. Farrugia, and S. Vella.
Economic vulneraility and resilience.
ONU-World Institute for Development Economics Research (WIDER), Research paper No. 2008/55, 2008.

R. Brouwer, S. Akter, L. Brander, and E. Haque.
Socioeconomic vulnerability and adaptation to environmental risk: A case study of climate change and flooding in bangladesh.
Risk Analysis, 27(2), 2007.

L. Brouwers and M. Boman.
A computational agent model of flood management strategies.
In H. A. do Prado, A. J. B. Luiz, and H. C. Filho, editors, *Computational Methods for Agricultural Research: Advances and Applications*, chapter 14. IGI Global, 2010.

E. Bruch and J. Atwell.
Agent-based models in empirical social research.
Sociological Methods & Research, 44(2):186–221, 2015.
doi:10.1177/0049124113506405.
PMID: 25983351.

P. Bubeck and H. Kreibich.
Natural hazards: direct costs and losses due to the disruption of production processes.
CONHAZ project WP1 Final Report, Helmholtz Centre Postdam, Sept. 2011.

T. Cannon and D. Muller-Mahn.
Vulnerability, resilience and development discourses in context of climate change.
Natural Hazards, 55(3), 2010.

O. D. Cardona.
The need for rethinking the concepts of vulnerability and risk from a holistic perspective: A necessary review and criticism for effective risk management.
In G. Bankoff, G. Frerks, and D. Hilhorst, editors, *Mapping Vulnerability: Disasters, Development and People*, chapter 3. Earthscan Publishers, 2003.

L. Carrera, G. Standardi, F. Bosello, and J. Mysiak.
Assessing direct and indirect economic impacts of a flood event through the integration of spatial and computable general equilibrium modelling.
Environmental Modelling and Software, 63(0):109–122, 2015.

Chambre d'agriculture Var.
Action 25 du PAPI d'intention de l'Argens. Réalisation de diagnostics de vulnérabilité d'installations agricoles en zone inondable, 2014.
URL http://www.viva2010.org/telechargements/2014-05-06_PAPI-Argens-intention_Diapos-ChAgri.pdf.

J.-M. Chevet.
Le rôle des caves coopératives dans le regroupement de l'offre en France au XXème siècle.
Technical Report 2004-12, INRA-CORELA working papers, 2004.
URL https://www6.versailles-grignon.inra.fr/aliss/content/download/3348/35635/file/WP04-12.pdf.

P.-Y. Collombat.
Rapport d'information fait au nom de la mission commune d'information sur les inondations qui se sont produites dans le Var, et plus largement, dans le sud-est de la France au mois de novembre 2011, 2012.

R. Costanza, L. Wainger, C. Folke, and K.-G. Mäler.
Modeling complex ecological economic systems.
Bioscience, 43(8), 1993.

V. Crespi, A. Galstyan, and K. Lerman.
Top-down vs bottom-up methodologies in multi-agent system design.
Autonomous Robots, 24(3):303–313, Apr 2008.
doi:10.1007/s10514-007-9080-5.

J. Cunado and S. Ferreira.
The macroeconomic impacts of natural disasters: The case of floods.
Land Economics, 90(1):149–168, 2014.

S. L. Cutter.
Vulnerability to environmental hazards.
Progress in Human Geography, 20(4), 1996.

T. Dalgaard, N. J. Hutchings, and J. R. Porter.
Agroecology, scaling and interdisciplinarity.
Agriculture, Ecosystems & Environment, 100(1):39 – 51, 2003.
doi:10.1016/S0167-8809(03)00152-X.

N. David.
Validating simulations.
In B. Edmonds and R. Meyer, editors, *Simulating Social Complexity. A Handbook*, Springer Complexity, chapter 8. Springer, first edition, 2013.

R. J. Dawson, R. Peppe, and M. Wang.
An agent-based model for risk-based flood incident management.
Natural Hazards, 59(1):167–189, 2011.
doi:10.1007/s11069-011-9745-4.

D. L. DeAngelis and V. Grimm.
Individual-based models in ecology after four decades.
F1000Prime Reports, 6, 2014.

G. Decrop.
L'expertise en question dans la gestion des risques naturels. le cas des ruines de séchilienne.
Vertigo, 14(1), 2014.

G. Deffuant, S. Huet, and S. Skerratt.
An agent based model of agri-environmental measure diffusion: What for?
In A. López Paredes and C. Hernández Iglesias, editors, *Agent Based Modelling in Natural Resource Management*, chapter 3. INSISOC. Madrid, Mar. 2008.
ISBN 978-84-205-4560-8.

A. Dekker.
Studying organisational topology with simple computational models.
Journal of Artificial Societies and Social Simulation, 10(4):6, 2007.

C. Dibble.
Computational laboratories for spatial agent-based models.
In L. Tesfatsion and K. L. Judd, editors, *Handbook of Computational Economics*, volume 2, chapter 31. Elsevier B.V., 2006.
doi:10.1016/S1574-0021(05)02031-9.

DIRECTIVE 2000/60/CE.
of the European Parliament and of the Council of the European Union, of 23 October 2000 establishing a framework for Community action in the field of water policy.

DIRECTIVE 2007/60/CE.
of the European Parliament and of the Council of the European Union, of 23 October 2007 on the assessment and management of flood risks.

K. P. Donaghy, N. Balta-Ozkan, and G. J. Hewings.
Modeling unexpected events in temporally disaggregated econometric input–output models of regional economies.
Economic Systems Research, 19(2):125–145, 2007.
doi:10.1080/09535310701328484.

K. Dow.
Exploring differences in our common future(s): the meaning of vulnerability to global environmental change.
Geoforum, 23(3), 1992.

J. Dubbelboer, I. Nikolic, K. Jenkins, and J. Hall.
An agent-based model of flood risk and insurance.
Journal of Artificial Societies and Social Simulation, 20(1)(6), 2017.

J. Duffy.
Agent-based models and human subject experiments.

In L. Tesfatsion and K. L. Judd, editors, *Handbook of Computational Economics*, volume 2, chapter 19. Elsevier B.V., 2006.
doi:10.1016/S1574-0021(05)02019-8.

H. Eakin.
Institutional change, climate risk, and rural vulnerability: cases from central mexico.
World Development, 33, 2005.

H. Eakin and A. L. Luers.
Assessing the vulnerability of social-environmental systems.
Annual Review of Environment and Resources, 31, 2006.

J. M. Epstein.
Why model?
Journal of Artificial Societies and Social Simulation, 11(4):12, 2008.

K. Erdlenbruch and B. Bonté.
Simulating the dynamics of individual adaptation to floods.
Environmental Science & Policy, 84:134 – 148, 2018.
doi:https://doi.org/10.1016/j.envsci.2018.03.005.

K. Erdlenbruch, S. Thoyer, F. Grelot, R. Kast, and G. Enjolras.
Risk-sharing policies in the context of the french flood prevention action programmes.
Journal of Environmental Management, 91(2), 2009.

S. Eriksen, K. Brown, and P. Kelly.
The dynamics of vulnerability: locating coping strategies in kenya and tanzania.
Geographical Journal, 171, 2005.

European Environment Agency.
Mapping the impacts of natural hazards and technological accidents in Europe.
Technical report, European Environment Agency (EEA), 2010.

European Environment Agency.
Climate change, impacts and vulnerability in Europe 2012.
Technical report, European Environment Agency (EEA), 2012a.

European Environment Agency.
Water resources in Europe in the context of vulnerability.
Technical report, European Environment Agency (EEA), 2012b.

J. K. Feibleman.
Theory of integrative levels.
The British Journal for the Philosophy of Science, 5(17):59–66, 1954.

A. Fekete, M. Damm, and J. Birkmann.
Scales as a challenge for vulnerability assessment.
Natural Hazards, 55(3):729–747, 2010.
doi:10.1007/s11069-009-9445-5.

T. Felbruegge and J. von Braun.
Is The World Becoming A More Risky Place? Trends In Disasters And Vulnerability To Them.
Discussion Papers 18730, University of Bonn, Center for Development Research (ZEF), 2002.

J. Ferber.
Multi-Agent Systems: An Introduction to Distributed Artificial Intelligence.
Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA, 1st edition, 1999.
ISBN 0201360489.

T. Filatova.
Empirical agent-based land market: Integrating adaptive economic behavior in urban land-use models.
Computers, Environment and Urban Systems, 54:397 – 413, 2015.
doi:https://doi.org/10.1016/j.compenvurbsys.2014.06.007.

T. Filatova, A. V. D. Veen, and D. C. Parker.
Land market interactions between heterogeneous agents in a heterogeneous landscape – tracing the macro-scale effects of individual trade-offs between environmental amenities and disamenities.
Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie, 57 (4):431–457, 2009.
doi:10.1111/j.1744-7976.2009.01164.x.

T. Filatova, D. Parker, and A. van der Veen.
The implications of skewed risk perception for a dutch coastal land market: Insights from an agent-based computational economics model.
Agricultural and Resource Economics Review, 40(3), 2011.

S. Förster, B. Kuhlmann, K.-E. Lindenschmidt, and A. Bronstert.
Assessing flood risk for a rural detention area.
Natural Hazards and Earth System Sciences, 8(2):311–322, 2008.
doi:10.5194/nhess-8-311-2008.

B. Foster and T. Ward.
Using cash flow trends to identify risks of bankruptcy.
The CPA journal, 60, 1997.

J. M. Galán, L. R. Izquierdo, S. S. Izquierdo, J. I. Santos, R. del Olmo, and A. López-Paredes.
Checking simulations: Detecting and avoiding errors and artefacts.
In B. Edmonds and R. Meyer, editors, *Simulating Social Complexity. A Handbook*, Springer Complexity, chapter 6. Springer, first edition, 2013.

G. C. Gallopin.
Linkages between vulnerability, resilience and adaptative capacity.
Global Environmental Change, 16:293–303, 2006.

M. Giampietro.
Using hierarchy theory to explore the concept of sustainable development.
Futures, 26(6), 1994.
doi:https://doi.org/10.1016/0016-3287(94)90033-7.

C. C. Gibson, E. Ostrom, and T. Ahn.
The concept of scale and the human dimensions of global change: a survey.
Ecological Economics, (32), 2000.

N. Gilbert.
Agent-Based Models.
SAGE publications, 2008.

A. Gissing and R. Blong.
Accounting for variability in commercial flood damage estimation.
Australian Geographer, 35(2):209–222, 2004.
doi:10.1080/0004918042000249511.

R. Gore, S. Diallo, C. Lynch, and J. Padilla.
Augmenting bottom-up metamodels with predicates.
Journal of Artificial Societies and Social Simulation, 20(1):4, 2017.
doi:10.18564/jasss.3240.

N. Graveline and M. Grémont.
Measuring and understanding the microeconomic resilience of businesses to lifeline service interruptions due to natural disasters.
International Journal of Disaster Risk Reduction, 24:526 – 538, 2017.
doi:https://doi.org/10.1016/j.ijdrr.2017.05.012.

C. Green.
The evaluation of vulnerability to flooding.
Disaster Prevention and Management, 13(4), 2004.

C. Green, C. Viavattene, and P. Thompson.
Guidance for assessing flood losses.
CONHAZ WP6 Final Report, Flood Hazard Research Center - Middlesex University, Sept. 2011.

F. Grelot, C. Bertrand, P. Besson, B. Bonté, P. Brémond, J.-P. Cherel, A.-L. Collard, S. Défossez, K. Erdlenbruch, C. Heaumé, A. Moatty, D. Nortes-Martínez, C. Payan, C. Richert, V. Sanseverino-Godfrin, F. Vinet, and N. Zerluth.
Résilience des territoires face à l'inondation. pour une approche préventive par l'adaptation post-événement.
Rapport final de contrat, 2017.

V. Grimm, U. Bergerb, F. Bastiansena, S. Eliassenc, V. Ginotd, J. Jarl Giskec, J. Goss-Custarde, T. Grandf, S. K. Heinzc, G. Huseg, A. Hutha, J. U. Jepsena, C. Jørgensenc, W. M. Mooijh, B. Müllera, G. Pe'eri, C. Pioub, S. F. Railsbackj, A. M. Robbinsk, M. M. Robbinsk, E. Rossmanithl, N. Rügera, E. Strandc, S. Souissim, R. A. Stillmane, R. Vabøg, U. Vissera, and D. L. DeAngelisn.
A standard protocol for describing individual-based and agent-based models.
Ecological modelling, 198:115–126, 2006.

V. Grimm, U. Berger, D. L. DeAngelis, J. G. Polhill, J. Giske, and S. F. Railsback.
The odd protocol: A review and first update.
Ecological Modelling, 221(23):2760 – 2768, 2010.
doi:https://doi.org/10.1016/j.ecolmodel.2010.08.019.

T. Haer, W. W. Botzen, and J. C. Aerts.
The effectiveness of flood risk communication strategies and the influence of social networks – insights from an agent-based model.
Environmental Science & Policy, 60:44 – 52, 2016a.
doi:https://doi.org/10.1016/j.envsci.2016.03.006.

T. Haer, W. J. Wouter Botzen, H. de Moel, and J. C. J. H. Aerts.
Integrating household risk mitigation behavior in flood risk analysis: An agent-based model approach.
Risk Analysis, 2016b.

S. Hallegate and V. Przyluski.
The Economics of Natural Disasters. Concepts and Methods.
Policy Research Working Paper 5507, The World Bank, 2010.

S. Hallegatte and M. Ghil.
Natural disasters impacting a macroeconomic model with endogenous dynamics.
ECOLOGICAL ECONOMICS, 68(1-2):582–592, DEC 1 2008.
doi:10.1016/j.ecolecon.2008.05.022.

M. Hare and P. Deadman.
Further towards a taxonomy of agent-based simulation models in environmental management.
Math. Comput. Simul., 64(1):25–40, Jan. 2004.
doi:10.1016/S0378-4754(03)00118-6.

M. Hare and P. Deadman.
Further towards a taxonomy of agent-based simulation models in environmental management.
In A. López Paredes and C. Hernández Iglesias, editors, *Agent Based Modelling in Natural Resource Management*, chapter 1. INSISOC. Madrid, Mar. 2008.
ISBN 978-84-205-4560-8.

T. Hartmann and P. Driessen.
The flood risk management plan: towards spatial water governance.
Journal of Flood Risk Management, 10(2):145–154, 2013.
doi:10.1111/jfr3.12077.

S. Heckbert, T. Baynes, and A. Reeson.
Agent-based modeling in ecological economics.
Annals of the New York Academy of Sciences, 1185(1):39–53, 2010.
doi:10.1111/j.1749-6632.2009.05286.x.
Herbert.

M. Hiete and M. Merz.
Indicator framework for the assessment of indirect industrial vulnerabilities.

In J. Landgren and S. Ju, editors, *Proceedings of the 6th International ISCRAM Conference*, Gothenburg, Sweden, May 2009.

C. S. Holling.
Resilience and stability of ecological systems.
Annual Review of Ecology and Systematics, 4(1):1–23, 1973.
doi:10.1146/annurev.es.04.110173.000245.

A. Hooijer, F. Klijn, G. B. M. Pedroli, and A. G. Van Os.
Towards sustainable flood risk management in the rhine and meuse river basins: synopsis of the findings of irma-sponge.
River Research and Applications, 20(3):343–357, 2004.
doi:10.1002/rra.781.

H. P. N. Hughes, C. W. Clegg, M. A. Robinson, and R. M. Crowder.
Agent-based modelling and simulation: The potential contribution to organizational psychology.
Journal of Occupational and Organizational Psychology, 85(3):487–502, 2012.
doi:10.1111/j.2044-8325.2012.02053.x.

J. Jacquleen.
Measuring vulnerability to natural hazards: a macro framework.
Disasters, 2(37), 2013.

J. Jansen, M. van Ittersum, S. Janssen, and P. Reidsma.
Integrated Assessment of Agricultural Systems at the European Level.
Policy Brief LIAISE, 2016.

M. A. Janssen and E. Ostrom.
Governing social-ecological systems.
In L. Tesfatsion and K. L. Judd, editors, *Handbook of Computational Economics*, volume 2, chapter 30. Elsevier B.V., 2006a.
doi:10.1016/S1574-0021(05)02030-7.

M. A. Janssen and E. Ostrom.
Empirically based, agent-based models.
Ecology and Society, 11(2), 2006b.

F. Jarrige and J. Touzard.
Les mutations de l'organisation coopérative à travers l'évolution de ses règles: La rémunération de la vendange dans les caves coopératives du Midi.
Revue International de L'Économie Sociale (RECMA), (280), 2001.

K. Jenkins, S. Surminski, J. Hall, and F. Crick.
Assessing surface water flood risk and management strategies under future climate change: Insights from an agent-based model.
Science of The Total Environment, 595:159 – 168, 2017.
doi:https://doi.org/10.1016/j.scitotenv.2017.03.242.

E. Joakim, L. Mortsch, and G. Oulahen.
Using vulnerability and resilience concepts to advance climate change adaptation.
Environmental Hazards, 14(2):137–155, 2015.

C. Johnson, E. Penning-Rowsell, and D. Parker.
Natural and imposed injustices: the challenges in implementing 'fair' flood risk management policy in england.
Geographical Journal, 173(4), 2007.

O. Jonkeren and G. Giannopoulos.
Analysing critical infrastructure failure with a resilience inoperability input–output model.
Economic Systems Research, 26(1):39–59, 2014.
doi:10.1080/09535314.2013.872604.

K. L. Judd.
Computationally intensive analyses in economics.
In L. Tesfatsion and K. L. Judd, editors, *Handbook of Computational Economics*, volume 2, chapter 17. Elsevier B.V., 2006.
doi:10.1016/S1574-0021(05)02017-4.

Y. Kajitani and H. Tatano.
Estimation of production capacity loss rate after the great east japan earthquake and tsunami in 2011.
Economic Systems Research, 26(1):13–38, 2014.
doi:10.1080/09535314.2013.872081.

Y. Kajitani and H. Tatano.
Applicability of a spatial computable general equilibrium model to assess the short-term economic impact of natural disasters.
Economic Systems Research, 0(0):1–24, 2017.
doi:10.1080/09535314.2017.1369010.

S. Kelly.
Estimating economic loss from cascading infrastructure failure: a perspective on modelling interdependency.
Infrastructure Complexity, 2015.

J. Kienberger, D. Contreras, and P. Zeil.
Spatial and Holistic Assessment of Social, Economic, and Environmental Vulnerability to Floods—Lessons from the Salzach River Basin, Austria.
In J. Birkmann, S. Kienberger, and D. E. Alexander, editors, *Assessment of Vulnerability to Natural Hazards*, chapter 3. Elsevier, 2014.

T. C. Knox.
Organization Change and Vinification Cooperatives in France's Midi.
Economics Working Papers. Paper 199804, University of Connecticut, 1998.

E. E. Koks and M. Thissen.
A multiregional impact assessment model for disaster analysis.
Economic Systems Research, 28(4):429–449, 2016.
doi:10.1080/09535314.2016.1232701.

E. E. Koks, L. Carrera, O. Jonkeren, J. C. J. H. Aerts, T. G. Husby, M. Thissen, G. Standardi, and J. Mysiak.

Regional disaster impact analysis: comparing input-output and computable general equilibrium models.
Natural Hazards and Earth System Sciences Discussions, 3:7053–7088, 2015.

H. Kreibich, K. Piroth, I. Seifert, H. Maiwald, U. Kunert, J. Schwarz, B. Merz, and A. H. Thieken.
Is flow velocity a significant parameter in flood damage modelling?
Natural Hazards and Earth System Sciences, 9(5):1679–1692, 2009.
doi:10.5194/nhess-9-1679-2009.

A. Laatabi, N. Marilleau, T. Nguyen-Huu, H. Hbid, and M. Ait Babram.
ODD+2D: An ODD Based Protocol for Mapping Data to Empirical ABMs.
Journal of Artificial Societies and Social Simulation, 21(2):9, 2018.
doi:10.18564/jasss.3646.

J.-P. Le Bourhis.
Du savoir cartographique au pouvoir bureaucratique. les cartes des zones inondables dans la politique des risques (1970-2000).
Genéses, 3(68):75–96, 2007.

A.-L. Lereboullet, D. Bardsley, and G. Beltrando.
Assessing vulnerability and framing adaptive options of two mediterranean wine growing regions facing climate change: Roussillon (france) and mclaren vale (australia).
EchoGéo, 23, 2013.
doi:10.4000/echogeo.13384 Haut de page.

M. M. Letsie and S. W. Grab.
Assessment of Social Vulnerability to Natural Hazards in the Mountain Kingdom of Lesotho.
Mountain Research and Development, 35(2):115–125, 2015.

J. Liu, T. Dietz, S. R. Carpenter, M. Alberti, C. Folke, E. Moran, A. N. Pell, P. Deadman, T. Kratz, J. Lubchenco, E. Ostrom, Z. Ouyang, W. Provencher, C. L. Redman, S. H. Schneider, and W. W. Taylor.
Complexity of coupled human and natural systems.
Science, 317, 2007.

J. Loomis, C. Bond, and D. Harpman.
The potential of agent-based modelling for performing economic analysis of adaptive natural resource management.
Journal of Natural Resources Policy Research, 1(1):35–48, 2008.

A. L. Luers, D. B. Lobell, L. S. Sklar, C. L. Addams, and P. A. Matson.
A method for quantifying vulnerability, applied to the agricultural system of the yaqui valley, mexico.
Global Environmental Change, 13, 2003.

M. Lysenko and R. M. D'Souza.
A Framework for Megascale Agent Based Model Simulations on Graphics Processing Units.

Journal of Artificial Societies and Social Simulation, 11(4):10, 2008.
ISSN 1460-7425.
URL http://jasss.soc.surrey.ac.uk/11/4/10.html.

M. W. Macy and R. Willer.
From factors to actors: Computational sociology and agent-based modeling.
Annual Review of Sociology, 28:143–166, 2002.

V. Markantonis, V. Meyer, and R. Schwarze.
The intangible effects of Natural Hazards.
CONHAZ WP3 Final Report, Helmholtz Centre for Environmental Research – UFZ/Department of Economics, Sept. 2011.

M. Marshall, L. Niehm, S. Sydnor, and H. Schrank.
Predicting small business demise after a natural disaster: an analysis of pre-existing conditions.
Nat Hazards, 2015.

M. D. McGinnis.
An Introduction to IAD and the Language of the Ostrom Workshop: A Simple Guide to a Complex Framework for the Analysis of Institutions and Their Development.
Research Paper 2011-02-01, School of Public and Environmental Affairs. Indiana University, 2010.

M. D. McGinnis and E. Ostrom.
Social-ecological system framework: initial changes and continuing challenges.
Ecology and Society, 19(2), 2014.

B. Merz, H. Kreibich, R. Schwarze, and A. Thieken.
Assessment of economic flood damage.
Natural Hazards and Earth System Sciences, 10:1697–1724, 2010.

V. Meyer, N. Becker, V. Markantonis, R. Schwarze, J. C. J. M. van den Bergh, L. M. Bouwer, P. Bubeck, P. Ciavola, E. Genovese, C. Green, S. Hallegatte, H. Kreibich, Q. Lequeux, I. Logar, E. Papyrakis, C. Pfurtscheller, J. Poussin, V. Przyluski, A. H. Thieken, and C. Viavattene.
Review article: Assessing the costs of natural hazards - state of the art and knowledge gaps.
Natural Hazards and Earth System Sciences, 13(5):1351–1373, 2013.

E. Michel-Kerjan.
Risques a grande echelle dans les systemes en reseau: quelques interrogations.
CIRANO, 2000.

F. Miller, H. Osbahr, E. Boyd, F. Thomalla, S. Bharwani, G. Ziervogel, B. Walker, J. Birkmann, S. Van der Leeuw, J. Rockstrom, J. Hinkel, T. Downing, C. Folke, and D. Nelson.
Resilience and vulnerability: complementary or conflicting concepts?
Ecology and Society, 15(3), 2010.

J. K. Mitchell.
European river floods in a changing world.
Risk Analysis, 23:567–574, 2003.

J. Morris and T. M. Hess.
Agricultural flood alleviation benefit assessment: A case study.
Journal of Agricultural Economics, 39(3):402–412, 1988.
doi:10.1111/j.1477-9552.1988.tb00600.x.

J. Morris, A. Bailey, C. Lawson, P. Leeds-Harrison, D. Alsop, and R. Vivash.
The economic dimensions of integrating flood management and agri-environment through washland creation: A case from somerset, england.
Journal of Environmental Management, 88(2), 2008.

S. Moulet and J. Rouchier.
The influence of sellers' beliefs and time constraint on a sequential bargaining in an artificial perishable goods market.
Journal of Economic Dynamics and Control, 32(7):2322–2348, 2008.

A. Müller, J. Reiter, and U. Weiland.
Assessment of urban vulnerability towards floods using an indicator-based approach – a case study for santiago de chile.
Natural Hazards and Earth System Sciences, 11(8):2107–2123, 2011.

B. Müller, F. Bohn, G. Dreßler, J. Groeneveld, C. Klassert, R. Martin, M. Schlüter, J. Schulze, H. Weise, and N. Schwarz.
Describing human decisions in agent-based models – ODD + D, an extension of the ODD protocol.
Environmental Modelling & Software, 48:37 – 48, 2013.
doi:https://doi.org/10.1016/j.envsoft.2013.06.003.

K. A. Nicholas and W. H. Durham.
Farm-scale adaptation and vulnerability to environmental stresses: Insights from winegrowing in northern california.
Global Environmental Change, 22, 2012.
doi:10.1016/j.gloenvcha.2012.01.001.

E. Norling, B. Edmonds, and R. Meyer.
Informal approaches to developing simulation models.
In B. Edmonds and R. Meyer, editors, *Simulating Social Complexity. A Handbook*, Springer Complexity, chapter 4. Springer, first edition, 2013.

Y. Okuyama.
Economics of natural disasters: A critical review.
In *50th North American Meeting, Regional Science Association International*, 2003.

Y. Okuyama.
Disaster and economic structural change: Case study on the 1995 kobe earthquake.
Economic Systems Research, 26(1):98–117, 2014.
doi:10.1080/09535314.2013.871506.

Y. Okuyama and J. R. Santos.
Disaster impact and input–output analysis.
Economic Systems Research, 26(1):1–12, 2014.
doi:10.1080/09535314.2013.871505.

A. Oliveira Tavares, P. Pinto dos Santos, P. Freire, A. Bustorff Fortunato, A. Rilo, and L. Sá.
Flooding hazard in the Tagus estuarine area: The challenge of scale in vulnerability assessments.
Environmental Science & Policy, 51, 2015.

E. Ostrom.
A diagnostic approach for going beyond panaceas.
Proceedings of the National Academy of Sciences, 104(39), 2007.

E. Ostrom.
A general framework for analyzing sustainability of social-ecological systems.
Science, 325, 2009a.

E. Ostrom.
Prize lecture: Beyond markets and states: Polycentric governance of complex economic systems.
In *Nobelprice.org*. The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel, 2009b.
URL https://www.nobelprize.org/nobel_prizes/economic-sciences/laureates/2009/ostrom-lecture.html.

C. Otto, S. Willner, L. Wenz, K. Frieler, and A. Levermann.
Modeling loss-propagation in the global supply network: The dynamic agent-based model acclimate.
Journal of Economic Dynamics and Control, 83:232 – 269, 2017.
doi:https://doi.org/10.1016/j.jedc.2017.08.001.

M. Papathoma-Köhle, T. Ulbrich, M. Keiler, L. Pedoth, R. Totsching, T. Glade, S. Schneiderbauer, and U. Eidswig.
Vulnerability to Heat Waves, Floods, and Landslides in Mountanious Terrain. Test Cases in South Tyrol.
In J. Birkmann, S. Kienberger, and D. E. Alexander, editors, *Assessment of Vulnerability to Natural Hazards*, chapter 8. Elsevier, 2014.

PAPI.
Programme d'actions de prevention des innondations 2015-2020.
Technical report, Syndicat Mixte des Milieux Aquatiques et des Rivieres, 2014.

D. C. Parker, D. G. Brown, J. G. Polhill, P. J. Deadman, and S. M. Manson.
Illustrating a new conceptual design pattern for agent-based models of land use via five case studies—the MR POTATOHEAD framework.
In A. López Paredes and C. Hernández Iglesias, editors, *Agent Based Modelling in Natural Resource Management*, chapter 3. INSISOC. Madrid, Mar. 2008.
ISBN 978-84-205-4560-8.

M. Pelling, A. Maskrey, P. Ruiz, and L. E. Hall.
Reducing disaster risk: A challenge for development. a global report.
Technical report, United Nations Development Programme. Bureau for Crisis Prevention and Recovery, 2004.
p. 146.

E. Penning-Rowsell, S. Priest, D. Parker, J. Morris, S. Tunstall, C. Viavattene, J. Chatterton, and D. Owen.
Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal.
Routledge, 2013.

E. C. Penning-Rowsell and C. Green.
New insights into the appraisal of flood-alleviation benefits: (1) flood damage and flood loss information.
Water and Environment Journal, 14(5):347–353, 2000.
doi:10.1111/j.1747-6593.2000.tb00272.x.

J.-M. Pivot and P. Martin.
Farms adaptation to changes in flood risk: a management approach.
Journal of Hydrology, 267(1):12 – 25, 2002.
doi:https://doi.org/10.1016/S0022-1694(02)00136-1.
Advances in Flood Research.

H. Posthumus, C. Hewett, J. Morris, and P. Quinn.
Agricultural land use and flood risk management: Engaging with stakeholders in north yorkshire.
Agricultural Water Management, 95(7), 2008.

H. Posthumus, J. Morris, T. Hess, D. Neville, E. Phillips, and A. Baylis.
Impacts of the summer 2007 floods on agriculture in england.
Journal of Flood Risk Management, 2(3), 2009.

A. Potochnik and B. McGill.
The limitations of hierarchical organization.
Philosophy of Science, 79(1), 2012.

V. Przyluski and S. Hallegatte.
Indirect costs of natural hazards.
CONHAZ WP2 Final Report, SMASH - CIRED, Sept. 2011.

H. C. Putra, H. Zhang, and C. Andrews.
Modeling real estate market responses to climate change in the coastal zone.
Journal of Artificial Societies and Social Simulation, 18(2):18, 2015.
doi:10.18564/jasss.2577.

T. Rashed and J. Weeks.
Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas.
Int. J. Geographical Information Science, 17(6), 2003.

C. L. Redman, J. M. Grove, and L. H. Kuby.
Integrating social science into the long-term ecological research (lter) network: Social dimensions of ecological change and ecological dimensions of social change.
Ecosystems, 7(2), Mar 2004.

P. Reidsma, S. Janssen, J. Jansen, and M. K. van Ittersum.
On the development and use of farm models for policy impact assessment in the European Union – A review.
Agricultural Systems, 159:111 – 125, 2018.

P. Reveau.
Intérêts et limites des études de vulnérabilité.
Risques Naturelles, (36), 2004.

M. Richiardi.
The Promises and Perils of Agent-Based Computational Economics.
Computational Economics 0401001, EconWPA, Jan. 2004.

P. Richmond and D. M. Romano.
Agent Based GPU, a Real-time 3D Simulation and Interactive Visualisation Framework for Massive Agent Based Modelling on the GPU.
In *Proceedings International Workshop on Super Visualisation (IWSV08)*, 2008.
URL `https://wayback.archive-it.org/all/20090115220835/http://www.dcs.shef.ac.uk/~daniela/Paul_abgpu_IWSV_2008.pdf`.

M. G. Rivera-Ferre, M. Ortega-Cerdà, and J. Baumgärtner.
Rethinking study and management of agricultural systems for policy design.
Sustainability, 5(9), 2013.

M. M. Roos, T. T. Hartmann, T. T. Spit, and G. G. Johann.
Constructing risks – internalisation of flood risks in the flood risk management plan.
Journal of Flood Risk Management, 74:145–154, 2017.
doi:10.1111/jfr3.12077.

A. Rose.
Input-output economics and computable general equiibrium models.
Structural change and Economic Dinamycs, 1995b.

A. Rose and D. Wei.
Estimating the economic consequences of a port shutdown: The special role of resilience.
Economic Systems Research, 25(2):212–232, 2013.
doi:10.1080/09535314.2012.731379.

J. Rouchier.
Agent-based simulation as a useful tool for the study of markets.
In B. Edmonds and R. Meyer, editors, *Simulating Social Complexity. A Handbook*, Springer Complexity, chapter 23. Springer, first edition, 2013.

J. Rouchier and E. Tanimura.
When overconfident agents slow down collective learning.
SIMULATION, 88(1):33–49, 2012.
doi:10.1177/0037549711428948.

J. Rouchier, F. Bousquet, M. Requier-Desjardins, and M. Antona.
A multi-agent model for describing transhumance in north cameroon: Comparison of different rationality to develop a routine.
Journal of Economic Dynamics and Control, 25(3):527 – 559, 2001.
doi:https://doi.org/10.1016/S0165-1889(00)00035-X.
Agent-based Computational Economics (ACE).

E. Rykiel Jr.
Testing ecological models: the meaning of validation.
Ecological Modelling, 90(3):229 – 244, 1996.
doi:http://dx.doi.org/10.1016/0304-3800(95)00152-2.

P. A. . Sabatier.
Top-Down and Bottom-Up Approaches to Implementation Research: a Critical Analysis and Suggested Synthesis.
Journal of Public Policy, 6(1), 1986.

S. Sacchelli, S. Fabbrizzi, and S. Menghini.
Climate change, wine and sustainability: A quantitative discourse analysis of the international scientific literature.
Agriculture and Agricultural Science Procedia, 8:167 – 175, 2016b.
doi:https://doi.org/10.1016/j.aaspro.2016.02.090.
Florence "Sustainability of Well-Being International Forum". 2015: Food for Sustainability and not just food, FlorenceSWIF2015.

J. R. Santos, K. D. S. Yu, S. A. T. Pagsuyoin, and R. R. Tan.
Time-varying disaster recovery model for interdependent economic systems using hybrid input–output and event tree analysis.
Economic Systems Research, 26(1):60–80, 2014.
doi:10.1080/09535314.2013.872602.

R. K. Sawyer.
Interpreting and understanding simulations: The philosophy of social simulation.
In B. Edmonds and R. Meyer, editors, *Simulating Social Complexity. A Handbook*, Springer Complexity, chapter 12. Springer, first edition, 2013.

T. Schelling.
Micromotives and Macrobehavior (Fels Lectures on Public Policy Analysis).
W. W. Norton & Company, Inc, 2006 revised edition, 1978.
ISBN 978-0-393-07568-7.

S. Schneiderbauer and D. Ehrlich.
Risk, hazard and people's vulnerability to natural hazards. a review of definitions, concepts and data.
Technical Report EUR 21410 EN, European Commission Joint Research Centre, 2004.

J. Schulze, B. Müller, J. Groeneveld, and V. Grimm.
Agent-based modelling of social-ecological systems: Achievements, challenges, and a way forward.
Journal of Artificial Societies and Social Simulation, 20(2):8, 2017.
doi:10.18564/jasss.3423.

R. Sendhil, A. Jha, A. Kumar, and S. Singh.
Extent of vulnerability in wheat producing agro-ecologies of india: Tracking from indicators of cross-section and multi-dimension data.
Ecological Indicators, 89:771 – 780, 2018.
doi:https://doi.org/10.1016/j.ecolind.2018.02.053.

R. Seppelt, F. Müller, B. Schröder, and M. Volk.
Challenges of simulating complex environmental systems at the landscape scale: A controversial dialogue between two cups of espresso.
Ecological Modelling, 220(24):3481–3489, 2009.

D. Sharma.
The role of cash flow information in predicting corporate failure: The state of the literature.
Managerial finance, 27(4), 2001.

Y. Shoham and K. Leyton-Brown.
Multiagent Systems. Algorithmic, Game-Theoretic, and Logical Foundations.
Cambridge University Press, 2009.
ISBN 0521899435.

H. A. Simon.
A behavioral model of rational choice.
Quarterly Journal of Economics, 69:99–118, 1955.

H. A. Simon.
The architecture of complexity.
Proceedings of the American Philosophical Society, 106(6):467–482, 1962.

H. A. Simon.
Theories of bounded rationality.
In C. B. McGuire and R. Radner, editors, *Decision and Organization*, chapter 8. North-Holland Publishing Company, 1972.

A. Smajgl and O. Barreteau.
Empiricism and agent-based modelling.
In A. Smajgl and O. Barreteau, editors, *Empirical Agent-Based Modelling - Challenges and Solutions*, volume 1, The Characterisation and Parameterisation of Empirical Agent-Based Models, chapter 1. Springer-Verlag New York, 2014a.
doi:10.1007/978-1-4614-6134-0.

A. Smajgl and O. Barreteau.
Framing options for characterising and parameterising human agents in empirical ABM.
Environmental Modelling & Software, 93:29 – 41, 2017.
doi:https://doi.org/10.1016/j.envsoft.2017.02.011.

E. R. Smith and F. R. Conrey.
Agent-based modeling: A new approach for theory building in social psychology.
Personality and Social Psychology Review, 11(1):87–104, 2007.
doi:10.1177/1088868306294789.
PMID: 18453457.

A. E. Steenge and M. Bočkarjova.
Thinking about imbalances in post-catastrophe economies: An input–output based proposition.
Economic Systems Research, 19(2):205–223, 2007.
doi:10.1080/09535310701330308.

A. Tanner and J. Árvai.
Perceptions of risk and vulnerability following exposure to a major natural disaster: The calgary flood of 2013.
Risk Analysis, 38(3):548–561, 2018.
doi:10.1111/risa.12851.

R. Taylor, M. Coll Besa, and J. Forrester.
Agent-based modelling: A tool for addressing the complexity of environment and development policy issues.
Working Paper 2016-12, Stockholm Environment Institute, 2016.
URL `https://www.sei.org/mediamanager/documents/Publications/SEI-WP-2016-12-Agent-based-modelling-MD-final.pdf`.

L. Tesfatsion.
Agent-based computational economics: Growing economies from the bottom up.
Artif. Life, 8(1):55–82, Mar. 2002.
doi:10.1162/106454602753694765.

L. Tesfatsion.
Agent based computational economics: a constructive approach to economic theory.
In L. Tesfatsion and K. L. Judd, editors, *Handbook of Computational Economics*, volume 2, chapter 16. Elsevier B.V., 2006.
doi:10.1016/S1574-0021(05)02016-2.

B. Thorne, H. Hayenga, J. Humphrey, and S. Peirce.
Toward a multi-scale computational model of arterial adaptation in hypertension: Verification of a multi-cell agent based model.
Frontiers in Physiology, 2:20, 2011.
doi:10.3389/fphys.2011.00020.

K. Thywissen.
Components of Risk. A comparative Glossary.
Studies of the University: Research, Counsel, Education (SOURCE). Publication Series of UNU-EHS, (2/2006), 2006.

K. Tierney.
The social roots of risk: Producing disasters, promoting resilience.
Stanford University Press., 2014.

G. L. Tonn and S. D. Guikema.
An Agent-Based Model of Evolving Community Flood Risk.
Risk Analysis, 2017.
doi:https://doi.org/10.1111/risa.12939.

J. Touzard.
Les caves coopératives dans la trasnformation du vignoble languedocien.
Etudes Héraultaises, hors série "Vingt siècles de viticulture...":101–112, 2011.

J. Touzard, C. Gaullier, and F. Jarrige.
Qualité du vin et prix du raisin. Trois lectures du changement dans les coopératives du Languedoc.
Etudes et Recherches sur les Systèmes Agraires et le Développement, 32:19–36, 2001.

J.-P. Treuil, A. Drogoul, and J.-D. Zucker.
Modélisation et simulation á base d'agents: exemples commentés, outils informatiques et questions théoriques.
Dunod, 2008.

S. Tsuchiya, H. Tatano, and N. Okada.
Economic loss assessment due to railroad and highway disruptions.
Economic Systems Research, 19(2):147–162, 2007.
doi:10.1080/09535310701328567.

B. Turner, R. Kasperson, P. Matson, J. McCarthy, R. Corell, L. Christensen, N. Eckley, J. Kasperson, A. Luers, M. Martello, C. Polsky, A. Pulsipher, and A. Schiller.
A framework for vulnerability analysis in sustainability science.
Proceedings of the National Academy of Sciences, 100(14), 2003a.

B. L. Turner, P. A. Matson, J. J. McCarthy, R. W. Corell, L. Christensen, N. Eckley, G. K. Hovelsrud-Broda, J. X. Kasperson, R. E. Kasperson, A. Luers, M. L. Martello, S. Mathiesen, R. Naylor, C. Polsky, A. Pulsipher, A. Schiller, H. Selin, and N. Tyler.
Illustrating the coupled human–environment system for vulnerability analysis: Three case studies.
Proceedings of the National Academy of Sciences, 100(14):8080–8085, 2003b.
doi:10.1073/pnas.1231334100.

N. Udumyan, J. Rouchier, and D. Ami.
Integration of path-dependency in a simple learning model: The case of marine resources.
Computational Economics, 43(2):199–231, Feb 2014.
doi:10.1007/s10614-013-9375-x.

A. Van der Veen and H. S. Otter.
Scales in space.
Integrated Assessment, 3(2-3):160–166, 2002.

J. C. Villagrán de León.
Vulnerability: A conceptual and methodological review.
Studies of the University: Research, Counsel, Education (SOURCE). Publication Series of UNU-EHS, (4/2006), 2006.

F. Vinet.
Crues et inondations dans la France méditerranéenne. Les crues torrentielles des 12 et 13 novembre 1999 (Aude, Tarn, Pyrénées Orientales et Hérault).
Editions du Temps, 2003.

C. Vogel and K. O'Brien.
Vulnerability and global environmental change: Rhetoric and reality.
AVISO - Information Bulletin on Global Environmental Change and Human Security, (13), 2004.

N. J. Vriend.
Ace models of endogenous interactions.
Working Paper 542, Queen Mary University of London. Department of Economics, May 2005.

B. Walker, C. S. Holling, S. R. Carpenter, and A. Kinzig.
Resilience, adaptability and transformability in social-ecological systems.
Ecology and Society, 9(2), 2004.

J. Walpole, J. A. Papin, and S. M. Peirce.
Multiscale computational models of complex biological systems.
Annual Review of Biomedical Engineering, 15, 2013.
doi:10.1146/annurev-bioeng-071811-150104.

H.-W. Wang, P.-H. Kuo, and J.-T. Shiau.
Assessment of climate change impacts on flooding vulnerability for lowland management in southwestern taiwan.
Natural Hazards, 68(2):1001–1019, Sep 2013.
doi:10.1007/s11069-013-0670-6.

T. Welle, Y. Depietri, M. Angignar, J. Birkmann, F. Renaud, and S. Greiving.
Vulnerability Assessment to Heat Waves, Floods, and Earthquakes Using the MOVE Framework: Test Case Cologne, Germany.
In J. Birkmann, S. Kienberger, and D. E. Alexander, editors, *Assessment of Vulnerability to Natural Hazards*, chapter 5. Elsevier, 2014.

A. Wilhite.
Economic activity on fixed networks.
In L. Tesfatsion and K. L. Judd, editors, *Handbook of Computational Economics*, volume 2, chapter 20. Elsevier B.V., 2006.
doi:10.1016/S1574-0021(05)02020-4.

B. Wisner.
Who? what? where? when? in an emergency: notes on possible indicators of vulnerability and resilience: by phase of the disaster management cycle and social actor.
In E. Plate, editor, *Environment and Human Security: Contributions to a Workshop in Bonn*, page 12/7–12/14. Bonn, Germany,, 2002.

S. Wolf.
Vulnerability and risk: comparing assessment approaches.
Natural Hazards, 2012.

S. Wolf, J.-P. Bouchaud, F. Cecconi, S. Cincotti, H. Dawid, H. Gintis, S. van der Hoog, C. C. Jaeger, D. V. Kovalevsky, A. Mandel, and L. Paroussos.
Describing economic agent-based models – Dahlem ABM documentation guidelines.
Complexity Economics, 2(1):63–74, 2013.
doi:10.7564/13-COEC12.

N. Yamano, Y. Kajitani, and Y. Shumuta.
Modeling the regional economic loss of natural disasters: The search for economic hotspots.
Economic Systems Research, 19(2):163–181, 2007.
doi:10.1080/09535310701330191.

L. Yang, Y. Kajitani, H. Tatano, and X. Jiang.
A methodology for estimating business interruption loss caused by flood disasters: insights from business surveys after tokai heavy rain in japan.
Natural Hazards, 84(1):411–430, Nov 2016.
doi:10.1007/s11069-016-2534-3.

K. D. S. Yu, R. R. Tan, K. B. Aviso, M. A. B. Promentilla, and J. R. Santos.
A vulnerability index for post-disaster key sector prioritization.
Economic Systems Research, 26(1):81–97, 2014.
doi:10.1080/09535314.2013.872603.

C. Zheng, Y. Liu, B. Bluemling, J. Chen, and A. P. Mol.
Modeling the environmental behavior and performance of livestock farmers in china: An abm approach.
Agricultural Systems, 122:60 – 72, 2013.
doi:https://doi.org/10.1016/j.agsy.2013.08.005.

Data and Databases

Agreste.
Recensement agricole 2010.
Technical report, 2011.

Atlas des Zones Inondables.
Ministère de la transition ecologique et solidaire.
URL `http://www.georisques.gouv.fr/dossiers/telechargement/azi`.

CCMSA.
Conférence de presse de rentrée de la CCMSA.
[Online press release], oct 2017.
Last access: January 2018.

CER France.
Références technico-économiques d'une vigne palissée en Languedoc Roussillon, 2014 edition, 2014.

CER France.
Références technico-économiques d'une vigne palissée en Languedoc Roussillon, 2017 edition, 2017.

Corine Land Cover.
European Environment Agency, 2012 edition.
URL https://land.copernicus.eu/pan-european/corine-land-cover.

FADN.
(Farm Accountancy Data Network).
European Comission.
URL http://ec.europa.eu/agriculture/rica/.

R. J. Folwell and M. A. Castaldi.
Bulk winery investment and operating costs.
Agricultural Research Center, College of Agricultural, Human, and Natural Resources Sciences, Washington State University, Pullman, Washington, 2004.

FranceAgriMer.
Observatoire de la viticulture française, 2012.
Last access: December 2016.

FranceAgriMer.
Constatation nationale des prix moyens d'achat de vin en vrac. Campagne vitivinicole 2015-2016, April/Mars 2016.

FranceAgriMer.
Les chiffres de la filière viti-vinicole 2006/2016.
Technical report, 2017.

INSEE.
Structure de l'emploi total par grand secteur d'activité en 2016.
Institut national de la statstique et des études économiques, 2016.
URL https://www.insee.fr/fr/statistiques/2012798#titre-bloc-1.

Registre parcellaire graphique.
Institut National de l'Information Géographique et Forestière, 2012 edition.
URL http://professionnels.ign.fr/rpg#tab-3.

GASPAR database.
Ministère de la transition ecologique et solidaire.
URL http://www.georisques.gouv.fr/dossiers/telechargement/gaspar.

RETINA.
Interviews from project Résilience des territoires face à l'inondation Pour une approche préventive par l'adaptation post-événement (RETINA), 2014-2016.
12 interviews focused on wine sector, vinegrowing and/or cooperative activities.

Coding environments

F. Mittelbach, R. Schöpf, C. Rowley, D. Carlisle, J. Braams, R. Fairbairns, M. Høgholm, J. Bezos, W. Robertson, J. Wright, B. Le-Floch, and E. Gregorio.
LaTeX.
The LaTeX3 project.

URL https://www.latex-project.org/.

R Core Team.
R: A Language and Environment for Statistical Computing.
R Foundation for Statistical Computing, Vienna, Austria, 2017.
URL https://www.R-project.org/.
Versions 3.1.2 "Pumpkin Helmet" to 3.4.4 "Someone to Lean On".

U. Wilensky.
NetLogo.
Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL., 1999.
URL https://ccl.northwestern.edu/netlogo/.
Version 5.3.1.

Technical references, packages and libraries

LaTeX Class and packages.
Class: *Memoir*
Packages: *amsfonts, amsmath, amssymb, amsthm, babel, bibtopic, booktabs, calc, color, comment, enumitem, eurosym, flafter, fontenc, footmisc, framed, geometry, glossaries, graphicx, hyperref, import, inputenc, memhfixc, microtype, moresize, multirow, natbib, pdfpages, placeins, rotating, subcaption, tabularx, tabulary, tcolorbox, wrapfig, xcolor.*

A. Baddeley, E. Rubak, and R. Turner.
Spatial Point Patterns: Methodology and Applications with R.
Chapman and Hall/CRC Press, 2015.

R. Bivand and N. Lewin-Koh.
maptools: Tools for Reading and Handling Spatial Objects, 2017.
URL https://CRAN.R-project.org/package=maptools.
R package version 0.8-41.

R. Bivand and C. Rundel.
rgeos: Interface to Geometry Engine - Open Source (GEOS), 2017.
URL https://CRAN.R-project.org/package=rgeos.
R package version 0.3-22.

R. Bivand, T. Keitt, and B. Rowlingson.
rgdal: Bindings for the Geospatial Data Abstraction Library, 2016.
URL https://CRAN.R-project.org/package=rgdal.
R package version 1.2-5.

R. S. Bivand, E. Pebesma, and V. Gomez-Rubio.
Applied spatial data analysis with R.
Springer, NY, second edition edition, 2013.

F. Briatte.
ggnetwork: Geometries to Plot Networks with 'ggplot2', 2016.

URL https://CRAN.R-project.org/package=ggnetwork.
R package version 0.5.1.

C. T. Butts.
network: a package for managing relational data in r.
Journal of Statistical Software, 24(2), 2008.
URL http://www.jstatsoft.org/v24/i02/paper.

C. T. Butts.
network: Classes for Relational Data.
The Statnet Project (http://statnet.org), 2015.
URL http://CRAN.R-project.org/package=network.
R package version 1.13.0.

C. T. Butts.
sna: Tools for Social Network Analysis, 2016.
URL https://CRAN.R-project.org/package=sna.
R package version 2.4.

W. Chang.
R Graphics Cookbook.
O'Reilly Media Inc, first edition, 2012.

D. B. Dahl.
xtable: Export Tables to LaTeX or HTML, 2016.
URL https://CRAN.R-project.org/package=xtable.
R package version 1.8-2.

M. Dowle and A. Srinivasan.
data.table: Extension of 'data.frame', 2017.
URL https://CRAN.R-project.org/package=data.table.
R package version 1.10.4.

GRASS Development Team.
Geographic Resources Analysis Support System (GRASS GIS) Software, Version 7.2.
Open Source Geospatial Foundation, 2017.
URL http://grass.osgeo.org.

Z. Gu, L. Gu, R. Eils, M. Schlesner, and B. Brors.
Circlize implements and enhances circular visualization in R.
Bioinformatics, 30:2811–2812, 2014.

R. J. Hijmans.
raster: Geographic Data Analysis and Modeling, 2016.
URL https://CRAN.R-project.org/package=raster.
R package version 2.5-8.

J. Lemon.
Plotrix: a package in the red light district of R.
R-News, 6(4):8–12, 2006.

Q. E. McCallum and S. Weston.
Parallel R.
O'Reilly Media Inc, first edition, 2012.

E. Neuwirth.
RColorBrewer: ColorBrewer Palettes, 2014.
URL https://CRAN.R-project.org/package=RColorBrewer.
R package version 1.1-2.

R. D. Pen.
R Programming for Data Science.
Leanpub, 2015 edition, 2015.

Revolution Analytics and S. Weston.
doParallel: Foreach Parallel Adaptor for the 'parallel' Package, 2015.
URL https://CRAN.R-project.org/package=doParallel.
R package version 1.0.10.

D. Robinson.
broom: Convert Statistical Analysis Objects into Tidy Data Frames, 2017.
URL https://CRAN.R-project.org/package=broom.
R package version 0.4.2.
O. Santos Baquero.
ggsn: North Symbols and Scale Bars for Maps Created with 'ggplot2' or 'ggmap', 2017a.
URL https://CRAN.R-project.org/package=ggsn.
R package version 0.4.0.

O. Santos Baquero.
ggsn: North Symbols and Scale Bars for Maps Created with 'ggplot2' or 'ggmap', 2017b.
URL https://CRAN.R-project.org/package=ggsn.
R package version 0.4.0.

B. Schloerke, J. Crowley, D. Cook, F. Briatte, M. Marbach, E. Thoen, A. Elberg, and J. Larmarange.
GGally: Extension to 'ggplot2', 2016.
URL https://CRAN.R-project.org/package=GGally.
R package version 1.3.0.

J. Thiele and V. Grimm.
Netlogo meets r: Linking agent-based models with a toolbox for their analysis.
Environmental Modelling and Software, 25(8):972 – 974, 2010.

J. C. Thiele.
R marries netlogo: Introduction to the rnetlogo package.
Journal of Statistical Software, 58(2), 2014.

J. C. Thiele, W. Kurth, and V. Grimm.
RNetLogo: An R package for running and exploring individual-based models implemented in NetLogo.

Methods in Ecology and Evolution, 3(3):480–483, 2012.
URL http://onlinelibrary.wiley.com/doi/10.1111/j.2041-210X.2011.00180.x/abstract.

J. M. Truppia.
tvm: Time Value of Money Functions, 2015.
URL https://CRAN.R-project.org/package=tvm.
R package version 0.3.0.

G. R. Warnes, B. Bolker, and T. Lumley.
gtools: Various R Programming Tools, 2015.
URL https://CRAN.R-project.org/package=gtools.
R package version 3.5.0.

H. Wickham.
Reshaping data with the reshape package.
Journal of Statistical Software, 21(12), 2007.
URL http://www.jstatsoft.org/v21/i12/paper.

H. Wickham.
ggplot2: Elegant Graphics for Data Analysis.
Springer-Verlag New York, 2009.
ISBN 978-0-387-98140-6.
URL http://ggplot2.org.

H. Wickham.
stringr: Simple, Consistent Wrappers for Common String Operations, 2017a.
URL https://CRAN.R-project.org/package=stringr.
R package version 1.2.0.

H. Wickham.
scales: Scale Functions for Visualization, 2017b.
URL https://CRAN.R-project.org/package=scales.
R package version 0.5.0.

H. Wickham, R. Francois, L. Henry, and K. Müller.
dplyr: A Grammar of Data Manipulation, 2017.
URL https://CRAN.R-project.org/package=dplyr.
R package version 0.7.4.

C. O. Wilke.
cowplot: Streamlined Plot Theme and Plot Annotations for 'ggplot2', 2016.
URL https://CRAN.R-project.org/package=cowplot.
R package version 0.7.0.

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List of Abbreviations and Acronyms

Glossary

Business as Usual scenario or Zero Flood Scenario Simulation scenario generated in Netlogo where no flood is simulated. It serves as baseline to be compared with the SFSs and calculate the impacts of the different floods. 64, 158, 242, 340

Central process unit It handles all instructions it receives from hardware and software running on the computer. Also known as processor, central processor, or microprocessor. 39, 340

Cluster Generally speaking a computer cluster refers to a group of computers capable to work as a one single unit. In our context, we are referring to the collection of CPUs used by the parallel processes in R to work simultaneously.
As a particularity R always uses one CPU no matter how many are present on the computer. When we provide our code parallel-ready, R is capable of launching tasks over all the CPUs we indicate when we set up the cluster. 39, 251

Cooperative winemaking system Assortment of vine-growers associated to a cooperative winery, the cooperative winery itself, and the institutional rules that define the relations between them. 4, 8, 25, 28, 38, 42, 64, 118, 170, 212, 232, 340

CORINE Land Cover Geographic database of biophysical soil occupation and use on the territory of the European Union. 43, 44, 339, 340

Damaging flood Hydrological flood in interaction with a given societal system, resulting in flood disasters.(European Environment Agency, 2010). 1, 2

Direct impact Impacts *related to direct exposure to the disaster* (physically flooded in our case). See Brémond et al. (2013). 92

GUI Acronym for Graphical User Interface. Type of interface that allows users to interact with electronic devices or software by direct manipulation of graphical elements, for instance icons, instead of typing command lines. 246, 341

Headless mode Feature of certain kinds of software that allows them to work without GUI. 246

Immediate impact Impacts which occurs during or immediately after the flood event. See Brémond et al. (2013). 91, 92

Indirect impact Impacts *which occurs in a area that has not been exposed to flooding*. See Brémond et al. (2013). 92

Induced impact Impacts which occurs occur later in time after the flood event. See Brémond et al. (2013). 92

Level Defined in the terms of Gibson et al. (2000): *"locations along a scale"*. 5–7, 10, 12–14, 16, 17, 22–25, 28–30, 34, 35, 38, 89, 118–120, 170, 171, 205, 212–214, 218, 226, 256–265

Netlogo Open source multi-agent programmable modeling environment supported by the Center for Connected Learning and Computer-Based Modeling at Northwestern University. 39, 68, 69, 241, 243, 246, 248, 251, 341, 342

Operational cost Costs linked to business' volume of activity. 61, 103, 104, 106, 107, 115

Parallel-ready Code capable of performing tasks simultaneously, using more than one of CPU cores, instead of performing tasks sequentially over one and only one CPU core. 251, 341

Patch Space unit in `Netlogo` terminology. 106

Prone area Area where floods will take place. 163

R Open source programming language and software environment for statistical computing and graphics, supported by the R Foundation for Statistical Computing. 63, 241, 243, 244, 248, 341

Random access memory Part of the computing device where ongoing tasks store data so it can be quickly reached by the device's processor, since it is much faster to read from and write to than other kinds of storage. 340

Random number generator Algorithm for generating sequences of numbers whose properties approximate the properties of sequences of random numbers.. 242, 340

Registre parcellaire graphique Geographic database of agricultural plots in the french territory. 44, 336, 340

RNetLogo Package that embeds NetLogo in R, providing functions to load models, execute commands, and get values from reporters. 241, 251

Scale Defined in the terms of Gibson et al. (2000): *"spatial, temporal, quantitative, or analytical dimensions used by scientist to measure and study objects and processes"*. 4–7, 12–14, 28–30, 38, 118, 170, 212, 213, 342, 343

Simulated Flood Scenario Simulation scenario generated in Netlogo where a flood of a given extent in a given season is simulated. When confronted with the BAUs, they allow disruptions and damages caused by the flood to emerge. 64, 121, 171, 242, 340

Simulation procedure Code dedicated to the simulation of impacts of a flood. It includes the `simulation launcher/iterator`, the `flood simulator` and the `impacts calculator`. 242, 246

Simulation process Entire process of simulation of impacts of a flood, including generation of inputs and output analysis. 242, 246, 251

Socio-ecological system i) a coherent system of biophysical and social factors that regularly interact in a resilient, sustained manner; ii) a system that is defined at several spatial, temporal, and organizational scales, which may be hierarchically linked; iii) a set of critical resources (natural, socioeconomic, and cultural) whose flow and use is regulated by a combination of ecological and social systems; and iv) a perpetually dynamic, complex system with continuous adaptation (Redman et al., 2004).. 4, 6, 64, 222, 340

Structural cost Fixed costs of the business. Resulting from long term decisions and choices. 61, 69, 80, 81, 89, 103, 104, 106, 107, 112, 115, 172, 215, 217

Stylized fact Simplified presentations of empirical findings. Term coined from the work of economist Nikolas Kaldor on economic growth. For a discussion, see Arroyo Abad and Khalifa (2015). 23, 42, 48, 55, 56, 58, 232–234

Tick Time step in `Netlogo` terminology. 68, 69

Topology Arrangement of system's composing entities, pattern of interconnections between them and functional form those connections adopt. 13, 20, 22, 23, 25, 29, 30, 34, 35, 38, 60, 64, 119, 120, 212, 227

Vegetative phase Plant's phase of growth between its germination and its blossoming. 24

Water Framework Directive Directive proposed by the European Commission, published on 22 December 2000, that aims for good qualitative and quantitative status for all ground and surface waters (rivers, lakes, transitional waters, and coastal waters) in the EU. See DIRECTIVE 2000/60/CE. 340