Conséquences et gestion des risques sanitaires épidémiques: Application à la production animale bretonne

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CONSEQUENCES ET GESTION DES RISQUES SANITAIRES EPIDEMIQUES : APPLICATION A LA PRODUCTION ANIMALE BRETONNE

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Sommaire

Introduction générale

Parmi les questions de santé publique, la lutte contre les maladies transmissibles occupe une place centrale. Les vecteurs de transmission de maladies sont divers, et l'alimentation en est un des premiers ; la sécurité sanitaire des aliments est ainsi au cœur de ces préoccupations. Du champ à l'assiette, nombreux sont les facteurs pouvant altérer la qualité sanitaire des productions alimentaires : mauvaises conditions de manipulation ou de stockage des aliments, présence d'agents néfastes (pesticides, médicaments) dans la nourriture, contamination des aliments par l'eau ou par des animaux nuisibles, rupture de la chaîne du froid entraînant le développement de microorganismes, animaux d'élevage malades. Les sources de contamination sont nombreuses au sein même de l'activité agricole ; la santé et la protection des animaux et végétaux sont ainsi capitaux pour la sécurité sanitaire des aliments.

En santé animale, on distingue généralement deux types de maladies : les maladies endémiques, qui sont celles habituellement persistantes sur le territoire, et sont considérées comme les maladies classiques d'élevage, et les maladies épidémiques, moins fréquemment présentes, mais dont la prévalence peut augmenter rapidement et occasionner des pics de maladie. Ces dernières constituent un risque de production aux implications nombreuses. Tout d'abord, l'occurrence d'une épizootie[1], comme par exemple la fièvre aphteuse, la fièvre catarrhale ovine ou la grippe aviaire, constitue un risque sanitaire et économique pour les exploitations touchées, de par son impact sur l'état des troupeaux et sur leur productivité. Ce risque de production peut ensuite affecter les élevages de fermes avoisinantes, par la propagation de la maladie à plus ou moins grande échelle. Sous l'effet de politiques de gestion (mesures de lutte contre la maladie, confinement des élevages exposés, restrictions aux échanges), le risque économique se diffuse à l'ensemble de la filière animale touchée. Par voie de conséquence, les industries d'amont (e.g. alimentation animale) et d'aval (e.g. industries bouchères) liées au secteur d'élevage touché sont également touchées par ce risque. Par ailleurs, la médiatisation de la maladie et la perception du risque sanitaire par les consommateurs fait naître des craintes vis-à-vis de la qualité sanitaire des produits animaux, voire des craintes de transmission de la maladie aux humains. Ces craintes influent sur les comportements de demande, entraînant généralement une baisse et un détournement des choix de consommation vers des substituts. Ainsi, la survenue d'une maladie épidémique peut affecter l'ensemble des marchés liés à la production animale, voire s'étendre à d'autres

[1] Les épizooties sont aux animaux ce que les épidémies sont à toutes les espèces animales, humains inclus. Dans la suite du texte, les deux termes sont employés indifféremment.

secteurs non agricoles ou alimentaires, tels que le tourisme et les transports, dans le cas de crises sanitaires de grande ampleur.

En Europe, certains bassins de production agricole témoignent d'une concentration géographique des productions animales. La survenue d'épidémies d'élevage constitue pour ces régions un choc économique conséquent, aux répercussions fortes sur la stabilité des filières animales et de l'économie locales. La déstabilisation brusque des niveaux d'offre et de demande peut occasionner des variations importantes du revenu de production en élevage, et les différents systèmes de production ne sont pas tous égaux face à ces perturbations de marché. En fonction des animaux élevés, la conduite de troupeaux peut s'adapter plus ou moins rapidement aux fluctuations des cours. Alors que les cheptels avicoles peuvent être renouvelés en totalité en quelques semaines, l'élevage de porcs et à plus forte raison de bovins sont des processus pluriannuels, pour lesquels l'obtention d'animaux productifs adultes nécessite des investissements lourds et/ou un temps de croissance des animaux incompressible. Ainsi, en fonction de la durée du cycle de vie, de la mobilité des animaux et de leur coût, la déstructuration des cheptels en raison d'une crise sanitaire peut avoir des effets de long terme au sein des élevages dont les marchés sont touchés par la crise.

La survenue d'une épizootie ne constitue donc pas un évènement anodin, tant le risque agricole initial peut avoir des répercussions sur l'ensemble des marchés et sur l'équilibre économique d'un territoire. C'est un évènement potentiellement catastrophique, dont un exemple probant est celui de la crise de la vache folle. L'encéphalopathie spongiforme bovine (ESB) est apparue en Grande-Bretagne en 1986 et y a atteint un pic épidémique en 1992, où près de 37000 animaux ont été déclarés malades (OIE). Jusqu'au début des années 2000, la maladie a été présente en Grande-Bretagne et des cas d'animaux atteints ont également été recensés ailleurs en Europe, en Amérique du Nord, au Proche Orient et en Asie. Outre les abattages massifs, des mesures d'embargos sanitaires et des boycotts ont été décidés pour les produits animaux en provenance des pays où la maladie était apparue. L'ampleur de la maladie a entraîné une crise économique pour les filières bovines, qui ont subi des chutes de consommation importantes. Des secteurs non agricoles ont également pâti de cette crise, et on a observé, à la suite de cette crise, un baisse de fréquentation touristique en Grande-Bretagne et en Irlande (Blake et al., 2002 ; O'Toole et al., 2002, Thompson et al., 2002).

Le coût économique lié à l'apparition d'une épizootie dépasse donc le simple cadre des dépenses d'intervention sanitaire, et comprend ses impacts potentiellement lourds sur l'ensemble des marchés du territoire concerné. Le maintien de la qualité sanitaire des productions agricoles constitue donc une préoccupation importante, qui engage la vigilance de tous les acteurs des filières de production. En France et en Europe, les mesures de prophylaxie sont nombreuses ; elles comprennent le suivi de la qualité sanitaire des productions agricoles, la traçabilité des aliments et l'identification des animaux d'élevage, l'engagement des agriculteurs à suivre des codes de bonnes pratiques.

Néanmoins, même si ces mesures tendent à en prévenir l'apparition, des épidémies d'élevage surviennent de temps à autres, pour lesquelles de nombreuses mesures politiques de gestion et de couverture existent en Europe, afin d'en limiter l'effet économique sur les filières touchées. Concernant le soutien aux filières, la couverture des pertes directes (e.g. compensation des pertes de production, aide à la reconstitution de cheptels) fait l'objet d'actions diverses, allant d'initiatives agricoles privées (e.g. fonds des Groupements de Défense Sanitaire en France) au déblocage d'aides publiques d'urgence, en passant par le recours à des assurances privées (Espagne) ou des systèmes de compensation mixtes publics/privés (Allemagne). La couverture des pertes de marché n'est, elle, pas tant développée. Le cadre de l'intervention publique se résume globalement au déblocage d'aides *ad hoc*, et non à un schéma d'aides défini, ce qui limite par ailleurs d'autant plus le développement d'initiatives privées de couverture des pertes de marché.

La survenue d'une épizootie a donc des effets de marché potentiellement importants et durables sur les filières animales et sur les territoires, constituant une préoccupation grandissante pour les pouvoirs publics. L'enjeu de cette thèse est la mise en évidence des effets de long terme d'un tel évènement catastrophique, et leur prise en compte dans l'estimation globale des effets d'une épidémie d'élevage sur un territoire. Elle vise à enrichir la connaissance sur les perturbations des filières animales causées par les crises sanitaires, tout autant que sur les impacts macroéconomiques et les effets de bien-être qui en résultent. Cette recherche économique est alors à même de guider les pouvoirs publics vers des politiques de gestion du risque sanitaire adaptées à l'ampleur et aux particularités de ce type de choc, pour *in fine* participer à améliorer la résilience des régions économiques touchées.

L'objectif majeur de la thèse est de rendre compte de la plus ou moins grande réactivité des agents économiques face à un tel évènement, dans un contexte où ces derniers sont soumis à des contraintes liées aux systèmes de production (particulièrement en élevage) et à des contraintes relatives aux marchés de facteurs de production. L'intégration d'effets retardés de crises sanitaires, qui perturbent les économies sectorielles sur le long terme, permet une identification précise de l'ensemble des conséquences de marché entraînées par un choc épidémique d'élevage, aussi bien en termes de revenus agricoles qu'en termes d'impact macroéconomique, à l'échelle des territoires.

Si les crises sanitaires ont d'importants effets économiques massifs dans l'immédiat, de récentes analyses ont montré qu'elles entraînaient des dynamiques économiques particulières, notamment en raison des délais nécessaires d'ajustement des systèmes d'élevage (e.g. Niemi et Lethonen, 2011). Or ces ajustements économiques supposent des décisions de consommation et d'investissement spécifiques. L'apport de la modélisation des dynamiques de capital à la ferme, et des dynamiques de troupeau, est d'introduire la question des disponibilités de crédit, et du risque de faillite des agriculteurs. Cette modélisation a pour objectif de montrer les effets retardés d'un choc de marché ponctuel et de grande ampleur, en particulier en termes de besoins nouveaux en capitaux pour les agriculteurs. On montre ainsi le rôle important des secteurs bancaires et de la capacité d'emprunt des agriculteurs, afin d'assurer la solvabilité des entreprises agricoles après ce type de choc.

Cette thèse apporte également une contribution méthodologique en intégrant les comportements dynamiques des éleveurs dans un cadre d'équilibre général calculable (EGC). Ce choix de modélisation est justifié dans le contexte de régions d'élevage, où l'apparition d'une maladie animale peut influer sur l'ensemble de l'économie d'un territoire, étant donné la multiplicité des effets d'une crise sanitaire et l'interdépendance des secteurs agricoles et agroalimentaires. La modélisation en EGC dynamique est à même de rendre compte des évolutions de long terme des décisions économiques des éleveurs et de leur interdépendance avec le reste des marchés, comme cela a été notamment relevé par Philippidis et Hubbard (2005). L'apport méthodologique de cette modélisation est d'introduire les décisions intertemporelles d'élevage et d'investissement dans un modèle d'EGC, sous l'influence de marchés imparfaits de facteurs de production. L'intégration des dynamiques économiques de capital et de cheptels permet alors de figurer les décisions de long terme des agents, et en particulier des éleveurs. L'intérêt de la modélisation en EGC dynamique est de montrer d'une part les interactions sectorielles liées à des décisions d'élevage, et d'autre part les conséquences de chocs de marché en termes de bien-être économique régional. Cette modélisation révèle l'incidence globale de contraintes sur les facteurs de production en cas de choc de type épidémique. D'une part, la modélisation de la plus ou moins grande facilité d'accès au capital met en relief le poids des organismes de crédit et le rôle des emprunts dans les décisions économiques de long terme. D'autre part, la modélisation de rigidité ou de flexibilité des salaires dans les secteurs d'amont et d'aval montre leur effet sur l'endettement supplémentaire nécessaire au maintien des rémunérations. La modélisation permet alors de mesurer le coût global potentiel d'une maladie d'élevage et ses effets de bien-être, et donc d'indiquer aux pouvoirs publics les implications économiques et financières qui en découlent, ainsi que le rôle et les leviers de soutien aux filières capables de soutenir la compétitivité des entreprises régionales.

Cette thèse propose de donner un éclairage sur ces questions, et elle est structurée comme suit. Le premier chapitre est consacré à la présentation de son contexte. Elle permet de définir les composantes de risque économique liées à l'apparition d'une épidémie d'élevage, ainsi que les développements et les enjeux de systèmes de gestion permettant de contenir l'effet d'un tel évènement catastrophique. Nous montrons, au travers d'une revue critique de travaux en économie de la santé animale, les développements permettant de comprendre l'impact économique de maladies animales, tant à la ferme pour les élevages touchés qu'à l'échelle des marchés. Il ressort de cette analyse l'intérêt d'une connaissance publique des conséquences d'une épizootie, et son importance pour la définition de politiques de gestion et de couverture des risques. L'étude des effets de long terme d'une épizootie a ainsi vocation à éclairer sur les changements de fonds qu'un événement de marché catastrophique entraîne. On met ainsi l'accent sur la pertinence d'une gestion rapide des coûts qui limite les conséquences induites et l'entraînement d'effets de marché.

Dans le deuxième chapitre, nous présentons un travail théorique sur les dynamiques de marché post-crise sanitaire. La survenue d'une épidémie est un évènement difficile à anticiper, les ajustements et la stabilisation de marchés nécessitent du temps dans les systèmes d'élevage. La modélisation des comportements agricoles inclut ici les décisions d'élevage, d'investissement et de consommation et les contraintes de capital qui y sont associées. On met ainsi en relief l'accroissement des charges d'entreprise liées à un important choc de marché en élevage, la difficulté à maintenir les niveaux d'actifs et l'endettement supplémentaire qui peut en découler. On montre que l'accès au crédit est un élément capital pour le retour à un équilibre de marché viable pour les éleveurs, et qu'au contraire la survenue d'une épizootie détériore le ratio actifs/dette des fermes et peut entraîner un risque de faillite.

Le troisième chapitre présente le travail de modélisation (EGC) adapté au cas de la région Bretagne. Cette région française témoigne d'une concentration forte des productions animales. Elle représente notamment plus de la moitié de la production porcine nationale, et concentre également 20% des troupeaux bovins en France. Les problématiques liées à la santé animale y revêtent donc une importance première, car une part significative de l'activité économique dépend des secteurs de l'élevage. La modélisation en EGC dynamique des conséquences d'une maladie épidémique d'élevage nécessite d'une part le recueil et la création de données régionales adaptées, et d'autre part la spécification de relations économiques reflétant les décisions de l'ensemble des agents d'une économie. La caractérisation fine des interactions de marché au sein des activités agricoles et agroalimentaires a nécessité un travail important concernant l'élaboration d'une matrice de comptabilité sociale (MCS) centrée sur l'agriculture et les IAA bretonne, dont nous décrivons les composantes. La structure générale du modèle est donnée ensuite, faisant état des décisions de production, de consommation des ménages et de l'équilibre macroéconomique de la Bretagne.

Le quatrième chapitre propose une mise en œuvre de ce modèle, au travers d'une simulation d'épidémie de fièvre aphteuse. La simulation porte sur le choc économique relatif à l'épidémie (chocs sur l'offre, sur les échanges, sur la demande) de courte durée, et propose une évaluation de ses coûts économiques à long terme. Elle met en évidence le poids de l'élevage dans l'économie bretonne et les effets importants d'une épizootie sur les marchés économiques régionaux. En particulier, l'accent est mis sur la difficulté au retour rapide à un état stationnaire en raison de contraintes de marché. Ces contraintes sont à la fois liées aux troupeaux et à l'effort nécessaire pour leur renouvellement, liées à l'investissement nécessaire à la compensation des pertes et au retour à la compétitivité des entreprises, et liées au maintien de la rémunération des emplois des secteurs touchés. On traduit ainsi les effets de bien-être que sous-tend un choc épidémique en Bretagne, et on souligne en creux la fragilisation de l'économie suite à un évènement de marché catastrophique, hors mesures de gestion.

Le cinquième et dernier chapitre de cette thèse montre le rôle de politiques de soutien aux agriculteurs. Elle met en perspective, dans le cadre breton, les effets du déblocage de subventions publiques pour la compensation des pertes de marché dues à une épidémie, en comparaison avec la mise en place d'une politique intégrant la participation des agriculteurs via la création de fonds mutuels. Ces simulations comparatives mettent en évidence divers leviers pour l'action publique, et donnent un éclairage sur les mesures en discussion au niveau européen pour une politique harmonisée de gestion du risque sanitaire, dans le cadre de l'évolution de la Politique Agricole Commune.

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Chapitre 1 Quels enjeux pour l'évaluation et la gestion des risques épidémiques en santé animale ?

Résumé

Les conséquences économiques des épidémies d'élevage ont longtemps été étudiées à des fins d'estimation des coûts vétérinaires de mesures préventives et curatives. Dans ce chapitre, nous montrons que ce risque catastrophique de maladie peut avoir de vastes conséquences de marché, et que les systèmes de gestion des risques restent, dans le contexte européen actuel d'accroissement des échanges, relativement limités pour en compenser les impacts économiques de long terme. Grâce à un examen détaillé de la littérature, nous présentons les principaux développements de la recherche économique mettant en évidence les conséquences économiques des épidémies animales comme la fièvre aphteuse. Nous reconnaissons que très peu d'études ont porté sur la dynamique économique et sur les effets à long terme survenant après l'apparition d'une maladie épidémique. Nous discutons ensuite de la pertinence d'une approche dynamique permettant de révéler que la déstructuration soudaine des marchés du bétail affecte à plus long terme les dynamiques de production ainsi que l'ensemble du secteur agricole. Les implications financières et les contraintes de marché peuvent révéler leur importance et restent peu étudiées dans les études sur les épidémies d'élevage. Nous insistons sur l'intérêt croissant d'une approche dynamique d'équilibre général calculable pour révéler les effets globaux des épidémies sur l'ensemble de l'économie. Cette recherche novatrice soulève des défis importants pour l'évaluation et la mise en œuvre des politiques de gestion des risques.

Ce chapitre fait l'objet d'un article scientifique, coécrit avec Stéphane Krebs, et présenté au 13^{e} Congrès EAAE, Zurich, 2011.

Introduction

Western France is a major livestock production area in Europe. Livestock activities (beef, pork and poultry production and to a lesser extent sheep and goat production) take a prominent place and are an essential part of regional economy. The stability of livestock sectors is therefore of particular importance to regional economic balance. The occurrence of epidemic animal outbreaks –such as Foot and Mouth Disease (FMD)– thus constitutes a risk that is highly detrimental to the regional agricultural economy. Epidemic diseases can indeed result in significant market disruption, inducing abrupt changes in the behavior of economic agents, sometimes lasting in the long-run.

The economic risk associated with epidemic disease risk may indeed be considered as systemic and catastrophic. In contrast with a hazard that affects a limited number of farms (idiosyncratic risk), this economic risk has a systemic dimension. In a short time, epidemic diseases can reach a large number of livestock farms, the whole market, and even the wide regional economy, both for reasons of pathology (impact on productivity, communicability of the disease) and for reasons of control measures (e.g. marketing restrictions on animals and animal products). Epidemic disease outbreaks are hardly predictable and have a low probability of occurrence. As a consequence, the economic risk can also be described as catastrophic as the occurrence of such an event has important economic consequences, going far beyond the losses of production and the costs of measures of disease control. They may indeed affect all firms engaged in the animal production chain (from the farm supply sector to the retailing sector) and by extension, the entire regional economy due to multiplier effects of those market impacts, and regulatory requirements.

This context highlights the importance of the implementation of effective mechanisms for risk management when epidemic disease outbreaks occur, especially in intensive livestock production areas.

Based on the recent developments of economic literature, this paper aims at identifying the economic behaviors and phenomena following an epidemic outbreak, in order to reveal the extent of the economic consequences of epidemic risks, and ultimately enhance the expertise to design management policies.

This article is organized as follows. We first look at the economic consequences of the epidemic diseases and draw up a quick inventory of the current measures of intervention, highlighting the heterogeneity of policies implemented at the European level. We then provide a review of economic studies for the evaluation of the economic consequences of epidemic outbreaks, for control strategies and risk management. Thanks to the identification of the main shortcomings of the analysis, we highlight the salient points of management methods of epidemic risk, and economic behavior barely touched upon in the field of animal health, including the importance of taking into account the economic dynamics generated by epidemics and their management. This paper allows us to conclude by outlining new perspectives in the field of economic research and of health risk management.

1.1 Public and private management of epidemic risk

At the European and global scale, livestock production is concentrated in a limited number of production areas. Animal densities are high and productions are particularly oriented towards export markets. Within these areas, the control of animal diseases raises a major issue because of the economic weight of livestock farming and the concentration of upstream and downstream industries, since an epidemic disease outbreak could have disastrous consequences on agriculture and local economic dynamism. Currently, this vulnerability to health hazards tends to be reinforced by the increasing openness of agricultural markets and increased flows of living animal and fresh meat resulting. It also tends to be enhanced by global warming, that promotes a shift towards the north of diseases originally coming from warmer geographic areas, as it was recently the case with bluetongue in Europe.

This section focuses on the health risks stemming from the epidemic and on the economic consequences of their occurrence on infected areas and agricultural markets. We also address the issue of management modes of this epidemic risk, noting the role of the public and private stakeholders in the management of such health crises.

1.1.1 Epidemic diseases: what about markets?

Livestock diseases cause many market distortions. A recent health crisis in the United Kingdom highlights the magnitude of the economic effects of animal disease outbreaks, and illustrates the potential implications of a health crisis. In the UK, the 2001 FMD outbreak led to the slaughter of 2,382,000 animals, including more than 1,800,000 sheeps, about 400,000 bovines and 110,000 pigs. The consumption of sheep meat dropped by 25% to 30% in the following months. To avoid the introduction of the disease, the French health authorities carried out the slaughter of 50,000 animals (mainly sheeps), imported or having been in contact with them defensively. For 2001 alone, UK gross domestic product was estimated to fall by more than 3 billion Euros (Thompson et al., 2002). The media impact of this crisis led to a decline of 9 billion Euros of tourism spending in that year, and these sectors only regained their previous levels of activity until several years later. This specific example is not isolated and many similar cases can also be described.

In the present section, we aim at providing keys for the understanding of the economic determinants of epidemic diseases, and at defining the sources of market risk associated.

1.1.1.1 Economic context and risk factors

Farms exposure to animal health risk is promoted by risk factors such as structural, political or geographical conditions. First, the trade liberalization facilitates the exchange of vectors of pathogens through the trade of living agricultural products. In recent decades, the Common Agricultural Policy (CAP) has been able to protect the European market and to limit the exposure of sectors to international competition, thanks to subsidies for exports and the establishment of tariff barriers to imports. In other words, this economic environment could help market prices not to suffer from significant changes. Accordingly, livestock farms have had an economic incentive to specialize their production and to increase the size of farms operations in order to realize scale economies.

However now, the phasing out of protection instruments of the CAP and the opening of European markets make livestock sectors more vulnerable to market fluctuations. Specialized livestock farms only derive their viability from their animal product; as a consequence they cannot benefit from an insurance effect related to a diversification of production facilities. Moreover, the growing transit of agricultural products increased exposure to animal health risks. The concentration of livestock production in limited geographical areas also contributes to ease the disease transmission from animal to animal, and from farm to farm.

1.1.1.2 Market risks

The occurrence of animal disease causes risks of varying magnitude in animal production chains. Endemic diseases are considered as commonly present across geographical areas. Their impact is generally limited to the infected farms and their control is mostly left to the (individual or collective) initiative of farmers. At the opposite, epidemic diseases occur in commonly disease-free regions, and as they are highly transmissible their occurrence may be highly detrimental to the livestock sector. This section focuses on epidemic non-zoonotic diseases such as FMD. The occurrence of this kind of disease implies a complex interplay of direct and indirect economic consequences (Junker et al., 2009). The highly contagious nature of certain diseases and/or their zoonotic potential may justify a public intervention. A list of diseases considered as contagious is established in the French *Code Rural* (Article n°D223-21), as for the World Organization for Animal Health.

The **direct effects** of such a disease focus on the supply levels of animals and animal products in the infected country. The supply of animals and animal products is directly impacted, because of the disease consequences on livestock (mortality, morbidity), which affect the technical and economic performance of the farms.

Indirectly, the policies implemented to control the disease have effects on both the supply and the demand for animals and animal products. Indeed, the control strategy has a depressive effect on the supply level, through the decisions of curative and preventive livestock slaughter, quarantine or bans and restrictions on marketing of animals and animal products. These measures include not only the infected farms, but also those located in a wider area (from a local to the national level).

A disease outbreak and the associated control measures also affect the demand side, since they can lead to a loss of consumer confidence in some animal products, and lead to fears linked to the disease, even in the absence of proven risk for human health. Nevertheless, the disease may have beneficial effects for the animal production sectors not directly concerned by the epidemic, since consumers can shift consumption toward animal products whose image is not tarnished by the disease. As an illustration, we can mention the case of the 1996 health crisis in Germany due to bovine spongiform encephalopathy, after which the beef consumption declined in favor of the pig sector. The economic impact of disease occurrence in the markets is difficult to grasp, because it largely depends on the extent of the impact on levels of supply and demand.

In an open economy and in the absence of a health event, the supply of livestock products can exceed the level of demand in the case of an exporting country. As a consequence, the coexistence of both domestic and international demands may lead to higher prices on the domestic market because of this high level of demand. In this situation, the exporting position of producers dictates the domestic market equilibrium; producers benefit from a market power. When an epidemic disease occurs and causes export restrictions, the amounts originally sold on the international markets remain available only on the domestic market. Consequently, the situation of oversupply in the domestic market leads to falling prices. While the welfare of consumers increases, on the contrary, there is a net loss of surplus to producers. Producers lose their flexibility for marketing opportunities (Schoenbaum and Disney, 2003). However, for importing and disease free countries, the decline in imports creates a situation of excess demand that can help to support prices and/or call a change in the geography of trade.

The economic disruption resulting from an outbreak encourages both private and public stakeholders to develop risk management systems for farms in the relevant markets.

1.1.2 Defining devices for epidemic risk management

In the European Union (EU), the economic policies of epidemic risk management and hedging strategies implemented by different EU countries are not harmonized. Even though some experienced systems are set for the management of direct economic losses due to disease, coverage for loss of market suffers from some limitations.

1.1.2.1 Covering direct losses

The coverage of direct losses is meant to include the compensation for the costs of slaughter, the aid for restocking and the compensation for production losses (milk, breeding of livestock ...).

In France, the coverage of those losses is almost exclusively in the public domain. When an outbreak occurs or when an exotic disease emerges, the government has historically played the role of insurer for compensation for economic losses. However, with the emergence or resurgence of certain animal diseases in the recent period, professional associations of health protection successively established a “FMD credit” in 1992 and an “animal health solidarity fund” in 2007 after the 2006 bluetongue outbreak. Nevertheless, most of the efforts of support remains in the public domain as membership in these funds is only voluntary.

With the exception of Denmark, which has a public device similar to that of France, EU compensation schemes involving farmers through levies exist in Germany, Belgium, Greece, Ireland and the Netherlands. The German system of state compensation is based on the tax levies to farmers and compensation amounts are limited; farmers also resort to private systems of insurance for uncovered losses. The Spanish system is based on voluntary private insurance, whose premiums are partially supported by the state.

Since 2009 however, Article 70 of the "Health Check" of the Common Agricultural Policy (CAP) provides a common framework for crop insurance animals and plants. It states that:

> "*Member States may grant a financial contribution to premiums for […] animal [...] insurance against economic losses caused by [...] animal or plant diseases.*" (OJEU, 2009)

The considered economic losses concern bans on marketing and production losses of sick and slaughtered animals. Article 71 of the "Health Check" of the CAP also provides for the establishment of mutual funds for animal disease outbreaks. It aims at supervising the public support to agricultural mutual funds for the compensation of economic losses related to a disease outbreak. This is to harmonize national measures whose implementation has already been initiated in many countries of the EU and make mandatory membership in mutual funds.

1.1.2.2 Covering indirect losses

Indirect losses due to epidemic diseases involve all stakeholders in the sector concerned by the epidemic. The coverage aims at supporting the market as it is destabilized and causes large drops in prices and thus reduces the farm income.

• Public intervention

French public authorities have no clear procedure to insure indirect losses due to epidemics. We generally observe specific releases of funds to support the productive sectors when market conditions weaken the agricultural sector at a systemic scale.

At the European level, Articles 44 to 46 from the recent Disposition No. 1234/2007 establishing a Common Market Organization (CMO) provide exceptional measures to support the market in the sectors of animal production. Article 44 states that:

> "*The Commission may adopt exceptional support measures for the affected market in order to take account of restrictions on intra-Community and third-country trade which may result from the application of measures for combating the spread of diseases in animals.*" (OJEU, 2007)

These supports are activated at the initiative of Member States, they only add to national support, and they cannot be implemented unless they are associated with sanitary measures to fight against the disease. Under the same conditions, the Commission may grant financial support to sustain the market during "*disturbances directly attributed to a loss in consumer confidence due to public health, or animal health risks.*" European support to national measures allow the application of principles of solidarity on a larger scale, which is necessary in cases of systemic risks.

• The difficulties of private action

In order to securitize insurance companies facing catastrophic and systemic risks, private reinsurance may be useful. These private-sector firms would play the role of "insurer of insurers"; they are built on the same principle as conventional insurance companies, by pooling uncorrelated risks. However, as the scale of systemic risk increases, as in the case of epidemic diseases, private funds reinsurance cannot always carry out the reinsurance of conventional insurance systems (Meuwissen et al., 2006). In practice, the private reinsurance is little involved in insurance systems linked to health risks, and that is a reason why the EU has recently proposed the previously mentioned public measures of the single CMO.

To conclude this section, the economic consequences of epidemic risks are potentially high as they affect agriculture and other sectors of the economy. Therefore, they are subject to public and private actions, which are sometimes limited. The study of these phenomena is discussed in the literature and actually does highlight the economic impact of animal diseases and their control. Their analysis is detailed in the next section.

1.2 The economic evaluation of the consequences of epidemic disease: literature review

The purpose of this section is to present the main developments in the economic literature relating to epidemic diseases. This work has emerged from veterinary scientists in the 1960's, which progressively assessed the economic cost and benefits associated with these diseases and their control. The methodologies implemented were inspired from accounting methods and have gradually integrated more complex reasoning, taking into account elements of welfare and exceeding the farm level. In this section, we focus on the close relationship between health risk and economic risk, detailing the behavior of the economic agents involved and their implications at the market level.

1.2.1 Brief overview of the analytical tools mobilized

The occurrence of epidemic diseases involves various economic costs and changes, which justify the diversity of approaches used in assessing the economic impact of epidemic diseases and their control. The economic literature provides a variety of tools to address issues of various spatial and temporal scales (Rich, et al., 2005). Thus, economic evaluation can be conducted at the farm level (loss of productivity, control measures put in place), but it can also take into account the impact on trade and prices, the impact in terms of employment or the overall economic welfare. Depending on the perspective chosen, the number and diversity of agents involved vary: from local (farms involved) to international level, via levels of analysis sized to multi-sector, regional or national scales.

Early works were placed on the scale of farms and agricultural complex. Mainly inspired from accounting methodologies, they aimed at estimating the losses caused by diseases around the farm, with some weighing the possible mitigation of these losses against the control strategy implemented. In essence multidisciplinary, this work (like Cost-Benefit Analysis (CBA) or linear programming) intended to participate in developing strategies for the management of veterinary health risks.

They generally omitted the indirect effects induced by the disease, such as the effects on markets (trading volume and price) and the welfare effects, although it seems necessary to understand all the economic consequences attributable to disease epidemics. Understanding these phenomena requires the analysis of economic equilibriums, through partial equilibrium models, input-output matrices, multi-market models, and computable general equilibrium models. The market reactions resulting from the occurrence of an epidemic can have a strong impact on farm structures and on various sectors of the economy. Therefore, it seems necessary that their understanding be fully integrated into management systems of the health risks linked to livestock activities.

1.2.2 Direct effects of epidemic diseases: estimating costs and mitigation strategies

The studies on direct effects of disease are mostly centered on agricultural activity and they are relatively numerous in the field of animal health. They were frequently used to estimate the cost of the epidemic, mostly across the farm, but their level of aggregation may also be higher. They are sometimes combined with epidemiological models to simulate and prioritize different control strategies by determining for each of them the costs and benefits.

1.2.2.1 Cost-benefit analysis and linear programming

Basic CBAs are built on accounting methods to calculate the direct expenditures incurred by the diseases. They are widely used because they are a quick way to assess the specific consequences of disease and of control strategies. In this sense, CBAs are an effective aid to decision for both producers and public authorities and veterinary services. For larger scale studies, farm-scale analyses can be extrapolated to a higher level by combinating CBA with a diffusion model of the disease (Disney et al. 2001). To capture time effects, Perry et al. (1999) conducted a multi-period CBA to assess the costs of management strategies in the case of FMD. However, this type of study remains only suitable in the short-run and it quickly reveals its conceptual inappropriateness for long-run analysis. Indeed, the producer behavior is not explicitly modeled, as well as market interactions between animals and animal products and other agricultural or non-agricultural markets. Using the CBA tools does not allow us to observe the economic behavior implemented in reaction to animal diseases.

Linear programming techniques offer more flexibility and allow for changes in producer behavior over time (e.g. related to the evolution of an epidemic). Based on optimization calculations, this technique allows to define endogenously economic behavior of farmers over time under different constraints, related to the both contexts of production and health. As an example, this method was used by Meuwissen et al. (1999) to estimate the financial consequences of classical swine fever along the production and processing chain. In this sense, linear programming may help to determine the levels of effort needed to face the emergence of epidemics.

CBA and linear programming give precise estimations of the direct costs of the disease. They constitute useful tools to support decision in terms of choice of an optimal control strategy. However, these tools face some methodological challenges for modeling market behavior. Indeed, they remain relevant only if the price effects and spillovers to other industries are negligible (Rich, et al., 2005).

1.2.2.2 Lessons from studies of economic equilibrium

Partial and general equilibrium modeling of behavior of economic agents is likely to provide a more systemic view of the economic impacts of animal epidemics. This kind of modeling contributes to identify optimal strategies for disease management, taking particular account of the potential interconnections between sectors.

Recent studies show that the evolution of the epidemic over time has an economic impact not only on the agricultural sector concerned, but also, on other animal and crop markets (Paarlberg, et al., 2008, Rich and Winter -Nelson, 2007). Indeed, the invasiveness and spread of an epidemic cause economic large scale consequences including the losses incurred by the upstream and downstream sectors of the livestock sector. The high livestock densities also increase the risk of severe economic losses resulting from an epidemic disease (Pendell, et al., 2007). The estimated magnitude of these consequences highlights the importance of preventive public policies and of effective mitigation strategies. More generally, the occurrence of an epidemic disease has a direct impact on the economic welfare of a region (Schoenbaum and Disney, 2003). Indeed, the direct impacts of the disease include among other costs of government control and eradication, production losses, loss of business due to declining supply, and the difficulty of re-access to markets.

A systemic view of the consequences of epidemic then allows the definition of more appropriate policies of risk management. Elbakidze and McCarl (2006) deal with the economic trade-off between prevention and control measures for FMD. The authors show that ex-ante expenditures in preventive strategies may have both economic and veterinary advantages compared to ex-post control costs. They conclude in favor of an effective prevention strategy to reduce the economic consequences of an epidemic.

To conclude, the literature clearly shows the extent of the direct consequences of epidemic disease on the whole agricultural sector, and therefore, stresses the importance of implementing appropriate management systems. Nevertheless, as pointed by Zhao et al (2006), the occurrence of an epidemic outbreak affects market conditions and induces behavioral changes for consumers and producers, as well as trade restrictions. As a result, they impact both on domestic markets (through supply and demand, multiplier effects°...) and on international trade (through volumes and prices of imports and exports). The study of these impacts is considered in the next subsection.

1.2.3 Systemic consequences of epidemic outbreaks

The application of international measures to limit the spread of the epidemic may impact on world agricultural markets. Moreover, the negative media coverage of these diseases can lead to changes in demand behavior, not only on the consumption of agricultural goods, but also on the global attractiveness of the areas concerned by the epidemic. These indirect effects are diffuse but remain fully involved in the destabilization of the markets following an epidemic outbreak. In this subsection we detail the induced effects of animal disease outbreaks analyzed in the economic literature.

1.2.3.1 Sector effects and international effects

Quantifying the impacts of livestock epidemics on the upstream and downstream sectors remains poorly addressed. However, their inclusion stresses the importance of the possible effects of animal health crises on this level, especially for manufacturing industries, and especially for markets mainly turned towards the domestic market as that of beef (Rich and Perry, 2011). The trade implications of an outbreak of FMD affects many other areas related to agricultural livestock, foremost among which there are the animal feeding markets (Paarlberg et al, 2008).

At the international level, the occurrence of an epidemic disease is sometimes accompanied by a decrease of demand for the concerned products. A main reason for this drop comes from health embargoes putted in place to prevent disease spread outside the borders of affected countries. This has been observed during various recent health events. Thus, during the epidemic of classical swine fever epidemic in the Netherlands in 1997-1998, the surplus of pig raising activity dropped because of export restrictions (Mangen and Burrell, 2003). The 2003 Bovine Spongiform Encephalopathy (BSE) outbreaks in Canada and the

United States have also led to restrictions on trade with direct impact on the levels of prices paid to producers (Panagiotou and Azzam, 2010). These two cases of BSE have modified trade patterns in animals and animal products in these traditionally exporting markets. After reopening the Canadian border to beef imports from the United States, the US price level has not returned gradually to its former level, but stabilized at a level of 35% lower than pre-crisis. However, the reopening of trade with Japan has led to greater export than before the outbreak. In the longer term, it was found that the BSE crisis had finally little effect on the domestic prices of livestock. In contrast, the reaction of other governments (Japan, Korea) had a greater impact and trade restrictions have been considered an important factor in lower prices, rather than the reaction of households in the U.S. (Marsh et al., 2008).

Morgan and Prakash (2006) explained the strong international impact of episodes of localized epidemics by the fact that the livestock industries and animal markets are becoming more internationalized, because of the surge in global demand of livestock products and the high concentration of livestock sector in the main exporting geographical areas. Indeed, in case of an epidemic, these factors are responsible for high price disturbances in international markets. Nevertheless, the volumes available on the international markets are poorly affected thanks to a quick increase of supply from free countries. Some countries can indeed benefit from sanitary embargoes; they also have export capacity and are not directly affected by the disease.

These examples of impacts on agricultural markets support the idea that the epidemic risk management should integrate these disturbances. Post-epidemic market shocks have an economic impact that affects the whole livestock market, and they may induce spillovers in the linked industries. Moreover, demand levels for livestock products may be more generally affected by modifications in consumers' behavior.

1.2.3.2 Effects on the demand behaviors

Consumption patterns are influenced by the occurrence of epidemic diseases. They may evolve in a more or less sharp and permanent way as a result of concerns expressed by consumers. Levels of demand for livestock products may shift due to deviations of preferences of domestic demand (Junker et al., 2009). Indeed, animal health crises have an incidence on consumption levels, which fell up to 20% during the recent France FMD crisis

(Lesdos-Cauhapé et al., 2007). Economic modeling can take into account the effects of changing demand on prices and demand levels in agricultural goods.

Demand behaviors remain closely linked to risk perception by consumers (Mazzocchi et al., 2007), not necessarily when the risks for human health are proved. The media coverage of an animal health event is likely to alter the perception that consumers have towards the products concerned. In regard to recent animal health scares, it appears that if the consumer perceives a risk for his health, he can divert his consumption of animal product for a longer or shorter time (Tonsor, et al., 2009), even if the risk to human health is not proven. Nevertheless, this diversion of consumption generally benefits to other animal production sectors. Therefore, the occurrence of epidemic diseases has potentially significant impacts on demand levels, which can variously affect animal production sectors. Böcker and Hanf (2000) explain changes in consumer confidence in the health quality of food in two stages. First, during the first moments after the media coverage of the health crisis, fears of food consumers relate to a wide range of products, which they turn away, possibly in favor of substitutes. In a second time, usually a few months later, there is a partial return of confidence in demand for these products. One can indeed observe sustainable diversion of part of the demand for meat products after a health crisis. Nevertheless, as pointed by Park et al. (2008), in most cases, the occurrence of epidemics in the beef industry actually induced falls in consumption and a return to its original level by about a year and a half after the illness. The recent example of the avian influenza crisis in France (2005-2006) exhibits a loss of confidence for a three month period (Magdelaine et al., 2008).

Moreover, an economic evaluation of the 2001 FMD outbreak in the United Kingdom showed that the losses associated with the disease greatly exceeded the agricultural sector. Sectors directly related to tourism spending have indeed suffered a financial loss levels equivalent to that of the agricultural sector and a decline in gross domestic product (GDP) of 0.2% was observed (Thompson et al., 2002). It seems that the economic activities related to tourism have indeed been significantly affected by negative media coverage related to health crises in the livestock sector. This result was corroborated by studies involving the use of Computable General Equilibrium (CGE) (Blake et al., 2002, O'Toole et al., 2002). The estimated market consequences of this crisis has highlighted that the most affected sectors were those related to tourism and food distribution. Concerning agriculture, the conclusions remain more controversial: the economic losses associated with the disease and control measures were in large part compensated by higher prices for beef, because of the tightening of supplies. However, these studies have not taken into account the effects of embargoes, particularly in terms of impact on the markets and farm incomes.

Understanding of economic phenomena arising from animal health crises in the livestock sector, which is allowed by the modeling of economic equilibrium, highlights the fact that health crises can modify the whole economy of the affected region. They disrupt the agricultural markets and activities and they may quickly become confidence crises on the quality of the product. They underpin the need for establishing strong support to the territories and the farming profession.

The economic literature on the economic consequences of health crises in livestock shows their systemic nature, the extent of their market impact and the importance of their understanding for the establishment of management systems. The exploration of multi-sector, regionalized and dynamic approaches will help to give new insights on economic consequences from health risks. These prospects are the subject of the next section.

1.3 On the utility of a dynamic approach to public management of epidemic risk

Economic studies relating on epidemic diseases (market impact and management) highlight the extent of the effects of health crises. Nevertheless, as revealed by the review of the economic literature, few studies are still exploring the long-term economic effects of catastrophic risks and the consequences potentially undermining the structures of farming. This section aims at suggesting some innovative ways of research to provide a more complete consideration of market behavior towards risk, in order to identify the place and timing of public action for their management.

1.3.1 Catastrophic risk and market dynamics

The main studies published in the literature related to the assessment of the economic consequences of epidemic outbreaks are based on a static framework as emphasized previously. Nevertheless, some recent studies have begun to think about economic dynamics resulting from such animal health crises. Zhao et al (2006) have combined epidemiological and economic models to analyze the possible effects of an FMD outbreak on breeding decisions. In the same vein, the study of Paarlberg et al (2008) showed the effects of short term to long term to an FMD outbreak, which were highly dependent on the length of livestock production cycles. The analysis proposed by Rich and Winter-Nelson (2007) also shows the existence of dynamic effects of an FMD outbreak through a multi-market model.

These few studies show that the shock induced by an outbreak can cause changes in the livestock breeding decisions, which result in productive and long-term economic consequences. This market disruption is an integral part of the indirect consequences of this catastrophic risk.

Moreover, the demand behavior and decisions on rules of trade are also changing consecutively to the occurrence of an animal health crisis. As pioneered by Philippidis and Hubbard (2005), modeling these various phenomena in dynamic CGE will allow the proposal of a joint study of intertemporal disturbances related to supply, demand, international markets, and their feedback effects. Similarly, this type of study provides a regionalized framework as to measure the systemic effects of an animal health crisis on the whole economy of a considered geographical area, as Western France. As far as we know, previous studies did not include livestock dynamics and market constraints.

An innovative dynamic CGE approach of the consequences of catastrophic risk including those elements may provide the opportunity to enrich the knowledge about the market consequences of an epidemic to support the implementation of management policies. To this end, this modeling approach may consider expectation schemes and market constraints (e.g. financial constraints) as well as livestock cycles and dynamics to measure the implications of such crisis on income and regional welfare.

1.3.1.1 Understanding the production dynamics

The occurrence of an epidemic disease modifies the behaviors of economic agents. These are related to the available information about the risk and its perception. These behavioral changes have economic implications, which must be included in the indirect economic effects induced by epidemic diseases. The prospect of falling prices, investment constraints as well as many other decision parameters may interfere with the productive strategy. This will in turn affects the amounts offered and consequently the prices.

In general, the occurrence of demand shocks and changes in the cost of inputs give rise to cycles of production (Rosen et al., 1994). The herd structure is thus a function of external economic factors. According to the animal production considered, the production cycles have different lengths. For example, poultry production is characterized by short production cycles. Poultry producers are able to counter the possible reduction of demand by reducing production capacities. Thus, during the 2005-2006 episode of avian influenza, the fall in demand, mainly due to the loss of export outlets, has led the industry to put less chicks up. With the recovery in demand following the lifting of the sanitary embargo, the industry has been able to adapt quickly to new circumstances, by setting up more chicks.

This responsiveness to changing market conditions is not as easy for all types of farms. The adjustment speed of supply for livestock is indeed variable among animal species (and production systems). In the case of cattle farms, this inelasticity is due to the relatively low fertility rate of cows and the time needed for breeding or fattening cattle. These long breeding periods (several years in the case of cattle) explain that production decisions are prior to business decisions; they set up the volumes available on markets. Production choices are based on expectations about future market conditions. Cyclical fluctuations of prices, due to significant delays in biological processes beef production (Chavas, 2000) and swine (Chavas, 1999), may be compatible with effective management of an animal population assuming rational expectations.

The price changes induced by market reactions to the health risk are a signal for producers, who react through various production decisions. Depending on the nature of the expectations of producers, they may result in a persistent supply shock over time. The destabilization of markets following an animal health event can therefore have lasting consequences on the markets, because of the disruption of production structures.

1.3.1.2 Financial consequences for the livestock sector

The destabilization of farming systems as a result of these market shocks has implications on the farm. The market turbulence induced by an epidemic disease can cause significant income fluctuations for farmers. When the income cannot be maintained by price support measures, farmers may be likely to borrow to maintain consumption. This debt nevertheless induces additional expenses (related to loan interests), which may threaten the solvency of the most financially vulnerable farms. The economic risk can then become a risk of bankruptcy (Gohin, et al., 2012). Quantifying that risk as part of a dynamic CGE modeling will provide more comprehension of the long-term effects of shocks due to an epidemic.

Long-run effects of catastrophic risk on the farm may be identified by a dynamic CGE modeling taking into account changes in demand and supply in such a particular epidemiological context. This innovative research will help study the role and development opportunities of management tools of the economic consequences of epidemic risk in the agricultural sector.

1.3.2 Prospects for the management of epidemic risk

The review of the economic literature on catastrophic animal health risks has led us to identify some key elements of its management and has given rise to some interesting research perspectives - the dynamic modeling of market behavior - to capture long term effects of a disease outbreak. The following section contains forward-looking elements for long term management of catastrophic risk.

1.3.2.1 Issues about private action

Systemic effects of catastrophic risks induce a high degree of spatial correlation of market losses that may suffer the farms, which complicates the development of farm income insurance mechanisms because it undermines the strategies of risk diversification for insurance companies (Skees and Barnett, 1999). In the context of climate risk on major crops, Miranda and Glauber (1997) showed that in the presence of systemic risk, insurance systems themselves are twenty to fifty times more exposed to risk than in more conventional and stochastically independent risks. In these circumstances and without adequate security assurances through reinsurance or public aid, the potentially exorbitant costs that the private insurance companies should bear could sharply raise insurance premiums.

The financial system has tools to fulfill an insuring role when risks are highly correlated (Mahul 2001). "Catastrophe Bonds” (Cat Bonds) are based on a risk transfer of agricultural production from insurance companies to investors in capital markets. Cat bonds operate the same way as conventional bonds; they are loans to corporate issuers by investors who, in turn, earn interest and repayments at the end of each agreement period. In return, investors agree to waive their interest and repayment of capital under certain conditions such as catastrophic events (as is the case of epidemic) (Vedenov, et al., 2006). These contracts transfer risk to capital markets. They are therefore attractive to insurance companies that face a strong systemic component in their portfolio of risks in case of an outbreak. Conversely, these bonds also attract financial markets, which are interested in investing in agricultural markets as it may be a source of diversification of their own risk.

This solution is also being considered by Phélippé-Guinvarc'h and Cordier (2006). They studied the possibility of bypassing the public sector on matters of reinsurance. The authors define a general pattern of agricultural insurance, including both classic and catastrophic risks. The authors showed that the insurance industry can adopt strategies for full risk management, by sharing their expertise and transferring the highest risks to the financial sectors through futures contracts on prices or on crop yields.

More structurally, integrating the agricultural sector in production chains (including the processing sector and possibly the retailing one) may contribute to share production risk over a wider range of players. In the case of animal products, the introduction of futures contracts between growers and processors of animal products could also help to share the risk, thanks to price settings before the marketing. Thus, the producer may receive an income guarantee that may prevent him from undergoing strong fluctuations of prices induced by epizootics (Meuwissen et al., 2001). The effects of falling prices may be mitigated if the processor is positioned in different markets, based on the enhancement of various raw materials. In fact, the adoption of these strategies was not widespread, partly because of increased exposure to risk for the slaughtering sector. Actually, meat processors do not have any economic interest to bear agricultural market risks, as the entire livestock marketing chain could suffer the consequences of any failures by slaughtering firms.

The ability to secure insurance markets for the market losses of these systems is not questioned, however private solutions remain scarce. Animal health policies reflect their role in collective control of animal health and management of epidemics, as we shall explain in the next section.

1.3.2.2 Issues and development of public action

Animal health is a great public concern. It responds to a societal demand, and its maintenance requires expenditures that private actors are not always able to bear alone (Sumner, et al., 2006). Epidemic diseases like FMD or BSE and the emergence of new diseases are furthermore subject to significant uncertainties: moral hazard and negative externalities associated with potential past outbreaks, systemic economic consequences, etc. These circumstances justify public intervention, and urge it to adopt measures to manage animal health, especially in areas where livestock takes an important economic role. Modeling the systems of public intervention using a dynamic CGE may give guidance to governments for the establishment of management systems. The issues relating to government intervention are the subject of this section.

• Preventive actions, control strategies and zoning

The public management of epidemics first requires the establishment of preventive measures to minimize their spread and thus their economic consequences. Governments play a critical role in providing incentives to private actors in the management of animal diseases (Gramig, et al., 2006). An essential point is the incentive to report disease outbreaks in the early times. Responsiveness is a key to a successful strategy, as the economic effects are even stronger when the disease spread widely (Devadoss et al., 2006). In addition, bans or restrictions on exports can be extremely costly for the livestock sector, hence the importance of early detection of disease to reduce these periods (Mahul and Durand, 2000).

The choice of an optimal strategy may still require a period of implementation, corresponding to the minimum time to acquire sufficient information about the disease, to calibrate the veterinary control measures and therefore cost management (Mahul and Gohin, 1999). Regardless of health management, public authorities send signals to markets, especially the demand sectors by influencing their own risk perception.

Management and mitigation of economic impacts of animal diseases also call for solving the problem with identifying infected areas and with land management. It was notably raised by Mahul and Durand (2000), which assessed the consequences of an FMD outbreak in France through the simulation of trade restrictions at various scales (from the region to the country). Trade restrictions to a level smaller than the country is likely to help restrain the market risk and thus minimize its impact at the national level. The zoning issue is particularly important for Western France. Although the spread probability of an epidemic outbreak occurring in a remote region can be low, a decision to restrict trade for the whole national territory may have a heavy economic impact. The statement of an area as free or infected is thus crucial in terms of impacts on agricultural markets. Modeling the market effects and the welfare effects linked to the extent of the trade restrictions areas may highlight spatial issues of the risk management.

• Supporting the producers and the supply levels

After a market shock related to an animal health event, maintaining the income levels and supporting animal production structures after a market shock can be achieved by setting up income insurance mechanisms, as Gohin et al (2012) underlie. These mechanisms may consist in subsidized interest rate loans to counter the risks of indebtedness/failure or to measures in order to encourage the constitution of a readily releasable savings, so as to enable farmers sustain themselves by their own activity. The establishment of franchises or compulsory contributions may help to reduce bias due to the asymmetry of information and limit the moral hazard of non-participants to bio-security measures (Gramig et al., 2009). Dynamic modeling of public support and financial incentives can reveal changes in farmer behavior.

Solutions to postpone the marketing of animal products are also possible to counter falling output prices. The storage of carcasses can indeed help limit the influx of animal products on the market and thereby support prices. Those stocks may be marketed thereafter when market conditions are more profitable. Note that in the cattle sector, living animals may also be held longer at the farm, which cannot be done in the case of poultry for example. Modeling this process management may measure the economic consequences of such a policy and its potential public costs of implementation. Moreover, the market impact of support measures for processing is also an important modeling issue of management measures. Indeed, industrial sectors may, under government leadership, act as a buffer during periods of falling prices. The processing of fresh and perishable animal products into more shelf-stable products may lead all or part of the surplus of animal products to new markets that are less tense than for fresh products. The study of such a measure would show its ability to limit fluctuations in prices received by producers.

To conclude, the behavior of market participants cause economic dynamics that constitute a source of market instability. They are an integral part of economic factors to be considered for an optimal management of epidemic risk. The study of these economic disturbances emphasizes the importance of an appropriate government intervention in crisis management, including measures of income support and measures to limit the productive effects relating to the uncertainties over the duration of the health risk and of the trade restrictions. The planned developments of the research (CGE modeling of the dynamics of production and market behaviors) can provide new insights to achieve this goal.

Conclusion

In this paper, we investigate an almost neglected field of study that is the long-run effect of catastrophic shocks on agricultural markets. Indeed, although direct losses and short-term effects are already well understood, the long-run market effects of epidemic outbreaks do not benefit from an expanded literature. Their comprehension raises the issue of how to cope with risk and uncertainty on agricultural markets due to catastrophic risks. We argue that a dynamic CGE model focused on the livestock sector may provide a general framework for the simulation of private and public management measures and for the measure of the wide effects –income, welfare– of catastrophic risks in a local economy.

Various crucial issues are raised by this kind of research. First, it may participate to policy research with respect to the necessary redefinition of common and harmonized European risk management measures to face the market consequences of epidemic outbreaks. In order to smooth the market effects of an animal health crisis, stakeholders may have a trade-off between various regulation mechanisms. One interesting question that remains to be explored is the effectiveness of physical markets regulation versus a financial intervention in order to improve the resilience of the economy to this catastrophic risk. More generally, thanks to dynamic CGE study, the economic research on market effects of epidemic disease outbreaks may provide useful guidelines for the potential reorientation of public support to agriculture within the EU and the role of risk management mechanisms in securing farm income.

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Chapitre 2 Effets dynamiques d'un aléa de production catastrophique : le cas de la fièvre aphteuse

Résumé

Dans les pays indemnes de fièvre aphteuse, la survenue d'une épidémie de fièvre aphteuse est un événement rare, aux pertes économiques potentiellement importantes. Dans ce chapitre, nous explorons les effets dynamiques qu'une épidémie de fièvre aphteuse peut avoir sur les marchés sectoriels et sur le surplus économique, et prenons en compte la problématique de la faillite agricole. Des simulations sont menées sur une économie agricole stylisée, exportatrice nette pour un produit homogène, dans la période qui suit une épidémie de courte durée.

Les résultats montrent des effets de marché dynamiques, dont la complexité est accentuée lorsqu'il y a une information imparfaite sur le marché du crédit, pouvant conduire à la fermeture d'entreprises agricoles. Les effets sur le bien-être sont également significatifs. Sur le long terme, les consommateurs locaux peuvent pâtir d'une épidémie de fièvre aphteuse en raison de la contraction de la demande. D'autre part, on montre que les éleveurs capables de résister à cet évènement de marché peuvent finalement voir leur surplus augmenter.

Ce chapitre fait l'objet d'un article scientifique, coécrit avec Alexandre Gohin, Stéphane Krebs et Jean Cordier, publié dans la revue Risk Analysis, 2012.

Introduction

The recent resurgence of animal disease outbreaks is a growing concern around the world. The highly contagious foot-and-mouth disease (FMD) is one of the most feared animal diseases. Affecting any cloven-hoofed animal, FMD reduces animal productivity and may even cause animal death. In addition to these productivity effects, an FMD outbreak also leads to market effects because importing countries usually react by imposing import bans on any country experiencing such disease. Thus an FMD outbreak can have large economic costs for affected farmers and also for the whole food chain (Pendell et al., 2007). The size of these direct and indirect costs partly depends on the public measures taken to eradicate the disease (Rich and Winter-Nelson, 2007). In fact, public authorities have two main ex post alternative strategies for coping with FMD, that have long been studied (Elbakidze et al., 2009; Garner and Lack, 1995; Schoenbaum and Disney, 2003). One consists of culling infected herds as well preventing stamping out of animals located around the infectious zone. This first strategy may involve massive slaughtering of animals if the virus spreads rapidly. The other strategy consists also in the culling of infected herds plus the vaccination of animals located in a ring vaccination zone. This second strategy imposes a priori less mandatory culling of animals but larger international trade restrictions compared to the stamping out strategy. As a consequence to the local health strategies implemented and according to the OIE (World Organisation for Animal Health), the international measures against FMD include the protection of FMD-free countries from any spread of the disease. This means the establishment of sanitary embargoes, such as import bans of animals in disease-free countries and strict restrictions on animal movements. To date economic evaluations show that these trade restrictions and the resulting demand decline lead to severe price drops because domestic demand is usually price inelastic (Devadoss et al., 2006; Mangen and Burrell, 2003). Indeed available analyses conclude that the trade-induced price effect of a FMD outbreak is much more important for producers as a whole than the production effect and represent the bulk of total FMD cost (for example, Rich and Winter-Nelson(2007) estimate a price drop up to -58% for South America, and Niemi and Lethonen (2011) up to -26% in Finland for a recent assessment). This leads some authors to propose the delaying of the implementation of a vaccination strategy (Mahul and Gohin, 1999).

In addition to choosing between ex post alternative strategies, the public authority may also implement preventive actions designed to limit the occurrence and extent of FMD effects (such as periodic animal testing, maintenance of veterinary laboratories). Farmers themselves also have some ex ante flexibility (albeit small in the short run) for coping with a potential FMD outbreak (such as choice of production type, the location of the farm, the sanitary and feed practices). In theory, we can determine the optimal levels of private and public, preventive and curative measures, including the adoption of risk managing instruments such as insurance, such that expected marginal benefits equal expected marginal costs (Elbakidze and McCarl, 2006). In practice, one first major issue is that FMD outbreaks are characterised by a low probability of occurrence with considerable potential economic losses due to the systemic price effects. In other words, FMD is potentially a catastrophic event and thus may not be privately insurable (Duncan and Myers, 2000; Skees and Barnett, 1999). Indeed there is presently no contingent market (in the Arrow Debreu sense) that allows economic agents to cope with the price effect of a FMD. Above all, assessing the costs of FMD and optimal levels of decision variables is challenging because there are lasting impacts due to the animal population dynamics.

Cost-benefit analyses of FMD outbreaks have long used static economic models. Recent works introduce dynamic elements (Rich and Winter-Nelson, 2007; Conrad, 2004; Paarlberg et al., 2008). Although the animal inventories rightly evolve over time in these dynamic studies, farmer optimal decisions are not derived from a well-behaved profit maximisation behaviour. The exception are Zhao et al. (2006) and Niemi and Lethonen (2011) who build on the Jarvis (1974) and Rosen (1994) modelling framework: farmer periodic breeding, feeding and culling decisions maximise profit function discounted over several years and subject to a linear biological reproduction process. With these consistent frameworks, these authors show that the impacts of FMD evolve from year to year before returning to a new steady state, which is typical when studying animal supply responses (2004).

Our main objective in this paper is to provide a new dynamic analysis of FMD impacts on livestock production, demand, trade, price and economic surplus by introducing the possibility that some farmers may go bankrupt. Indeed an FMD outbreak may induce a temporary price drop due to trade restrictions. As explained earlier, even if only one farm among all farms in a given country is affected by FMD, all farmers in this country suffer from this price drop. In order to smooth this abrupt income loss over time, farmers may contract new debts and/or reduce their final consumption levels and/or delay investments in physical capital, if not disinvest. Lenders, more generally the functioning of the farm credit market, have clearly a great role here by supplying or not new debts to farmers. For instance, if they supply new loans using standard rules, then farmers may effectively be able to deal with the immediate negative consequences of the FMD outbreak over several years. On the other hand, if lenders apply a standard insolvency rule for determining farm bankruptcy without recognizing the exceptional character of the FMD episode, some highly indebted farms may be forced to exit the market in the next period. This may create new types of dynamic effects on the market in addition to that induced by the animal reproduction process.

We generalise previous economic works on FMD in two main directions in order to focus on the long run effects of a potential FMD outbreak, rather than on the short term (during the outbreak) where agents can hardly respond to a sudden and unexpected shock in the short run. This is particularly the case of cattle farmers where supply is subject to biological constraints. First, we add capital investment, consumption and financing decisions into the farmer's dynamic behaviour. In addition to animal herds and animal feeds, we introduce physical capital and labour in an annual constant returns to scale production function. This annual production function is specified with a dual quadratic cost function. Farm labour is supposed to be fixed in the short run, hence the positive slope of the supply curve in the steady state. Farmers maximise their discounted expected utility subject to three dynamic constraints: the standard animal reproduction process, the accumulation of physical capital and finally the accumulation of debts. Second, we allow for farm bankruptcy. We always assume that the lending sector operates in a competitive environment without full information on farm's characteristics and markets. We distinguish two cases. In the first case, we assume that the lending sector always provides loans to farmers and they never force farm bankruptcy, even when they are highly indebted. As such they recognize the exceptional character of the FMD episode. On the contrary, we assume in the second case that the competitive lending sector applies standard rules and thus force farmers into bankruptcy when their current net equity falls to a critical level. In other words, the lending sector does not recognize the exceptional situation created by the FMD or does not believe that future output prices will be sufficient to compensate the new debt induced by the FMD.

The conceptual framework that we develop is dynamic and does not lead to analytical solutions. Accordingly we implement it on a stylised agricultural economy with farms differentiated according to their initial feeding costs and initial net debts. These farms initially produce one animal product and initial export represents a non trivial outlet. We then simulate the dynamic consequences of a hypothetical FMD outbreak limited to only one farm and one year. Exports are banned during this period but borders are reopened afterwards. We exclude potential adverse selection behaviours to minimize the global costs of this shock and isolate the long run market impacts. Our dynamic model is first simulated assuming that all farms are allowed to pursue their productive operations irrespective of their level of debts. On the contrary, our second series of simulations assume that some highly indebted farms are forced to exit the sector by theirs lenders. Their physical capital is sold on the market and remaining farms can buy it and expand their activity. In both cases, we assume that lenders do not have full information on farmers' characteristics and markets. We logically assume that farmers also do not have full information on their entire sector and thus may make mistakes when anticipating output prices. Accordingly we explore the consequences of different types of expectations by farmers regarding the evolution of output prices.

This paper is organised as follows. The conceptual framework is described in the second section with great details on the dynamic behaviour of farmers. The calibration and resolution of this framework is explained in the third section. Simulation results are reported in the fourth section. Section five provides concluding comments.

2.1 Modelling framework

We consider an agricultural economy where there are initially N heterogeneous cattle farmers producing only one homogeneous product which is sold both domestically and in the international market. These farms together constitute a small sector in their economy in the sense that they consider the prices of inputs (such as feed or capital) as given. This exogeneity of input prices implies in particular that farmers can expand by investing in new capital goods or by purchasing capital goods of bankrupted farms. On the other hand, we assume that the animal exports of the sector are significant on the international markets and thus influence the world price. We first list the major assumptions of our conceptual framework, then formally describe the supply side of our stylised economy before moving to the specifications of the demand side.

2.1.1 Basic assumptions

On the supply side, we assume that each farm maximises the expected discounted utility of their consumption levels. At each period (each period standing for a year), they decide on four choice variables: the output level (the number of animals sold/bought), the variable inputs level (we consider an aggregate of variable inputs to simplify the notations), the investment in physical capital (disinvestment if negative) and the final consumption level (or their debt level as these two variables are simultaneously determined, see below). These decisions are constrained by a periodic constant returns to scale production function resumed in a (quadratic) feed cost function, by the dynamics of animal herds, capital and debt accumulations. Investments are subject to rising marginal costs of installation (we adopt the traditional Uzawa's approach stipulating that a farm needs to purchase a larger quantity of capital goods to install a given amount of new capital, see below).

As usual, we assume that these decisions are made at the beginning of the period while production volumes are only available at the end of the period. Accordingly these periodic farm decisions depend on expected output prices for the current period and expected (input/output) prices for subsequent periods. At the farm level, the prices of output, variable inputs and capital good are assumed exogenous.

On the other hand, the interest rate on farm debt is not exogenous: it depends on the net equity hold by the farmer. Following a large literature (for instance, Mishra et al., 2008; Vercammen, 2007), we assume that farms with lower net debts face a lower interest rate. This is justified by the fact that lenders do not have full information on farmer's characteristics and on the evolution of markets: they get financial compensation for the fact that they provide loans to farmers who may be unable to reimburse them. Indeed livestock farms in most countries are quite heterogeneous for many reasons (soil quality, managerial capacities, age of the farm, feeding systems, etc.). Understanding this heterogeneity by gathering all this information is extremely costly for lenders. Hence the farm credit market is characterized by informational asymmetries about the farm profitability as well as by incentive issues because lenders cannot control the diligence of farmers. The main consequence of this information asymmetry is that lenders charge higher interest rates in order to cope with the potential repayment default of farmers. We underline that our assumptions do not prevent a strict competition among lenders and thus that farmers are able to learn about lender behaviour. Accordingly they can take into account this supply curve of farm credit in their dynamic behaviour, in that there is an optimal farm debt to asset ratio.

On the demand side of this market, we make quite simple assumptions such as we only consider demand for this animal product (domestic demand and export) instead of modelling the whole food demand behaviour. In addition, our model does not include the possible development of a black market supply during the crisis, where producers may try to bypass international trade restrictions. The development of such a market remains highly dependent on local conditions of demand, and a market price equilibrium is hardly observable. That is, we assume that consumers determine their level of consumption with current prices rather than expected price. In fact, market prices clear (domestic and foreign) demands to pre determined supplied quantities. We thus consider a succession of temporary equilibria.

2.1.2 Specification of the supply side

We now provide the formal program of a farmer able to pursue his production activity because the competitive lending sector always provides him a loan if needed (for instance following an unexpected FMD outbreak leading to an output price drop and income loss). However it should be clear that the lender can force one farm into bankruptcy by selling the farm's capital assets when its net debt reaches a critical level. In that case, the bankrupt farm exits the sector. The program of a present farm at each period is given by:

$$\max_{Y,X,I} \sum_{t=0}^{\infty} \beta^t E_0 u(X_t)$$

subject to three dynamic constraints:

$$H_{t+1} \leq (1+g)H_t - Y_t \qquad t = 0, \dots, \infty \qquad H_0 = \overline{H_0}$$

$$K_{t+1} \leq (1-\delta)K_t - I_t \qquad t = 0, \dots, \infty \qquad K_0 = \overline{K_0}$$

$$D_{t+1} \geq (1+r_t)D_t + px_t X_t + C_t(w_t, H_t, K_t, l) \qquad t = 0, \dots, \infty \qquad D_0 = \overline{D_0}$$

$$+pi_t\left(1 + \frac{\gamma}{2}\frac{I_t}{K_t}\right)I_t - p_t Y_t$$

Where β is the farmer discounting factor, X_t the consumption level and px_t the corresponding price, p_t the expected output price, Y_t the output supply, w_t the variable input (feed) price, H_t the animal herd, K_t the stock of physical capital, *l* the fixed level of farmer labour allocated to farming, $C_t(.)$ is the variable cost function of feeding, more generally taking care of the animal herd, I_t the level of investment (disinvestment if negative), pi_t the price of the capital good, g is the animal reproduction rate, δ is the depreciation rate of physical capital, γ is the non negative parameter governing the marginal cost of capital installation, D_t the debt level and r_t is the interest rate charged by lenders. To save notation, we assume without loss of generality that the price of final good equals one.

The first constraint is a simplified representation of the animal reproduction process taken from Rosen (1994). It stipulates that the next period animal herd equals the initial animal herd plus net birth (gH) less animal supply. The second constraint is the standard physical capital accumulation process where we allow for new investments to increase the capital stocks and disinvestments as well. Finally the last constraint describes the evolution of farmer debt. The next period debt increases with the initial debt augmented by the interest charge, the final expenditure by the farm household, the variable input costs and the new investment augmented by installation costs. This debt decreases with production receipts. It should be clear here that the farm can also sell part of its capital stock to reduce debts. We also underline that we assume, following Barry and Robison (Barry and Robison, 2001), that farmers finance their capital only with debts and not by issuing equity.

As stated above, all prices are assumed to be independent of the decision variables of the farmer. The exception is the interest rate which is given by:

$$r_t = r_t(D_t, A_t) = r_t\left(D_t, p_t H_t + pi_t\left(1 - \frac{\gamma}{2}\right)K_t\right)$$

This specification of the credit supply curve deserves some explanations. This interest rate function is increasing with debts and decreasing with assets. This function may even reach infinity for highly indebted farms, in which case it may be optimal to voluntary exit the sector. The value of assets includes the value of the animal herd hold by the farmers and the selling value of the physical capital. The latter takes into account the costs due to capital desinstallation. We also underline that the value of assets depends on the output price expected by the lenders. Some farms may indeed be declared bankrupt if lenders have less optimist price expectations than farmers. In the derivation below we simplify the analysis by assuming that these expectations about price (and market) developments are shared between lenders and farmers. In order to solve the dynamic program of the producer, one can rewrite it using value function and the definition of three state variables (the initial levels of herd, physical capital and debt):

$$V_t(H_t, K_t, D_t) = \max_{Y,X,I} u(X_t) + \beta V_{t+1}(H_{t+1}, K_{t+1}, D_{t+1})$$

subject to the three dynamic constraints stated above.

First order conditions are given by[2]:

$$\frac{\partial u}{\partial X_t} + \beta \frac{\partial V_{t+1}}{\partial D_{t+1}} = 0$$

$$\frac{\partial V_{t+1}}{\partial H_{t+1}} + \frac{\partial V_{t+1}}{\partial D_{t+1}} p_t = 0$$

$$\frac{\partial V_{t+1}}{\partial K_{t+1}} + \frac{\partial V_{t+1}}{\partial D_{t+1}} pi_t \left(1 + \gamma \frac{I_t}{K_t}\right) = 0$$

These first order conditions cannot be directly interpreted because the derivatives of the value function must be known. We get them by applying the envelop theorem to the value function:

$$\frac{\partial V_t}{\partial H_t} = \beta \left(\frac{\partial V_{t+1}}{\partial H_{t+1}} (1+g) + \frac{\partial V_{t+1}}{\partial D_{t+1}} \left(\frac{\partial C_t}{\partial H_t} + D_t \frac{\partial r_t}{\partial A_t} p_t \right) \right)$$

$$\frac{\partial V_t}{\partial K_t} = \beta \left(\frac{\partial V_{t+1}}{\partial K_{t+1}} (1-\delta) + \frac{\partial V_{t+1}}{\partial D_{t+1}} \left(\frac{\partial C_t}{\partial K_t} + D_t \frac{\partial r_t}{\partial A_t} pi_t \left(1 - \frac{\gamma}{2}\right) - pi_t \frac{\gamma}{2} \left(\frac{I_t}{K_t}\right)^2 \right) \right)$$

$$\frac{\partial V_t}{\partial D_t} = \beta \frac{\partial V_{t+1}}{\partial D_{t+1}} \left(1 + r_t(D_t, A_t) + D_t \frac{\partial r_t}{\partial A_t} \right)$$

Combining these expressions, we obtain Euler type equations describing the optimal evolution of choice variables:

1) $$\frac{\partial u}{\partial x_t} p_t = \beta \frac{\partial u}{\partial x_{t+1}} \left(p_{t+1}(1+g) - \left(\frac{\partial C_{t+1}}{\partial H_{t+1}} + D_{t+1} \frac{\partial r_{t+1}}{\partial A_{t+1}} p_{t+1} \right) \right)$$

[2] Second order conditions for an optimal solution are satisfied if the variable (feed) marginal cost function is increasing with the animal herd and decreasing with the capital stock. In the empirical application, we ensure that these conditions are always satisfied by the choice of a globally regular quadratic cost function.

2) $$\frac{\partial u}{\partial x_t} pi_t \left(1 + \gamma \frac{I_t}{K_t}\right) = \beta \frac{\partial u}{\partial x_{t+1}} \begin{pmatrix} (1-\delta) pi_{t+1} \left(1 + \gamma \frac{I_{t+1}}{K_{t+1}}\right) - \frac{\partial C_{t+1}}{\partial K_{t+1}} \\ -D_{t+1} \frac{\partial r_{t+1}}{\partial A_{t+1}} pi_{t+1} \left(1 - \frac{\gamma}{2}\right) + pi_{t+1} \frac{\gamma}{2} \left(\frac{I_{t+1}}{K_{t+1}}\right)^2 \end{pmatrix}$$

3) $$\frac{\partial u}{\partial x_t} = \beta \frac{\partial u}{\partial x_{t+1}} \left(1 + r_{t+1}(D_{t+1}, A_{t+1}) + D_{t+1} \frac{\partial r_{t+1}}{\partial A_{t+1}}\right)$$

Equation (1) determines the optimal evolution of production (and combined with the dynamic herd constraint, the optimal herd level). The left hand side of this equation computes the cost (in terms of foregone utility) of keeping one additional animal in the herd rather than selling it on the market. The right hand side computes the benefit (in terms of discounted future utility) of keeping this additional animal: this benefit equals the selling value of this animal and its progeny minus the marginal cost of breeding it. It also includes the effect on the future interest rate because it increases the next period asset value of the farm.

Equation (2) determines the optimal evolution of investment (and combined with the dynamic capital constraint, the optimal capital stock). Again this equation equates the marginal cost of investment (left hand side) to the discounted marginal benefit (right hand side). Compared to the equation (1) this expression is made slightly more complex due to the assumption of cost of installation.

Finally equation (3) determines the optimal evolution of consumption (and combined with the dynamic debt constraint, the optimal debt). By increasing consumption today (the left hand side), the debt level increases and the cost of this debt is higher in the next period (the right hand side).

These three equations and the three dynamic constraints determine the evolution of decision and state variables given initial levels of state variables and exogenous prices. In order to solve such dynamic program for each farmer, some terminal conditions must be specified. These terminal conditions are defined at the farm level and may not ensure a steady state at the market level if price expectations by farmers are not self fulfilling. We assume that at the terminal period, the farm reaches a steady state such as the state variables no longer change.

Formally we impose:

$$g.H_{ss} = Y_{ss}$$

$$(1-\delta)K_{ss} = I_{ss}$$

$$r_{ss}D_{ss} + X_{ss} + C(w_{ss}, H_{ss}, K_{ss}, l) + pi_{ss}\left(1 + \frac{\gamma}{2}\frac{I_{ss}}{K_{ss}}\right)I_{ss} = p_{ss}Y_{ss}$$

In this setting, let us consider analytically the impact of a temporary unexpected price drop due to an FMD outbreak affecting another farm in the country. Production, investment and final consumption plans were made with previous expected prices and the farm household has no possibility to modify these plans in the short run. Accordingly, the farm household is not able to satisfy its credit commitments resulting from previous financial decisions, resulting in higher debt. If the lender agrees to postpone debt repayments and/or to provide new credits, the farmer can continue his productive activity starting in the subsequent period with higher debt. Nevertheless this higher level of debt leads the producer to modify his previous production/investment/consumption plans; otherwise the debt will accumulate leading to explosive interest rate and the likely possibility of being bankrupt. In order to do so, the farmer can reduce his final expenditure. He may also disinvest (or reduce investment) or sell more animals. These two latter decisions have some impacts on the next period availability of state variables. For example, by selling more animals in the period after the outbreak, the farmer may be able to reduce debt levels on one hand. On the other hand, this leads to a decrease in the next period production and asset; hence the interest rate charged by lenders will increase. It should be added that the selling decision of animals can also modify the output price by initially increasing supplied quantities. Depending on the extent of price variation, the farmer may revise his expectation on output price, leading to a further source of dynamics in our framework. Accordingly the ultimate impact on each farmer decision variable and his welfare cannot be determined analytically as many forces are operating simultaneously.

These effects on the output market are obviously reinforced if some farms are declared bankrupt by their lender and are forced to stop their operations.

2.1.3 Specifications of the demand side and the market equilibrium

So far we have presented the domestic supply of our agricultural economy. Total domestic production is obviously the sum over all active farmers of individual production. This production is sold in the domestic market and can be exported as well. These two demands are inversely related to the domestic price. We also introduce the possibility of imports if their price is lower than the domestic price. We consider only one foreign zone and that the animal product is a homogenous good. Thus imports and exports cannot coexist. In fact we model a net trade function. Formally this implies that we have:

$$\sum_i Y_t^i = D_t(p_t) + X_t(p_t)$$

We assume that the domestic consumption derives from a well behaved utility maximization program and depends on the realised market price (not an expected one). We also make this accommodating assumption for the net trade function. In the empirical section, we will assume that an FMD outbreak leads to a banning of exports to the foreign zone during the outbreak period. We will also assume the destruction of animals on the infected farm. Then this farm receives subsidies to rebuild the breeding stock from imports.

2.2 Parameterization and resolution of the model

We simulate the dynamic impacts of an FMD outbreak on a stylised agricultural economy. We suppose that there are initially 100 farms endowed with the same level of breeding stocks ($H_0 = 100$) and labour force ($l = 1$) and facing the same output price ($p = 1000$), capital purchasing price ($pi = 1000$) and feed unit price ($w = 1$). The progeny rate, capital depreciation rate and installation cost parameter are also common across all farms ($g = 1$, $\delta = 0.1$, $\gamma = 0.5$). The latter parameter implies that farms sell their entire capital stock at 25 per cent of market prices if they are forced to exit the market. These farms differ in terms of feed costs and debt to asset ratios. These feed costs are uniformly distributed and represent between 40 and 60 per cent of sale values. Debt-to-asset ratios are also uniformly distributed and span the 20 to 80 per cent interval. Most of these data can usually be retrieved from farm accounting data.

Regarding the interest rate, we suppose, like Monge-Arino and Gonzalez-Vega (2007), that the supply curve of farm credit is given by:

$$r_t(D_t, A_t) = r_0 + \chi \left(\frac{D_t}{A_t}\right)^2$$

Where r_0 is the minimum interest rate (fixed at 5 per cent) and χ is a reduced form parameter capturing the issues of information asymmetries. We assume that this parameter equals 5 per cent as well, so that the total interest rate equals 10 per cent when farm debts equal farm total assets.

We suppose that these generated data represent a steady state and that farmers correctly anticipate market prices, so that we are able to consistently determine the initial values of other variables (such as final consumption, debt, capital stock, investment, the farm discounting rate). In particular, the final consumption level is calibrated such as to allow different debt levels in the steady state situation. These last variables are usually not easily observable in farm accounting data.

Finally we need to determine the values of two types of behavioural parameters: preference parameters and technological parameters. Regarding the first one, we assume a standard logarithmic instantaneous utility function which implicitly imposes a unitary risk aversion coefficient (equal to the inter-temporal substitution elasticity due to additive separability). Regarding the technological parameters, we specify a dual quadratic cost function:

$$C_t(w_t, H_t, K_t, l) = w_t \begin{pmatrix} \alpha_H H_t + \alpha_K K_t + \alpha_l l \\ + \frac{1}{2}(\alpha_{HH} H_t^2 + \alpha_{KK} K_t^2 + \alpha_{ll} l^2) \\ + \alpha_{HK} H_t K_t + \alpha_{Hl} H_t l + \alpha_{Kl} K_t l \end{pmatrix}$$

Parameters of this cost function are calibrated using the initial values of variables as well by providing three substitution elasticities between labour, physical capital and feeds. Following an OECD literature review, we assume the following Allen substitution elasticities:

$\sigma_{feed,K} = 0.1$

$\sigma_{feed,l} = 0.1$

$\sigma_{K,l} = 0.3$

In order to assess the calibration of the model, we compute supply price elasticities by simulating the model.[3] We suppose the expected output price will increase in the long run by 1 per cent. The price elasticity of aggregate supply at the steady state equals 0.59 and at the farm level, elasticities vary between 0.20 and 2.09. In the first period, supply decreases because farmers want to increase their breeding stocks. The short term aggregate supply elasticity equals -0.34. This is a standard short run effect in the supply of animals where the supply function is price decreasing in the first period and price increasing afterwards when shocks are permanent (Rosen et al., 1994; Aadland, 2004). We also compute the production response to initial debt changes. A 1 per cent increase of debt induces a long run decrease of aggregate production by 0.1 per cent and a first period increase by 0.05 per cent. The elasticities obviously depend on our assumption regarding the interest rate function. If we assume that the interest rate is exogenous, then a 1 per cent increase of debt has no production effect (only an effect on the consumption by farmers). At the other hand, if we assume that the supply curve of the farm credit is steeper (χ equals 10 per cent for example), then the production effects are increased (0.17 per cent in the long run). It should be clear that final consumption and investment also changes when initial debt or prices change. For instance, the investment decreases by 0.95 per cent in the short run, by 0.18 in the long run when the initial debt level increases by one per cent.

Turning to the demand side of our stylised agricultural economy, we suppose that 90 per cent of domestic production is sold in the domestic market. The remaining 10 per cent are initially exported to the international market. Domestic demand is price inelastic (-0.25) while the export demand is price elastic (-20). Both demands are specified using a simple linear form.

This model is solved sequentially. For each period, we first solve the program of active farmers with given price expectations. To do this, we will formulate different expectation schemes below. We implicitly assume that future markets are unavailable for all periods upon which farmers optimize. We thus first determine aggregate supply with given price expectations for different periods. Then we determine current prices by equating the current aggregate supply with domestic and international demands. The latter may be zero if there is an FMD outbreak during the period. Once current prices are determined, we compute realized

[3] We assume that the steady state solution is reached after 6 periods at the individual farm level. Results are globally unchanged if we extend to 7 periods.

end-of-current period debt for each farm. This realized debt may differ from the planned one if the output price expectations are not perfect. If the debt to asset ratio remains below a critical level, the farm household is allowed to pursue farming. This farm household optimizes its program in the following period with a new debt level and with animal herds and capital stocks as determined in the previous period. This will determine aggregate supply in the second period given new price expectations by farmers and so on.

On the other hand, if their new debt-to-asset ratio reaches a critical level (we fix this at 85 per cent), then lenders force these farms to exit the market. All animals in the herds are sold in the market (either for slaughtering or for breeding in other farms). Their physical capital is also seized and sold on the capital good market. In this second setting, there may be few farms in the markets, leading to more significant impact.

2.3 Results

We simulate an FMD outbreak occurring in the first period on only one farm. In both settings, farmers have been unable to anticipate this outbreak; the level of aggregate supply is fixed in this period. So the drop in market price in the first period due to the loss of the export market is independent of the assumptions on bankruptcy. Thus the market price decreases by 40 per cent in order to stimulate domestic demand to equal domestic production. This figure is in the range of already simulated price effect (Niemi and Lethonen, 2011; Paarlberg et al., 2008). We now examine the dynamic effects of this FMD outbreak over the 20 following periods. We start assuming that farmers and lenders' expectations about output price are static and are given by pre-FMD levels.

Note that our results reveal the potential wide market effects of a small FMD outbreak. In the case of a larger outbreak (more farms affected), one may also consider in addition the greater costs of the culling and/or vaccination strategy.

2.3.1 Without bankruptcy

We first consider that lenders recognize the exceptional character of the FMD and allow farmers to continue their operations even if they are critically indebted. At the aggregate level, debts increase by 38 per cent in the period following the FMD outbreak (see table I). As explained above, this higher level of debt induces farmers to reduce their consumptions, their investment and to sell more animals. We observe that total production increases by 1.7 per cent compared to a no FMD benchmark. This additional supply obviously leads to lower market price (reduction by 0.8 per cent) in order to stimulate both domestic demand (it increases by 0.2 per cent) and foreign demand (it increases by 15.3 per cent).

Table 2.1: Dynamic impacts of an FMD outbreak without farm bankruptcy and static expectations (in per cent compared to the pre-FMD levels)

1.a) Market effects

Period	Output price	Production	Domestic demand	Initial herd
1	-0,76	1,70	0,19	0,00
2	0,42	-0,94	-0,11	-1,70
3	0,96	-2,14	-0,24	-2,45
4	1,21	-2,69	-0,30	-2,77
5	1,30	-2,89	-0,33	-2,85
6	1,31	-2,92	-0,33	-2,81
7	1,28	-2,85	-0,32	-2,71
8	1,22	-2,72	-0,31	-2,57
9	1,15	-2,57	-0,29	-2,41
10	1,08	-2,41	-0,27	-2,25
11	1,01	-2,25	-0,25	-2,10
12	0,94	-2,09	-0,24	-1,95
13	0,87	-1,94	-0,22	-1,81
14	0,81	-1,80	-0,20	-1,68
15	0,75	-1,67	-0,19	-1,56
16	0,70	-1,55	-0,17	-1,44
17	0,65	-1,44	-0,16	-1,34
18	0,60	-1,33	-0,15	-1,24
19	0,55	-1,23	-0,14	-1,15
20	0,51	-1,14	-0,13	-1,07

1.b) Welfare effects

Period	Debts	Producer surplus	Consumer surplus	Total welfare
1	38,00	-19,95	0,01	-0,05
2	30,78	-19,36	0,00	-0,06
3	25,86	-18,24	-0,01	-0,07
4	22,27	-16,94	-0,01	-0,06
5	19,48	-15,61	-0,01	-0,06
6	17,20	-14,31	-0,01	-0,06
7	15,27	-13,07	-0,01	-0,05
8	13,61	-11,92	-0,01	-0,05
9	12,14	-10,85	-0,01	-0,05
10	10,84	-9,87	-0,01	-0,04
11	9,67	-8,97	-0,01	-0,04
12	8,62	-8,14	-0,01	-0,03
13	7,66	-7,39	-0,01	-0,03
14	6,80	-6,70	-0,01	-0,03
15	6,02	-6,08	-0,01	-0,03
16	5,31	-5,51	-0,01	-0,02
17	4,67	-4,99	-0,01	-0,02
18	4,09	-4,51	-0,01	-0,02
19	3,56	-4,08	-0,01	-0,02
20	3,08	-4,86	-0,01	-0,08

With these first period changes, aggregate debt level decreases but remains higher than without the FMD: one period after the outbreak, aggregate debt level is still 30.8 per cent higher. Accordingly farmers pursue this strategy of reducing their animal herds in the second period. The aggregate animal herd reduction amounts to 2.5 per cent at the end of this second period. However the impact on aggregate production is no longer positive. Rather we obtain a 0.9 per cent reduction because the aggregate herd at the beginning of this second period was lower, resulting from the decisions taken at the first period following the outbreak. This lower production induces a slight increase of the market price (by 0.4 per cent) and reduction of both domestic and foreign demand.

Again, with these second period changes, aggregate debt level decreases without reaching the pre-FMD level. Farmers pursue the same strategy and this process repeats during five periods. Five periods after the FMD outbreak, the aggregate herd has decreased by 2.85 per cent while the debt level increase has been reduced by half (to 19.5 per cent). Output price are 1.3 per cent higher. At this stage, we observe a turning point at the aggregate level: the aggregate animal herd no longer decreases. In other words, farmers globally start rebuilding their herd and capital stock. In fact few farmers already modify their strategy on the previous fourth period. They do so because their endowments of productive factors (animal herd, capital stock) are already low compared to the labour force. They do so also because the reduction of debt level goes faster than expected due to their imperfect expectation of output price.

At the aggregate level, the increase of animal herd is modest at each period from the sixth period onwards. Twenty periods after the outbreak, we find that the aggregate herd is 1 per cent lower than without a FMD, the production is 1.1 per cent lower and the output price 0.5 per cent higher. The aggregate debt level is 3 per cent higher. At the individual level, we even find that some farms are less indebted (by at most 3 per cent).

We also provide the periodic welfare effects on the farmers, final consumers and our domestic agricultural economy. The welfare of farmers is computed using their periodic final consumption, except the final (20) period where we add their net assets in their consumption value. As already underlined, farmers suffer a lot in the first periods following the FMD. In the first period, their welfare decreases by 20 per cent (equivalently their final consumption decreases by the same percentage). This reduction of welfare amounts to less than 4.86 per cent in the last simulated period. This figure takes into account the fact that debts are higher. On the contrary, the percentage impact on the final consumer welfare is more modest and positive during the outbreak period: the consumer surplus amounts to 0.4 percent of their initial consumption. The effect is even more modest the following periods and is slightly negative due to the price increase. Summing these two welfares, we find that the aggregate welfare is negative for all periods, again except during the outbreak period where final consumers enjoy the huge price decrease. We recall here that we suppose that only one farm is affected by the FMD and the price effect mainly come from trade decisions. We thus suppose that the meat sold on the domestic market is completely safe. If we sum over all period using the minimum interest rate to discount future welfare, we find that the total discounted welfare evaluated at the outbreak period decreases by 0.17 per cent of initial consumption, with gains for final consumers (0.32 per cent).

2.3.2 With bankruptcy

We now introduce the possibility that lenders do not recognize the exceptional situation created by the FMD or do not believe that some highly indebted farms are able to pay back their new debts. Even if farmers and lenders anticipate that the domestic price will return to pre-FMD levels after the outbreak, it appears that eight of the 100 farmers are forced to exit the market at the 85 per cent debt-to-asset critical ratio. Accordingly these farms are forced to sell their capital and animal herds. The remaining farms expand slightly their production as before in order to reduce their debts. We find that, with bankruptcy, total production increases by 1.4 per cent one period after the outbreak (see table II). This figure must be compared to 1.7 per cent without bankruptcy. The difference only comes from the fact that bankrupt farms do not continue their farming operations. Regarding global debt levels, it should be underlined that farms able to stay in business do not necessarily have lower debts, they have lower debt to asset ratios. Indeed it appears that those farms globally have greater debts than farms declared bankrupt (the aggregate debt level increases by 41.6 per cent after the outbreak).

Table 2.2: Dynamic impacts of an FMD outbreak with farm bankruptcy and static expectations(in per cent compared to the pre-FMD levels)

2.a) Market effects

Period	Output price	Production	Domestic demand	Initial herd
1	-0,63	1,40	0,16	-8,00
2	3,97	-8,84	-0,99	-9,40
3	4,44	-9,89	-1,11	-9,95
4	4,57	-10,17	-1,14	-10,01
5	4,54	-10,11	-1,14	-9,85
6	4,44	-9,89	-1,11	-9,59
7	4,31	-9,60	-1,08	-9,30
8	4,17	-9,29	-1,04	-9,00
9	4,04	-8,98	-1,01	-8,71
10	3,91	-8,69	-0,98	-8,44
11	3,78	-8,42	-0,95	-8,19
12	3,67	-8,17	-0,92	-7,95
13	3,57	-7,93	-0,89	-7,74
14	3,47	-7,72	-0,87	-7,54
15	3,38	-7,53	-0,85	-7,36
16	3,30	-7,35	-0,83	-7,20
17	3,23	-7,18	-0,81	-7,04
18	3,16	-7,03	-0,79	-6,90
19	3,10	-6,89	-0,77	-6,78
20	3,04	-6,77	-0,76	-6,66

2.b) Welfare effects

Period	Debts	Producer surplus	Consumer surplus	Total welfare
1	41,61	-18,70	0,01	-0,06
2	34,14	-18,01	-0,04	-0,10
3	25,59	-15,17	-0,04	-0,10
4	19,18	-12,36	-0,05	-0,09
5	14,01	-9,70	-0,05	-0,08
6	9,60	-7,23	-0,04	-0,08
7	5,71	-4,96	-0,04	-0,07
8	2,21	-2,89	-0,04	-0,06
9	-1,00	-1,00	-0,04	-0,05
10	-3,96	0,72	-0,04	-0,05
11	-6,69	2,29	-0,04	-0,04
12	-9,24	3,72	-0,04	-0,04
13	-11,60	5,03	-0,04	-0,03
14	-13,81	6,23	-0,03	-0,03
15	-15,87	7,33	-0,03	-0,02
16	-17,80	8,34	-0,03	-0,02
17	-19,60	9,26	-0,03	-0,01
18	-21,28	10,11	-0,03	-0,01
19	-22,86	10,89	-0,03	-0,01
20	-24,35	22,31	-0,03	0,24

The effects on the output market are thus quite similar in the first period following the outbreak, whether some farms are bankrupt or not. The situation is much more different in the second period after the outbreak. The reduction of production now amounts to 8.8 per cent (compared to 0.9 per cent without bankruptcy), simply because eight farms are no longer active. Their animals have already been slaughtered because other farms do not want to expand their farming system. This huge decrease of production has obviously an important impact on the market price: it increases by 4 per cent. Thanks to this price effect, the debt levels of remaining farms decrease faster than expected. At the global level, the animal herd decreases during four periods and starts increasing from the fifth period. The turning period thus occurs earlier because debts of active farms return to their pre-FMD levels more rapidly. For instance, they are only 9.6 per cent higher in the sixth period (compared to 17.2 without bankruptcy). We even find that active farms expand their activity above pre-FMD levels, that their debt becomes lower, mainly because they enjoy greater output prices. Twenty periods after the outbreak, we find that the aggregate herd is 6.6 per cent lower than without a FMD. Average animal herd of remaining farms thus increases by 1.4 per cent. Also worth stressing is that the aggregate debt level is 24 per cent lower. These results are mainly explained by the price effects induced by initially bankrupt farmers. Despite the slight expansion of remaining farms, the export decreases by more than 60 per cent in the last simulated period. This reduction even reaches 91 per cent in the fourth turning period.

Turning to the welfare effects, we now find that farmers do not systematically lose from the FMD. On the whole, they reduce their final consumption during the ninth period following the outbreak. From the tenth period onwards, they enjoy welfare gains. These gains are quite significant in the last simulated period because their debts decreased. On the contrary, we find that the consumer suffer from greater loss from the second period onward because of higher prices. Again, if we sum over all period using the minimum interest rate to discount future welfare, we find that the total discounted welfare evaluated at the outbreak period decreases by 0.19 per cent of initial consumption with now losses as well for consumers (0.02 per cent).[4]

2.3.3 The issue of price expectations

So far we have assumed that farmers and lenders have static price expectations. This assumption is not realistic in both settings because the long run prices are higher than the pre-FMD ones. This assumption was made in order to identify already complex dynamic results.

[4] The total welfare impact is computed assuming that bankrupt farms do not find alternative jobs. On the contrary, if we assume that they are able to find jobs such as to maintain their pre-FMD consumption levels, then the total welfare decreases by only 0.06 per cent.

These expectations are not self fulfilling and explain why we do not reach a steady state after twenty periods. Departing from static expectations is not a trivial matter particularly just after the outbreak. Even if all stakeholders know that the loss of exports is temporary, farmers and lenders do not know the capacity of each farmer to cope with the price drop. Again we simplify the analysis by assuming that future markets are absent or not available for all periods. In this section we explore one alternative price expectation scheme. We assume that both farmers and lenders have simple adaptive expectations (Chavas, 1999; Thijssen, 1996). More precisely they anticipate that the prices of animals in all future periods will be an average of past five periods, ignoring the exceptional price level during the outbreak period. Indeed, if lenders should consider the outbreak price to compute asset values, then more farms would be declared bankrupt, leading to greater effects than those reported earlier. We report in table III the case with bankruptcy as it leads to the most important price effects.

Table 2.3: Dynamic impacts of an FMD outbreak with farm bankruptcy and adaptive expectations (in per cent compared to the pre-FMD levels)

3.a) Market effects

Period	Output price	Production	Domestic demand	Initial herd
1	-0,63	1,40	0,16	-8,00
2	3,96	-8,81	-0,99	-9,40
3	4,56	-10,14	-1,14	-9,98
4	4,61	-10,26	-1,15	-9,83
5	4,44	-9,89	-1,11	-9,40
6	4,20	-9,35	-1,05	-8,91
7	3,97	-8,83	-0,99	-8,46
8	3,77	-8,38	-0,94	-8,09
9	3,60	-8,02	-0,90	-7,81
10	3,48	-7,75	-0,87	-7,60
11	3,40	-7,56	-0,85	-7,46
12	3,34	-7,42	-0,83	-7,35
13	3,29	-7,33	-0,82	-7,28
14	3,26	-7,26	-0,82	-7,22
15	3,24	-7,21	-0,81	-7,18
16	3,23	-7,18	-0,81	-7,15
17	3,21	-7,15	-0,80	-7,12
18	3,20	-7,12	-0,80	-7,10
19	3,19	-7,10	-0,80	-7,08
20	3,18	-7,08	-0,80	-7,06

3.b) Welfare effects

Period	Debts	Producer surplus	Consumer surplus	Total welfare
1	41,61	-18,70	0,01	-0,06
2	34,14	-18,40	-0,04	-0,11
3	25,35	-12,92	-0,05	-0,09
4	20,34	-7,88	-0,05	-0,08
5	17,61	-3,77	-0,04	-0,07
6	16,18	-0,63	-0,04	-0,05
7	15,46	1,66	-0,04	-0,04
8	15,07	3,27	-0,04	-0,04
9	14,82	4,38	-0,04	-0,03
10	14,59	5,13	-0,03	-0,03
11	14,36	5,65	-0,03	-0,03
12	14,09	6,02	-0,03	-0,03
13	13,79	6,30	-0,03	-0,02
14	13,46	6,51	-0,03	-0,02
15	13,12	6,70	-0,03	-0,02
16	12,77	6,86	-0,03	-0,02
17	12,42	7,02	-0,03	-0,02
18	12,08	7,17	-0,03	-0,02
19	11,75	7,31	-0,03	-0,02
20	11,42	-1,54	-0,03	-0,12

In the first period, results obviously equal the previous ones because price expectations remain based on the past observations. The second period results are also very similar because the price change in the first year is modest (decrease by 0.6 per cent). Results are more differentiated from the third period. Compared to the case of static expectations, we observe that remaining farmers rebuild earlier their animal herd. The turning period occurs already at this third period. Two main reasons explain this difference: a first one is the standard price effect on animal supply, a second one is the lower interest rate charged by lenders because their valuation of farm assets increases.

Despite these comparatively greater production levels, debts hold by farmers decrease less. For example, the aggregate debt level is lower than the pre-FMD one after nine periods with the static expectation scheme. This level is still 14.8 per cent higher at that period with the adaptive expectation scheme. This may appear counterintuitive. In fact this simply comes from the systematic expectation errors associated with the static expectation scheme. In other words, with adaptive expectations, farmers better response to market incentives by increasing their animal herd and production. This is to the detriment of a fast recovery of their initial debt level.

We find that after eighteen periods, production recovery at the aggregate level is lower with the adaptive expectation scheme compared to the static one. For example, in the last simulated period, the aggregate production is 7.1 per cent lower than the pre-FMD level with the former scheme; this production is 6.8 per cent lower with the latter scheme. This reversal of effects comes from the aforementioned effects on debts. We also find that our last simulated period is very close to a steady state as far as the animals are concerned: the reduction of aggregate production and herd are quite similar.

As far as welfare effects are concerned, once again we find that farmers able to remain after the FMD outbreak are able to quickly enjoy welfare gains (seven years after the outbreak), even if their debt remain higher.

Conclusion

In FMD free countries, the occurrence of an FMD outbreak is a rare event with potentially large economic losses. In this paper we explore the dynamic effects of an FMD outbreak taking into account the largely neglected issue of farm bankruptcy. We find complex dynamic effects when the farm credit market suffers from information imperfections leading to farm closure. Many dynamic mechanisms govern our simulation results, leading to very complex and non monotone effects. Welfare effects are also dramatically altered when the farm bankruptcy risk is introduced. Contrary to a widespread result obtained from static analysis (Mangen and Burrell, 2003), we find that domestic consumers may lose in the long run from an FMD outbreak because domestic supply contracts while farmers able to resist this event may ultimately gain. We also show that price expectations add further complexities in our dynamic analysis of a potentially catastrophic risk.

This paper must be viewed only as a first step in the analysis of the optimal role of public intervention in managing the consequences of an FMD outbreak. In this paper we perform a determinist partial equilibrium analysis. We deliberately exclude stochastic production factors and policy instruments in order to measure whether FMD alone is really a catastrophic economic event. Thus we compute the dynamic effects of such a disease in order to reveal the potential losses. As expected we find that this depends on the functioning of private markets. If the farm credit market suffers from asymmetry information issues and markets are incomplete, then there is a potential role for public intervention (Leathers and Chavas, 1986). The next step will consider the optimal articulation of public and private risk instruments (such as public and private stocks). The economic framework developed in this paper, once applied to realistic figures, will be relevant to investigate this long standing issue (Koontz et al., 2006).

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Chapitre 3 Un modèle d'équilibre général calculable pour la Bretagne

Résumé

Dans ce chapitre, nous décrivons la construction d'un modèle d'équilibre général calculable dynamique, pour l'analyse des effets de marché d'une épidémie d'élevage. Le modèle est élaboré pour une seule région en économie ouverte. Nous adoptons une modélisation dynamique, qui intègre les décisions intertemporelles d'épargne et d'investissement des agents. Une matrice de comptabilité sociale est créée pour cette étude ; elle concerne l'économie bretonne pour l'année 2003, est désagrégé selon plus de cinquante activités et produits, et donne un niveau de détail élevé pour les activités agricoles et agroalimentaires, secteurs les plus directement affectés par un choc sanitaire en élevage. En particulier, afin de prendre en compte explicitement les décisions dynamiques d'élevage de gros bétail (bovins, porcins), les troupeaux sont désagrégés par classes d'âges annuelles et par activités. Ils entrent comme facteurs de production dans notre économie, et la modélisation rend compte des évolutions des troupeaux régionaux.

Introduction

L'agriculture et les activités liées sont des secteurs de première importance pour l'économie bretonne. En 2003, l'agriculture représentait 7% des emplois bretons contre 4% au niveau national. Les industries agro-alimentaires employaient 7% des actifs régionaux, soit 34% des emplois de l'industrie bretonne (contre respectivement 3% et 14% au niveau français). L'économie bretonne est ainsi fortement tournée vers le secteur primaire et sa valorisation alimentaire. En outre, l'agriculture bretonne est dominée par les secteurs d'élevage, qui représentait en 2003 sept exploitations agricoles sur dix. L'élevage de vaches laitières regroupe le tiers des exploitations régionales, et compte pour 36% de la marge brute standard (MBS) globale de l'agriculture bretonne. Les exploitations spécialisées en production porcine comptent par ailleurs pour 13% de la MBS régionale (Cébron, 2004).

La survenue d'une maladie d'élevage, ou à plus forte raison d'une crise sanitaire, peut alors avoir des conséquences lourdes pour l'économie régionale. En effet, comme on l'a déjà montré, l'apparition d'une épizootie entraîne des pertes et une déstructuration lourdes et durables pour les secteurs d'élevage touchés. Dans une région telle que la Bretagne, où une part significative de l'activité économique est tournée vers l'élevage et les IAA, un tel évènement peut avoir de lourdes conséquences sur l'économie locale et affecter de manière marquée le bien-être économique régional.

La modélisation économique permet de simuler un évènement de marché tel qu'une épidémie d'élevage et d'en estimer les pertes. Dans cet objectif, et au vu du poids de l'élevage et des activités liées dans l'économie bretonne, le choix d'une modélisation en équilibre général calculable est apparu comme le plus adapté. Cette modélisation permet en effet non seulement de mesurer les effets sectoriels d'un choc de marché du type de la survenue d'une épizootie d'élevage, mais également d'estimer la réaction globale de l'économie à ce choc. Il est ainsi possible de simuler, à partir de ce type de modélisation, les incidences de chocs de marché le revenu régional, et plus généralement sur la création de valeur ajoutée et sur le produit intérieur brut de la région. De plus, afin de tenir compte des conséquences potentiellement persistantes de chocs de marché, la prise en compte des dynamiques économiques et des dynamiques agricoles doit être intégrée à la modélisation. L'analyse des effets d'une épizootie sur l'économie bretonne passe donc par une modélisation en EGC dynamique.

La mise en œuvre de modèles d'EGC suppose à la fois la mise en ordre d'un corpus de données cohérents avec les choix de modélisation souhaités, et l'élaboration d'un ensemble d'équations structurant le modèle. Cette section est donc articulée en deux parties. La première détaille l'étape de création de la matrice de comptabilité sociale (MCS) pour la Bretagne, la collecte et les hypothèses nécessaires à son élaboration. En second lieu, on explicite le modèle créé pour l'analyse de maladies d'élevage, la spécification des équations et l'inclusion de processus économiques dynamiques.

3.1 Les données : matrice de comptabilité sociale pour la Bretagne

Une MCS a pour spécificité de représenter, à des niveaux plus ou moins agrégés, l'ensemble des flux économiques marchands de l'économie considérée. Dans le cadre de cette étude, un détail particulier est apporté aux secteurs et aux productions agricoles et agroalimentaires bretons. Un haut niveau de désagrégation est proposé pour ces activités. La MCS présente des informations comptables comptant pour l'année 2003, année choisie pour le haut niveau de disponibilité des données et pour leur validation. Les informations collectées permettent ainsi de retranscrire avec précision l'état de l'économie bretonne dans la matrice.

La disponibilité inégale des données a mené à des choix de représentation. Les informations sur les résultats d'activité des entreprises ont pu être recensées simplement, grâce notamment aux Tableaux de l'Agriculture Bretonne (2004). En revanche, concernant l'emploi de ces ressources, on dispose de relativement peu d'informations au niveau régional, aussi bien pour les niveaux de consommations intermédiaires que pour la rémunération des facteurs de production. Comme le soulignent Maupertuis et Vellutini (2008) pour le cas de la Corse, « l'information économique est au mieux éparse, le plus souvent manquante » lors de la recherche de données économiques régionales précises. Il a donc fallu, en raison du manque de références régionales, procéder à des choix d'allocation des ressources. Pour ce faire, nous avons pris pour modèle les informations économiques existantes au niveau national (données Agreste). En d'autres termes, on pose l'hypothèse que les agents économiques bretons sont représentatifs des français. Cela signifie que, sur la base des résultats comptables français, des coefficients de proportionnalité ont été établis, menant à l'obtention de taux de consommations intermédiaires et de taux de valeur ajoutée. Cette hypothèse signifie également que nous considérons que les modes et technologies de productions bretonnes et ceux du reste de la France sont homogènes. La MCS de la Bretagne 2003 complète est présentée en fin de chapitre.

3.1.1 Les secteurs agricoles

On distingue dans cette MCS vingt-trois secteurs d'activités agricoles distincts pour vingt-cinq produits issus de l'agriculture. Le niveau de désagrégation de l'agriculture bretonne est synthétisé dans le tableau suivant.

Tableau 3.1: Désagrégation des activités agricoles

<table>
<tr><th colspan="2">Activités</th><th>Produits</th></tr>
<tr><td rowspan="10">Productions végétales</td><td>Blé</td><td>Blé, paille</td></tr>
<tr><td>Maïs grain</td><td>Maïs grain</td></tr>
<tr><td>Orge et escourgeon</td><td>Orge et escourgeon, paille</td></tr>
<tr><td>Autres céréales</td><td>Autres céréales, paille</td></tr>
<tr><td>Oléagineux</td><td>Oléagineux</td></tr>
<tr><td>Protéagineux</td><td>Protéagineux</td></tr>
<tr><td>Maïs fourrage</td><td>Maïs fourrage</td></tr>
<tr><td>Autres fourrages</td><td>Autres fourrages</td></tr>
<tr><td>Culture de pommes de terre</td><td>Pommes de terre</td></tr>
<tr><td>Maraîchage</td><td>Produits maraîchers</td></tr>
<tr><td rowspan="3">Productions animales</td><td>Élevages bovins*
(9 activités)</td><td>Lait, bovins vivants, bovins de boucherie, déjections animales</td></tr>
<tr><td>Élevages porcins*
(2 activités)</td><td>Porcins vivants, porcs de boucherie, déjections animales</td></tr>
<tr><td>Élevage de volailles</td><td>Volailles, œufs</td></tr>
<tr><td colspan="2">Autres activités agricoles</td><td>Autres produits agricoles</td></tr>
</table>

*Les secteurs de l'élevage bovin et de l'élevage porcin sont détaillés ultérieurement

Parmi ces activités, on distingue dix secteurs dédiés aux productions végétales dont huit pour les grandes cultures, ainsi que douze secteurs pour les productions animales, avec une forte désagrégation au sein même des activités d'élevage bovin et porcin. On peut noter la présence de deux secteurs résiduels : « Autres fourrages », et « Autres activités agricoles ». Ces secteurs regroupent l'ensemble des activités non isolées individuellement en raison de leur faible importance économique dans l'agriculture bretonne. En particulier, le secteur « Autres activités agricoles » regroupe les activités d'élevage minoritaires dans la région, que sont les élevages caprin, ovin, cunicole etc. Ce secteur sert également à l'ajustement de la MCS au niveau agricole, et à sa mise en cohérence avec les résultats agricoles agrégés de 2003.

La particularité et l'originalité de cette MCS tient à la spécification et à la désagrégation fine des secteurs d'élevages bovin et porcin. Ce travail a constitué une première étape nécessaire pour la modélisation des dynamiques de cheptel.

Tout d'abord, les activités d'élevage ont été désagrégées selon des tranches d'âge annuelles pour les animaux. Les troupeaux ont également été différenciés selon les divers ateliers de production auxquels les animaux sont affectés. Cela a conduit à la désagrégation de l'élevage bovin en neuf activités distinctes, et à celle de l'élevage porcin en deux activités, comme le montre le tableau suivant. En effet, les élevages de porcs et de bovins sont des activités pluriannuelles, pour lesquelles des décisions de conduite du troupeau sont menées chaque année. Les décisions d'élevage amènent à de possibles modifications de la structure-même de ces troupeaux en réaction à des signaux économiques. Ainsi, on ne peut par exemple pas considérer le cheptel bovin d'une ferme laitière comme un tout, mais comme l'agrégat de troupeaux de vaches laitières, de génisses et de veaux. On comprend bien que, en conséquence, chaque décision d'élevage sur un de ces troupeaux a des conséquences l'année suivante sur la structure et les décisions économiques à prendre pour le troupeau de classe d'âge supérieure.

Tableau 3.2: Désagrégation des élevages bovins et porcins

Activités	Troupeaux (facteurs de production)	Produits	
		dont animaux vivants	
Veaux de renouvellement	Veaux	Taureaux	Déjections animales
Veaux à l'engraissement		-	Bovins de boucherie, déjections animales
Velles de renouvellement	Velles	Génisses	Déjections animales
Velles à l'engraissement		-	Bovins de boucherie, déjections animales
Génisses de renouvellement	Génisses	Vaches	Déjections animales
Génisses d'engraissement		-	Bovins de boucherie, déjections animales
Bovins mâles d'engraissement	Taureaux	-	Bovins de boucherie, déjections animales
Vaches allaitantes	Vaches allaitantes	Veaux, velles	Bovins de boucherie, déjections animales
Vaches laitières	Vaches laitières	-	Bovins de boucherie, déjections animales
Engraissage de porcelet	Porcelets	Jeunes truies	Porcs de boucherie, déjections animales
Truies de reproduction	Truies	Porcelets	Porcs de boucherie, déjections animales

Le niveau de désagrégation des productions animales a été permis par une ventilation des résultats agrégés des élevage sur la base des informations fournies par la base de données du modèle Common Agricultural Policy Regionalised Impact (CAPRI)[5]. Cela a permis d’obtenir des résultats économiques annuels pour les différentes classes d’âge de troupeau, et de mettre en cohérence cette activité pluriannuelle avec l’ensemble des données de la MCS.

En second lieu, et toujours afin de prendre en compte la nature dynamique des cycles de croissance et de reproduction des cheptels, la MCS créée a pour particularité de considérer les animaux présents comme des facteurs de production, et non leur usage comme des consommations intermédiaires. C’est ce que montre également le tableau précédent, où huit troupeaux distincts sont explicitement identifiés pour les onze activités d’élevage. Nous envisageons six différents stocks de bétail: vaches laitières et vaches allaitantes (animaux de plus de deux ans), veaux mâles et femelles (animaux de moins d'un an), taureaux et génisses

[5] CAPRI est un modèle économique développé par le fonds de recherche de la Commission Européenne, dont la finalité est l’évaluation des impacts de politiques agricoles et commerciales. Le modèle est alimenté par une importante base de données, fournissant notamment des informations économiques précises sur les productions agricoles européennes à l’échelle des régions.

(animaux de moins de deux ans). Deux stocks de porcs sont également pris en compte: les porcelets (animaux de moins d'un an) et les truies.

A partir des informations sur les cheptels des Tableaux de l'Agriculture Bretonne 2004, on peut définir, pour chacun des cheptels identifiés, la taille des cheptels et le nombre d'animaux produits dans l'année. Sous l'hypothèse de maintien de la taille des troupeaux, on déduit, à partir des informations sur la taille des troupeaux et sur les productions annuelles d'animaux de boucherie, le nombre d'animaux nécessaires au renouvellement des troupeaux et donc les échanges d'animaux nécessaire au statu quo. Les volumes d'usage et d'échanges d'animaux d'élevage sont synthétisés dans le tableau suivant.

Tableau 3.3: Cheptels bovins et porcins : effectifs et dynamiques

		Troupeau	Production	Besoins en renouvellement	Echanges	Prix
		(nombre de têtes)				*(€/tête)*
Veaux mâles	renouvellement	119 500	386 880	502 944	-116 064	129
	engraissement	383 444				
Veaux femelles	renouvellement	460 586	367 772	637 472	-269 700	122
	engraissement	176 886				
Génisses	renouvellement	482 000	460 586	527 200	-66 614	525
	engraissement	45 200				
Bovins mâles adultes		119 500	119 500	119 500		577
Vaches	laitières	766 500	482 000	258 360	223 640	1 021
	allaitantes	135 100				
Porcelets		14 408 172	17 713 688	14 408 172	3 305 516	21
Truies		553 010	260 354	260 354		311

D'un point de vue formel, ces stocks d'animaux maintenus, produits, acquis et échangés figurent dans la MCS et permettent d'intégrer dans cette matrice comptable la valorisation correspondant aux dynamiques de cheptel. Les animaux produits, acquis pour le renouvellement des troupeaux et échangés sont valorisés à des niveaux de prix cohérents avec les prix moyens de vente constatés en 2003. Concernant les troupeaux maintenus en élevage, leur valorisation correspond à la rémunération annuelle de ces facteurs de production.

Concernant productions végétales, huit des dix secteurs considérés dans la MCS se rapportent aux grandes cultures. L'agriculture bretonne est caractérisée par la prédominance de l'élevage, et les cultures de céréales et d'oléoprotéagineux présentes en région servent principalement à l'alimentation animale. En conséquence, les productions animales et végétales bretonnes sont fortement interdépendantes ; un choc sur l'un de ces marchés peut rapidement se répercuter sur l'autre. En particulier, les fourrages produits (maïs fourrage et autres fourrages) sont consommés par les activités d'élevage bovin. Les céréales produites sont d'abord conditionnées, passent par les circuits de distribution et entrent dans les consommations intermédiaires des élevages avicoles et porcins. Les oléoprotéagineux entrent par ailleurs dans la composition d'aliments pour animaux, et, notamment dans le cas des oléagineux, sont valorisés en tourteaux après trituration. Notons par ailleurs que les valeurs productions secondaires –ou coproduits– que sont les pailles (produites par les activités blé tendre, orge et escourgeon, et autres céréales), tout comme les déjections animales (des activités d'élevages avicoles, porcins et bovins) ont été obtenues par désagrégation des valeurs fournies par Agreste pour les productions principales, sur la base des proportions fournies par la base de données CAPRI.

3.1.2 Les industries agroalimentaires et la distribution

La MCS créée présente également un niveau de désagrégation important pour les industries agroalimentaires et les circuits de distribution des produits issus de l'agriculture. Comme le détaille le tableau suivant, on distingue huit activités agroalimentaires pour neuf productions, ainsi que seize activités et produits de distribution.

Tableau 3.4: Désagrégation des secteurs de l'IAA et de la distribution

Activités		Produits
IAA	Industrie de la viande bovine	Viande bovine
	Industrie de la viande porcine	Viande porcine
	Industrie des viandes de volaille	Viande de volaille
	Industrie charcutière	Charcuterie
	Industrie laitière	Lait et produits laitiers
	Fabrication d'aliments pour animaux	Alimentation animale
	Industrie des corps gras	Huile, tourteaux
	Autres industries alimentaires	Autres produits agro-alimentaires
Distribution	Blé	Blé
	Maïs grain	Maïs grain
	Orge et escourgeon	Orge et escourgeon
	Autres céréales	Autres céréales
	Produits maraîchers	Produits maraîchers
	Pommes de terre	Pommes de terre
	Œufs	Œufs
	Autres produits agricoles	Autres produits agricoles
	Viande bovine	Viande bovine
	Viande porcine	Viande porcine
	Viande de volaille	Viande de volaille
	Charcuterie	Charcuterie
	Lait et produits laitiers	Lait et produits laitiers
	Alimentation animale	Alimentation animale
	Autres produits agro-alimentaires	Autres produits agro-alimentaires
	Produits d'autres industries	Produits d'autres industries

Ici, le seul secteur d'activité multiproduit est l'industrie des corps gras, qui traite les oléagineux pour en tirer des huiles et des tourteaux. Les résultats d'activités sont tirés de l'Enquête Annuelle d'Entreprise dans les Industries Agroalimentaires (Agreste), de la Revue de l'Observatoire des IAA de Bretagne (2005) et des Tableaux de l'Economie Bretonne (2004). Pour ces secteurs d'activités, les informations sur les volumes de consommations intermédiaires sont très rares ; ces données ont donc été obtenues indirectement, sur la base d'autres informations disponibles.

Les valeurs ajoutées dans les secteurs de transformation et de distribution des biens agricoles sont tirées des enquêtes annuelles entreprises (INSEE) et des enquêtes annuelles entreprises IAA (Agreste), et nous ont permis de déterminer précisément les taux de marge des entreprises. Concernant le partage de la valeur ajoutée, la Revue de l'Observatoire des IAA de Bretagne (2005) donne les montants correspondant aux frais de personnel dans les diverses industries agroalimentaires, permettant d'en déduire les parts allouées à la rémunération du travail, et par déduction à la rémunération du capital. Concernant les secteurs de la distribution, en raison de l'absence d'information sur le partage de valeur ajoutée, la répartition entre capital et travail a été établie sur la base des comptes nationaux de l'INSEE (tous secteurs confondus), où il est estimé que la rémunération des salariés entre à 56% dans le partage de la valeur ajoutée. Ces calculs de valeur ajoutée permettent de définir les niveaux de consommations intermédiaires dans ces secteurs d'activités.

Concernant plus précisément les consommations intermédiaires des secteurs de la distribution, nous faisons l'hypothèse que les biens consommés en Bretagne par les ménages ne sont pas directement issus de l'agriculture mais passent par au moins un circuit de distribution, et nous considérons que les biens de consommation finale entrant dans le panier des ménages proviennent des circuits de distribution régionaux. Il a ainsi été possible de déterminer, pour chaque secteur de la distribution, les niveaux et l'origine des consommations intermédiaires de ces secteurs, par allocation des productions agricoles et agroalimentaires vers les consommations intermédiaires des secteurs concernés.

3.1.3 Autres branches de l'économie et autres dimensions

La MCS créée donne un niveau de détails élevé pour les secteurs agricoles et les secteurs de transformation et de distribution de ces biens. Le reste de l'économie bretonne est quant à lui assez agrégé dans la matrice ; on distingue en particulier trois secteurs d'activités : un secteur industriel agrégé hors IAA (appelé autres industries), un secteur regroupant les activités d'hôtellerie, de restauration et de commerce, et un dernier secteur pour les services. Les données économiques relatives aux activités de ces secteurs sont issues du bilan économique et social 2003 de la Bretagne de la revue Octant (Luong, 2004). Il est à noter que le secteur des services a servi de variable d'ajustement de la MCS, et a permis d'en corriger les imprécisions afin d'assurer l'équilibre global de la matrice.

Les données de commerce extérieur sont issues des Douanes Françaises (au niveau de désagrégation CPF4) pour ce qui concerne les échanges hors France, c'est-à-dire entre la Bretagne, l'Union Européenne et le reste du monde. Les échanges interrégionaux en France sont très difficilement mesurables, et ne font pas l'objet de statistiques à notre connaissance. Ils sont ici déduits à partir des données connues (production, consommations, échanges hors France), et assurent donc l'équilibre de la MCS pour les marchés des biens. Leur calcul permet notamment d'observer que les IAA bretonnes ont des parts de débouchés très fortes vers les autres régions françaises.

La consommation des ménages bretons a été déterminée sur la base de résultats nationaux (INSEE). Connaissant les quantités de biens consommés en France, et considérant le comportement des ménages bretons comparable à celui des français, les résultats de consommation sont obtenus par extrapolation, proportionnellement à la taille de la population bretonne de 2003.

3.2 Les spécifications du modèle

Cette section permet de décrire la structure du modèle d'équilibre général calculable dynamique, créé pour l'analyse des effets de long terme d'une épizootie sur le tissu économique breton. L'ensemble des équations constitutives de ce modèle est explicité, et une attention particulière est donnée aux composantes dynamiques, à savoir les décisions d'investissement et d'accumulation de capital, les dynamiques d'élevage, et les décisions de consommation et d'épargne des consommateurs.

Nous adoptons l'hypothèse que les agents économiques ont des anticipations de prix rationnelles, ce qui implique, dans la construction du modèle, que les prix anticipés par les agents correspondent aux prix réels de marché. Nous considérons de plus que l'ensemble des marchés du modèle est en concurrence parfaite.

Dans la suite de cette section, nombre de notations sont utilisées pour figurer les variables du modèle, les paramètres et les indices. Ces dernières sont regroupées et définies dans les tableaux suivants.

Tableau 3.5: Définition des indices

i	Bien	f	Facteur de production, tel que : K : capital L : travail T : terre H : cheptel
j	Secteur d'activité		
r	Région d'échange		
t	Temps		

Tableau 3.6: Variables endogènes

$Y_{j,t}$	Production totale de l'activité *j*	$P_{i,t}$	Prix producteur du bien *i*
$YS_{i,j,t}$	Production de bien *i* par l'activité *j*	$PC_{i,t}$	Prix à la consommation du bien *i*
$YD_{i,t}$	Offre domestique totale de bien *i*	$PD_{i,t}$	Prix domestique du bien *i*
$YDD_{i,t}$	Production de bien *i* vendue sur le marché intérieur	$PJ_{j,t}$	Prix à la production composite de l'activité *j*
$X_{f,j,t}$	Quantité de facteur de production *f* utilisé par l'activité *j*	$PE_{i,r,t}$	Prix à l'exportation du bien *i* dans la région *r*
$VA_{j,t}$	Agrégat de valeur ajoutée de l'activité *j*	$PWE_{i,r,t}$	Prix du bien *i* dans la région *r*
$CI_{i,j,t}$	Consommation intermédiaire de bien *i* par l'activité *j*	$PM_{i,r,t}$	Prix à l'importation du bien *i* depuis la région *r*
$CIT_{i,t}$	Consommation intermédiaire totale de bien *i*	$PWM_{i,r,t}$	Prix du bien *i* de la région *r* à l'import
$XC_{i,t}$	Demande domestique de bien *i*	$PVA_{j,t}$	Prix de l'agrégat de valeur ajoutée
$QD_{i,t}$	Demande finale de bien *i*	$PI_{j,t}$	Prix d'investissement
$E_{i,r,t}$	Exportations du bien *i* dans la région *r*	$PH_{j,t}$	Prix de la bête d'élevage pour l'activité *j*
$M_{i,r,t}$	Importations du bien *i* depuis la région *r*	$W_{f,j,t}$	Rémunération du facteur de production *f* de l'activité *j*
$I_{j,t}$	Investissement sectoriel de l'activité *j*	WH_t	Richesse des ménages
$IH_{j,t}$	Investissement en animaux d'élevage de l'activité *j*	$DD_{i,r,t}$	Droit de douane appliqué au bien *i* importé depuis la région *r*
$Inv_{i,t}$	Investissement dans le bien *i*	$IMP_{j,t}$	Impôt sur l'activité *j*
R_t	Revenu	$AC_{j,t}$	Subvention à l'activité *j*
S_t	Epargne	$AF_{f,j,t}$	Subvention au facteur *f* de l'activité *j*
D_t	Dette, actifs extérieurs	$TVA_{i,t}$	Taxe sur la valeur ajoutée du bien *i*
$B_{r,t}$	Solde commercial vis-à-vis de la région *r*	$SUBX_{i,r,t}$	Subvention à l'exportation du bien *i*

Tableau 3.7: Variables exogènes et paramètres

$\alpha_{j,t}$	Paramètre d'échelle de l'activité j (fonction CES)	$io_{H,j}$	Coefficient input-output d'usage des *H* animaux d'élevage de l'activité *j*
$\varphi_{f,j}$	Paramètre de distribution des facteurs de production de l'activité j (fonction CES)	$\aleph_{j,t}, \phi_j$	Paramètres de coût d'installation du capital de l'activité *j*
ρ_j	Paramètre de substitution entre facteurs de production de l'activité j (fonction CES)	$\delta_{j,t}$	Taux de dépréciation du capital
αm_i	Paramètre d'échelle des biens d'importation et domestiques *i* (fonction CES)	$\delta h_{j,t}$	Taux de dépréciation du cheptel
$\varphi m_{i,r}$	Paramètre de distribution des biens d'importation et domestiques *i* (fonction CES)	$\beta_{i,t}$	Part relative de consommation du bien *i*
ρm_i	Paramètre de substitution entre biens d'importation et domestiques *i* (fonction CES)	r	Taux d'intérêt
σm_i	Elasticité de substitution entre produits domestiques et d'importation	η	Taux d'actualisation
$io_{i,j}$	Coefficient input-output des *i* consommations intermédiaires de l'activité *j*	$Tac_{j,t}$	Taux d'aide à l'activité *j*
$\gamma_{i,j}$	Paramètre de partage des *i* production de l'activité *j*	$Taf_{f,j,t}$	Taux d'aide au facteur *f*
$\mu e_{i,r,t}$	Paramètre d'échelle de la fonction de demande d'exportation	$Tsubx_{i,r,t}$	Taux de subvention à l'exportation du bien *i*
$\mu i_{i,r,t}$	Paramètre d'échelle de la fonction de demande d'importation	$Tdd_{i,r,t}$	Taux de droit de douane
$\varepsilon e_{i,r,t}$	Elasticité d'export	$Timp_{j,t}$	Taux d'imposition à l'activité *j*
$\varepsilon i_{i,r,t}$	Elasticité d'import	$Ttva_{i,t}$	Taux de TVA

3.2.1 L'offre

La structure générale des secteurs de production suppose une séparabilité entre les intrants. La fonction a ainsi une structure à deux niveaux. En premier lieu, les producteurs disposent, selon l'hypothèse de Leontief, d'intrants en proportions fixes ; cela concerne les diverses consommations intermédiaires et un facteur valeur ajoutée agrégé regroupant les facteurs de production capital et travail. Les consommations intermédiaires ne sont donc pas substituables, ni entre elles, ni avec les facteurs primaires de productions. De manière formelle, on peut alors écrire que :

$$CI_{i,j,t} = io_{i,j} Y_{j,t}$$

Les consommations de biens intermédiaires i pour les besoins de l'activité j $CI_{i,j,t}$ ne dépendent donc pas des prix des intrants. Le coefficient input-output $io_{i,j}$ rend compte des règles de proportionnalité, au sein d'une technologie de production, entre l'utilisation d'intrants et la production de biens ;

En second lieu, le facteur agrégé comptant pour la valeur ajoutée combine les facteurs de production via une fonction de production de type Constant Elasticity of Substitution (CES). Les producteurs ont ainsi pour objectif la minimisation du coût de production de la valeur ajoutée agrégée, tel qu'exprimé dans le programme suivant :

$$\min_{X_{f,j,t}} \sum_{f} (W_{f,j,t} - Taf_{f,j,t}) X_{f,j,t}$$

Sous la contrainte (s.c.) $VA_{j,t} = \alpha_{j,t} \left(\sum_f \varphi_{f,j} X_{f,j,t}^{-\rho_j} \right)^{-1/\rho_j}$

La résolution de ce programme d'optimisation permet de déterminer la demande de facteurs de production $X_{f,j,t}$ tel que :

$$X_{f,j,t} = \frac{VA_{j,t}}{\alpha_{j,t}} \left(\frac{\varphi_{f,j}}{W_{f,j,t} - Taf_{f,j,t}} \right)^{1/\rho_j+1} \left(\sum_f \left(\varphi_{f,j}^{1/\rho_j+1} (W_{f,j,t} - Taf_{f,j,t})^{\rho_j/\rho_j+1} \right) \right)^{1/\rho_j}$$

On obtient ainsi les demandes optimales de facteurs de production en fonction de la rémunération de ces facteurs $W_{f,j,t}$ (modulo d'éventuelles taxes et subventions) du volume de valeur ajoutée $VA_{j,t}$. Sous l'hypothèse de rendements d'échelle constants, l'expression $\sum_f (W_{f,j,t} - Taf_{f,j,t}) X_{f,j,t}$, est égale au coût de production de la valeur ajoutée $PVA_{j,t}\, VA_{j,t}$. On peut alors en déduire l'expression du prix de l'agrégat de valeur ajoutée $PVA_{j,t}$:

$$PVA_{j,t} = \frac{1}{\alpha_{j,t}} \left(\sum_f \left(\varphi_{f,j}^{1/\rho_j+1} (W_{f,j,t} - Taf_{f,j,t})^{\rho_j/\rho_j+1} \right) \right)^{1+1/\rho_j} \quad (3.1)$$

Cette expression nous permet de réécrire $X_{f,j,t}$ en fonction de $PVA_{j,t}$ tel que :

$$X_{f,j,t} = VA_{j,t} \alpha_{j,t}^{-\rho_j/\rho_j+1} \left(\varphi_{f,j} \frac{PVA_{j,t}}{W_{f,j,t} - Taf_{f,j,t}} \right)^{1/\rho_j+1} \quad (3.2)$$

Dans ce modèle les producteurs optimisent également leurs décisions d'investissement. Nous posons l'hypothèse qu'à chaque période t ces investissements sont financés par les bénéfices d'entreprise. L'investissement a pour objectif de soutenir le niveau des actifs de l'entreprise, et est par ailleurs sujet à des coûts d'installation. Les producteurs maximisent donc leur profit intertemporel, comme le montre le programme suivant :

$$\max \pi_j = \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t \begin{pmatrix} PJ_{j,t}Y_{j,t} - \sum_i (PC_{i,t}CI_{i,j,t}) \\ -PI_{j,t}(1+\aleph_{j,t})I_{j,t} - W_{L,j,t}X_{L,j,t} - W_{T,j,t}X_{T,j,t} \end{pmatrix}$$

s.c. $F_{j,t}(Y_{j,t}, CI_{i,j,t}, X_{k,j,t}, X_{L,j,t}, X_{T,j,t}) = 0$

s.c. $X_{K,j,t+1} = X_{K,j,t}(1-\delta_{j,t}) + I_{j,t}$ (3.3)

Les producteurs maximisent donc le produit de leurs ventes, tout en faisant face à des coûts de consommations intermédiaires, d'investissement, du travail et de rémunération de la terre (dans le cas des agriculteurs). Ce programme est sujet à une contrainte d'accumulation du capital $X_{K,j,t}$, dont l'évolution tend à la baisse en raison de sa dépréciation annuelle (selon $\delta_{j,t}$), et à la hausse par les décisions d'investissement $I_{j,t}$. Le paramètre $\aleph_{j,t}$ représente les coûts unitaires de transaction du capital ; il est spécifié selon la forme d'Uzawa (1969) comme suit :

$$\aleph_{j,t} = \frac{\phi_j}{2}\frac{I_{j,t}}{X_{K,j,t}}$$

Les décisions intratemporelles de production, de consommations intermédiaires, de demande de travail et de terre sont déterminées dans un premier temps. Elles permettent de déterminer également la rémunération du capital $W_{K,j,t}$. Dans un deuxième temps, on détermine les niveaux optimaux d'investissement et de stocks de capital en fonction du prix et du niveau initial de capital. On peut ainsi résumer le programme à l'expression suivante :

$$\max \pi_j = \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t \left(W_{K,j,t}X_{K,j,t} - PI_{j,t}(1+\aleph_{j,t})I_{j,t}\right)$$

s.c. $X_{K,j,t+1} = X_{K,j,t}(1-\delta_{j,t}) + I_{j,t}$ (3.4)

La condition de premier ordre qui résulte de ce programme s'écrit :

$$\begin{aligned} &WX_{K,j,t+1} + (1-\delta_{j,t})PI_{j,t+1} = (1+r)PI_{j,t} \\ &+\phi_j\left((1+r)PI_{j,t}\left(\frac{I_{j,t}}{X_{K,j,t}}\right) - (1-\delta_{j,t})PI_{j,t+1}\left(\frac{I_{j,t+1}}{X_{K,j,t+1}}\right) - \frac{PI_{j,t+1}}{2}\left(\frac{I_{j,t+1}}{X_{K,j,t+1}}\right)^2\right) \end{aligned} \tag{3.5}$$

Si on considère des coûts de transaction nuls ($\phi_j = 0$), cette condition définit simplement l'égalité entre le revenu marginal actuel d'un investissement passé et le coût marginal de cet investissement passé (actualisé selon le taux d'intérêt *r*). En cas d'existence de coûts de transaction ($\phi_j \neq 0$), le premier terme exprime le coût marginal de transaction de l'investissement en cours (évalué en $t+1$) ; le second terme est le bénéfice marginal de transaction si le capital est partiellement cédé en $t+1$; et le dernier terme la baisse de coût de transaction d'un investissement futur en cas d'augmentation du capital par les investissements actuels.

Les quantités totales de facteur terre $\sum_j X_{T,j,t}$ et travail $\sum_j X_{L,j,t}$ sont fixées initialement, selon les volumes d'usage définis par la MCS, et sont stables dans le temps. On considère donc (très logiquement pour la terre) que ces facteurs ne sont pas mobiles d'une région à une autre. La rémunération de ces facteurs permet d'en ajuster le coût.

On adopte par ailleurs l'hypothèse que le niveau d'output de l'activité *j* ($Y_{j,t}$), en volume, est égal au niveau de valeur ajoutée, tel que :

$$VA_{j,t} = Y_{j,t} \tag{3.6}$$

La condition de profit nul dans l'activité *j* permet d'écrire la relation suivante, décrivant l'égalité entre les recettes d'activité et l'allocation de ces ressources à la consommation de bien intermédiaires et à la rémunération des facteurs de production.

$$PJ_{j,t}(1 - Timp_{j,t} + Tac_{j,t})Y_{j,t} = PVA_{j,t}VA_{j,t} + \sum_i (io_{i,j}PC_{i,t})\,Y_{j,t}$$

D'après les relations définies précédemment, on peut réécrire cette équation sous forme d'une relation de prix, comme suit :

$$PVA_{j,t} = PJ_{j,t}\left(1 - Timp_{j,t} + Tac_{j,t}\right) - \sum_i\left(io_{i,j}PC_{i,t}\right) \tag{3.7}$$

Certaines activités agricoles et agroalimentaires sont génératrices de divers biens. Une des particularités de ce modèle est d'inclure l'existence de tels secteurs d'activités multi-produits, comme par exemple les élevages de volaille (production de viande de volaille et d'œufs) ou l'industrie des corps gras (production d'huile et de tourteaux). On considère alors que la production $Y_{j,t}$ d'une activité *j* correspond à un bien agrégé (e.g. production de l'industrie des corps gras), qui est ensuite subdivisé en productions individuelles $YS_{i,j,t}$ (huile et tourteau). Cette transformation de la production agrégée en productions individuelles est classiquement opérée à l'aide d'une fonction Constant Elasticity of Transformation (CET). Afin de maintenir l'homogénéité des technologies de production, les CET sont paramétrées de manières à conserver des proportions de productions $YS_{i,j,t}$ fixes au sein des activités *j*. Cette décision permet de conserver des technologies de production réalistes (e.g. les proportions d'huile et de tourteaux sont relativement fixes à la trituration d'oléagineux), et est exprimée comme suit :

$$YS_{i,j,t} = \gamma_{i,j}Y_{j,t} \tag{3.8}$$

Par voie de conséquence, la recette d'activité du secteur j correspond à la somme des recettes de ventes des *i* productions du secteur, comme exprimé dans la relation suivante :

$$PJ_{j,t}\,Y_{j,t} = \sum_i\left(P_{i,t}YS_{i,j,t}\right) \tag{3.9}$$

Dans le cas particulier des activités d'élevage, on considère dans ce modèle que les animaux d'élevage constituent des facteurs de production, et que de la taille de ces cheptels dépendent directement les volumes de production des activités concernées. Les troupeaux $X_{H,j,t}$ constituent donc des proportions fixes de la valeur ajoutée des activités d'élevage, comme décrit dans la relation suivante :

$$X_{H,j,t} = io_{H,j}VA_{j,t} \tag{3.10}$$

L'équation définissant le prix de l'agrégat de valeur ajoutée $PVA_{j,t}$ est alors modifiée afin d'intégrer la rémunération annuelle des facteurs troupeaux.

$$PVA_{j,t} = PJ_{j,t}\left(1 - Timp_{j,t} + Tac_{j,t}\right) - \sum_i \left(io_{i,j}PC_{i,t}\right) + io_{H,j}\left(W_{H,j,t} - Taf_{H,j,t}\right) \qquad (3.11)$$

Les élevages bovins et porcins sont des activités agricoles de cycle long échelonnées sur plusieurs périodes, pour lesquelles les animaux sont élevés sur plusieurs années. On considère ainsi des décisions intertemporelles d'élevage. De manière analogue aux dynamiques de capital explicitées précédemment, on considère que le maintien des troupeaux est possible via des investissements spécifiques $IH_{j,t}$, ce qui vient modifier le programme du producteur comme suit :

$$\max \pi_j = \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t \begin{pmatrix} PJ_{j,t}.Y_{j,t} - \sum_i \left(PC_{i,t}CI_{i,j,t}\right) \\ -PI_{j,t}\left(1 + \aleph_{j,t}\right)I_{j,t} - PH_{j,t}IH_{j,t} - W_{L,j,t}X_{L,j,t} - W_{T,j,t}X_{T,j,t} \end{pmatrix}$$

s.c. $F_{j,t}\left(Y_{j,t}, CI_{i,j,t}, X_{K,j,t}, X_{L,j,t}, X_{T,j,t}\right) = 0$

s.c. $X_{K,j,t+1} = X_{K,j,t}\left(1 - \delta_{j,t}\right) + I_{j,t}$

s.c. $X_{H,j,t+1} = X_{H,j,t}\left(1 - \delta h_{j,t}\right) + IH_{j,t}$ (3.12)

Ici, chaque troupeau suit une dynamique interannuelle. La taille du troupeau diminue selon un taux de dépréciation $\delta h_{j,t}$ défini, et il est possible d'en maintenir voire d'en accroître la taille via un effort d'investissement spécifique $IH_{j,t}$. Nous rappelons ici que dans ce modèle chaque troupeau H est défini par une classe d'âge d'animal et une activité d'élevage particulière. Les valeurs des taux de dépréciation des cheptels sont rappelés en fin de chapitre. La résolution de ce programme aboutit à la condition de premier ordre supplémentaire suivante :

$$W_{H,j,t+1} + \left(1 - \delta h_{j,t}\right)PH_{j,t+1} = (1+r)PH_{j,t} \qquad (3.13)$$

Cette relation définit implicitement l'effort optimal d'investissement en troupeaux pour les secteurs d'élevage. Son expression et son interprétation sont analogues à celles de la condition de premier ordre définie pour les dynamiques de capital, cette fois en l'absence de coût de transaction. On suppose en effet que les coûts de transaction en matière d'acquisition d'animaux sont négligeables, et que les transactions de ventes et d'achats se compensent. Le modèle permet ainsi de tenir compte des animaux d'élevage comme d'un capital vivant.

3.2.2 Demande et échanges

Les choix optimaux des consommateurs résultent classiquement d'un arbitrage pour l'allocation de leur revenu entre consommation de biens et épargne, dans le but de maximiser une fonction d'utilité intertemporelle, sujette à une contrainte de budget intertemporelle. Ce programme des ménages s'exprime de la façon suivante :

$$\max U = \sum_{t=0}^{\infty} \left(\frac{1}{1+\eta}\right)^{t} U\left(QD_{i,t}\right)$$

s.c.

$$WH_{t+1} - WH_t = \sum_j \pi_{j,t} + \sum_j \left(W_{L,j,t}.X_{L,j,t} + W_{T,j,t}.X_{T,j,t}\right) + \sum_i \left(TVA_{i,t} + \sum_r \left(DD_{i,r,t} - SUBX_{i,r,t}\right)\right) + \sum_j \left(IMP_j - AC_{j,t} - \sum_f AF_{f,j,t}\right) - rD_t - \sum_i \left(QD_{i,t}.PC_{i,t}\left(1 + Ttva_{i,t}\right)\right)$$

La contrainte associée à ce programme exprime la variation de richesse des ménages WH_t d'une période à la suivante. Le processus dynamique d'accumulation de richesse est dépendant de deux éléments : le revenu distribué aux ménages, et la consommation de biens et services en valeur, représentée par $\sum_i \left(QD_{i,t}.PC_{i,t}\left(1 + Ttva_{i,t}\right)\right)$. Au temps *t*, le revenu distribué aux ménages correspond aux profits distribués par les entreprises, à la rémunération des facteurs terre et travail, et aux recettes nettes du gouvernement, et minoré par les éventuels intérêts relatifs à des actifs extérieurs.

Or, on peut considérer que la variation de richesse correspond à la différence entre la capacité à épargner et les besoins d'investissement sectoriel, tel que :

$$WH_{t+1} - WH_t = S_t - \sum_j \left(PI_{j,t}\left(1 + \aleph_{j,t}\right)I_{j,t}\right)$$

On peut alors redéfinir le niveau d'épargne régional en fonction de la contrainte définie précédemment. On obtient donc :

$$S_t = \sum_j (W_{L,j,t}X_{L,j,t} + W_{T,j,t}X_{T,j,t}) + \sum_j (\pi_{j,t} + PI_{j,t}(1 + \aleph_{j,t})I_{j,t}) - rD_t + \sum_i (TVA_{i,t} + \sum_r (DD_{i,r,t} - SUBX_{i,r,t})) + \sum_j (IMP_j - AC_{j,t} - \sum_f AF_{f,j,t}) - \sum_i \left(QD_{i,t}.PC_{i,t}(1 + Ttva_{i,t})\right)$$

$$S_t = \sum_j (W_{L,j,t}.X_{L,j,t} + W_{T,j,t}X_{T,j,t} + W_{K,j,t}X_{K,j,t}) - rD_t + \sum_i (TVA_{i,t} + \sum_r (DD_{i,r,t} - SUBX_{i,r,t})) + \sum_j (IMP_j - AC_{j,t} - \sum_f AF_{f,j,t}) - \sum_i \left(QD_{i,t}PC_{i,t}(1 + Ttva_{i,t})\right)$$

$$S_t = R_t - \sum_i \left(QD_{i,t}PC_{i,t}(1 + Ttva_{i,t})\right) \tag{3.14}$$

Avec $$R_t = \sum_f \sum_j (W_{f,j,t}X_{f,j,t}) - r.D_t + \sum_i (TVA_{i,t} + \sum_r (DD_{i,r,t} - SUBX_{i,r,t})) + \sum_j (IMP_j - AC_{j,t} - \sum_f AF_{f,j,t}) \tag{3.15}$$

Où le revenu disponible R_t est égal à la rémunération des facteurs de production et aux recettes de gouvernement, déduction faite des intérêts de la dette extérieure. La résolution de ce programme s'opère en deux temps. On détermine d'abord les niveaux de consommation des ménages pour chaque période, compte tenu d'un niveau de revenu et de niveaux d'épargne donnés, tel que :

$$QD_{i,t}PC_{i,t}(1 + Ttva_{i,t}) = \beta_{i,t}R_t - S_t \tag{3.16}$$

Les arbitrages de consommation des ménages sont ainsi définis par une fonction Cobb-Douglas, où la part de consommation $\beta_{i,t}$ de chaque bien *i* figure comme une proportion du revenu disponible, tel que $\sum_i \beta_{i,t} = 1$. En second lieu, une fois les choix de consommation intratemporels effectués, on peut déterminer la condition de premier ordre définissant les choix intertemporels d'épargne à partir de la relation (3.13). En effet, nous avons :

$$\begin{aligned} R_t - S_t &= \sum_i \left(QD_{i,t}PC_{i,t}(1 + Ttva_{i,t})\right) \\ &= \left(\frac{1+r}{1+\eta}\right) \sum_i \left(QD_{i,t-1}PC_{i,t-1}(1 + Ttva_{i,t-1})\right) \end{aligned}$$

D'où :

$$R_{t+1} - S_{t+1} = \left(\frac{1+r}{1+\eta}\right)(R_t - S_t) \tag{3.17}$$

En conséquence, en cas de modification des prix sur les marchés des biens de consommations, les niveaux de revenu aussi bien que d'épargne seront affectés.

La demande spécifique de biens s'établit autour d'un arbitrage entre les productions domestiques $YDD_{i,t}$ et les importations $M_{i,r,t}$ de bien *i* depuis la région *r*, selon une fonction CES. Le consommateur fait face à un programme de minimisation des coûts liés à l'acquisition de ce bien, tel que :

$$\min_{YDD_{i,t}, M_{i,r,t}} PD_{i,t}\, YDD_{i,t} + PM_{i,r,t} M_{i,r,t}$$

$$\text{s.c. } XC_{i,t} = \alpha m_i \left(\sum_r \varphi m_{i,r} M_{i,r,t}^{-\rho m_i} + \left(1 - \sum_r \varphi m_{i,r}\right) YDD_{i,t}^{-\rho m_i}\right)^{-1/\rho m_i}$$

$$\text{Avec } P_{i,t} = PD_{i,t} \tag{3.18}$$

$$\text{Et où } \rho m_i = \frac{1}{\sigma m_i} - 1$$

Où les prix des biens domestiques et d'importations sont définis respectivement par $PD_{i,t}$ et $PM_{i,r,t}$. La demande agrégée est représentée par une fonction CES, considérant qu'il peut y avoir substitution imparfaite entre des produits similaires provenant de régions extérieures ou du marché intérieur (hypothèse d'Armington). La résolution de ce programme d'optimisation permet d'obtenir, à partir des conditions de premier ordre, l'équation de demande d'importation et l'équation de demande du produit en provenance du marché intérieur. Ces équations se définissent par :

$$M_{i,r,t} \geq \frac{XC_{i,t}}{\alpha m_i}\left(\alpha m_i \varphi m_{i,r} \frac{PC_{i,t}}{PM_{i,r,t}}\right)^{1/1+\rho m_i} \quad \perp M_{i,r,t} \tag{3.19}$$

$$YDD_{i,t} = \frac{XC_{i,t}}{\alpha m_i}\left(\alpha m_i \left(1 - \sum_r \varphi m_{i,r}\right) \frac{PC_{i,t}}{PD_{i,t}}\right)^{1/1+\rho m_i} \tag{3.20}$$

Ces fonctions de demande d'importation et de consommation locale sont homogènes de degré 1 par rapport à la demande domestique totale de bien i $XC_{i,t}$. Par ailleurs le prix total des achats domestiques pour un bien i est défini par :

$$PC_{i,t}.XC_{i,t} = \sum_r \left(PM_{i,r,t}M_{i,r,t}\right) + PD_{i,t}YDD_{i,t}$$

Cette expression définit la demande en valeur comme la somme de la demande de bien domestique et de la demande d'importation. En remplaçant les demandes de bien domestique et d'importation par leurs expressions, on peut définir le prix $PC_{i,t}$ de l'agrégat de demande comme :

$$PC_{i,t} = \frac{1}{\alpha m_i}\begin{bmatrix} \sum_r \left(\varphi m_{i,r}^{1/\rho m_i+1} PM_{i,r,t}^{\rho m_i/\rho m_i+1}\right) \\ +\left(1-\sum_r \varphi m_{i,r}\right)^{1/\rho m_i+1} PD_{i,t}^{\rho m_i/\rho m_i+1}\end{bmatrix}^{1+1/\rho m_i} \tag{3.21}$$

L'offre d'importation et la demande d'exportation de bien i sont spécifiées selon l'hypothèse d'Armington, via des fonctions à élasticité constante des prix de i. Ces expressions permettent de donner, en fonction des prix extérieurs d'un bien, les niveaux d'offre d'importation et de demande d'exportation correspondants, tel que :

$$M_{i,r,t} = \mu i_{i,r,t} PWM_{i,r,t}^{\varepsilon i_{i,r,t}} \tag{3.22}$$

$$E_{i,r,t} = \mu e_{i,r,t} PWE_{i,r,t}^{\varepsilon e_{i,r,t}} \tag{3.23}$$

On rappelle que les valeurs des paramètres sont fournies en fin de chapitre. La position dominante de la Bretagne pour la production de lait et de produits laitiers fait notamment l'objet d'une spécification d'élasticité particulière.

L'offre d'exportation est définie de telle sorte que les prix à l'exportation soutiennent les prix intérieurs. En d'autres termes, on a :

$$P_{i,t} \geq PE_{i,r,t} \qquad \perp E_{i,r,t} \tag{3.24}$$

Le prix domestique du bien importé est équivalent à son prix sur le marché de la région considérée, modulé éventuellement par un taux de droit de douane.

$$PM_{i,r,t} = PWM_{i,r,t}(1 + Tdd_{i,r,t}) \qquad (3.25)$$

Le prix d'exportation du bien *i* est équivalent aux prix sur les marchés étrangers, et peut éventuellement bénéficier d'une subvention aux exportations.

$$PE_{i,r,t}(1 - Tsubx_{i,r,t}) = PWE_{i,r,t} \qquad (3.26)$$

L'hypothèse a été faite ici qu'aucun taux de change n'est appliqué aux prix extérieurs, en raison du fait que le modèle est appliqué à la région Bretagne et que, comme le montrent les résultats décrits dans la MCS, la grande majorité des échanges économiques de la région ont lieu avec le reste de la France.

Sur le marché intérieur, l'offre domestique totale d'un bien *i* est définie par :

$$YD_{i,t} = \sum_j YS_{i,j,t} \qquad (3.27)$$

Les producteurs peuvent offrir leur production sur le marché intérieur aussi bien que sur les marchés d'export. L'offre domestique total se décompose ainsi tel que :

$$YD_{i,t} = \sum_r E_{i,r,t} + YDD_{i,t} \qquad (3.28)$$

L'intervention du gouvernement dans l'économie est visible via divers outils politiques. Des droits de douane $DD_{i,r,t}$ peuvent être appliqués aux produits d'importation, tout comme des subventions à l'exportation $SUBX_{i,r,t}$ pour les produits destinés aux marchés extérieurs.

$$DD_{i,r,t} = Tdd_{i,r,t}PWM_{i,r,t}M_{i,r,t} \qquad (3.29)$$

$$SUBX_{i,r,t} = Tsubx_{i,r,t}PE_{i,r,t}E_{i,r,t} \qquad (3.30)$$

L'activité des entreprises peut être sujette à une imposition $IMP_{j,t}$, et à l'inverse des aides sous forme de soutien à l'activité $AC_{j,t}$ et aux facteurs de production $AF_{f,j,t}$ peuvent être décidées.

$$IMP_{j,t} = PJ_{j,t}Timp_{j,t}Y_{j,t} \tag{3.31}$$

$$AC_{j,t} = PJ_{j,t}Tac_{j,t}Y_{j,t} \tag{3.32}$$

$$AF_{f,j,t} = Taf_{f,j,t}X_{f,j,t} \tag{3.33}$$

Enfin, le gouvernement perçoit une taxe sur la valeur ajoutée $TVA_{i,t}$ pour le commerce des biens de consommation finale

$$TVA_{i,t} = Ttva_{i,t}PC_{i,t}QD_{i,t} \tag{3.34}$$

La demande domestique totale de bien *i* correspond à la somme de l'ensemble des consommations intermédiaires de ce bien $CIT_{i,t}$, de sa consommation finale $QD_{i,t}$ et de la demande d'investissement en ce bien $Inv_{i,t}$. L'équation correspondante est :

$$XC_{i,t} = CIT_{i,t} + QD_{i,t} + Inv_{i,t} \tag{3.35}$$

Avec $CIT_{i,t} = \sum_j CI_{i,j,t}$ (3.36)

Comme défini précédemment, à l'équilibre de marché domestique des biens, la valorisation de cette demande totale au prix $PC_{i,t}$ égalise l'offre domestique correspondante, décrite comme la somme de la production domestique non exportée $PD_{i,t}.YDD_{i,t}$ et de l'offre d'importation $\sum_r(PM_{i,r,t}M_{i,r,t})$.

Le solde commercial de la Bretagne vis-à-vis des diverses régions d'échange est quant à lui défini comme :

$$B_{r,t} = \sum_i(PWE_{i,r,t}E_{i,r,t}) - \sum_i(PWM_{i,r,t}M_{i,r,t}) \tag{3.37}$$

3.2.3 Bouclage macroéconomique et état stationnaire

Le bouclage macroéconomique du modèle est assuré par la spécification de la dette. Tout d'abord, les intérêts annuels de la dette sont intégrés dans la définition du revenu (c.f. équation (3.14)). On intègre ainsi la dynamique d'accumulation des actifs étrangers. Cette dynamique de dette est définie comme :

$$D_{t+1} - D_t = \sum_i \left(PC_{i,t} Inv_{i,t} \right) - S_t \quad ; \quad D_0 = \overline{D_0} \tag{3.38}$$

Où la dette initiale est égale au déficit de balance commerciale ($\overline{D_0} = \sum_r B_{r,t}$). Cette relation signifie que l'équilibre dynamique entre l'investissement régional et l'épargne régionale est ajusté par les flux d'actifs étrangers dans la région. En d'autres termes, les investissements étrangers dans la région permettent de soutenir l'investissement dans les biens produits sur le marché intérieur. Grâce à cette relation, l'équilibre macroéconomique du modèle est respecté pour chaque période.

La résolution d'un modèle d'EGC dynamique sur un horizon de long terme impose au modélisateur de définir des conditions d'équilibre stationnaire pour la dernière période de simulation. Dans le cas de ce modèle, les équations (3.4) et (3.5) permettent de déterminer les décisions intertemporelles d'investissement, et l'équation (3.17) celle d'épargne. Nous posons alors l'hypothèse que, à l'état stationnaire, l'investissement sectoriel équivaut à la dépréciation du capital ($I_{j,t} = \delta_{j,t} K_{j,t}$) de sorte que $K_{j,t+1} = K_{j,t}$, et que la dynamique des actifs étrangers est stable ($D_{t+1} - D_t = 0$), autrement dit que l'épargne égalise l'investissement ($S_t = \sum_i \left(PC_{i,t} Inv_{i,t} \right)$).

3.2.4 Calibrage et paramètres

Les valeurs des paramètres utilisés dans ce modèle sont regroupées dans les tableaux suivants. On recense en premier lieu les élasticités relatives aux échanges de biens entre la Bretagne et ses régions d'échanges. Dans le tableau suivant figurent les taux de dépréciation du capital et des cheptels. Dans le cas des animaux, les taux de dépréciations sont fixés à 1 pour les troupeaux jeunes, correspondant au fait que ce sont des stades transitoires dans le cycle de vie des animaux. Concernant les animaux adultes (vaches et truies), le taux de dépréciation correspond au taux de renouvellement des cheptels/taux d'abattage annuel des animaux. Enfin, le dernier tableau montre les proportions de revenu allouées aux consommations de divers biens.

Tableau 3.8: Elasticités de substitution entre produits domestiques et d'importation, élasticités-prix de demande d'exportation et d'offre d'importation

	σm_i	$\varepsilon e_{i,r}$		$\varepsilon i_{i,r}$
		France	UE, Reste du monde	France, UE, Reste du monde
produits laitiers	20	-5	-5	20
hôtellerie, restauration, commerces	2	-5	-10	20
industries hors IAA	2	-5	-10	20
services	2	-5	-10	20
autres produits	20	-5	-10	20

Tableau 3.9: Taux de dépréciation annuel du capital et des cheptels d'élevage bovins et porcins

$\delta_{j,t}$	0.66
$\delta h_{j,t}$ veaux mâles	1
$\delta h_{j,t}$ veaux femelles	1
$\delta h_{j,t}$ génisses	1
$\delta h_{j,t}$ taureaux	1
$\delta h_{j,t}$ vaches laitières	0.287
$\delta h_{j,t}$ vaches allaitantes	0.287
$\delta h_{j,t}$ porcelets	1
$\delta h_{j,t}$ truies	0.45

Conclusion

Cette section fait état des choix de modélisation adoptés pour l'analyse des effets indirects liés à la survenue d'une maladie épidémique à l'échelle de la Bretagne. Ces effets pouvant être élevés et observés sur le long terme, le choix de modélisation en équilibre général calculable dynamique a été adopté. Ce choix paraît d'autant plus pertinent que, comme le montrent les résultats économiques recensés dans la matrice de comptabilité sociale, les secteurs agricoles et agroalimentaires occupent une part importante de l'économie régionale. Le travail de modélisation, recueil de données inclus, a donc consisté à détailler finement les secteurs d'élevage bretons. Des données économiques précises et très désagrégés ont été créées pour ces activités, permettant ainsi une modélisation fine. Les conséquences de marché d'une épidémie d'élevage, potentiellement diffuses dans le temps, ont amené à la spécification de composantes dynamiques dans le modèle. Outre les dynamiques interannuelles d'accumulation de capital et les décisions d'investissement qui en découlent, les dynamiques de croissance et de reproduction au sein des cheptels bovins et porcins ont également été intégrées. Cette modélisation constitue ainsi une première étape pour la simulation des conséquences de marché d'une épidémie de type fièvre aphteuse en Bretagne.

Tableau 3.10: Matrice de comptabilité sociale désagrégée pour la Bretagne 2003 (milliards d'Euros)

Pour davantage de visibilité des données, la MCS est découpée par blocs, comme explicité dans le tableau récapitulatif qui suit.

<table>
<tr><th></th><th colspan="2">Activités</th><th colspan="2">Biens</th><th>Institutions, exportations</th></tr>
<tr><td>Activités</td><td colspan="2"></td><td>(1)</td><td>(2)</td><td>(3)</td></tr>
<tr><td>Biens</td><td>(4)</td><td>(5)</td><td colspan="2"></td><td>(6)</td></tr>
<tr><td>Valeur ajoutée
Institutions
Importations</td><td>(7)</td><td>(8)</td><td>(9)</td><td>(10)</td><td>(11)</td></tr>
</table>

(1)

		BIENS																									
														Bovins								Porcins					
ACTIVITES		Blé tendre	Maïs grain	Orge	Autres céréales	Paille	Oléagineux	Protéagineux	Maïs fourrage	Autres fourrages	Légumes frais	Pommes de terre	Lait et produits laitiers (vache)	Jeunes taureaux (1-2 ans)	Jeunes génisses (1-2 ans)	Jeunes vaches (>2 ans)	Jeunes veaux mâles (<1 an)	Jeunes veaux femelles (<1 an)	Bovins de boucherie	Volaille	Oeufs	Jeunes porcelets	Jeunes truies	Porcs bouchers	Déjections animales	Autres produits agricoles	**Total produits agricoles**
Grandes cultures	Blé tendre	0,2				0,012																					**0,2120**
Grandes cultures	Maïs grain		0,081																								**0,0810**
Grandes cultures	Orge et escourgeon			0,042		0,004																					**0,0460**
Grandes cultures	Autres céréales				0,043	0,003																					**0,0460**
Grandes cultures	Oléagineux						0,018																				**0,0180**
Grandes cultures	Protéagineux							0,004																			**0,0040**
Grandes cultures	Maïs fourrage								0,171																		**0,1710**
Grandes cultures	Autres fourrages									0,351																	**0,3510**
Elevage volaille																				0,736	0,456				0,117		**1,3090**
Elevage porcin	Truies																					0,35		0,081	0,032		**0,4630**
Elevage porcin	Porcelets																						0,072	1,415	0,095		**1,5820**
Elevage bovin	Veaux mâles de renouvellement													0,069											0,004		**0,0730**
Elevage bovin	Veaux femelles de renouvellement														0,242										0,006		**0,2480**
Elevage bovin	Génisses de renouvellement															0,492									0,019		**0,5110**
Elevage bovin	Veaux mâles à l'engrais																		0,227						0,003		**0,2300**
Elevage bovin	Veaux femelles à l'engrais																		0,105						0,001		**0,1060**
Elevage bovin	Génisses à l'engrais																		0,041						0,003		**0,0440**
Elevage bovin	Bovins mâles adultes à l'engrais																		0,127						0,009		**0,1360**
Elevage bovin	Vaches allaitantes																0,009	0,008	0,035						0,015		**0,0670**
Elevage bovin	Vaches laitières												1,483				0,041	0,037	0,2						0,135		**1,8960**
Légumes frais											0,471																**0,4710**
Pommes de terre												0,104															**0,1040**
Autres activités agricoles																										0,97	**0,9700**
Total Agriculture		0,2000	0,0810	0,0420	0,0430	0,0190	0,0180	0,0040	0,1710	0,3510	0,4710	0,1040	1,4830	0,0690	0,2420	0,4920	0,0500	0,0450	0,7350	0,7360	0,4560	0,3500	0,0720	1,4960	0,4390	0,9700	**9,1390**
Industrie de la viande bovine																											
Industrie du porc																											
Industrie des viandes de volailles																											
Industrie des charcuteries																											
Industrie laitière																											
Fabrication d'aliments pour animaux																											
Industrie des corps gras																											
Autres industries alimentaires																											
Total Industrie Agro-alimentaire																											
Distribution	Blé																										
Distribution	Maïs grain																										
Distribution	Orge et escourgeon																										
Distribution	Autres céréales																										
Distribution	Produits maraîchers																										
Distribution	Pommes de terre																										
Distribution	Œufs																										
Distribution	Autres produits agricoles																										
Distribution	Viande bovine																										
Distribution	Viande porcine																										
Distribution	Viande de volaille																										
Distribution	Charcuterie																										
Distribution	Lait et produits laitiers																										
Distribution	Alimentation animale																										
Distribution	Autres produits agro-alimentaires																										
Distribution	Produits d'autres industries																										
Distribution	**Total distribution**																										
Autres industries																											
Hôtel- Restaurant, Commerce																											
Services (y compris construction)																											
Total Reste de l'économie																											
TOTAL ACTIVITES		**0,2000**	**0,0810**	**0,0420**	**0,0430**	**0,0190**	**0,0180**	**0,0040**	**0,1710**	**0,3510**	**0,4710**	**0,1040**	**1,4830**	**0,0690**	**0,2420**	**0,4920**	**0,0500**	**0,0450**	**0,7350**	**0,7360**	**0,4560**	**0,3500**	**0,0720**	**1,4960**	**0,4390**	**0,9700**	9,1390

(2)

ACTIVITES												Distribution																					
		Viande bovine	Viande porcine	Viande de volaille	Charcuterie	Lait	Alimentation animale	Huile	Tourteaux	Autres	**Total produits agro-alimentaires**	Blé	Maïs grain	Orge et escourgeon	Autres céréales	Produits maraîchers	Pommes de terre	Œufs	Autres produits agricoles	Viande bovine	Viande porcine	Viande de volaille	Charcuterie	Lait et produits laitiers	Alimentation animale	Autres produits agro-alimentaires	Produits d'autres industries	Total pdts distribués	Autres industries	Hôtel-Restaurant, Commerce	Services (y compris construction)	**Total Reste de l'économie**	**TOTAL PRODUITS**
Grandes cultures	Blé tendre																																**0,2120**
Grandes cultures	Maïs grain																																**0,0810**
Grandes cultures	Orge et escourgeon																																**0,0460**
Grandes cultures	Autres céréales																																**0,0460**
Grandes cultures	Oléagineux																																**0,0180**
Grandes cultures	Protéagineux																																**0,0040**
Grandes cultures	Maïs fourrage																																**0,1710**
Grandes cultures	Autres fourrages																																**0,3510**
Elevage volaille																																	**1,3090**
Elevage porcin	Truies																																**0,4630**
Elevage porcin	Porcelets																																**1,5820**
Elevage bovin	Veaux mâles de renouvellement																																**0,0730**
Elevage bovin	Veaux femelles de renouvellement																																**0,2480**
Elevage bovin	Génisses de renouvellement																																**0,5110**
Elevage bovin	Veaux mâles à l'engrais																																**0,2300**
Elevage bovin	Veaux femelles à l'engrais																																**0,1060**
Elevage bovin	Génisses à l'engrais																																**0,0440**
Elevage bovin	Bovins mâles adultes à l'engrais																																**0,1360**
Elevage bovin	Vaches allaitantes																																**0,0670**
Elevage bovin	Vaches laitières																																**1,8960**
	Légumes frais																																**0,4710**
	Pommes de terre																																**0,1040**
	Autres activités agricoles																																**0,9700**
	Total Agriculture																																**9,1390**
	Industrie de la viande bovine	0,947									**0,9470**																						**0,9470**
	Industrie du porc		1,978								**1,9780**																						**1,9780**
	Industrie des viandes de volailles			1,143							**1,1430**																						**1,1430**
	Industrie des charcuteries				1,59						**1,5900**																						**1,5900**
	Industrie laitière					2,486					**2,4860**																						**2,4860**
	Fabrication d'aliments pour animaux						1,903				**1,9030**																						**1,9030**
	Industrie des corps gras							0,104	0,11		**0,2140**																						**0,2140**
	Autres industries alimentaires									4,309	**4,3090**																						**4,3090**
	Total Industrie Agro-alimentaire	0,9470	1,9780	1,1430	1,5900	2,4860	1,9030	0,1040	0,1100	4,3090	**14,5700**																						**14,5700**
Distribution	Blé											0,475																0,4750					**0,4750**
Distribution	Maïs grain												0,145															0,1450					**0,1450**
Distribution	Orge et escourgeon													0,112														0,1120					**0,1120**
Distribution	Autres céréales														0,046													0,0460					**0,0460**
Distribution	Produits maraîchers																	0,051										0,0510					**0,0510**
Distribution	Pommes de terre															0,473												0,4730					**0,4730**
Distribution	Œufs																0,058											0,0580					**0,0580**
Distribution	Autres produits agricoles																		1,228									1,2280					**1,2280**
Distribution	Viande bovine																			0,322								0,3220					**0,3220**
Distribution	Viande porcine																				0,815							0,8150					**0,8150**
Distribution	Viande de volaille																					0,256						0,2560					**0,2560**
Distribution	Charcuterie																						0,466					0,4660					**0,4660**
Distribution	Lait et produits laitiers																							0,707				0,7070					**0,7070**
Distribution	Alimentation animale																								1,978			1,9780					**1,9780**
Distribution	Autres produits agro-alimentaires																									4,308		4,3080					**4,3080**
Distribution	Produits d'autres industries																										24,021	24,0210					**24,0210**
Distribution	**Total distribution**											**0,4750**	**0,1450**	**0,1120**	**0,0460**	**0,4730**	**0,0580**	**0,0510**	**1,2280**	**0,3220**	**0,8150**	**0,2560**	**0,4660**	**0,7070**	**1,9780**	**4,3080**	**24,0210**	35,4610					**35,4610**
	Autres industries																												13,855		0,066	**13,9210**	**13,9210**
	Hôtel- Restaurant, Commerce																													30,776		**30,7760**	**30,7760**
	Services (y compris construction)																												0,061	0,118	24,634	**24,8130**	**24,8130**
	Total Reste de l'économie																												13,9160	30,8940	24,7000	**69,5100**	**69,5100**
	TOTAL ACTIVITES	**0,9470**	**1,9780**	**1,1430**	**1,5900**	**2,4860**	**1,9030**	**0,1040**	**0,1100**	**4,3090**	**14,5700**	**0,4750**	**0,1450**	**0,1120**	**0,0460**	**0,4730**	**0,0580**	**0,0510**	**1,2280**	**0,3220**	**0,8150**	**0,2560**	**0,4660**	**0,7070**	**1,9780**	**4,3080**	**24,0210**	35,4610	**13,9160**	**30,8940**	**24,7000**	**69,5100**	**128,6800**

(3)

			INSTITUTIONS			compte de capital	RDM - Exports Biens agricoles				
			Ménages	Subventions agricoles	TOTAL INSTITUTIONS	ΔS Bretagne	Reste de la France	Reste de l'UE hors France (14)	Reste du monde hors UE	TOTAL RESTE DU MONDE	TOTAL
ACTIVITES	Grandes cultures	Blé tendre		0,091	**0,091**						**0,3030**
		Maïs grain		0,038	**0,038**						**0,1190**
		Orge et escourgeon		0,021	**0,021**						**0,0670**
		Autres céréales		0,02	**0,02**						**0,0660**
		Oléagineux		0,009	**0,009**						**0,0270**
		Protéagineux		0,004	**0,004**						**0,0080**
		Maïs fourrage		0,114	**0,114**						**0,2850**
		Autres fourrages		0,003	**0,003**						**0,3540**
	Elevage volaille			0,012	**0,012**						**1,3210**
	Elevage porcin	Truies		0,003	**0,003**						**0,4660**
		Porcelets		0,012	**0,012**						**1,5940**
	Elevage bovin	Veaux mâles de renouvellement		0,005	**0,005**						**0,0780**
		Veaux femelles de renouvellement		0,006	**0,006**						**0,2540**
		Génisses de renouvellement		0,029	**0,029**						**0,5400**
		Veaux mâles à l'engrais		0,006	**0,006**						**0,2360**
		Veaux femelles à l'engrais		0,002	**0,002**						**0,1080**
		Génisses à l'engrais		0,006	**0,006**						**0,0500**
		Bovins mâles adultes à l'engrais		0,02	**0,02**						**0,1560**
		Vaches allaitantes		0,006	**0,006**						**0,0730**
		Vaches laitières		0,052	**0,052**						**1,9480**
	Légumes frais			0,004	**0,004**						**0,4750**
	Pommes de terre			0,001	**0,001**						**0,1050**
	Autres activités agricoles			0,008	**0,008**						**0,9780**
	Total Agriculture		0,0000	0,4720	**0,4720**						**9,6110**
	Industrie de la viande bovine										**0,9470**
	Industrie du porc										**1,9780**
	Industrie des viandes de volailles										**1,1430**
	Industrie des charcuteries										**1,5900**
	Industrie laitière										**2,4860**
	Fabrication d'aliments pour animaux										**1,9030**
	Industrie des corps gras										**0,2140**
	Autres industries alimentaires										**4,3090**
	Total Industrie Agro-alimentaire										**14,5700**
	Distribution	Blé									**0,4750**
		Maïs grain									**0,1450**
		Orge et escourgeon									**0,1120**
		Autres céréales									**0,0460**
		Produits maraîchers									**0,0510**
		Pommes de terre									**0,4730**
		Œufs									**0,0580**
		Autres produits agricoles									**1,2280**
		Viande bovine									**0,3220**
		Viande porcine									**0,8150**
		Viande de volaille									**0,2560**
		Charcuterie									**0,4660**
		Lait et produits laitiers									**0,7070**
		Alimentation animale									**1,9780**
		Autres produits agro-alimentaires									**4,3080**
		Produits d'autres industries									**24,0210**
		Total distribution									**35,4610**
	Autres industries										**13,9210**
	Hôtel- Restaurant, Commerce										**30,7760**
	Services (y compris construction)										**24,8130**
	Total Reste de l'économie										**69,5100**
	TOTAL ACTIVITES		**0,0000**	**0,4720**	**0,4720**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**129,1520**

(4)

		ACTIVITES																						
		Grandes cultures									Elevage porcin		Elevage bovin											
		Blé tendre	Maïs grain	Orge et escourgeon	Autres céréales	Oléagineux	Protéagineux	Maïs fourrage	Autres fourrages	Elevage volaille	Truies	Porcelets	Veaux mâles de renouvellement	Veaux femelles de renouvellement	Génisses de renouvellement	Veaux mâles à l'engrais	Veaux femelles à l'engrais	Génisses à l'engrais	Bovins mâles adultes à l'engrais	Vaches allaitantes	Vaches laitières	Légumes frais	Pommes de terre	Autres activités agricoles	Total Agriculture
BIENS	Blé tendre																							0,0000
	Maïs grain																							0,0000
	Orge																							0,0000
	Autres céréales																							0,0000
	Paille												0,001	0,001		0,001	0,001				0,014				0,0180
	Oléagineux																							0,0000
	Protéagineux																							0,0000
	Maïs fourrage												0,002	0,003	0,017	0,004	0,002	0,004	0,012	0,005	0,103			0,001	0,1530
	Autres fourrages												0,001	0,001	0,007	0,002	0,001	0,002	0,005	0,002	0,272				0,2930
	Légumes frais																							0,0000
	Pommes de terre																							0,0000
	Lait et produits laitiers (vache)																							0,0000
Bovins	Jeunes taureaux (1-2 ans)																							0,0000
Bovins	Jeunes génisses (1-2 ans)																							0,0000
Bovins	Jeunes vaches (>2 ans)																							0,0000
Bovins	Jeunes veaux mâles (<1 an)																							0,0000
Bovins	Jeunes veaux femelles (<1 an)																							0,0000
Bovins	Bovins de boucherie																							0,0000
	Volaille																							0,0000
	Oeufs																							0,0000
Porcins	Jeunes porcelets																							0,0000
Porcins	Jeunes truies																							0,0000
Porcins	Porcs bouchers																							0,0000
	Déjections animales	0,042	0,015	0,009	0,01	0,003	0,001	0,056	0,084													0,006	0,007		0,2330
	Autres produits agricoles																							0,0000
	Total produits agricoles	0,0420	0,0150	0,0090	0,0100	0,0030	0,0010	0,0560	0,0840	0,0000	0,0000	0,0000	0,0040	0,0050	0,0240	0,0070	0,0040	0,0060	0,0170	0,0070	0,3890	0,0060	0,0070	0,0010	0,6970
	Viande bovine																							0,0000
	Viande porcine																							0,0000
	Viande de volaille																							0,0000
	Charcuterie																							0,0000
	Lait																							0,0000
	Alimentation animale																							0,0000
	Huile																							0,0000
	Tourteaux									0,028	0,008	0,035	0,004	0,005	0,014	0,004	0,002	0,003	0,009	0,004	0,034				0,1500
	Autres																							0,0000
	Total produits agro-alimentaires	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0280	0,0080	0,0350	0,0040	0,0050	0,0140	0,0040	0,0020	0,0030	0,0090	0,0040	0,0340	0,0000	0,0000	0,0000	0,1500
Distribution	Blé									0,049	0,01	0,04									0,007				0,1060
Distribution	Maïs grain									0,016	0,003	0,013									0,003				0,0350
Distribution	Orge et escourgeon									0,011	0,002	0,009									0,002				0,0240
Distribution	Autres céréales									0,008	0,001	0,007													0,0160
Distribution	Produits maraîchers																							0,0000
Distribution	Pommes de terre																							0,0000
Distribution	Œufs																							0,0000
Distribution	Autres produits agricoles																							0,0000
Distribution	Viande bovine																							0,0000
Distribution	Viande porcine																							0,0000
Distribution	Viande de volaille																							0,0000
Distribution	Charcuterie																							0,0000
Distribution	Lait et produits laitiers																							0,0000
Distribution	Alimentation animale									0,643	0,138	0,613	0,004	0,005	0,013	0,005	0,002	0,002	0,008	0,004	0,174			0,367	1,9780
Distribution	Autres produits agro-alimentaires																							0,0000
Distribution	Produits d'autres industries	0,136	0,036	0,022	0,033	0,008	0,002	0,116	0,153	0,027	0,002	0,011	0,006	0,007	0,005	0,006	0,003	0	0,001	0,002	0,087	0,095	0,027	0,179	0,9640
Distribution	**Total pdts distribués**	0,1360	0,0360	0,0220	0,0330	0,0080	0,0020	0,1160	0,1530	0,7540	0,1560	0,6930	0,0100	0,0120	0,0180	0,0110	0,0050	0,0020	0,0090	0,0060	0,2730	0,0950	0,0270	0,5460	3,1230
	Autres industries																							0,0000
	Hôtel- Restaurant, Commerce																							0,0000
	Services (y compris construction)	0,042	0,017	0,009	0,008	0,003	0,001	0,037	0,09	0,125	0,144	0,222	0,009	0,013		0,006	0				0,125	0,073	0,019	0,346	1,2890
	Total Reste de l'économie	0,0420	0,0170	0,0090	0,0080	0,0030	0,0010	0,0370	0,0900	0,1250	0,1440	0,2220	0,0090	0,0130	0,0000	0,0060	0,0000	0,0000	0,0000	0,0000	0,1250	0,0730	0,0190	0,3460	1,2890
	TOTAL PRODUITS	0,2200	0,0680	0,0400	0,0510	0,0140	0,0040	0,2090	0,3270	0,9070	0,3080	0,9500	0,0270	0,0350	0,0560	0,0280	0,0110	0,0110	0,0350	0,0170	0,8210	0,1740	0,0530	0,8930	5,2590

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	BIENS	Industrie de la viande bovine	Industrie du porc	Industrie des viandes de volailles	Industrie des charcuteries	Industrie laitière	Fabrication d'aliments pour animaux	Industrie des corps gras	Autres industries alimentaires	Total Industrie Agro-alimentaire	Distribution: Blé	Maïs grain	Orge et escourgeon	Autres céréales	Produits maraîchers	Pommes de terre	Œufs	Autres produits agricoles	Viande bovine	Viande porcine	Viande de volaille	Charcuterie	Lait et produits laitiers	Alimentation animale	Autres produits agro-alimentaires	Produits d'autres industries	Total distribution	Autres industries	Hôtel-Restaurant, Commerce	Services (y compris construction)	Total Reste de l'économie	TOTAL ACTIVITES
	Blé tendre									0,0000	0,43																0,4300				0,0000	0,4300
	Maïs grain									0,0000		0,13															0,1300				0,0000	0,1300
	Orge									0,0000			0,101														0,1010				0,0000	0,1010
	Autres céréales									0,0000				0,043													0,0430				0,0000	0,0430
	Paille									0,0000																	0,0000				0,0000	0,0180
	Oléagineux						0,033	0,153		0,1860																	0,0000				0,0000	0,1860
	Protéagineux						0,036			0,0360																	0,0000				0,0000	0,0360
	Maïs fourrage									0,0000																	0,0000				0,0000	0,1530
	Autres fourrages									0,0000																	0,0000				0,0000	0,2930
	Légumes frais									0,0000						0,331											0,3310				0,0000	0,3310
	Pommes de terre									0,0000							0,029										0,0290				0,0000	0,0290
	Lait et produits laitiers (vache)					1,483				1,4830																	0,0000				0,0000	1,4830
Bovins	Jeunes taureaux (1-2 ans)									0,0000																	0,0000				0,0000	0,0000
Bovins	Jeunes génisses (1-2 ans)									0,0000																	0,0000				0,0000	0,0000
Bovins	Jeunes vaches (>2 ans)									0,0000																	0,0000				0,0000	0,0000
Bovins	Jeunes veaux mâles (<1 an)									0,0000																	0,0000				0,0000	0,0000
Bovins	Jeunes veaux femelles (<1 an)									0,0000																	0,0000				0,0000	0,0000
Bovins	Bovins de boucherie	0,735								0,7350																	0,0000				0,0000	0,7350
	Volaille			0,736						0,7360																	0,0000				0,0000	0,7360
	Oeufs									0,0000					0,025												0,0250				0,0000	0,0250
Porcins	Jeunes porcelets									0,0000																	0,0000				0,0000	0,0000
Porcins	Jeunes truies									0,0000																	0,0000				0,0000	0,0000
Porcins	Porcs bouchers		1,496							1,4960																	0,0000				0,0000	1,4960
	Déjections animales									0,0000																	0,0000				0,0000	0,2330
	Autres produits agricoles									0,0000								0,958									0,9580				0,0000	0,9580
	Total produits agricoles	0,7350	1,4960	0,7360	0,0000	1,4830	0,0690	0,1530	0,0000	4,6720	0,4300	0,1300	0,1010	0,0430	0,0250	0,3310	0,0290	0,9580	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	2,0470	0,0000	0,0000	0,0000	0,0000	7,4160
	Viande bovine									0,0000									0,163								0,1630				0,0000	0,1630
	Viande porcine									0,0000										0,773							0,7730				0,0000	0,7730
	Viande de volaille									0,0000											0,142						0,1420				0,0000	0,1420
	Charcuterie									0,0000												0,233					0,2330				0,0000	0,2330
	Lait									0,0000													0,372				0,3720				0,0000	0,3720
	Alimentation animale									0,0000														1,701			1,7010				0,0000	1,7010
	Huile									0,0000																	0,0000	0,043			0,0430	0,0430
	Tourteaux						0,498			0,4980																	0,0000				0,0000	0,6480
	Autres									0,0000															2,838		2,8380				0,0000	2,8380
	Total produits agro-alimentaires	0,0000	0,0000	0,0000	0,0000	0,0000	0,4980	0,0000	0,0000	0,4980	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,1630	0,7730	0,1420	0,2330	0,3720	1,7010	2,8380	0,0000	6,2220	0,0430	0,0000	0,0000	0,0430	6,9130
Distribution	Blé						0,346		0,023	0,3690																	0,0000				0,0000	0,4750
Distribution	Maïs grain						0,11			0,1100																	0,0000				0,0000	0,1450
Distribution	Orge et escourgeon						0,088			0,0880																	0,0000				0,0000	0,1120
Distribution	Autres céréales						0,03			0,0300																	0,0000				0,0000	0,0460
Distribution	Produits maraîchers								0,188	0,1880																	0,0000				0,0000	0,1880
Distribution	Pommes de terre									0,0000																	0,0000				0,0000	0,0000
Distribution	Œufs									0,0000																	0,0000				0,0000	0,0000
Distribution	Autres produits agricoles								0,577	0,5770																	0,0000	0,01	0,09	0,012	0,1120	0,6890
Distribution	Viande bovine									0,0000																	0,0000				0,0000	0,0000
Distribution	Viande porcine				0,731					0,7310																	0,0000				0,0000	0,7310
Distribution	Viande de volaille									0,0000																	0,0000				0,0000	0,0000
Distribution	Charcuterie									0,0000																	0,0000				0,0000	0,0000
Distribution	Lait et produits laitiers									0,0000																	0,0000				0,0000	0,0000
Distribution	Alimentation animale									0,0000																	0,0000				0,0000	1,9780
Distribution	Autres produits agro-alimentaires									0,0000																	0,0000		1,318	0,049	1,3670	1,3670
Distribution	Produits d'autres industries		0,001						1,958	1,9590																	0,0000	3,907	3,328	0,758	7,9930	10,9160
Distribution	**Total pdts distribués**	0,0000	0,0010	0,0000	0,7310	0,0000	0,5740	0,0000	2,7460	4,0520	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	3,9170	4,7360	0,8190	9,4720	16,6470
	Autres industries									0,0000																15,586	15,5860				0,000	15,5860
	Hôtel- Restaurant, Commerce								0,369	0,3690																	0,0000	0,195	4,261	0,18	4,6360	5,0050
	Services (y compris construction)	0,047	0,205	0,261	0,472	0,808	0,572	0,042	0,2	2,6070																	0,0000	1,193	7,787	2,226	11,2060	15,1020
	Total Reste de l'économie	0,0470	0,2050	0,2610	0,4720	0,8080	0,5720	0,0420	0,5690	2,9760	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	15,5860	15,5860	1,3880	12,0480	2,4060	15,8420	35,6930
	TOTAL PRODUITS	0,7820	1,7020	0,9970	1,2030	2,2910	1,7130	0,1950	3,3150	12,1980	0,4300	0,1300	0,1010	0,0430	0,0250	0,3310	0,0290	0,9580	0,1630	0,7730	0,1420	0,2330	0,3720	1,7010	2,8380	15,5860	23,8550	5,3480	16,7840	3,2250	25,3570	66,6690

(6)

			INSTITUTIONS			compte de capital	RDM - Exports Biens agricoles				
			Ménages	Subventions agricoles	TOTAL INSTITUTIONS	ΔS Bretagne	Reste de la France	Reste de l'UE hors France (14)	Reste du monde hors UE	TOTAL RESTE DU MONDE	TOTAL
BIENS		Blé tendre			0,0000					0,0000	0,4300
		Maïs grain			0,0000					0,0000	0,1300
		Orge			0,0000					0,0000	0,1010
		Autres céréales			0,0000					0,0000	0,0430
		Paille			0,0000		0,001			0,0010	0,0190
		Oléagineux			0,0000					0,0000	0,1860
		Protéagineux			0,0000					0,0000	0,0360
		Maïs fourrage			0,0000	0,0180				0,0000	0,1710
		Autres fourrages			0,0000	0,0580				0,0000	0,3510
		Légumes frais			0,0000		0,046	0,116	0,008	0,1700	0,5010
		Pommes de terre			0,0000		0,075			0,0750	0,1040
		Lait et produits laitiers (vache)			0,0000					0,0000	1,4830
	Bovins	Jeunes taureaux (1-2 ans)			0,0000	0,069				0,0000	0,0690
	Bovins	Jeunes génisses (1-2 ans)			0,0000	0,277				0,0000	0,2770
	Bovins	Jeunes vaches (>2 ans)			0,0000	0,258	0,234			0,2340	0,4920
	Bovins	Jeunes veaux mâles (<1 an)			0,0000	0,065				0,0000	0,0650
	Bovins	Jeunes veaux femelles (<1 an)			0,0000	0,078				0,0000	0,0780
	Bovins	Bovins de boucherie			0,0000					0,0000	0,7350
		Volaille			0,0000					0,0000	0,7360
		Oeufs			0,0000		0,347	0,04	0,044	0,4310	0,4560
	Porcins	Jeunes porcelets			0,0000	0,2850	0,065			0,0650	0,3500
	Porcins	Jeunes truies			0,0000	0,0720				0,0000	0,0720
	Porcins	Porcs bouchers			0,0000					0,0000	1,4960
		Déjections animales			0,0000		0,206			0,2060	0,4390
		Autres produits agricoles			0,0000			0,029	0,015	0,0440	1,0020
		Total produits agricoles	**0,0000**	**0,0000**	**0,0000**	**1,1800**	**0,9740**	**0,1850**	**0,0670**	**1,2260**	**9,8220**
		Viande bovine					0,829	0,096	0,004	0,9290	1,0920
		Viande porcine					0,865	0,285	0,055	1,2050	1,9780
		Viande de volaille					0,494	0,341	0,194	1,0290	1,1710
		Charcuterie					1,253	0,077	0,027	1,3570	1,5900
		Lait					1,824	0,197	0,093	2,1140	2,4860
		Alimentation animale					0,202			0,2020	1,9030
		Huile					0,014	0,025	0,022	0,0610	0,1040
		Tourteaux								0,0000	0,6480
		Autres					1,757	0,186	0,062	2,0050	4,8430
		Total produits agro-alimentaires	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**7,2380**	**1,2070**	**0,4570**	**8,9020**	**15,8150**
	Distribution	Blé			0,0000					0,0000	0,4750
	Distribution	Maïs grain			0,0000					0,0000	0,1450
	Distribution	Orge et escourgeon			0,0000					0,0000	0,1120
	Distribution	Autres céréales			0,0000					0,0000	0,0460
	Distribution	Produits maraîchers	0,317		0,3170					0,0000	0,5050
	Distribution	Pommes de terre	0,064		0,0640					0,0000	0,0640
	Distribution	Œufs	0,057		0,0570					0,0000	0,0570
	Distribution	Autres produits agricoles	0,599		0,5990					0,0000	1,2880
	Distribution	Viande bovine	0,349		0,3490					0,0000	0,3490
	Distribution	Viande porcine	0,094		0,0940					0,0000	0,8250
	Distribution	Viande de volaille	0,27		0,2700					0,0000	0,2700
	Distribution	Charcuterie	0,521		0,5210					0,0000	0,5210
	Distribution	Lait et produits laitiers	0,745		0,7450					0,0000	0,7450
	Distribution	Alimentation animale			0,0000					0,0000	1,9780
	Distribution	Autres produits agro-alimentaires	3,268		3,2680					0,0000	4,6350
	Distribution	Produits d'autres industries	12,845		12,8450	3,828				0,0000	27,5890
	Distribution	**Total pdts distribués**	**19,1290**	**0,0000**	**19,1290**	**3,8280**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**39,6040**
		Autres industries			0,0000			2,08	1,409	3,4890	19,0750
		Hôtel- Restaurant, Commerce	4,256		4,2560		21,772	0,848		22,6200	31,8810
		Services (y compris construction)	30,945		30,9450	8,932		0,013		0,0130	54,9920
		Total Reste de l'économie	**35,2010**	**0,0000**	**35,2010**	**8,9320**	**21,7720**	**2,9410**	**1,4090**	**26,1220**	**105,9480**
		TOTAL PRODUITS	**54,3300**	**0,0000**	**54,3300**	**13,9400**	**29,9840**	**4,3330**	**1,9330**	**36,2500**	**171,1890**

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		ACTIVITES																							
		Grandes cultures								Elevage volaille	Elevage porcin		Elevage bovin									Légumes frais	Pommes de terre	Autres activités agricoles	Total Agriculture
		Blé tendre	Maïs grain	Orge et escourgeon	Autres céréales	Oléagineux	Protéagineux	Maïs fourrage	Autres fourrages		Truies	Porcelets	Veaux mâles de renouvellement	Veaux femelles de renouvellement	Génisses de renouvellement	Veaux mâles à l'engrais	Veaux femelles à l'engrais	Génisses à l'engrais	Bovins mâles adultes à l'engrais	Vaches allaitantes	Vaches laitières				
VA	Travail	0,025	0,02	0,01	0,003	0,005	0,002	0,016	0,005	0,248	0,047	0,207	0,021	0,096	0,13	0,094	0,045	0,01	0,029	0,007	0,521	0,177	0,03	0,051	**1,7990**
	Capital	0,017	0,014	0,007	0,002	0,004	0,001	0,011	0,004	0,166	0,031	0,138	0,014	0,0634	0,087	0,062	0,0298	0,006	0,02	0,005	0,347	0,118	0,02	0,034	**1,2012**
	Terre	0,041	0,017	0,01	0,01	0,004	0,001	0,049	0,018													0,006	0,002		**0,1580**
	Truies										0,08														**0,0800**
	Porcs bouchers (<1 an)											0,299													**0,2990**
	Vaches laitières																				0,259				**0,2590**
	Vaches allaitantes																			0,044					**0,0440**
	Veaux mâles												0,016			0,052									**0,0680**
	Veaux femelles													0,0596			0,0222								**0,0818**
	Génisses														0,267			0,023							**0,2900**
	Taureaux																		0,072						**0,0720**
	VALEUR AJOUTEE	**0,0830**	**0,0510**	**0,0270**	**0,0150**	**0,0130**	**0,0040**	**0,0760**	**0,0270**	**0,4140**	**0,1580**	**0,6440**	**0,0510**	**0,2190**	**0,4840**	**0,2080**	**0,0970**	**0,0390**	**0,1210**	**0,0560**	**1,1270**	**0,3010**	**0,0520**	**0,0850**	**4,3520**
Institutio	TVA grevant les produits																								
	Droits de douane à l'import																								
	TOTAL INSTITUTIONS																								
RDM	Reste de la France																								
	Reste de l'UE (14) hors France																								
	Reste du monde hors UE																								
	TOTAL RESTE DU MONDE																								
	TOTAL	**0,3030**	**0,1190**	**0,0670**	**0,0660**	**0,0270**	**0,0080**	**0,2850**	**0,3540**	**1,3210**	**0,4660**	**1,5940**	**0,0780**	**0,2540**	**0,5400**	**0,2360**	**0,1080**	**0,0500**	**0,1560**	**0,0730**	**1,9480**	**0,4750**	**0,1050**	**0,9780**	**9,6110**

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		Industrie de la viande bovine	Industrie du porc	Industrie des viandes de volailles	Industrie des charcuteries	Industrie laitière	Fabrication d'aliments pour animaux	Industrie des corps gras	Autres industries alimentaires	**Total Industrie Agro-alimentaire**	Distribution																	Autres industries	Hôtel-Restaurant, Commerce	Services (y compris construction)	**Total Reste de l'économie**	**TOTAL ACTIVITES**
											Blé	Maïs grain	Orge et escourgeon	Autres céréales	Produits maraîchers	Pommes de terre	Œufs	Autres produits agricoles	Viande bovine	Viande porcine	Viande de volaille	Charcuterie	Lait et produits laitiers	Alimentation animale	Autres produits agro-alimentaires	Produits d'autres industries	**Total distribution**					
VA	Travail	0,12	0,2	0,14	0,244	0,187	0,123	0,012	0,306	**1,3320**	0,029	0,01	0,007	0,002	0,017	0,091	0,019	0,173	0,102	0,027	0,073	0,149	0,214	0,177	0,941	5,398	**7,4290**	5,693	8,927	12,243	**26,8630**	**37,4230**
	Capital	0,045	0,076	0,006	0,143	0,008	0,067	0,007	0,688	**1,0400**	0,016	0,005	0,004	0,001	0,009	0,051	0,01	0,097	0,057	0,015	0,041	0,084	0,121	0,1	0,529	3,037	**4,1770**	2,88	5,065	9,345	**17,2900**	**23,7082**
	Terre																															**0,1580**
	Truies																															**0,0800**
	Porcs bouchers (<1 an)																															**0,2990**
	Vaches laitières																															**0,2590**
	Vaches allaitantes																															**0,0440**
	Veaux mâles																															**0,0680**
	Veaux femelles																															**0,0818**
	Génisses																															**0,2900**
	Taureaux																															**0,0720**
	VALEUR AJOUTEE	**0,1650**	**0,2760**	**0,1460**	**0,3870**	**0,1950**	**0,1900**	**0,0190**	**0,9940**	2,3720	**0,0450**	**0,0150**	**0,0110**	**0,0030**	**0,0260**	**0,1420**	**0,0290**	**0,2700**	**0,1590**	**0,0420**	**0,1140**	**0,2330**	**0,3350**	**0,2770**	**1,4700**	**8,4350**	11,6060	**8,5730**	**13,9920**	**21,5880**	44,1530	62,4830
Institutio	TVA grevant les produits																															
	Droits de douane à l'import																															
	TOTAL INSTITUTIONS																															
RDM	Reste de la France																															
	Reste de l'UE (14) hors France																															
	Reste du monde hors UE																															
	TOTAL RESTE DU MONDE																															
	TOTAL	**0,9470**	**1,9780**	**1,1430**	**1,5900**	**2,4860**	**1,9030**	**0,2140**	**4,3090**	**14,5700**	**0,4750**	**0,1450**	**0,1120**	**0,0460**	**0,0510**	**0,4730**	**0,0580**	**1,2280**	**0,3220**	**0,8150**	**0,2560**	**0,4660**	**0,7070**	**1,9780**	**4,3080**	**24,0210**	**35,4610**	**13,9210**	**30,7760**	**24,8130**	**69,5100**	**129,1520**

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		BIENS																									
														Bovins								Porcins					
		Blé tendre	Maïs grain	Orge	Autres céréales	Paille	Oléagineux	Protéagineux	Maïs fourrage	Autres fourrages	Légumes frais	Pommes de terre	Lait et produits laitiers (vache)	Jeunes taureaux (1-2 ans)	Jeunes génisses (1-2 ans)	Jeunes vaches (>2 ans)	Jeunes veaux mâles (<1 an)	Jeunes veaux femelles (<1 an)	Bovins de boucherie	Volaille	Oeufs	Jeunes porcelets	Jeunes truies	Porcs bouchers	Déjections animales	Autres produits agricoles	Total produits agricoles
VA	Travail																										
	Capital																										
	Terre																										
	Truies																										
	Porcs bouchers (<1 an)																										
	Vaches laitières																										
	Vaches allaitantes																										
	Veaux mâles																										
	Veaux femelles																										
	Génisses																										
	Taureaux																										
	VALEUR AJOUTEE																										
Institutio	TVA grevant les produits																										0,0000
	Droits de douane à l'import																										0,0000
	TOTAL INSTITUTIONS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
RDM	Reste de la France	0,23	0,049	0,059	0			0,032						0	0,035		0,015	0,033								0,002	0,4550
	Reste de l'UE (14) hors France										0,028															0,009	0,0370
	Reste du monde hors UE						0,168				0,002															0,021	0,1910
	TOTAL RESTE DU MONDE	0,2300	0,0490	0,0590	0,0000	0,0000	0,1680	0,0320	0,0000	0,0000	0,0300	0,0000	0,0000	0,0000	0,0350	0,0000	0,0150	0,0330	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0320	0,6830
	TOTAL	0,4300	0,1300	0,1010	0,0430	0,0190	0,1860	0,0360	0,1710	0,3510	0,5010	0,1040	1,4830	0,0690	0,2770	0,4920	0,0650	0,0780	0,7350	0,7360	0,4560	0,3500	0,0720	1,4960	0,4390	1,0020	9,8220

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												Distribution																					
		Viande bovine	Viande porcine	Viande de volaille	Charcuterie	Lait	Alimentation animale	Huile	Tourteaux	Autres	**Total produits agro-alimentaires**	Blé	Maïs grain	Orge et escourgeon	Autres céréales	Produits maraîchers	Pommes de terre	Œufs	Autres produits agricoles	Viande bovine	Viande porcine	Viande de volaille	Charcuterie	Lait et produits laitiers	Alimentation animale	Autres produits agro-alimentaires	Produits d'autres industries	Total pdts distribués	Autres industries	Hôtel-Restaurant, Commerce	Services (y compris construction)	**Total Reste de l'économie**	**TOTAL PRODUITS**
VA	Travail																																
	Capital																																
	Terre																																
	Truies																																
	Porcs bouchers (<1 an)																																
	Vaches laitières																																
	Vaches allaitantes																																
	Veaux mâles																																
	Veaux femelles																																
	Génisses																																
	Taureaux																																
	VALEUR AJOUTEE																																
Institutio	TVA grevant les produits										**0,0000**	0	0	0	0	0,032	0,006	0,006	0,06	0,027	0,01	0,014	0,055	0,038	0	0,327	3,568	4,1430		0,145	2,914	**3,0590**	**7,2020**
	Droits de douane à l'import	0,012		0,006							**0,0180**																	0,0000				**0,0000**	**0,0180**
	TOTAL INSTITUTIONS	**0,0120**	**0,0000**	**0,0060**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0180**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0320**	**0,0060**	**0,0060**	**0,0600**	**0,0270**	**0,0100**	**0,0140**	**0,0550**	**0,0380**	**0,0000**	**0,3270**	**3,5680**	4,1430	**0,0000**	**0,1450**	**2,9140**	**3,0590**	**7,2200**
RDM	Reste de la France										**0,0000**																	0,0000	1,01		26,936	**27,9460**	**28,4010**
	Reste de l'UE (14) hors France	0,122		0,014						0,291	**0,4270**																	0,0000	2,163	0,842		**3,0050**	**3,4690**
	Reste du monde hors UE	0,011		0,008					0,538	0,243	**0,8000**																	0,0000	1,986		0,442	**2,4280**	**3,4190**
	TOTAL RESTE DU MONDE	**0,1330**	**0,0000**	**0,0220**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,5380**	**0,5340**	**1,2270**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	**0,0000**	0,0000	**5,1590**	**0,8420**	**27,3780**	**33,3790**	**35,2890**
	TOTAL	**1,0920**	**1,9780**	**1,1710**	**1,5900**	**2,4860**	**1,9030**	**0,1040**	**0,6480**	**4,8430**	**15,8150**	**0,4750**	**0,1450**	**0,1120**	**0,0460**	**0,5050**	**0,0640**	**0,0570**	**1,2880**	**0,3490**	**0,8250**	**0,2700**	**0,5210**	**0,7450**	**1,9780**	**4,6350**	**27,5890**	**39,6040**	**19,0750**	**31,8810**	**54,9920**	**105,9480**	**171,1890**

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		INSTITUTIONS			compte de capital	RDM - Exports Biens agricoles				
		Ménages	Subventions agricoles	TOTAL INSTITUTIONS	ΔS Bretagne	Reste de la France	Reste de l'UE hors France (14)	Reste du monde hors UE	TOTAL RESTE DU MONDE	TOTAL
VA	Travail									37,4230
	Capital									23,7082
	Terre									0,1580
	Truies									0,0800
	Porcs bouchers (<1 an)									0,2990
	Vaches laitières									0,2590
	Vaches allaitantes									0,0440
	Veaux mâles									0,0680
	Veaux femelles									0,0818
	Génisses									0,2900
	Taureaux									0,0720
	VALEUR AJOUTEE									62,4830
Institutio	TVA grevant les produits									7,2020
	Droits de douane à l'import									0,0180
	TOTAL INSTITUTIONS									7,2200
RDM	Reste de la France				1,583				0,0000	29,9840
	Reste de l'UE (14) hors France				0,864				0,0000	4,3330
	Reste du monde hors UE				-1,486				0,0000	1,9330
	TOTAL RESTE DU MONDE	0,0000	0,0000	0,0000	0,9610	0,0000	0,0000	0,0000	0,0000	36,2500
	TOTAL	54,3300	0,4720	54,8020	14,9010	29,9840	4,3330	1,9330	36,2500	

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Chapitre 4 Évaluation des coûts économiques d’une épidémie de fièvre aphteuse en Bretagne

Résumé

Dans ce chapitre, nous mettons en œuvre le modèle d’EGC dynamique afin de quantifier les effets dynamiques consécutifs à une épidémie de fièvre aphteuse en Bretagne, où l’élevage est l’activité agricole principale. Nous simulons les effets d’une épidémie dont les implications de marché incluent l’abattage d’animaux, une baisse temporaire de la demande en viande, ainsi que des décisions publiques de restrictions de mouvements pour les animaux et les viandes pendant la période de crise sanitaire.

Les résultats de simulations montrent que, à la suite de la maladie, les pertes économiques s’étalent sur de nombreuses périodes, même lors d’un choc sanitaire ponctuel. Nous mettons aussi en évidence que les effets sur les secteurs primaires et sur les industries alimentaires d’aval sont très différents, et que le recouvrement rapide des pertes est très dépendant des capacités de production et d’exportation initiales des entreprises. Les résultats d’équilibre général montrent l’influence forte des contraintes pouvant affecter les marchés des facteurs. Les contraintes de capital et de salaires accroissent ainsi les coûts agrégés d’une telle maladie.

Ce chapitre fait l’objet d’un article scientifique, coécrit avec Alexandre Gohin, accepté pour publication dans la revue Food Policy.

Introduction

Epidemic outbreaks are uncertain events of great concern for agriculture and related sectors. Animal diseases, such as foot and mouth disease (FMD), can lead to severe reductions in animal productivity and may even cause animal death. Moreover, FMD is a highly contagious disease and thus can quickly cause large production and economic damages in livestock-intensive regions. Because infected animals are usually killed and movements of healthy animals in infected areas are prohibited during an FMD outbreak, upstream and downstream industries are also negatively impacted by a reduction in their activity. Livestock farms and industries located outside the infected area may not necessarily benefit from a FMD outbreak. It depends on the price evolution of livestock products which may ultimately decrease if import bans by foreign countries and/or a reduction in domestic consumption are larger than the supply reduction in the infected area. Thus a FMD outbreak can have important economic costs for infected farmers and the whole food chain as well. These costs extend to the whole economy if other sectors are also directly affected by the outbreak. For example, some studies show that the 2001 FMD outbreak in the United Kingdom (UK) imposed important economic losses on the whole British economy due to the impact on tourism (Blake et al., 2002; O'Toole et al., 2002).

The computation of the expected indemnities of well known risks does not pose great challenges. This allows for the pricing of private risk instruments, such as insurance, and hence the optimal sharing of these expected costs among economic agents. A FMD outbreak is not presently an insurable risk because expected indemnities are difficult to compute for at least the three following reasons. First, a FMD outbreak is today characterized by an uncertain, presumably low, probability of occurrence with potential considerable and systematic economic losses. From an economic point of view, this first characteristic already makes FMD potentially a catastrophic and non-insurable risk. Second, the economic costs of a FMD outbreak depend on the public measures taken to manage and/or eradicate the disease. Public authorities may implement preventive actions to limit the occurrence and extent of FMD effects, through regular veterinary monitoring. In addition, during the crisis period they can choose among alternative strategies, including the culling of infected herds, the preventive stamping out of animals located around the infected zone, and the vaccination of animals located within a ring vaccination zone. These discretionary public decisions in control strategy have different consequences with respect to the length of measures, the number of killed animals and, hence, the length and magnitude of economic costs. Third, the dynamic dimensions linked to animal production economics add another challenge to the computation of expected economic costs. Effects of a FMD outbreak do not stop with the eradication of the disease since time is obviously needed to rebuild the livestock herd after preventive and curative culling.

With FMD, we are thus presently in a second best world characterised by incomplete contingent markets in the Arrow Debreu sense and potential optimal public intervention. In the European Union (EU), public measures funded by a veterinary fund include, in particular, co-financing of emergency measures for the slaughter of infected animals and the support of a vaccination bank. Exceptional market support measures can also provide support to farmers and breeders affected by restrictions imposed by the veterinary authorities. However, this EU public policy is currently under debate in the context of the Common Agricultural Policy (CAP) reform, due to the heterogeneous national complementary measures leading to potential distortions on the EU market, and also due to a lack of clear and transparent rules for exceptional market measures.

In this context, the purpose of this article is to provide an assessment of the market and welfare impacts of a potential FMD outbreak in a European livestock-intensive region. Our ultimate goal is to compute the aggregate and dynamic economic costs of such a disease and their distribution both among economic stakeholders and through time. Such an assessment is the necessary first step in providing new insights and in helping to design an optimal articulation of private/public permanent/crisis measures to cope with such stochastic event.

From a methodological perspective, the cost-benefit analyses of FMD have long used static economic models focusing on the direct costs incurred by infected farms (see for example the review by Rich et al, 2005). These first analyses have been improved by introducing the indirect effects on other economic agents. This has been done using static input-output models (without price effects) or using Partial Equilibrium (PE) and Computable General Equilibrium (CGE) models (with price and income effects). The dynamic dimension has also been introduced into the first static cost-benefit analyses. In particular, epidemiological models have been coupled to economic ones focusing on production, in order to analyze the costs of the disease over time in relation to the evolution of the animal health context. Recent works have started to include dynamic economic elements in PE models. In particular, Zhao et al. (2006) build a PE model where farmers take optimal decisions based on intertemporal profit maximization behaviours. These authors show that the impacts of FMD change from year to year before returning to a new steady state, which is typical when studying animal supply responses. In the same vein, Rich and Winter-Nelson (2007) and Paarlberg et al. (2008) use PE models to show the short term and long term effects of an FMD outbreak, which are highly dependent on the length of livestock production cycles.

While these dynamic PE analyses provide valuable insights, they measure neither the economic impacts on non agricultural and food sectors nor the macro-economic impacts of such a disease. Yet determining these effects can be useful in order to define appropriate risk management schemes. This can be done using a dynamic CGE model as pioneered by Philippidis and Hubbard (2005). They use the dynamic version of the Global Trade Analysis Project (GTAP) model to show the lasting effects of such a disease. However, their analysis uses the GTAP data where the different livestock animals are not distinguished. Hence, the dynamic biological constraints are imperfectly captured in their analysis. Moreover, these authors assume that all primary factor markets are perfect. This implies that labour and land are fully mobile between sectors and that the capital market is efficient: investment by sector is never constrained nor faces sunk transaction costs. Accordingly these authors implicitly assume that the costs of FMD incurred by the livestock and related sectors are shared with all other economic sectors (through the impacts on labour and land) and are efficiently spread over time (through the impacts on sector investment). In other words, these assumptions of perfect factor markets minimize the aggregate economic costs of a FMD outbreak (as already mentioned in another risky context by Leathers and Chavas, 1986). Yet factor markets in the EU are characterized by different distortions/imperfections, such as minimum wages that imply involuntary unemployment, or credit rationing implying constrained sector investment (see, for instance, Blancard et al., 2006).

Our methodological contribution is to build a new dynamic CGE model in the vein of Philippidis and Hubbard (2005) improved in two ways. The first improvement consists of the explicit specification of all livestock sectors and their herds, so that the multi-annual dynamic biological constraints for cattle and swine are captured in our analysis. The second is the specification of rigidity/imperfections in labour and capital markets. This allows us to measure the sensitivity of economic costs of a FMD outbreak to these real characteristics of factor markets. Our dynamic CGE model is applied to Brittany which is the most livestock-intensive French region. Brittany ranks first in terms of French milk, veal, pig and poultry production, and second in terms of cattle production. Farm and food processing industries represent 12 per cent of Brittany's total employment, compared to 6 per cent at the national level (Cébron, 2004).

The article is organised as follows. In the second section we present the main specifications of our dynamic CGE analysis. We first describe the general features of our model and then detail our novel representation of the cattle and swine sectors. We also explain how we specify distortions and imperfections in the primary factor markets. In the third section, we report our simulation experiments. First, we assess the economic costs of a potential FMD outbreak assuming perfect factor markets. Then, we measure the robustness of these costs to distortions and imperfections in the primary factor markets. The last section concludes with some policy and research recommendations.

4.1 Modelling framework

In this section we present the main specifications of our dynamic CGE model. First we provide a general description of the standard version of our model, highlighting the dynamic behaviours of the producers and the macro-economic closure of the model. Then we describe the livestock sectors with the dynamics implemented to reflect the animal cycles. Finally we detail the modelling of imperfections/distortions on factor markets.

Our model goes into great detail on the livestock sectors and downstream-related sectors. To do this, we built a Social Accounting Matrix (SAM) for the Brittany region calibrated for the year 2003 owing to data constraints. In particular, the data set on agricultural production costs could be completed thanks to the database of the Common Agricultural Policy Regional Impact (CAPRI) model. This SAM gives information on 50 sectors in total, including 23 agricultural activities and 53 products. Of these products, 25 are agricultural ones (see Annex 1). It should be underlined that we allow for multi-product activities, such as the dairy cow activity producing milk, bovine for slaughter, new born calves and organic manure.

4.1.1 Main features of the model

The basic structure of our dynamic CGE model is standard for a single country model in an open economy (see, for instance, Devarajan and Go, 1998; Vellinga, 2008). On the "static" components of the model, all economic agents are assumed to be price takers. Perfect competition is assumed on all markets and prices ensure market equilibrium. Trade between Brittany and other regions (rest of France, rest of the EU and Rest of the World) is specified in the Armington tradition (with the elasticity potentially set to infinity for homogeneous goods), with Brittany potentially a large player on foreign regions. Preferences and technologies are represented by globally regular, nested Constant Elasticity of Substitution (CES) functional forms.

On the "dynamic" components of the model, producers are assumed to maximize their intertemporal profit, subject to capital constraints and investment costs. We assume in the standard case that the capital market is efficient: all producers have access to the capital market at an exogenous interest rate, so that the financial structure of each firm (ratio of debts to equities) does not matter. One financial structure must still be determined and we assume that producers finance all investment outlays by retaining profits and maintaining the number of equities. This assumption fits best with the structure of farm capital mostly owned by farmers. On the demand side, we assume the existence of one representative consumer maximizing an intertemporal utility function subject to intertemporal budget constraints. This representative consumer also participates in the financial capital market by saving at the same exogenous interest rate.

One unavoidable critical issue with dynamic models is the determination of the nature of expectations by economic agents. In this article, we assume that all economic agents are endowed with bounded rationality, due to their impossibility to expect the FMD outbreak. On the other hand, they know all other parameters of the economy (full information and rationality outside the FMD shock). We believe that this assumption fits best with a scenario of a FMD outbreak, which is an uncertain -but presumably rare- event. Indeed, bounded rational expectation schemes are consistent with that kind of potential shock since economic agents – both livestock producers and related industries – do not make their production decisions taking into account a hypothetical epidemic outbreak. Our assumption allows us to abstract from informational welfare issues on the true structure of the economy. This assumption is indeed mainly justified as such by other authors as well (Lence, 2009, for instance).

Since our methodological contributions mostly concern the production side of the model, we describe below the modelling of producers in the standard version of our model. The optimization program of producer *j* is given by:

$$\max \pi_j = \sum_{t=0}^{\infty}\left(\frac{1}{1+r}\right)^t \begin{pmatrix} \sum_i\left(P_{i,t}Y_{i,j,t} - PC_{i,t}IC_{i,j,t}\right) \\ -PI_{j,t}\left(1+\aleph_{j,t}\right)I_{j,t} - WL_{j,t}L_{j,t} - WT_{j,t}T_{j,t} \end{pmatrix} \tag{1}$$

s.t. $F_{j,t}\left(Y_{i,j,t}, IC_{i,j,t}, K_{j,t}, L_{j,t}, T_{j,t}\right) = 0$

s.t. $K_{j,t+1} = K_{j,t}\left(1-\delta_{j,t}\right) + I_{j,t} \qquad K_{j,0} = \overline{K_{j,0}}$

Where $Y_{i,j,t}$ is the production of good *i* by producer *j* at time *t* (the corresponding price net of taxes/subsidies is $P_{i,t}$), *r* is the discount rate, $IC_{i,j,t}$ is the intermediate consumption (the corresponding net price is $PC_{i,t}$), $I_{j,t}$ is the investment level (the corresponding net price is$PI_{j,t}$), $L_{j,t}, T_{j,t}$the levels of labour and land use (the corresponding net prices are $WL_{j,t}, WT_{j,t}$), $K_{j,t}$ is the stock of physical capital, $\delta_{j,t}$ the depreciation rate of capital. The parameter $\aleph_{j,t}$ represents the unitary transaction cost of capital and, following Uzawa (1969), is specified as follows:

$$\aleph_{j,t} = \frac{\phi_j}{2}\frac{I_{j,t}}{K_{j,t}} \tag{2}$$

where ϕ_j is the non negative parameter governing the marginal cost of capital installation. $F_{j,t}(.)$ is a constant return to scale production function. The production technology is specified with multi-level nested CES functions (with some substitution between capital and labour, as well as between feedstuff ingredients). In the particular case of agriculture, multi-product activities may be encountered as is, for example, the case for the dairy cow sector. The amounts of the various products obtained from those activities are quite interdependent and inflexible, leading us to specify Leontief (fixed proportions) functions. This production function is the first constraint of the producer program. The second constraint concerns capital accumulation: it stipulates that next period capital stock equals the current investment plus the current capital stock and minus the depreciation. It should be noted that, as is usual, investment is assumed to occur at the end of period and is only available for future periods.

Solving this producer program can be decomposed into two steps. The first step determines optimal intra-temporal decisions of production, intermediate consumption, land and labour demands conditional on the production technology, the level of capital stocks and prices. This first step simultaneously determines the periodic capital return (denoted below by $WK_{j,t}$). The second step determines the optimal levels of investment and capital stocks conditional on prices and the initial level of capital stocks ($K_{j,0}$). Indeed, the optimal level of current investment is implicitly determined by the first order condition of the following program:

$$\max \pi_j = \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t \left(WK_{j,t}K_{j,t} - PI_{j,t}\left(1 + \aleph_{j,t}\right)I_{j,t}\right) \tag{3}$$

$$\text{s.t. } K_{j,t+1} = K_{j,t}\left(1 - \delta_{j,t}\right) + I_{j,t} \qquad K_{j,0} = \overline{K_{j,0}}$$

The first order condition is then:

$$WK_{j,t+1} + \left(1 - \delta_{j,t}\right)PI_{j,t+1} = (1 + r)PI_{j,t}$$
$$+\phi_j \left((1 + r)PI_{j,t}\left(\frac{I_{j,t}}{K_{j,t}}\right) - \left(1 - \delta_{j,t}\right)PI_{j,t+1}\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right) - \frac{PI_{j,t+1}}{2}\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right)^2\right) \tag{4}$$

If we first assume that there are no capital transaction costs ($\phi_j = 0$), this equation simply represents the equality between the marginal cost of current investment at time *t* evaluated at the next period (on the right hand side) and the marginal revenue of that current investment at time *t+1* (on the left hand side). This marginal revenue has two terms, the next period expected capital returns and the next period expected price of the (depreciated) investment good (in case the capital stock is partly sold). The second line of the equation 4 introduces the transaction costs. The first term of the second line is the marginal transaction cost of the current investment (again evaluated at the next period). The second term is the marginal transaction benefit in the case where the capital stock is partly sold in the following period. Finally the last term of this second line captures the lower transaction costs of future investment due to greater capital stock following current investment.

This first order condition implicitly determines current investment conditional on existing capital stocks, current and future prices as well as future decisions on investment and capital stocks. Hence a similar first order condition determines the next period investment and so on. The final level of investment for each period will depend on the steady state conditions that we impose on the model. As is usual, we impose that investment by firms equals their capital depreciation in the steady state.

As explained earlier, in the standard version of the model we assume that the capital market is perfect and consequently that all investment decisions are always financed at the exogenous interest rate. This interest rate also influences the decisions of our representative household to consume or save for future consumptions. The amount of domestic savings may not correspond to the level of domestic investment, leading to a modification of the capital account (and of the current account to ensure the balance of payments). In the steady state, we assume that domestic savings equal domestic investment, so that the net debt of our Brittany economy with other regions remains unchanged (see Vellinga, 2008, for a more detailed explanation). With this assumption, we implicitly impose that the exchange rate between Brittany and other regions is fixed. This is justified in our case since Breton products are mostly traded within France.

4.1.2 The specification of the cattle and swine sectors

In the previous standard programs of producers, we specify only one capital good used in the production process. Dynamics only occur because of the depreciation of this capital good and the associated investment. This does not acknowledge the various steps necessary to produce cattle and pig, nor the fact that the animal stocks are factors of production and not simply an intermediate consumption. This is, for example, also omitted in the analysis by Philippidis and Hubbard (2005) using the GTAP model. Our methodological contribution is to introduce these animal stocks as factors of production in the economy. These factors of production depreciate and the resulting animal stocks also change over time following the decisions of livestock farmers.

More precisely, in order to take into account the dynamic nature of the breeding cycles, our original data set gives details on the distribution of the cattle and swine according to different age classes. We consider six different cattle stocks or herds: dairy cows, suckler cows, male calves and female calves (animals of less than one year old), bulls and heifers (animals of less than two years old). Two swine stocks are also considered: piglets (animals of less than one year old) and sows. These herds are used by eleven different activities due to the distinction between raising and fattening activities for cattle (see below). The activities together supply five types of products: bovine for slaughter, pork for slaughter, milk, organic manure and live animals. The links between herds, activities and products are described in table 1.

Table 4.1: Disaggregation of the cattle and swine sectors

Herds used by the activity	Activity	Types of outputs produced by the activity		
		of which live animals		
Dairy cows	Dairy cows	dairy cows, male & female calves	milk, bovine for slaughter	organic manure
Suckler cows	Suckler cows	Suckler cows, male & female calves	bovine for slaughter	
Bulls	Fattening bulls	-		
Heifers	Fattening heifers	-		
	Raising heifers	dairy cows, suckler cows	-	
Male calves	Raising male calves	bulls	-	
	Fattening male calves	-	bovine for slaughter	
Female calves	Fattening female calves	-		
	Raising female calves	heifers	-	
Sows	Sows for piglet production	piglets	pork for slaughter	
Piglets	Pig fattening activity	young sows		

To illustrate the cattle dynamics, the domestic production of calves comes from the suckler and dairy cow activities. In order to get new productive cows from these domestic calves, two more years are required. In its second year of life, the female calf is raised to become a young heifer, and in its third year it may become a cow and give birth to a new calf, through the dairy or suckler activity, and so on. On the other hand, the male calf can be directly slaughtered for veal production or alternatively raised for the consecutive production of steers or bulls. The dynamics is similar for piglets and sows.

To our knowledge, such disaggregation of the animal sectors in a CGE model has never been performed. By definition, it allows us to trace the dynamic and lasting impacts of a shock on these sectors and the time needed to return to a new steady state. While an improvement on available models on these grounds, our approach still suffers from at least two limitations. First, animal scientists may consider it too aggregated since we do not distinguish cattle breeds because of data constraints. Indeed, our disaggregation is based on the CAPRI one, where the production costs and revenues of these activities are detailed. Second, we distinguish live animals by their age as if they are all born on the same day (the first day of the period/year) and they are distinguished on a yearly basis. Again, data constraints at present prevent us from going further in the temporal disaggregation of animals and related activities.

Regarding the modelling of our cattle activities, we assume as usual that each farm in each activity maximises its inter-temporal profit. In reality, some farms may pursue different activities (such as dairy farms with milking dairy cows and raising heifers). Our approach of splitting cattle farms by activity is not fundamentally different from splitting mixed farms as usually done in CGE analyses (for instance, splitting farms producing poultry and crop into two activities). Moreover, some Breton cattle farms are specialised in raising animals, others in fattening animals, others in milking dairy cows. These specialised farms purchase the animals making up their initial herds at each period.

In a similar way to the capital dynamics previously described, we assume that each herd stands for animal capital that depreciates over time and needs investment to maintain its level. This statement induces a new constraint in the program of cattle and pig producers:

$$H_{j,t+1} = H_{j,t}\left(1 - \delta h_{j,t}\right) + IH_{j,t} \quad (5)$$

where $H_{j,t}$ is the level of the herd held by activity j at the beginning of period t, $IH_{j,t}$ is the investment level reflecting the effort of obtaining new herd. As with physical capital, we assume that the investment is made at the end of the period for the next period production. The parameter $\delta h_{j,t}$ is the depreciation rate of the considered herd. Annually this parameter δh depreciates totally for young animals ($\delta h_{j,t} = 1$) as these herds represent only temporary states in the life cycle of the animals (e.g. after one year each calf becomes a young heifer or bull). On the other hand, for suckler cows, dairy cows and sows this parameter $\delta h_{j,t}$ reflects the culling rate decided by farmers based on the lower productivity of old animals or for sanitary reasons. This parameter is lower than one (all productive adult animals are not culled at the same time in a steady state solution).

Formally, the program of each animal activity is given by:

$$\max \pi_j = \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t \begin{pmatrix} \sum_i \left(P_{i,t} Y_{i,j,t} - PC_{i,t} IC_{i,j,t}\right) \\ -PI_{j,t}\left(1 + \aleph_{j,t}\right) I_{j,t} - PH_{j,t} IH_{j,t} - WL_{j,t} L_{j,t} - WT_{j,t} T_{j,t} \end{pmatrix} \quad (6)$$

s.t. $F_{j,t}\left(Y_{i,j,t}, IC_{i,j,t}, K_{j,t}, L_{j,t}, T_{j,t}\right) = 0$

s.t. $K_{j,t+1} = K_{j,t}\left(1 - \delta_{j,t}\right) + I_{j,t}$ $\qquad K_{j,0} = \overline{K_{j,0}}$

s.t. $H_{j,t+1} = H_{j,t}\left(1 - \delta h_{j,t}\right) + IH_{j,t}$ $\qquad H_{j,0} = \overline{H_{j,0}}$

In the objective function, we obviously introduce the expenditures made by each activity to purchase new animals at prices $PH_{j,t}$. We assume that there are no transaction costs when investing in new animals. The production function now includes the level of the herd at the beginning of the period. We assume that there is no substitution between this factor of production and other inputs/factors.

Again, this program can be solved in two steps: first, the intra-period decisions, and second, the inter-period investment decisions. From the first step, we obtain the capital return and the herd return (denoted below by $WH_{j,t}$). In the second step, the first order condition implicitly determines the optimal investment in the herd by cattle farms:

$$WH_{j,t+1} + \left(1 - \delta h_{j,t}\right) PH_{j,t+1} = (1 + r) PH_{j,t} \quad (7)$$

Similarly, the right hand side corresponds to the marginal cost of investment in the herd in period *t* evaluated in period *t+1*. The left hand side is the marginal revenue of this investment in the herd: it equals the next period expected return for the herd and the next period expected purchase price of the (depreciated) herd. In the case of activities with young animals, this last term obviously equals zero – because one young animal grows and cannot stay within an annual category.

The above programs determine *inter alia* the domestic demand and domestic supply of live animals. Trade in these live animals with France is also permitted in our model. We depart here from the Armington specification and assume that live animals are homogenous products. However, we assume that Brittany is potentially an influential region affecting these prices in other regions. As for any other products, prices ensure that these markets are in equilibrium.

4.1.3 Specification of imperfections in factor markets

4.1.3.1 On the labour market

In the standard version of our model, labour is assumed to be fully mobile between activities and no public intervention prevents a real wage decrease following a negative economic shock such as a FMD event. Yet unemployment amounts to around 8 per cent of the active population in Brittany in recent years (Malpot, 2003). There are certainly many different reasons for this situation, one being the minimum wages imposed by public regulation. Moreover, most French wages are not indexed to business results and are rigid downward. In the second version of our CGE model, we acknowledge this feature of the labour market in order to assess its impact on the welfare effects of a FMD outbreak.

Formally, we consider that unemployment is partly governed by the inflexibility of wages and by the existence of minimum wages, below which the demand for labour cannot be satisfied. In order to introduce this regulation into our model, we constrain real wages not to fall below their base value and assume that there is some unused labour endowment. This mechanically induces rigidities in the labour market because changes in labour demand will result in changes in the amount of labour effectively employed. This quite simplistic representation of the labour market cannot best reflect the French employment structure; nevertheless this specification has long been used in the literature, as mentioned by Gohin and Moschini (2006).

4.1.3.2 On the financial capital market

In the standard version of our model, the capital market is assumed to be perfect. Producers face no constraints when investing, except the terminal steady state condition where investment equals the depreciation of capital. For example, they can invest more than the current profit if they expect an increase of future capital returns (see program 3 and the first order condition 4). Yet sectors facing economic crisis (a severe drop of capital returns) are often credit constrained leading, for example, the French public authorities to intervene *inter alia* in credit markets (such as taking interest charges and postponing debt repayments). Moreover, a large economic literature has developed which identifies the extent to which farmers are credit constrained (such as Phimister, 1995). In the case of French agriculture, Blancard *et al.* (2006) show that almost all farms suffer from credit constraints when financing their investments.

Accordingly, we develop a new version of our CGE model where we try to take into account this well established fact. This is, however, not immediate as our CGE model focuses on the real side of the Breton economy and moreover assumes bounded rational behaviour (hence excluding informational issues leading to credit limitations). We thus specify a reduced form constraint on investment. We assume that current investment by firms is constrained if current capital return decreases below a threshold level. Formally, we introduce the following constraint for all sectors:

$$I_{j,t} \leq I_{j,0}\left(\alpha \frac{WK_{j,t}}{WK_{j,0}} + \beta\right) \tag{8}$$

where 0 is the calibrated year without the FMD outbreak, α, β are reduced form parameters governing the severity of the investment constraint. For example, if we impose $\alpha = 0, \beta = \infty$, then the constraint is never binding. On the other hand, if we impose $\alpha = 1, \beta = 0$, then the current investment level must be lower than the pre-FMD level if the current capital return is lower than the pre-FMD capital return. This reduced form constraint thus allows us to impose investment restrictions on sectors facing a drop of their capital return. For example, if a FMD outbreak leads firms to temporarily decrease their activity, their current profit decreases. They may face difficulties in financing their current investment despite potential future positive prospects following the resolution of the FMD outbreak.

In this alternative version with investment constraints, the program of producers (the second step) becomes:

$$\max \pi_j = \sum_{t=0}^{\infty}\left(\frac{1}{1+r}\right)^t \left(WK_{j,t}K_{j,t} - PI_{j,t}\left(1 + \aleph_{j,t}\right)I_{j,t}\right) \tag{9}$$

s.t. $K_{j,t+1} = K_{j,t}\left(1 - \delta_{j,t}\right) + I_{j,t}$ $\qquad$ $K_{j,0} = \overline{K_{j,0}}$

s.t. $I_{j,t} \leq I_{j,0}\left(\alpha \frac{WK_{j,t}}{WK_{j,0}} + \beta\right)$

The first order condition is modified so that:

$$WK_{j,t+1} + (1-\delta_{j,t})(PI_{j,t+1} + \mu_{j,t+1}) = (1+r)(PI_{j,t} + \mu_{j,t})$$
$$+\phi_j\left((1+r)PI_{j,t}\left(\frac{I_{j,t}}{K_{j,t}}\right) - (1-\delta_{j,t})PI_{j,t+1}\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right) - \frac{PI_{j,t+1}}{2}\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right)^2\right) \quad (10)$$

$\mu_{j,t}$ is the Lagrangian multiplier associated with the investment constraint and hence measures the price of this constraint. This equation is indeed very similar to the former first order condition. When the current constraint is binding (the current multiplier is positive but the next period one is not), the investment level is determined by the constraint, and this first order condition determines the price of the capital good which is necessary to obtain that level of current investment. However, if the current multiplier is zero and the one in the next period is positive (hence, next period investment is a constraint), this equation shows that there is an incentive to invest more in the current period.

By calibrating the parameters α and β, we can make investment more or less constrained. We explore this in the simulations, to which we now turn.

4.2 Simulations

An unexpected FMD outbreak alters the economy by different mechanisms acting on supply, demand and trade. On the supply side, the major impact of a FMD outbreak is that it may induce massive mandatory culling, not only of infected animals but also of animals located in the infectious zone as designated by the public authorities. On the demand side, the major impact is the immediate (usually negative) reaction of domestic consumers and then a gradual partial/complete recovery to pre-FMD consumption levels. On trade, major impacts are due to restrictions on the movements of live animals (no imports/exports) and import bans on livestock products from foreign countries. In our simulation of a hypothetical FMD outbreak, we consider the supply shock, trade shock on live animals and meats, and a demand shock.

More precisely, we simulate the economic consequences of a public decision to cull 10 per cent of the total cattle and swine herds as a response to a FMD outbreak (a one-time period supply shock). This represents about 200,000 cattle and 1,400,000 swine and is comparable to the 2001 UK case (Follett, 2002), where some 6 million of the total 55 million animals were culled. In addition, at the initial year of this simulation we consider that such culling is accompanied by a preventive sanitary ban on the movement of live animals. Animal products (meat) cannot be exported abroad as well during the outbreak period. In both Brittany and other French regions, we simulate an exogenous 25% decrease of the consumers' demand, which is consistent with past observations while greater than observations in other countries (Lesdos-Cauhapé et al, 2007). From the second year of simulation, the sanitary bans are lifted and demand functions return to pre-crisis levels.

We first assess the consequences of this FMD scenario with the standard version of our CGE model and then use the alternative versions with imperfections on factor markets. When using these different dynamic versions, we need to determine the horizon needed to reach a new steady state. Results below are computed assuming that 15 years are needed to reach a new equilibrium. We performed the same simulation with horizons of 10 years versus 20 years and our results appear robust. Before interpreting the results, we recall that our dynamic CGE model is calibrated on a SAM that is an annual database, as commonly observed in CGE studies; the results below refer to annual time step estimations. As a result, the specifications of our data and model lead us to consider the FMD outbreak as an event lasting a year.

Thanks to our CGE model including dynamics in the breeding sectors, the simulations permit to observe economic consequences of a brief FMD outbreak over a long period, affecting not only the agriculture but also all sectors. Significant losses of economic welfare are highlighted and reveal that diseases such as FMD lead to large and lasting consequences going beyond the outbreak period.

4.2.1 Impacts of a FMD scenario with perfect factor markets

4.2.1.1 Market impacts

Production impacts on selected agricultural commodities from the standard version of the model are provided in table 2. By definition, we find that in the FMD year, domestic productions of milk (and dairy products), cattle (and beef) and swine (and pork) decrease by 10 per cent. We observe that other farm sectors/productions are affected as well. Obviously, according to the demand shock, domestic poultry production increases slightly, by 2.81 per cent. The price effect of the culling decision for swine and cattle is balanced by the demand shocks and trade bans on animals and more specifically on meats (see table 3). This shock finally induces a fall of the prices of beef and pork (respectively -5.45 per cent and -7.80 per cent), which is similar for cattle and swine (-5.24 per cent and -8.82 per cent). The domestic prices of dairy products and milk increase in the first year, owing to the unchanged demand structure and the reduced domestic supply (by, respectively, 2.51 per cent and 4.52 per cent). We also find that the domestic wheat production increases (by 2.29 per cent). The interpretation of this is as follows. The decrease in the cattle and swine herds is supposed to occur at the beginning of the period. Farmers have fewer animals to feed and accordingly they reduce their fodder acreage in favour of cereal or oilseed production (all these crop production technologies are modelled in a usual static way). This extra production of wheat is mostly exported and is accompanied by a small price decrease (0.91 per cent). The nature of all these market results is quite standard in a static CGE framework.

Table 4.2: Production impacts (scenario with perfect factor markets) (pre-FMD number of animals, and in % with respect to the initial steady state levels)

Period	Pre-FMD	1	2	3	4	5	15
Milk/Dairy prod.		-10.00	5.56	-0.29	-0.25	-0.03	0.01
Cattle/Beef		-10.00	-14.38	-3.30	-0.88	-0.69	-0.34
Pig/pork		-10.00	9.42	-2.34	0.09	-0.17	0.02
Poultry		2.81	-0.60	0.47	0.12	0.11	0.04
Wheat		2.29	-0.70	0.65	0.04	-0.01	-0.01
live animals							
Male calves	386,000	-10.00	15.28	1.44	-0.62	0.37	0.42
Female calves	367,772	-10.00	15.16	1.42	-0.62	0.37	0.41
Heifers	460,586	-10.00	-51.70	-1.20	-1.40	-1.30	-0.58
Bulls	119,500	-10.00	-20.39	-1.12	-1.53	-1.51	-1.04
Cows	482,000	-10.00	-21.62	-5.75	-0.31	-0.52	-0.11
Sows	260,354	-10.00	10.53	-2.43	0.18	-0.14	0.02
Piglets	17,713,688	-10.00	-10.00	-0.76	-1.52	-0.75	0.02

Table 4.3: Price impacts (scenario with perfect factor markets) (pre-FMD prices in euros per animal, and in % with respect to the initial steady state prices)

Period	Pre-FMD	1	2	3	4	5	15
Milk		4.52	-2.13	0.16	0.11	0.02	0.00
Cattle		-5.24	5.71	1.16	0.19	0.13	0.06
Pig		-8.82	-3.97	1.15	0.00	0.11	0.00
Poultry		0.22	0.17	-0.07	-0.02	-0.02	-0.01
Wheat		-0.91	0.49	-0.20	-0.01	-0.01	0.00
Beef		-5.45	2.77	0.59	0.15	0.12	0.06
Dairy products		2.51	-1.24	0.07	0.06	0.01	0.00
Pork		-7.80	-2.04	0.58	-0.02	0.05	0.00
live animals							
Male calves	129	122.47	-3.30	-0.46	-0.10	-0.25	-0.16
Female calves	122	147.60	-1.28	-0.26	-0.11	-0.16	-0.10
Heifers	525	23.54	7.32	0.24	0.23	0.20	0.10
Bulls	577	18.40	16.44	-0.72	-0.25	-0.15	-0.01
Cows	1,021	-8.52	2.81	1.45	0.67	0.42	0.12
Sows	311	30.75	5.87	5.26	2.64	1.50	-0.21
Piglets	21	-35.46	11.97	1.01	1.58	0.80	0.00

Much more interesting and original are the results for the period just after the FMD outbreak. We find that one year after the outbreak, domestic milk (dairy product) production is greater than the pre-FMD level (by 5.56 per cent) while the domestic cattle (and beef) production is lower (by 14.38 per cent). In order to understand these results, it is useful to report the evolution of cattle and swine herds, production, trade and price of live animals (see tables 2,3 and 4).

From these tables, we observe that before the FMD outbreak, Brittany imports calves and heifers and exports young cows and piglets (see table 4). During the outbreak period, these trade flows are not permitted. This implies in particular that the herds of cows are increasing at the beginning of the second period: the herd of dairy cows increases by 5.56 per cent (similarly to the domestic production of milk) and the herd of suckler cows by 59.56 per cent (see table 4). Consequently, the domestic production of calves increases in the second period (by around 15.2 per cent, see table 2). Despite these increases, the domestic production of beef decreases because other herds at the beginning of the second period (calves, heifers and bulls) are decreasing compared to the pre FMD level, by as much as 48.08 per cent for the herd of female calves.

Returning to the impacts on markets (tables 2 and 3), the increased production of milk is consistently accompanied by a price decrease (by 2.13 per cent) while the reduced production of beef induces an increase in price (by 2.77 per cent for beef, 5.71 per cent for cattle for slaughter). On other markets, results become more marginal. However, we underline that domestic wheat production decreases by 0.70 per cent in the second period. Again, this is explained by competition on the land market with an increase in areas of fodder to feed the increased herds of cows. Concerning the swine sector, we also find an important increase of production in the second year because piglet exports have been prohibited during the FMD outbreak period.

Moving to the third period, we find quite limited price/quantity effects on most markets, with the exception of beef and pork. The domestic productions are still lower than pre-FMD levels (-3.30 per cent for beef and -2.34 per cent for pork) because the herd structures have still not recovered their initial steady states. In particular, adult animals (heifers, bulls and sows) are still less numerous at the beginning of the second year as it takes time to grow these animals (table 4). Finally, the market impacts are very modest in the steady state solution.

Table 4.4: Impacts on the herds and trade of live animals (scenario with perfect factor markets) (pre-FMD numbers of animals traded, and in % with respect to the initial steady state levels)

Period	Pre-FMD	1	2	3	4	5	15
Herds							
Male calves	502944	-10.00	-30.77	0.47	-0.94	-0.96	-0.41
Female calves	637472	-10.00	-48.08	-0.86	-1.33	-1.26	-0.61
Heifers	527200	-10.00	-21.37	-5.94	-0.43	-0.64	-0.26
Bulls	119500	-10.00	-10.00	-20.39	-1.12	-1.53	-1.04
Dairy cows	766500	-10.00	5.56	-0.29	-0.25	-0.03	0.01
Suckler cows	135100	-10.00	59.56	9.32	-2.34	2.20	2.30
Sows	553010	-10.00	-10.00	-0.76	-1.52	-0.75	0.02
Piglets	14408172	-10.00	10.53	-2.43	0.18	-0.14	0.02
Trade							
Male calves	-116,064	-100.00	-48.90	-8.85	-2.06	-4.87	-3.16
Female calves	-269,700	-100.00	-22.70	-5.08	-2.13	-3.17	-2.02
Heifers	-66,614	-100.00	310.52	4.90	4.62	4.06	2.01
Bulls	0						
Cows	223,640	-100.00	-12.94	-6.95	-3.28	-2.06	-0.61
Sows	0						
Piglets	3305,516	-100.00	-43.18	-4.91	-7.54	-3.91	-0.08

4.2.1.2 Welfare impacts

We now examine the welfare impacts of our scenario, looking first at the value added (net of taxes/subsidies) of the different activities (table 5). Obviously, the major economic losses are observed at the initial period of simulation, when the supply shock, the trade shock and the demand shock occur. Due to the sharply declining level of demand (domestic and for export), the cattle sector and the swine sector suffer important losses of value added (respectively -8.08 per cent and -34.75 per cent). The swine sector, for which trade outside Brittany is the main outlet (mainly to the rest of France), faces the most severe losses since both exports of piglets and of pork meat are forbidden during the crisis. We find that the dairy cow activity finally gains during the FMD outbreak period by as much as 48.9 million Euros (4.34 per cent) mainly because of the milk price increase and the lower production costs (including feed). The nature of this result is not original per se (see, for example, Mangen and Burrell, 2003).

These effects on the animal sectors are obviously major among agricultural activities. Globally we find that the value added generated by agriculture decreases by 334.37 million Euros (or 7.68 per cent), which approximately equals the losses in the animal sectors. For other agricultural sectors, the main losses are observed in the fodder sectors, while the poultry activity benefits from the temporary shift in demand and from lower feed costs.

Table 4.5: Impacts on net values added (scenario with perfect factor markets) (million euros, and in % with respect to the initial steady state levels)

Period	Pre-FMD	1	2	3	4	15
Dairy cows	1,127	48.89 4.34%	37.83 3.36%	3.61 0.32%	-0.11 -0.01%	0.19 0.02%
Other cattle	1,275	-102.96 -8.08%	-267.80 -21.00%	-37.41 -2.93%	-6.31 -0.50%	-2.96 -0.23%
Swine	802	-278.66 -34.75%	22.08 2.75%	10.36 1.29%	6.71 0.84%	0.03 0.00%
Total agriculture	4,352	-334.37 -7.68%	-211.68 -4.86%	-24.17 -0.56%	-0.11 0.00%	-2.68 -0.06%
Beef industry	165	-28.24 -17.11%	-37.22 -22.56%	-8.32 -5.04%	-1.36 -0.82%	-0.46 -0.28%
Dairy industry	195	-22.50 -11.54%	11.47 5.88%	-0.90 -0.46%	-0.58 -0.30%	0.00 0.00%
Pork industry	276	-47.45 -17.19%	46.78 16.95%	-12.10 -4.38%	-0.06 -0.02%	0.00 0.00%
Food industries	2,372	-37.76 -1.59%	42.77 1.80%	-25.09 -1.06%	-1.24 -0.05%	-0.26 -0.01%
Other sectors	55,759	-1.81 0.00%	65.44 0.12%	10.71 0.02%	-1.15 0.00%	-2.97 -0.01%
GDP	69,231	-214.84 -0.31%	-79.57 -0.12%	-5.48 -0.01%	8.68 0.01%	-4.32 -0.01%

Not surprisingly, we find that the beef and dairy industries suffer from the FMD outbreak by respectively 28.24 (17.11 per cent) and 22.50 (11.54 per cent) million Euros. The loss is thus greater for the beef industry and much greater than the decrease in production volume (10 per cent). The economic logic for this is as follows. In both industries, raw agricultural products represent a large share of production costs. The value added generated is rather small and, in the case of the Breton dairy industry, serves mostly to pay wages to workers. However, the small value added generated by the beef industry is used to pay wages to workers and to provide dividends for capital holders. In other words, in the initial situation, the capital invested in the beef industry is relatively more important than the capital invested in the dairy industry. The consequence is that the dairy firms are unable to smooth the price effects of the FMD while the beef firms have some latitude to absorb part of the shock (by reducing dividends). These latter also suffer more initially such as to ensure the future supply of cattle for slaughter and hence their future activity and capital returns. We also logically find that the pork industry faces a -17.19 per cent reduction of value added, which is due to the trade restrictions on pork and to the lower level of domestic demand, despite the reduced cost of buying swine.

The Breton food industries globally experience a negative evolution of their value added during the FMD outbreak period (-1.59 per cent) due the previous effects on the beef, pork and dairy industries. It should be noted that the animal feed industry also suffers from a FMD outbreak (by 6.8 per cent).

Turning to the second period, when trade bans are lifted and consumption behaviours have returned to their initial structures, impacts on the value added are still consequential. The dairy cow activity gains (by 37.83 million Euros or 3.36 per cent). This is now mainly explained by the increased volume of production (due to the former impossibility to export cows) and the lower costs of young cow while the output price effect is now working on the negative side. It appears that other cattle activities still lose significantly in this second period (by 267.80 million Euros or 21 per cent). The main reason is the much lower level of herds at the beginning of this second period (by as much as 48 per cent for female calves, see table 4). This is the delayed impact of the restriction concerning the movement of animals (including the imports of calves). One additional reason is that the reintroduction of competition from foreign products limits the price increase of domestic live animals. This impact on other cattle sectors largely determines the aggregate negative impact on agriculture (by 211.68 million euros or by 4.86 per cent). This result is slightly balanced by the net gain in the swine sector (+22.08 million euros or +2.75 per cent), where a larger amount of piglets retained during the crisis can now be sold. Hence we find that the negative impact of a FMD outbreak on agriculture not only occurs during the crisis, but also in the immediate next period because of trade disruptions that affect animal dynamics. The aggregate impact on the food industries is slightly positive in the second period (by 42.77 million Euros or 1.80 per cent). The dairy and pork industries are now benefitting from activity increases while the beef industry is still suffering from a loss of activity. The beef industry suffers most in the immediate periods following the FMD outbreak.

From this second period to the end of simulation, we find that impacts on value added quickly converge to their steady state values. In the steady state solution, impacts are marginal; the only significant impacts concern the beef industry and the other cattle sectors. They are both affected by less than 0.3 per cent due to the reduced level of activity by period 15.

The macroeconomic impacts of our scenario are reported in the first column of table 6. Before interpreting these results, we recall that we develop a dynamic CGE model with one representative household. We are thus unable to identify the impacts on each type of household (farm versus non-farm) but only the aggregate impacts. This representative household owns primary production factors (labour, land, physical and cattle capital) and thus receives the corresponding factor returns. With these returns (net of taxes/subsidies) forming the household income, the representative household consumes final goods and saves for future periods. The periodic consumption of final goods provides some satisfaction (utility). The FMD outbreak alters the household income and prices, hence the final consumption. In table 6, we first report the periodic equivalent variation which is the periodic amount of money (Euros) that the representative household is ready to pay to accept the scenario (for more details on the way it is computed, see Keen, 1990). We find that this annual equivalent variation is negative and amounts to only 20.78 million Euros. This is quite low compared to the value added losses of the agricultural and food sectors (372.13 million Euros in the first period, 168.91 million Euros in the second period, 2.94 million Euros in the end of simulation). This is first explained by the fact that other sectors in the economy may not suffer. Indeed we find that the total value added generated in the second period decreases by 79.57 million Euros (compared to the 168.91 million Euros for agri-food sectors). This is mostly explained by the fact that the representative household saves less and globally maintains its consumption expenditures following the income drop. This is reflected in the increased global debt at the steady state with respect to foreign economic agents: this debt increases by 500.92 million Euros, in part due to the culling of infected animals. In other words, Breton investments are financed to a greater extent by foreign agents. In fact, the representative household has no incentive to save more because it always perceives the same exogenous interest rate.

We also report the steady state valuation of other assets (land, physical capital and cattle & swine herds). The values of these assets are relatively stable. In the last line of table 6, we aggregate the annual equivalent variations with these "wealth" effects by discounting all values with the exogenous interest rate. The resulting discounted aggregate welfare amounts to a loss of 398.39 million Euros.

Compared to the size of the shock, this welfare loss is rather small. Indeed, the lost animals are initially valued at 188.3 million Euros. In addition, the trade restrictions on live animals and meats in the first period represent a loss of 1.08 billion Euros of net export earnings. However, this second component of the shock is partly smoothed by price effects stimulating current demands as well as by postponing trade until the future periods. On the other hand the killing of infected animals is a definitive loss. In other words, the aggregate loss is lower than the shocks owing to compensating price effects. We check this result by performing another simulation where the only shock consists of culling 10 per cent of the initial cattle and swine herds. Then the aggregate loss amounts 82.56 million Euros, for a shock of 188.3 million Euros.

Table 4.6: Macro economic impacts (million euros)

Version of the model	Perfect factor markets	Constraint on investment	Constraint on wages	Both constraints
Annual Equivalent variation	-20.78	-9.07	-54.13	-123.22
Value of land	-2.12	-102.60	-3.62	-114.75
Value of physical capital	0.54	-188.90	-60.17	-504.15
Value of cattle herd	2.08	-67.13	1.95	-68.71
Value of swine herd	-0.25	-9.30	-0.33	-9.45
Value of foreign debt	500.92	511.67	640.62	408.53
Discounted welfare	-398.39	-459.12	-841.76	-1,752.60

4.2.2 Impacts of a FMD scenario without perfect factor markets

4.2.2.1 With constraints on investment

The results presented so far are obtained in a context that is very close to a first best world: firms are always able to finance their investment at an exogenous interest rate to return to pre-FMD steady state levels. We now assess the sensitivity of these results to some real features of factor markets, starting with the possibility that firms are investment constrained. As mentioned in the previous section, we can introduce such a feature into our model by introducing constraints on investment. We now assume that cattle and swine sectors and downstream industries (dairy, beef and pork industries) are potentially constrained in the amount of investment.

To calibrate the two parameters governing the severity of the constraint, α and β, we need two pieces of information. First, we assume that if the current capital return is 5 per cent lower than the pre-FMD steady state capital return, then the constraint becomes binding. Second, we assume that if the current capital return decreases by 25 per cent compared to the pre-FMD level, then firms are constrained to not invest at all: they may even be forced to dis-invest. Formally, we impose that $\alpha = 5, \beta = -15/4$. These parameters imply that, if the current capital return equals the pre-FMD level, then firms are allowed to invest 25 per cent more than before the constraint becomes binding. We admit here that we have little information to justify these parameters. For instance, Blancard et al. (2006) find that 99.7 per cent of French arable crop farms are credit constrained and one unit relaxation of the credit constraint will add 1.35 to farm profit in the long run. They develop a static framework that hinders direct use of this information in our setting. Nevertheless, by assuming that firms are initially not constrained, our calibration can be seen as introducing moderate investment constraints.

The market impacts of the same FMD scenario with investment constraints are reported in table 7. The impacts obtained in the first period are roughly similar to those obtained with the standard version of the model. However, starting from the third period results on the beef/cattle variables are very different. In particular, we observe that the domestic production of cattle and beef decreases by 12.16 per cent, compared to 3.30 per cent with the standard version and respectively -5.21 per cent compared to -2.34 per cent in the standard version for swine/pork. The main reason for this is that livestock sectors and the meat industries are not allowed to invest as much as they want, given their returns in the first and second periods. Accordingly the physical capital stock starts becoming the limiting factor in these sectors, whereas only the size of the animal herds were limiting in the previous results. In other words, following the FMD outbreak, few firms are allowed to pursue their investment levels to maintain their production capacity. This also takes time to be reflected in market equilibrium. We find that the economy reaches a completely new steady state equilibrium characterised by much lower beef production (-7.12 per cent) and a slightly lower level for pig production (-1.02 per cent).

The new market impacts are obviously accompanied by new welfare impacts. The aggregate cost of the FMD reaches 459.12 million Euros (see table 6). Not surprisingly, we find that the value of physical capital significantly decreases (by 188.90 million Euros). Land values also decrease (by 102.60 million Euros) as a result of lower animal production.

Table 4.7: Production and price impacts under the scenario with investment constraints (in % with respect to the initial steady state levels)

Period	1	2	3	4	5	15
Production						
Milk/Dairy prod.	-10.00	5.85	-3.15	-3.77	-3.40	-1.01
Cattle/Beef	-10.00	-14.45	-12.16	-12.84	-12.75	-7.12
Pig	-10.00	9.42	-5.21	-2.51	-2.48	-1.02
Poultry	3.35	-1.16	0.81	0.72	0.79	0.65
Wheat	2.76	-1.46	0.47	0.30	0.28	-0.34
Price						
Milk	4.73	-2.31	1.31	1.57	1.41	0.42
Cattle	-5.12	4.86	3.13	3.44	3.43	1.49
Pig	-8.64	-5.44	1.67	0.48	0.57	0.26
Poultry	0.29	0.28	-0.11	-0.09	-0.11	-0.11
Wheat	-0.92	0.55	-0.38	-0.24	-0.23	-0.01
Beef	-5.45	2.76	2.28	2.43	2.41	1.30
Dairy products	2.51	-1.31	0.75	0.90	0.81	0.23
Pork	-7.75	-2.05	1.30	0.61	0.60	0.23

4.2.2.2 With constraints on wages

Up to now we assume that the labour market is perfect with a fixed endowment of the working force in Brittany. Real wages adjust to ensure that the demand by activities equals this fixed supply. With the standard version of our model, it appears that wages slightly decrease in the first few periods (by 0.87 in the first, 0.14 in the second, and 0.13 in the third). This does not recognise the fact that there could be additional unemployment. We now introduce a constraint on real wages, so that they cannot fall below pre-FMD levels.

The market impacts of our FMD scenario with the wage rigidity are quite close to those obtained with the standard version. This result is again not original (see, for instance, Gohin and Moschini, 2006). Nevertheless, the macro-economic impacts are significantly modified. The annual equivalent variation now decreases by 54.13 million Euros (see table 6). Overall, the aggregate discounted cost of the FMD outbreak amounts to 841.76 million Euros, which is 2.11 times greater than the estimate obtained with the standard version of the model. The reason is that some workers become unemployed in the first periods of simulations: total employment decreases by 0.7 per cent in the first period and by 0.17 per cent in the second and third periods. In the steady state solution, total employment has decreased by 0.04 per cent. This still represents an increase of 0.2 per cent of total unemployment (the unemployment rate is 8 per cent in the initial situation). So, two main effects on the aggregate welfare effects are revealed: one is the income loss that was generated by these newly unemployed workers (considering that they receive lump sum transfers from other households); the other is the income loss from capital/land returns for other households/workers.

4.2.2.3 With both constraints

We perform a final simulation, which can be considered as the most severe context, where both constraints on investment and wages are specified. As expected the market impacts are close to those obtained with the constraint on investment only. However, it appears that the macro-economic impacts are large. Both constraints interact in non additive ways because of the non linearities in production technologies (between labour and capital). The cumulative effects induce a depreciation of 504.15 million Euros of the physical capital. This also results in a discounted welfare loss of as much as 1752.60 million Euros (see table 6). This is 4.4 times higher than our first estimate with perfect factor markets, and the annual equivalent variation reaches -123.22 million Euros (5.9 times greater than in the standard case).

Conclusions

In this paper we investigate the dynamic effects of an outbreak of FMD which is usually considered to be a catastrophic shock on agricultural and food markets. We build a new dynamic CGE model focused on a French livestock intensive region with a detailed representation of the livestock sectors dynamics. We find diffuse effects of a FMD outbreak that have not previously been identified in the economic literature. In particular, we show that beyond the immediate negative impacts of the crisis, effects on agriculture and food industries last over many years. Differentiated consequences are highlighted on livestock and downstream sectors depending on their initial trade positions. Our CGE approach also allows us to focus on the factor markets and their role in smoothing the shock over time and over sectors. When we assume that the factor markets are not perfect because of financial constraints (investment limitations) and institutional constraints (minimum wage), economic equilibrium can only reach a second best position with forced unemployment and foreclosure. The aggregate cost of a potential FMD outbreak appears to be highly dependent on the assumptions made concerning the factor markets.

By providing new insights into the long run losses due to a FMD outbreak, these results raise the issue of how to cope with uncertainty on agricultural and food markets. Current crisis policies in Europe do not cover those lasting consequences on farm activities, as well as on downstream industries. Our results also lead us to argue that the currently debated European farm crisis policy in the context of the CAP reform should be designed consistently with the primary factor regulations that exist in the different European countries.

Table 4.8: Disaggregation of the 2003 SAM of Brittany by Activities and Products

	Activities		Products	
Agriculture	Wheat		Wheat	
	Corn grain		Corn grain	
	Barley		Barley	
	Other cereals		Other cereals	
			Straw	
	Oleaginous crops		Oleaginous plants	
	Protein		Protein	
	Fodder corn		Fodder corn	
	Other fodder		Other fodder	
	Market gardening		Fruit and vegetables	
	Potato cultivation		Potatoes	
	Poultry farm		Poultry, eggs	
	Cattle sectors:	Calves male raising activity	Living animals:	Young bulls
		Calves female raising activity		Young heifers
		Heifers raising activity		Young cows
		Calves male fattening activity		Young male calves
		Calves female fattening activity		Young female calves
		Heifers fattening activity		Young piglets
		Male adult fattening activity		Young sows
		Suckler cows production activity	Bovine for slaughter	
		Dairy cows production activity	Milk	
	Swine sectors:	Sows for piglet production	Pork for slaughter	
		Pig fattening activity		
			Animal waste	
	Other agricultural activities		Other agricultural products	
Food industries	Beef industry		Beef	
	Pork Industry		Pork	
	Poultry meat industry		Poultry	
	Cooked pork industry		Cooked pork meats	
	Dairy industry		Milk and milk products	
	Feed industry		Feed	
	Oils and fats industry		Oil, meal	
	Other food industries		Other food products	
Retailing sectors	Wheat		Wheat	
	Corn grain		Corn grain	
	Barley		Barley	
	Other cereals		Other cereals	
	Fruit and vegetables		Fruit and vegetables	
	Potatoes		Potatoes	
	Eggs		Eggs	
	Other agricultural products		Other agricultural products	
	Beef		Beef	
	Pork		Pork	
	Poultry		Poultry	
	Cooked pork meats		Cooked pork meats	
	Milk and milk products		Milk and milk products	
	Feed		Feed	
	Other food products		Other food products	
	Products of other industries		Products of other industries	
Rest of the economy	Other industries		Products of other industries	
	Hotels, restaurants, shops		Commercial products, catering and hotel	
	Services		Valuation of services	

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Chapitre 5 Épidémies d'élevage et risques de marchés : Effets de la mise en place de fonds mutuels en Bretagne

Résumé

La fièvre aphteuse, à l'instar d'autres épizooties, peut avoir des répercussions de marché durables, dont l'ampleur dépasse la sphère agricole. En Europe, diverses politiques ad hoc existent pour faire face à ces conséquences. Dans ce chapitre, nous étudions les effets de la mise en œuvre de politiques de gestion et de couverture de ces risques agricoles, comme la compensation publique des pertes et la mise en place d'un fonds mutuel. Nos résultats montrent qu'un soutien financier aux agriculteurs via un fonds mutuel peut favoriser un recouvrement rapide des pertes de marché, notamment en aidant à reconstruire les troupeaux de bovins après une période d'interdiction de commercialisation. Néanmoins, des effets contre-productifs sont mis en évidence dans le cas de la participation obligatoire des agriculteurs pour financer ce fonds.

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Introduction

Epidemic outbreaks are uncertain events of great concern for agriculture and related sectors. Animal diseases, such as foot and mouth disease (FMD), can quickly cause large production and economic damages in livestock-intensive regions (Blake et al. 2002). Because of the high transmissibility of the disease, consumption scares and potential trade bans, economic consequences of the disease may also have a significant and lasting impact on the whole food chain at the regional or national level, including disease-free areas. These important costs raise the issue of risk management policies in Europe. Although direct losses are usually covered by public subsidies for infected farms, market disruptions due to disease crises only benefit from very specific and *ad hoc* supports. However, the definition of structural policies of risk management in agriculture tends to provide a more standardized management system for the agricultural sector. Among other measures, the creation of mutual funds is intended to provide exceptional financial support in case of economic and trade losses due to animal diseases. The objective of this study is to evaluate the effectiveness of these mutual funds and to which extent they can limit losses of markets and enable the agricultural sector to regain its competitiveness quickly. This research work aims at computing the effects of this risk management tool on the value added in the food chain and on the whole regional welfare through a dynamic computable general equilibrium (CGE) model.

Recent French and European policies aim at providing structural support for exceptional events such as FMD outbreaks (Cafiero et al. 2007). After a catastrophic market event, a major challenge for farmers is the access to credit, especially when the level of assets is low and even if the prospects for recovery are good. This has a direct impact on the ability of livestock farms to rebuild their herds and their production capacity quickly, especially in the presence of imperfections in some factor markets. As a consequence, on the long run it may also cause heavy losses for downstream industries, especially in livestock-intensive regions. The current literature highlights the credit constraints of farmers (Blancard et al. 2006), and has also long focused on issues of income securitization, including CAT bonds or income insurance (Mahul, 2001, Schaufele et al. 2010, Mussel and Martin, 2001). The contribution of this study is to evaluate the ability of mandatory precautionary savings (mutual funds) to release credit constraints in a distorted market. This study brings new insights for the design of risk management policies with public-private participation. A particular focus will be given to the ability of farmers to take an active role in the management of catastrophic economic events through the creation of mutual funds, which are designed to support the agricultural activity in case of a catastrophic event

The modelling framework consists of a dynamic CGE model for a single region, including two particular features. On the one hand we give the explicit specification of all livestock sectors and their herds, so that the dynamic biological constraints are perfectly captured in the analysis, and we also specify rigidities in labour and capital markets (respectively minimum wages and investment constraints) to reflect better the various productive, financial and institutional constraints in the economy. On the other hand, the mutual fund is modelled as mandatory savings with subsidised interest rate and it is fed by livestock farmers at the steady state. Then we may be able to highlight the effects of the implementation of mutual funds as a risk management policy to face the market effects of a potential FMD outbreak.

The dynamic CGE model is applied to Brittany which is the most livestock-intensive French region. Both a production shock (public decision to cull 10 per cent of the total cattle herd as a response to a FMD outbreak) and a trade shock (preventive sanitary ban on the movement of live animals) are simulated. Then we assess the economic consequences of this one-time period shock over a 15-year horizon.

5.1 Modelling framework

In order to study the effects of the implementation of a mutual fund aiming to limit the economic losses due to a FMD outbreak, we use a dynamic CGE model developed by Gohin and Rault (Gohin A., Rault., 2012), built on former studies on livestock (Philippidis and Hubbard, 2005), featuring the specific intertemporal decisions of farmers in the presence of cattle dynamics (Zhao et al, 2006), and imperfections on factor markets. The main elements of this model are developed in this section, as well as some new elements relative to the implementation of the mutual fund.

5.1.1 Main dynamics and the livestock sectors

The basic structure of our dynamic CGE model is standard for a single country model in an open economy (Devarajan and Go, 1998; Vellinga, 2007). Two main types of dynamics are implemented. First, we classically consider that the main intertemporal decision is the behaviour towards capital accumulation. In addition, we introduce the cattle stocks as factors of production in the economy, and we define their dynamics.

Producers in each *j* sector are assumed to maximize their intertemporal profit π, more precisely the discounted value of their future profits minus investment costs, as follows:

$$\max \pi_j = \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t \left(WK_{j,t}K_{j,t} - PI_{j,t}\left(1 + \frac{\phi_j}{2}\frac{I_{j,t}}{K_{j,t}}\right) I_{j,t}\right)$$

s.t. $K_{j,t+1} = K_{j,t}(1-\delta_{j,t}) + I_{j,t}$ $\qquad\qquad K_{j,0} = \overline{K_{j,0}}$

Where $K_{j,t}$ is the stock of physical capital and $WK_{j,t}$ the capital income, $I_{j,t}$ is the investment level (the corresponding net price is $PI_{j,t}$), and ϕ_j is the non negative parameter governing $\frac{\phi_j}{2}\frac{I_{j,t}}{K_{j,t}}$ which represents the marginal cost of capital.

Producers' objective function is constrained by the intertemporal investment decisions, which relate to capital accumulation over time. These capital dynamics are defined by $K_{j,t+1} = K_{j,t}(1-\delta_{j,t}) + I_{j,t}$ where $\delta_{j,t}$ is the annual depreciation rate of capital.

The resolution of this program producer leads to determine the first order condition defining the optimal level of current investment:

$$WK_{j,t+1} + (1-\delta_{j,t})PI_{j,t+1} = (1+r)PI_{j,t}$$
$$+\phi_j\left((1+r)PI_{j,t}\left(\frac{I_{j,t}}{K_{j,t}}\right) - (1-\delta_{j,t})PI_{j,t+1}\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right) - \frac{PI_{j,t+1}}{2}\left(\frac{I_{j,t+1}}{K_{j,t+1}}\right)^2\right)$$

If we assume that there are no capital transaction costs ($\phi_j = 0$), this equation simply represents the equality between the marginal cost of current investment at time *t* evaluated at the next period and the marginal revenue of that current investment at time *t+1*.

To sum up, the main dynamics of our model occur because of the depreciation of the capital good and the associated investment. In the particular case of livestock producers, we also need to take into account the dynamic nature of the breeding cycles and the fact that the cattle stocks are factors of production and not simply an intermediate consumption.

To achieve this, we consider six different cattle stocks or herds: male and female calves (year-born animals), bulls and heifers (under two years old), and dairy and suckler cows. These herds are used by nine different activities due to the distinction between raising and fattening activities. The activities together supply four types of products: bovine for slaughter, milk, organic manure and live animals.

In a similar way to the capital dynamics, we assume that each herd stands for animal capital that depreciates over time and that may be maintained by investment. As a consequence, cattle dynamics are defined by $H_{j,t+1} = H_{j,t}\left(1 - \delta h_{j,t}\right) + IH_{j,t}$ where $H_{j,t}$ is the level of the herd held by activity j at the beginning of period t, $IH_{j,t}$ is the investment level reflecting the effort level of obtaining new herd. The parameter $\delta h_{j,t}$ is the depreciation rate of the considered herd. Annually for young animals $\delta h_{j,t} = 1$ as these herds represent only temporary states in the life cycle of the animals (e.g. after one year each calf becomes a young heifer or bull). For dairy and suckler cows $\delta h_{j,t}$ reflects the culling of cows decided by cattle farmers based on the lower productivity of old animals or for sanitary reasons($\delta h_{j,t} < 1$).

Note that due to data constraints, our approach suffers from two limitations: animal breeds are not distinguished, and the yearly time step of the model leads to a rather simplified biological cycle.

Including the cattle dynamics as a dynamic constraint for livestock producers gives an additional condition for the optimisation problem:

$$WH_{j,t+1} + \left(1 - \delta h_{j,t}\right)PH_{j,t+1} = (1 + r)PH_{j,t}$$

Where $PH_{j,t}$ is the purchase price of new animals and $WH_{j,t}$ the herd return in the j activities. In the particular case of young animals, the renewal of the herd is complete each year as $\delta h_{j,t}$ is null. This all permits to determine the domestic demand and supply of live animals.

Turning to the demand side, we assume the existence of one representative consumer maximizing an intertemporal utility function subject to intertemporal budget constraints. This representative consumer also participates in the financial capital market by saving at the same exogenous interest rate. In the steady state, we assume that domestic savings equal domestic investment, so that the net debt of our economy with other regions remains unchanged. This assumption means that the exchange rate with other regions is fixed, which is justified in our application as Breton products are mostly traded within France.

In a dynamic perspective, the determination of expectations by economic agents takes a central place. In this article, we assume that all economic agents have rational expectations, meaning that in a standard context they do not suffer from any lack of information in order to adapt their decisions to the current economic context. This assumption fits best with a scenario of FMD outbreak since this kind of rare event is quite unpredictable, and producers do not make their production decisions taking into account such a hypothetical and unpredictable epidemic outbreak.

5.1.2 Imperfect factor markets

To reflect better the economic and financial structure of our economy, we specify constraints on the financial capital market and on the labour market.

In the program previously explained, producers face no constraints when investing. They may invest more than the current profit if they expect an increase of future capital returns; they have a full access to credit, which is barely realistic. As in our model we focus on the real side of the economy, we specify a reduced form constraint on investment to act as a brake on credit access. The program of producers is then subject to another constraint on investment which is:

$$I_{j,t} \leq I_{j,0}\left(\alpha \frac{WK_{j,t}}{WK_{j,0}} + \beta\right)$$

Current investment by firms is constrained if current capital return decreases below a threshold level. Parameters α and β are reduced form parameters governing the severity of the investment constraint, and $WK_{j,0}$ is the capital return at steady state. This reduced form constraint allows us to impose investment restrictions on sectors facing a drop of their capital return. By calibrating the parameters α and β, we can make investment more or less constrained. For example, if a FMD outbreak leads to a temporarily decrease of activity, the current profit decreases. Firms may face difficulties in financing their current investment despite potential future positive prospects following the resolution of the FMD outbreak.

Turning to the labour market, we introduce the possibility of involuntary unemployment. To achieve this, we impose labour returns not to fall below their base value. This means that wages cannot decrease, or in other words that the existence of minimum wages is an institutional constraint below which demand for labour cannot be satisfied. This induces rigidities in the labour market; a temporary decrease in labour supply leads to additional unemployment due to the existence of a minimum wage, and on the contrary an increase in labour supply first leads to full employment and then to wage increase.

5.1.3 Modelling of mutual funds

The implementation of a mandatory mutual fund extended to all cattle farmers aims at participating to the change from *ad hoc* emergency assistance systems to more structural policies involving farmers themselves. In other words, it results in a long term policy which permits not only to support time to time the agricultural revenue during market crises, but also to impose mandatory precautionary savings when market conditions are profitable.

Two economic tools are implied in this risk management policy. On the one hand, the precautionary savings are imposed as a tax on agricultural production in order to finance the mutual fund, and on the other hand a subsidy is activated to help maintain a minimum income level. Formally, the mutual fund can be considered as a capital stock whose evolution is governed by both contributions from farmers and support given to sectors in crisis. It can be modelled as follows.

$$MF_t = \sum_j \tau PY_{j,t} - \sum_j K_{j,t}^{MF} + MF_{t-1}(1-\sigma_t) \qquad ; \qquad MF_0 = 0$$

Where MF_t is the mutual fund, σ_t is the annual interest rate of this fund (potentially publicly subsidized). The sum of the savings collected in the j activities is represented by $\sum_j \tau PY_{j,t}$, where τ represents the fixed proportion of capital which is deducted to the farmer profit in order to supply the mutual fund. At the opposite, $K_{j,t}^{MF}$ represents the amount taken from the mutual fund to compensate the j farmers for a catastrophic market event. In summary, the mutual fund is managed as a financial reserve, which public participation is the payment of interest on those savings. By calibrating the saving rate and the minimum income to activate the subsidy, we can simulate the effect of various policies, to which we turn now.

5.2 Simulation and results

In this section we detail our simulations. We first give a brief overview of the data used and of the scenario of FMD outbreak and policy responses to the market effects. Then we analyse the results of the simulations, disentangling the effects of the mutual fund policy from the market effects of the FMD outbreak.

5.2.1 Data and simulation

Our model is applied to the Brittany region in France, for which we built a social accounting matrix for the year 2003. The SAM has a high disaggregation level including 52 activities and 54 products (of which respectively 23 and 24 agricultural sectors and products). Each activity can be multi-output, such as the dairy cow activity producing milk, bovine for slaughter, new born calves and organic manure.

We simulate the occurrence of a FMD outbreak at the first period of simulation. To do this, we impose a fall of the cattle herd by 10% due to both the consequences of the disease and of the sanitary measures to prevent its extent. In addition, we assume that all movements of live livestock between Brittany and other regions are prohibited the year of the FMD outbreak (period 1 of simulation). From the second year of simulation, we consider that the region has returned to a disease-free status, consequently that no more animals are culled, and the trade bans no longer apply. Note that in order to restrict our analysis on the agricultural and related sectors, we deliberately do not simulate any loss of consumption of beef or dairy products although they may occur in reality.

Concerning the calibration of the mutual fund, we first assume a production income threshold equivalent to 90% of the production income at steady state. This threshold serves in the decision of activation of a release of liquidities from the mutual fund to support farm activity. Concretely, a financial support from the mutual fund is given to the farmer when its production income falls below this threshold. In addition, we decide that the mandatory precautionary saving is equivalent to a tax of 0,5% of annual income. This assumption permits to differentiate the level of savings among participants depending on their volume of activity rather than a fixed amount imposed independently to all participants. We precise that in our simulation, agents participating in the mutual fund are all livestock farmers.

5.2.2 Induced effects of the implementation of mutual funds

The constitution of mutual funds permits to the implementation of precautionary savings for farmers as a mandatory measure has market effects, even in the absence of sanitary crisis. Indeed, the strong incentive or the obligation for farmers to participate in the establishment of precautionary savings makes this participation equivalent to a tax on agricultural production. As a result, its implementation tends to induce a change in market equilibriums. Indeed, a levy on farmers' incomes has mechanical effect as a disincentive to produce. In our simulation, we implement mandatory participation set at 0.5% of annual income of farmers over 10 years, as shown in table 2 and table 3.

Table 5.1: Constitution of the mutual fund (in million euros)

period	1	2	3	4	5	10
Mutual fund constitution	17	34	52	71	91	206
Annual precaut. savings	17	16	16	16	16	16

On the one side, the annual mandatory savings increased by a public interest rate permit to create a growing mutual fund, with a quite stable participation level of farmers.

Table 5.2: Production and price effect of the mandatory mutual fund (in % with respect to the initial steady state)

period	1	2	3	4	5	10
production						
milk/dairy prod.		-0,46	-0,62	-0,73	-0,82	-1,06
cattle/beef		-0,39	-0,74	-0,92	-1,08	-1,58
price						
milk		0,19	0,25	0,3	0,33	0,44
cattle		0,12	0,23	0,27	0,3	0,43

On the other side, this taxation induces a modification of the behaviour of the farmers. Over a 10-year period, the overall production of cattle for beef decreases by -1,58% and the production of milk by -1,06%, confirming the fact that the tax implementation generates an additional cost which has counterproductive effects for farmers. These slight falls in production mean reductions of the size of the herds. Obviously, the decreases in production induces some increases in prices of about +0,4% for both milk and cattle.

Table 5.3: Impacts on net value added for livestock activities and related industries (in % with respect to the initial steady state)

period	1	2	3	4	5	10
raising male calves	-2	-1,72	-1,87	-2,03	-2,18	-2,73
raising female calves	-1	-1,8	-2,08	-2,36	-2,6	-3,43
raising heifers	-0,89	-1,55	-1,73	-1,85	-1,99	-2,46
fattenig male calves	-0,55	-0,91	-0,81	-0,83	-0,86	-0,94
fattening female calves	-0,54	-0,81	-0,63	-0,58	-0,53	-0,3
fattening heifers	-0,56	-0,94	-1,05	-1,11	-1,18	-1,45
fattening bulls	-0,56	-0,39	-1,32	-1,51	-1,71	-2,42
suckler cows	-0,64	-0,88	-3,12	-4,78	-6,05	-10,66
dairy cows	-0,85	-0,97	-1	-1,03	-1,06	-1,13
beef industry	-0,01	-0,55	-1,01	-1,2	-1,34	-1,78
dairy industry	-0,01	-0,51	-0,68	-0,79	-0,88	-1,11

Now turning to the effects on value added, we first obviously observe that the production decrease induces a global loss of value added for both farm sectors and food sectors. More precisely, thanks to the table 4 we disentangle variable effects over the 9 livestock activities defined in the model. Indeed, the greatest loss is observed for the suckler cow activity (-10,66%) in comparison to other sectors losing in a range of 0,30 to 3,43%. This can be explained by the fact that this particular activity, whose main selling output is cow beef (except the production of live calves), has a very small size in our economy, about 20 times smaller than the dairy cows activity. As a consequence, including an incompressible financial charge has a huge weigh and it leads farmers to disinvest as to try to maintain their valuation of production factors. This has side effects on other activities, explaining why raising activities are more impacted than the fattening ones, since less raised bovines enter the suckler herd. The mandatory savings have also downstream impacts, as the decrease in farm production constitutes a loss of agricultural raw material for the beef and dairy industries.

More generally, this simulation of the implementation of mandatory precautionary savings leads to a double conclusion. First, public regulation needs to define a maximum level for the financial reserve of the mutual fund after which precautionary savings are not needed. As a consequence farmers are not charged indefinitely for the benefit of a mutual fund that grows and nobody benefits from, this to avoid long term growing counterproductive effects. Second, as the mutual fund is a financial support to help recover the livestock activities when a sanitary crisis occurs, the risk management policy needs to take into account those negative effects; mandatory savings may be suspended while farmers rebuild their production capacity.

5.2.3 Effectiveness of the risk management tool

In this section we examine the effect of the implementation of a mutual fund when a FMD outbreak occurs. In order to analyse its economic impact, we compare three simulations corresponding to three different cases. We first report results of the impacts of the FMD outbreak in the absence of risk management policy. Then we analyse the same situation including a totally public support to farmers, equivalent to authorise for subsidies from the mutual fund without any counterpart for the farmers to pay off for that financial help (i.e. no mandatory savings to bail out the losses in the mutual fund). Finally we compute the consequences of a full implementation of the mutual fund, including both the financial support when farm income falls below the defined threshold and the mandatory savings for farmers finance the mutual fund.

- Herd structure and market effects

Table 5.4: Impact on herd structure (% with respect to the initial steady state)

period	1	2	3	4	5	15
no risk management policy						
dairy cows	-10	5,84	-3,13	-3,79	-3,47	-1,13
suckler cows	-10	57,88	6,16	-16,22	-22,42	-33,35
male calves	-10	-29	-11,38	-17,19	-15,63	-8,55
female calves	-10	-34,15	-23,03	-21,38	-19,62	-11,28
heifers	-10	-21,37	-15,96	-12,39	-11,04	-5,9
bulls	-10	-10	-18,34	-5,99	-9,3	0,2
public support						
dairy cows	-10	5,72	-3,26	-3,74	-3,54	-1,23
suckler cows	-10	58,58	8,16	-9,54	-11,8	-10,78
male calves	-10	-18,69	-10,86	-11,41	-10,51	-5,47
female calves	-10	-20,27	-13,42	-12,75	-11,97	-7,37
heifers	-10	-21,37	-13,62	-10,87	-9,34	-4,34
bulls	-10	-10	-14,78	-8,06	-7,99	-1,7
mixed public/private system						
dairy cows	-10	5,64	-3,75	-4,37	-4,32	-2,48
suckler cows	-10	59,07	8,19	-9,81	-12,14	-11,41
male calves	-10	-18,97	-11,07	-11,98	-11,35	-6,94
female calves	-10	-20,51	-13,72	-13,12	-12,47	-9,25
heifers	-10	-21,37	-13,88	-11,57	-10,16	-5,93
bulls	-10	-10	-15,18	-8,72	-9,22	-4,72

On table 5 are reported the evolutions of the cattle after the FMD outbreak in the three scenarios of simulation. As already explained, on first period we simulate that 10% of the herd is culled because of the presence of the disease. To understand the dynamic evolutions of the herds, one may be aware that Brittany traditionally imports calves and heifers and export young cows. So turning to the second period and in the absence of any management policy, we first notice that both suckler and dairy cow livestock increase. This is explained by the fact that Brittany traditionally exports cows. As movements of live animals are banned the year of the FMD outbreak, those stocks are not sold outside the region. Therefore, the year after, these cows participate to the quick recovery of the herds, and even to make it grow higher than the pre-FMD levels.

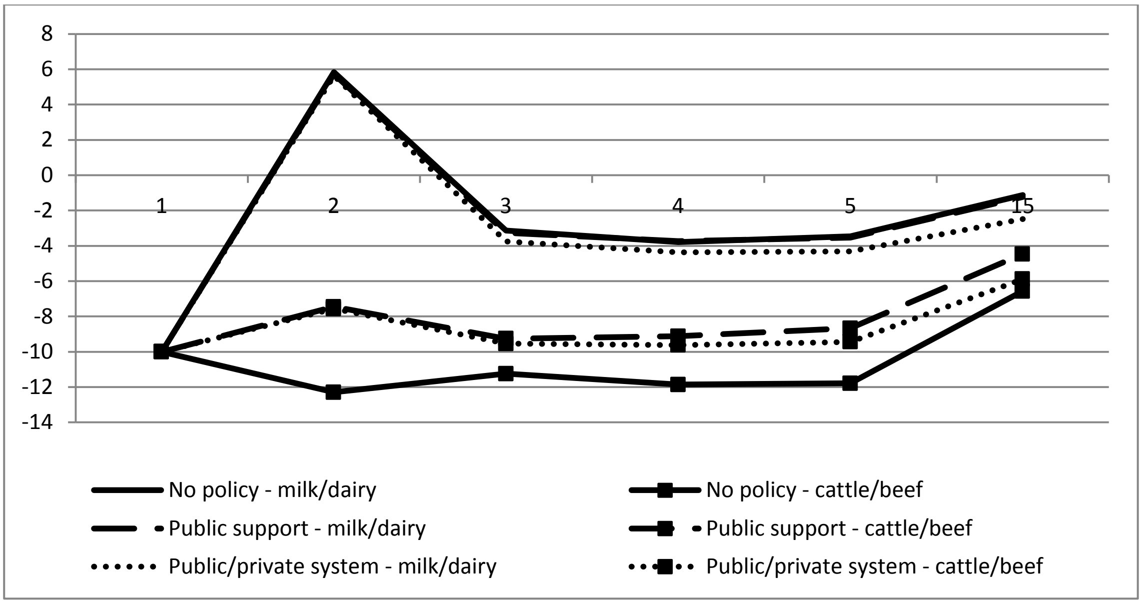
In parallel, on period 2 the herds of calves and heifers decrease as a result to the bans on import in the first period. Those deficits of young livestock result in lasting lacks of animals until the end of simulation. Indeed, the decrease of calves on second period results in a decrease of heifers on third period and so on. Thereafter, until the end of simulation, herds tend to reach slowly their initial value. One may wonder why the missing stocks are not completely filled with imports. Our simulations show that this is due to the limitation in investment capacity that prevents from massive expenditures to rebuild the herds. In the case of suckler cows, because of constraints on factor markets the activity tends to be much less profitable, driving farmers to prefer heifers to enter the dairy sector rather than the suckler one.

As a conclusion, our first simulation shows that a one-period shock due to a FMD outbreak causes dynamic long term variations of the herd structures, which may last all the more that factor markets are constrained. Comparing those raw effects with the evolution of the cattle in presence of risk management policies, we observe some significant differences. They are the most observable in period 2 for calves, where in both setting the subsidy helps to limit the loss of animals (-19% and -20% in comparison to respectively -29% and -34%) by the release of capital to import more young cattle (see table 8). On third period the subsidy mainly has the same target. Helping a quicker recovery of the young herd, the subsidy participates in the long run rebuilding of the whole cattle. Indeed, the lower loss of calves in the second period permits to obtain more young heifers and bulls on third period and so on. By this way, the deficit of cattle in the end of simulation is lower thanks to the financial support to farm activity.

However, we observe a slight difference between the public system and the participative one where farmers participate in precautionary savings (there they are more repayment of aid paid as an advance on cash). This result confirms the counterproductive effects of the implementation of mandatory savings/repayments.

Focusing on market impacts for the livestock sector and downstream industries (see figure 6), the culling of 10% of the regional livestock in the initial period of simulation obviously induces 10% losses of productions in livestock farms and therefore in dairy and beef industries in the absence of imports. This has a mechanical consequence on agricultural prices (see table 7) which increase y about 4%. As already observed with the cattle dynamics, the main effect of the policy is to help provide new animals. As a consequence, the cattle and the beef supplies are less impacted when a risk management policy is implemented. Thanks to this table we still observe that obviously, the mandatory precautionary savings tend to slightly lower the production levels.

Figure 5.1: Impact on production (% with respect to the initial steady state)



The same way, the implementation of support policy during a FMD outbreak tends to smooth price evolutions. Lowering levels of production induce increases in price, and the benefit of the financial help for farmers to maintain their activity permits to obtain smaller price variations.

Production results from other agricultural activities are not detailed in this article; let us just mention that due to the increase in price for beef, demand lowers to the benefit of other meat (pig). In addition, the lowering production of cattle, due to the decreased herd, induces a lower demand for feed and fodder. As a result, we observe marginal land use changes due to the FMD outbreak.

- Net value added and regional welfare consequences

In terms of welfare effects, the implementation of a subsidizing system has a significant positive effect on net value added in agriculture, and as a consequence in the related industries. Indeed, except the case of dairy farms which benefit from more cows producing more milk (because of export bans the year of FMD), cattle sectors for beef production suffer a loss of -196M€ of value added the year of the outbreak and -251M€ the year after due to ban restrictions and credit limitations. When a financial support to revenue is settled, those losses of income are largely reduced. The most striking result is when no farm participation is required, the cattle sector does not face any loss of net value at the FMD period. This can be explained by the fact that since imports for the renewal of the herd are banned, the totality of the subsidy is used to compensate for the income loss due to the decreasing production. However, this subsidy absolutely does not benefit to the beef industry, because they still fail at acquiring a missing cattle. This explains why in the first period the only benefit from the management policy goes to the agricultural activity (+0,63% in comparison to -4,31%) although the food industries suffer from the same level of loss.

In second period, the effects of the management policy are much more efficient for the whole sector and not only the livestock farms thanks to the reopening of borders. Indeed, the subsidy still permits to limit the loss of value added in the cattle sector (-5,56% in comparison to -19,66%), and additional income now permits to help rebuild the herds. As a consequence, more cattle is available for beef processing and beef industries can now enjoy the benefits of the agricultural support, their value added decreasing only by -8,16% in comparison to -16,23% without risk management policy. On the long run, no significant effects are observed due to our definition of simulation (production income is subsidized if it falls below 10% under its base value).

Table 5.5: Impacts on net value added (M€ and %with respect to the initial steady state)

period	1	2	3	4	5	15
no risk management policy						
dairy cows	37	4	-1	-11	-9	-2
	3,28%	0,34%	-0,86%	-0,98%	-0,81%	-0,17%
other cattle	-196	-251	-171	-152	-145	-89
	-15,41%	-19,66%	-13,44%	-11,90%	-11,34%	-6,97%
agriculture	-171	-242	-189	-171	-161	-94
	-4,31%	-6,09%	-4,75%	-4,30%	-4,06%	-2,36%
dairy industry	-21	13	-6	-7	-7	-2
	-10,77%	6,87%	-3,02%	-3,77%	-3,44%	-1,07%
beef industry	-27	-27	-2	-22	-22	-1
	-16,39%	-16,23%	-12,38%	-13,32%	-13,18%	-5,85%
food industries	-4	-1	-24	-27	-26	-1
	-1,67%	-0,40%	-1,01%	-1,13%	-1,10%	-0,42%
public support						
dairy cows	3,27%	1,73%	-0,90%	-1,06%	-1,00%	-0,35%
other cattle		-5,56%	-8,49%	-7,96%	-7,38%	-4,28%
agriculture	0,63%	-1,10%	-3,15%	-3,04%	-2,82%	-1,53%
dairy industry	-10,77%	6,74%	-3,16%	-3,71%	-3,51%	-1,17%
beef industry	-16,39%	-8,16%	-10,99%	-10,63%	-9,86%	-3,91%
industries	-1,68%	0,10%	-0,94%	-0,96%	-0,89%	-0,32%
mixed public/private system						
dairy cows	2,46%	0,76%	-1,91%	-2,11%	-2,11%	-1,63%
other cattle	-0,71%	-6,04%	-9,00%	-8,80%	-8,40%	-6,12%
total agriculture	0,17%	-1,53%	-3,61%	-3,62%	-3,48%	-2,53%
dairy industry	-10,77%	6,64%	-3,68%	-4,36%	-4,32%	-2,44%
beef industry	-16,39%	-8,34%	-11,35%	-11,25%	-10,82%	-5,48%
food industries	-1,67%	0,09%	-1,00%	-1,04%	-1,01%	-0,52%

Concerning the possible participation of farmers to this financial support through precautionary savings, again the results on net value added show that this levy has counterproductive effects and it tends to lower the benefit of the exceptional subsidy. On the long run, net values added are even comparable or lower than in the total absence of any risk management policy. Indeed, the dairy activity (through the production of milk) does not suffer much from the FMD crisis, but its participation to the repayment/saving for the public support to the cattle activity tends to lower its production level. In addition to credit limitations and the effort to rebuild the herds, other cattle sectors face this extra constraint for a higher lasting rebuilding period.

In those two scenarios of management systems involving farmers' participation or not, some important amouns are transferred to help support agricultural activity and limit the market effect of the FMD outbreak, as shown on table 8. As indicated, the subsidy is only activated when production income falls below 10% under its base value; this explains why the level of subsidies is mainly observable in the first times after the outbreak occurs.

Nevertheless, the remaining subsidy that is allowed until the end of simulation is mainly devoted to the suckler cow activity, for which the acquisition of new cows is not only limited by credit constraints but also by the fact that the usage of cows is more profitable for milk production.

Table 5.6: Annual financial transfers in the two types of management policies (M€)

period	1	2	3	4	5	15
public support						
subsidy	131	112	17,16	6,69	4,6	0,32
mixed public/private system						
subsidy	137	115	20,49	8,35	5,75	0,63
savings	16,07	16,05	14,96	14,95	14,95	15,01

Some regional macroeconomic impacts in the end of simulations are reported in table 9. At the end of simulation, the value of land diminishes due to the reduced cattle sizes. Thanks to a public support, the fall of value of land can be smoothed (-73,08M€ / -94,80M€). This public support also permits to limit the impacts on financial capital and on the cattle herd value. However, this kind of policy has a cost; if the production effects of the policy permit to limit the increase of the debt, the public support to livestock sectors needs to be financed, increasing the debt (payment of the loan interests on the mutual fund). Moreover, the total amount spent through this public management policy is 277M€, which can also be added to the debt. Nevertheless, this risk management strategy permits to limit the loss of discounted welfare of the representative household (930,53M€ / 1228,96M€), which represents an aggregate of the annual equivalent variations.

In the case of a full implementation of a mutual fund system, where the support to farm activity is partly financed by farmers themselves though annual savings, we distinguish mixed macroeconomic effects. On the one hand, the mandatory savings/repayments permit to limit the public expenditure, which is reduced by about 102M€ while farmers support now about 57% of the entire cost.

Table 5.7: Macroeconomic impacts (M€)

	no risk management policy	Public support	mixed public/private system
value of land	-94,8	-73,08	-120,84
value of physical capital	-376,04	-278,18	-381,92
value of cattle herd	-66,39	-33,8	-49,22
value of foreign debt (out of mut. f.)	245,31	260,14	100,19
- policy public cost		277,83	175,85
- policy farm cost			237,2
discounted welfare	-1228,96	-930,53	-1097,58

As a consequence, the value of the general debt is much lower than with the only public support. Logically, the levy on farm production tends to limit the effects of the policy on the value of the cattle herd. More striking are the falls in the value of land and in the value of physical capital. This can be explained by the fact that farmers bear the cost of the FMD outbreak through mandatory savings. On the one hand, the subsidies from the mutual fund can help rebuild –to a limited extent– the herds, and on the other hand the savings/repayments induce much lower amounts to value the land factor and physical capital investment.

Conclusion

In this study we experience the implementation of a risk management policy for the lasting market effects of a potential FMD outbreak. More precisely, we introduce mutual funds, a mixed public-private management system, and we analyze their ability to cope with such a catastrophic event. On the basis of a dynamic CGE framework, we highlight the fact that potential losses are great and that the implementation of any management policy, totally public or with the participation of farmers themselves, can smooth he effects of the catastrophic shock.

Nevertheless we also show that the risk management policy has a non trivial cost. We underline that if this cost is totally supported be the regional public authorities, the global debt amount may reach high levels. On the other hand, intending to finance the exceptional supports by farmers themselves may also have significant repercussions on the farm activity and income, since farmers are all the more weakened by this mandatory participation that they already face high constraints to rebuild their production capacity quickly (credit, wages).

These results highlight the catastrophic nature of a FMD outbreak, and they indicate that the successful constitution of mutual funds to cope with this kind of hazard depend on two main factors. First, public authority may pay attention to a right calibration of the level of participation to the fund in order to avoid counterproductive effects. Second, a sufficient delay should be left to farmers after the market crisis and before participating anew to the fund, this delay permitting to recover more safely from the losses induced by the disease. In addition, our analysis shows that the financial help to farmers does not benefit the whole sector when a trade ban is imposed, because the cattle cannot be renewed so that the food industries do not benefit from that help at all.

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Conclusion générale

La Bretagne est caractérisée par une forte densité des activités agricoles et des filières agroalimentaires, développées dans une logique d'économies d'échelle. En termes de santé animale, cette concentration présente des avantages, mais aussi des inconvénients. La proximité géographique des acteurs est en effet de nature à faciliter la mise en œuvre d'actions collectives de maîtrise des maladies et à faciliter la coordination des différents agents. En revanche, cette même concentration, synonyme de fortes densités d'élevage, implique que les maladies peuvent se propager rapidement d'une ferme à l'autre. Par ailleurs, la contribution des filières animales à l'économie bretonne est forte ; l'apparition de maladies animales d'ampleur peut donc induire des conséquences économiques et sociales importantes. L'évaluation du risque sanitaire, la compréhension des retombées économiques d'une maladie animale et l'élaboration d'outils de gestion sont donc cruciaux, tant à l'échelle nationale que celle de régions d'élevage telles que la Bretagne.

L'apparition de maladies épidémiques, du type de la fièvre aphteuse, peut toucher à la fois les élevages bovins et porcins, majoritaires en Bretagne, et est difficile à anticiper. Malgré l'encadrement des pratiques agricoles et les politiques de gestion *ex ante*, un tel évènement peut survenir et affaiblir les filières animales. L'élaboration d'outils de gestion *ex post* comprend alors à la fois le contrôle sanitaire de la maladie et le soutien aux filières touchées. La mise en place de politiques de gestion économique suppose une connaissance précise des risques de marché encourus par les filières animales. Cette thèse a eu pour objectif d'étudier les phénomènes de marché consécutifs à la survenue d'une épidémie d'élevage. Au-delà des conséquences immédiates, dues aux effets de la maladie elle-même et aux mesures de contrôle qui en découlent, la recherche a porté sur les perturbations de long terme qu'un évènement de marché de grande ampleur peut entraîner. Face à ce type de choc, la réaction et l'adaptation des filières de production bovine et porcine peut ne pas être immédiate, de par l'inertie des structures d'élevage et les efforts d'investissement nécessaires. Il a donc paru opportun d'adopter des formes de modélisation dynamiques, permettant de capter les décisions économiques interannuelles des éleveurs et industriels, tout comme les dynamiques de troupeaux. En particulier, ce choix de modélisation a permis d'aborder les problématiques de marché liées aux besoins d'investissement et aux dynamiques de capital des entreprises. Grâce à une modélisation en équilibre général calculable (EGC) dynamique, nous avons pu intégrer ces dimensions dans le cadre de l'économie bretonne. On a ainsi mis en évidence les effets massifs et durables d'une épidémie d'élevage sur le tissu économique régional, avec une attention particulière portée sur les marchés des facteurs de production et leur poids dans le coût agrégé d'une épidémie sur le long terme. Nous avons enfin pu simuler les effets de la mise en place de mesures de soutien à l'activité agricole après une crise sanitaire, et mesurer les effets variés de bien-être suite au choix de divers outils.

Cette thèse a permis, dans une première partie, de définir le cadre actuel des systèmes de gestion du risque épidémique. On a pu montrer qu'en Europe les politiques de soutien nationales ne sont pas harmonisées, et que des outils de gestion variés existent, exigeant une implication financière plus ou moins grande de la part des agriculteurs. La couverture des pertes de marché et le soutien aux secteurs en crise passent la plupart du temps par des déblocages de fonds d'urgence, décidés de manière *ad hoc* en fonction du contexte. Ce manque de prévisibilité et de clarté dans l'implication des pouvoirs publics freine par ailleurs le développement de systèmes de couverture privés, au-delà du fait que le risque à couvrir soit potentiellement catastrophique. La définition de politiques structurelles de gestion du risque épidémique, en discussion depuis 2008 et le « bilan de santé » de la Politique Agricole Commune, suppose une évaluation précise des composantes du risque épidémique. Une revue de la littérature en économie de la santé animale montre que l'estimation des coûts d'une maladie épidémique inclut diverses composantes. On recense en premier lieu les coûts directs de la maladie, en termes de baisse de la productivité des élevages et de stratégies de maîtrise sanitaire. L'analyse économique montre également des effets indirects multiples : effets sur l'ensemble du secteur agricole touché, sur les activités d'amont et d'aval, sur les marchés internationaux, sur la demande etc. Quelques analyses montrent par ailleurs que, pour les fermes élevant du gros bétail, le choc de marché brutal occasionné par l'apparition de la maladie entraîne des perturbations durables au sein des exploitations. En ressort alors l'importance de la prise en compte des dynamiques de marché causées par un choc épidémique. De plus, dans l'optique de donner une vision globale des effets de marché d'une épidémie, la modélisation en EGC dynamique apparaît comme la plus à même d'intégrer toutes les composantes du risque, et de prendre en compte ses implications intersectorielles et temporelles.

La seconde partie de cette thèse est consacrée à un premier travail de modélisation qui a permis, dans un cadre théorique, de montrer les effets dynamiques d'une épidémie de fièvre aphteuse et le rôle du marché du crédit, en présence d'informations imparfaites et avec le risque de faillite agricole. Nous montrons que le risque de faillite entraîne des effets de bien-être variés. Son impact sur les secteurs productifs (arrêt de la production et faillite de certaines fermes) a des répercussions négatives sur les consommateurs à long terme, en raison de la contraction de l'offre ; au contraire, les fermes ayant pu résister au choc de marché sortent finalement gagnantes en tirant profit de l'augmentation de prix. Notre analyse constitue donc un apport théorique sur les implications financières de long terme liées à un choc catastrophique. Elle constitue une première étape dans la compréhension des mécanismes de marché imputables à la survenue d'une maladie épidémique, mettant en évidence la fragilisation de l'activité agricole qui en résulte.

La troisième partie de cette thèse s'intéresse à la définition d'un modèle pour l'analyse des crises sanitaires dans le contexte économique breton. Nous détaillons l'élaboration du modèle d'EGC dynamique, de la construction de la MCS à la spécification de ses équations. Avec l'objectif d'analyser les effets régionaux d'un choc sur les marchés agricoles, une attention particulière est donnée à la modélisation et aux données relatives aux secteurs agricoles. L'originalité de ce modèle tient à la prise en compte des dynamiques interannuelles d'investissement et d'épargne des agents. En particulier, les décisions des éleveurs intègrent la gestion des cheptels. Les truies de reproduction sont en moyenne abattues vers deux ans et demi, et les vaches laitières ne sont réformées qu'au bout de cinq à six ans. Ces animaux sont ainsi élevés et peuvent être maintenus à la ferme plusieurs années ; la modélisation tient compte de cette spécificité. Les troupeaux sont considérés non plus comme des intrants permettant la production d'outputs (viande, lait) mais comme des facteurs de production, dont l'évolution intertemporelle (nombre de têtes) dépend des cycles de croissance, de reproduction et des échanges sur les marchés. Cette considération nécessite une désagrégation fine des données concernant les cheptels, différenciés selon leur classe d'âge annuelle, leur sexe et l'atelier de production dans lequel ils se trouvent. Outre les élevages, on a aussi désagrégé finement l'ensemble des activités agricoles et agroalimentaires, afin de capter les effets intersectoriels de chocs, tant en amont qu'en aval des productions animales.

La quatrième partie de cette thèse est consacrée à la mise en application du modèle d'EGC dynamique, au travers d'une simulation d'épidémie de fièvre aphteuse. Le scénario de simulation porte sur une crise sanitaire soudaine et contenue sur une seule année, et les effets de ce choc sont observés sur une période longue, les quinze années suivantes. Diverses composantes du choc sanitaire sont intégrées : abattage de troupeaux infectés, restrictions aux échanges d'animaux vivants et de produits animaux, recul temporaire de la demande. Cette évaluation macroéconomique des effets d'une crise sanitaire met en évidence le poids d'un tel évènement sur le bien-être économique et social de la région, et la persistance d'effets de long terme au-delà des conséquences immédiates de la crise. Les effets économiques perceptibles par cette modélisation sont d'autant plus forts et durables si on prend en compte des rigidités sur les marchés des facteurs de production. En effet, le choc de marché peut être amorti dans les secteurs touchés, par un recours massif à l'investissement et par une baisse temporaire des niveaux de salaires, en particulier dans les industries bouchères. L'analyse montre que la difficulté d'accès au crédit (donc la limitation de recours à l'endettement) freine les élevages à retrouver rapidement leurs capacités de production. D'un autre côté, dans les secteurs en difficulté temporaire, on montre que si le maintien des rémunérations est de nature à soutenir la consommation et l'épargne des ménages, il représente néanmoins une charge supplémentaire pour les entreprises et limite leurs possibilités d'investissement à un moment où la mobilisation de capitaux pourrait soutenir l'activité. L'analyse montre que les imperfections sur les marchés du travail et du capital accroissent ainsi lourdement le coût économique total de l'épidémie, et multiplient par plus de quatre la perte de bien-être économique régional. Cette simulation montre enfin que, vu l'importance des filières animales dans l'économie bretonne, ces répercussions sectorielles entraînent un recul significatif du produit intérieur brut régional, une balance commerciale en recul, et un recours grandissant à l'investissement d'actifs extérieurs dans la région.

La cinquième et dernière partie de cette thèse est dédiée à l'analyse de l'effet de politiques de soutien après la survenue d'une crise sanitaire. Nous simulons dans le modèle d'EGC dynamique les effets de soutiens publics à l'activité agricole et fonds mutuels agricoles, comme il peut en exister en Allemagne par exemple, et dont la mise en place est débattue au niveau européen. Ce mode de gestion des risques catastrophiques est un système mixte privé-public, impliquant la participation financière des agriculteurs et de l'État. Notre analyse permet de montrer que ces deux modes de gestion ont des effets positifs sur le retour rapide à l'équilibre de marché, mais qu'elles engagent des coûts variés. Si un soutien totalement public se traduit directement par une perte du revenu régional, la mise en place de fonds mutuels reporte une partie du coût public sur les agriculteurs eux-mêmes, et apparaît comme plus coûteuse *in fine*. Elle constitue en effet une charge supplémentaire pour éleveurs, ce qui ralentit le retour de l'activité aux niveaux d'avant la crise, et a ainsi des répercussions sur la création de valeur ajoutée en élevage et dans les secteurs d'amont et d'aval. Par ailleurs, ce travail permet de souligner l'importance des modalités de la définition de fonds de mutualisation : fixation des niveaux de participation au fonds mutuels calibrés pour ne pas générer d'effets contre-productifs, constitution de fonds spécifiques pour chaque type de risque agricole (e.g. maladie animale, intempérie) ou fonds commun à toutes les activités agricoles etc.

L'ensemble des travaux menés dans cette thèse apportent des éléments de connaissance des effets de maladies épidémiques à l'échelle des marchés et des territoires. Ils ne constituent toutefois pas une réponse définitive à cette problématique. Certaines limites à l'étude n'ont pas été levées, et des perspectives de recherche restent à explorer.

Pour l'élaboration du modèle d'EGC dynamique, nous n'avons que peu abordé la question des anticipations des agents. Nous posons en effet l'hypothèse que les agents ont des anticipations rationnelles (hors choc épidémique). Dans le contexte de notre étude, cette hypothèse convient à un scénario d'épidémie de fièvre aphteuse, où les agents ont une information complète et non biaisée des évolutions de marché après le choc. Néanmoins, d'autres formes d'anticipations peuvent être adoptées. Le choix d'anticipations adaptatives, basées sur les évolutions passées des marchés, ne convient pas à ce type de scénario qui n'est pas représentatif des fluctuations classiques des cours. Néanmoins, ce type de choc étant un évènement rare, les agents font face à une information incomplète, concernant le prix de vente de leurs outputs, et les décisions de consommation et d'usage d'intrants peuvent être décidées en amont de la crise (qui reste inconnue), en fonction du contexte de marché du moment. En particulier, les décisions de production dépendent de la taille du troupeau avant crise, et des dépenses d'alimentation et d'élevage sont engagées. Lorsque l'épidémie a lieu, sur une période de simulation donnée, les choix de production ont déjà été définis. En conséquence, on se trouve face à des anticipations imparfaites en raison de la crise, malgré la rationalité apparente des agents économiques, effective en l'absence de ce type d'évènement rare. On peut donc considérer que, même si l'information est complète sur les marchés quand la situation sanitaire est maîtrisée, la rationalité des agents est limitée par l'aléa dû à la crise. Une amélioration possible du modèle serait de prendre en compte cet aléa dans sa résolution. A chaque période, le modèle peut être résolu dans son ensemble deux fois, séquentiellement. Une première résolution, calculée sur l'horizon d'anticipation des agents, permet de définir les décisions d'usage d'intrants des agents en fonction des rapports de prix courants si une crise épidémique n'intervient pas. Une seconde résolution du modèle pour la même période permet de définir la réalité de marché, en fonction des choix de production précédemment évalués, et dans laquelle le choc épidémique peut être simulé. Cette spécification du modèle permet, en l'absence de fluctuations de marché, de conserver un schéma d'anticipations rationnelles des agents, tout en intégrant les imperfections d'information inhérentes à la survenue inopinée d'une épizootie.

Les questions d'aversion au risque ont également été exclues de cette thèse. La représentation des attitudes des agents face au risque est néanmoins une problématique centrale dans l'étude des comportements vis-à-vis des maladies d'élevage. Nous avons émis l'hypothèse que les agriculteurs, en raison d'un manque certain d'information sur le risque de survenue d'une épizootie, ne tiennent pas compte de cette éventualité dans leurs choix de production. Toutefois, même si la probabilité d'occurrence d'une crise sanitaire reste très faible (grâce notamment aux systèmes de surveillance sanitaire), un risque faible d'épizootie existe, que les agriculteurs peuvent effectivement percevoir (Meuwissen et al., 2001). Les modifications de comportement liées au risque de maladie animale sont connues et font d'ailleurs l'objet de nombreuses études (Koontz et al., 2001), notamment pour l'analyse des asymétries d'information et des questions de sélection adverse liées à l'assurance du risque sanitaire. La prise en compte de cette aversion, et des attitudes face au risque en présence de mécanismes de soutien, tendrait à affiner l'analyse sur la mise en place de politiques de gestion du risque épidémique. A notre connaissance, les travaux dans ce domaine sont néanmoins très limités en équilibre général calculable.

Enfin, l'étude territoriale menée dans cette thèse reste limitée au cas de la région Bretagne, et ignore en partie les effets d'un choc épidémique sur le reste du territoire français. La majeure partie des productions animales françaises est concentrée dans les régions du Grand Ouest, et une recherche de données a été menée durant les travaux de thèse pour les autres régions qui la compose (Basse-Normandie, Pays-de-la-Loire, Poitou-Charentes). L'élaboration de MCS pour ces régions n'a pu aboutir à un résultat aussi satisfaisant que pour la Bretagne, et s'est heurtée à des problèmes de disponibilité des données. En particulier, il est très difficile de quantifier les échanges commerciaux entre régions, les données douanières ne recensant que les échanges internationaux. L'acquisition ou l'estimation de ces informations serait à même de donner un éclairage sur les modifications des termes d'échange agricoles dans le Grand Ouest, où les filières agricoles et alimentaires sont fortement interdépendantes. Par ailleurs, l'étude d'outils de gestions du risque sanitaire (e.g. les fonds mutuels) est également pertinente à une échelle interrégionale, voire nationale ; elle permet d'analyser les mécanismes de compensation entre des zones diversement affectées par ce choc de marché.

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Table des matières

Résumé

Cette thèse quantifie les répercussions économiques liées à la survenue d'une épidémie d'élevage. Ces maladies constituent un risque de production aux implications multiples, occasionnant parfois un risque qui s'étend à toute la filière animale, voire à l'ensemble de l'économie du territoire touché, comme le montre par exemple la crise de la vache folle de la fin des années 1990. La littérature économique montre que ces crises constituent un évènement catastrophique de marché, qui entraîne un ajustement progressif dans la conduite des troupeaux. Nous proposons donc une modélisation des dynamiques de marché en élevage, permettant de capter les effets indirects et de long terme liés à la survenue d'une épizootie. L'analyse révèle que ce choc pèse sur l'endettement et peut mener à la faillite d'exploitations agricoles. L'accès au crédit joue un rôle déterminant pour la pérennité des activités d'élevage, qui *in fine* pénalise aussi les consommateurs. A l'échelle des territoires, la compréhension des répercussions d'une crise sanitaire passe par une modélisation en équilibre général calculable dynamique, intégrant à la fois les décisions intertemporelles des agents, dont les éleveurs, et des imperfections des marchés des facteurs de production. Le modèle est appliqué à la région Bretagne, dont les secteurs d'élevage occupent une place importante pour le tissu économique local. Les résultats de simulations montrent que le choc sanitaire pèse sur l'ensemble des filières animales, pour finalement toucher l'économie locale dans son ensemble. Dans ce contexte, le manque de flexibilité des marchés du capital et du travail accroît significativement le coût social de la maladie et freine le retour de l'activité économique. Enfin, nous montrons qu'un soutien public aux revenus des agriculteurs en période de crise tend à diminuer l'ampleur du choc et sa durée. La participation des agriculteurs à cette politique, via la mise en place de fonds mutuels, déplace le coût de gestion du risque vers ces acteurs, mais se révèle finalement plus coûteuse socialement.

Abstract

This PhD is focused on the economic impacts due to a livestock disease outbreak. This kind of sanitary shock represents a productive risk with many implications, extending its effects to the whole livestock industry or even to the overall economy of the region or country, as observed for example during the mad cow disease crisis in the late 1990s. From the economic literature, it appears that these crises are catastrophic market events, and that they lead to a gradual adjustment in the herd. Thus we propose an economic modelling of market dynamics in livestock, in order to capture the indirect and long run effects related to the occurrence of a disease outbreak. The analysis reveals that the shock makes indebtedness grow and may lead to farm closure. The access to credit plays a crucial role for farm solvency, and this situation may also ultimately penalize consumers as well. At the country level, the comprehension of the impacts of a health crisis is possible thanks to a dynamic computable general equilibrium modelling, which integrates intertemporal decisions of farmers –including livestock farmers–, and market imperfections for production factors. The model is applied to Brittany, a French livestock-intensive region. Simulation results show that the health shock weighs on all livestock sectors, and finally affects the whole regional economy. In this context, the lack of flexibility in capital and labour markets increases the social cost of the disease, and delays the return of economic activity. Finally, we show that public support for farm income in a period of crisis tends to reduce the magnitude and the duration of the shock. Participation of farmers in this policy, through the implementation of mutual funds, moves the risk management costs to those agents, but ultimately proves more costly socially.