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How do farmers' environmental preferences influence the efficiency of information instruments for water quality management? Evidence from a social-ecological agent-based model

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ABSTRACT

Diverse public policies encourage farmers to adopt eco-friendly practices to address the issue of diffuse pollution from agriculture, including measures based on the provision of information on the environment. Indeed, farmers' perception of the state of the water body and their awareness of the causes and consequences of water pollution affect their willingness to adopt eco-friendly farming practices. Public policies therefore have a role to play in disseminating environmental information. In this article, we investigate how information measures may exert influence on changes in farming practices and thereby water pollution. We extend an existing agent-based model of a social-ecological system representing a drinking water catchment area. In the decision-making process based on the theory of planned behaviour we integrate a dynamical environmental component of farmers' attitude towards eco-friendly practices, in order to take into account the effect of information on the ecological system. We explore the impact of information measures, heterogeneity in farmers' environmental preferences and variations in the initial level of water pollution on farmers' participation to a water catchment protection programme. Our results show that: (1) targeting farmers who have higher environmental preferences is more effective than no targeting; (2) the heterogeneity in farmers' environmental preferences impacts their involvement in the programme depending on the average environmental preferences; (3) the higher the initial pollution, the higher the farmers are involved in the protection programme; (4) when two different measures are combined, once a certain threshold of public awareness is reached, there is a synergy between them.

Keywords: agent-based model; governance; information; social–ecological system; theory of planned behaviour; water quality.

1. INTRODUCTION

The world's freshwater resources face different sources of pollution: organic waste, pathogens, fertilizers and pesticides, heavy metals or emerging pollutants (UN Water 2020). These pollutions lead to a degradation of water quality with various economic, social and environmental consequences (FAO 2011). More specifically, in the case of the production of drinking water, restoring and protecting water quality is an important issue due to the impact of pollution on health and the increased production costs for providing drinking water (Bommelear et al. 2011).

Water quality refers to the chemical, physical and biological dimensions of water, based on the standards of its usage. In Europe, for instance, the European Union Drinking Water Directive set the legal framework to protect human health from the adverse effects of any contamination of water intended for human consumption by ensuring that it is wholesome and clean. It defines and values a set of bacteriological, physico-chemical and radiological parameters (European Parliament and Council, 2020).

Because farming practices are one of the major sources of diffuse pollution in drinking water catchment areas, understanding farmers' motivations to adopt eco-friendly practices may provide new insights for designing efficient policies. Among the various factors that influence farmers' choices regarding agricultural practices promoted by environmental policies (see for instance Dessart et al. 2019), their perception of water quality, i.e., the subjective evaluation of water quality, is an important one (Amblard 2019, Bosc and Doussan 2009, Gachango et al. 2015, Lubell et al. 2002, Moser 1984, Michel-Guillou 2009). For example, Gachango et al. (2015) found that, in specific areas in Denmark, farmers perceive the water quality to be above average the effective water quality and, consequently, they feel that the removal of the regulatory measures would have little or no effect in terms of reducing the water quality. The decision-making process of farmers was also shown to be influenced by their awareness of the consequences of water pollution (Michel-Guillou and Moser 2006), their awareness of the consequences of their farming practices (Hu and Morton 2011) or their environmental concern, i.e., their interest in water quality and sense of responsibility towards the environment (Toma and Mathijs 2007).

Recent studies show that farmers do not behave in favour of water quality due to a lack of information, perspective and understanding of the benefits of eco-friendly behaviours (Popp and Rodrigez 2007, Floress et al. 2017, Inman et al. 2018, Okumah et al. 2018). Thus, public policies have a major role to play in disseminating information on water quality and on the consequences of water pollution. Indeed, information measures may improve the effect of financial or regulatory instruments (Sheeder

& Lynne, 2011, Barnes et al. 2013, Kuhfuss et al 2016). Land managers, such as farmers, are different in terms of their constraints to change, the factors that motivate their decisions, or in how they balance business, social and personal factors (Liu et al., 2018, Dessart et al. 2019). This diversity means that different types of information may be required at different times, with differing degrees of advice and prescription for environmental policies (Garforth et al. 2003). Thus, recognising the diversity of farming styles related to management decisions is essential in supporting the integrated management of diffuse agricultural pollution.

For addressing such issues, we extended an agent-based model of a drinking water catchment area (Bourceret et al. 2022). The conceptual framework of the model is based on the Social-Ecological Systems (SES) framework (Ostrom 2009; McGinnis and Ostrom 2014). The SES framework was developed from the Institutional Analysis and Development (IAD) approach (Ostrom, 2011) for analysing the governance of common-pool resources (Ostrom, 2007, 2009). It is now being used more widely, including for the analysis of the various public goods and services generated by SESs (McGinnis and Ostrom, 2014; Ban et al., 2015; Bennett and Gosnell, 2015). The model represents a water catchment area where farmers decide on their farming practices, which impact water quality. The decision-making process of farmers is based on the theory of planned behaviour and takes into account social influences as well as the heterogeneity of farmers. We integrate the influence of the perception of water quality in farmers' motivations through a dynamical environmental component of the attitude towards eco-friendly practices. The main purpose of the model is to perform a dynamical analysis of the adoption of low-input farming practices. We use this model to simulate behavioural reactions of farmers, who are sensitive to the quality of the water, to policy interventions. In Section 2, we present an overview of the impact of information policies on water pollution before describing the agent-based model of a water catchment area in Section 3. This model allows us to analyse the impact of information-related instruments on water quality (Section 4). First, we characterise the effectiveness of different water quality protection programmes. We focus on the role of two types of information measures: one measure based on the provision of information about the concentration of pollutants in water and a second measure including additionally the provision of information about the consequences of the pollution (Section 4.1). Second, we assess the impact of the state of the water body, here a groundwater body, on farmers' decisions. More particularly, we analyse the impact of the initial concentration of pollutants in water on farmers' behaviour (Section 4.2). Third, we characterise how the diversity amongst farmers affects policy effectiveness, with a focus on the heterogeneity in environmental preferences (Section 4.3). Finally, we discuss our findings and results in Section 5.

2. OVERVIEW OF THE IMPACT OF INFORMATION-BASED POLICIES ON WATER POLLUTION

First, we present how information-based policy instruments may complement regulatory and financial instruments in the context of water quality management. Then, we discuss how the water quality and awareness of water quality issues influence the decision-making process of farmers with regard to the adoption of eco-friendly practices.

2.1. Information instruments for enhancing water quality

Environmental policy instruments include a diversity of instruments such as economic, command-and-control and information instruments (Villamayor et al. 2019). Economic instruments rely on market forces and changes in relative prices to modify the behaviour of actors in a way that supports environmental protection or improvement. Command-and-control tools influence environmental outcomes by regulating processes or products, limiting the discharge of specified pollutants, and by restricting some polluting activities to specific times or areas. Although these instruments have demonstrated their effectiveness for managing environmental problems, they have shown some limitations in the case of agricultural nonpoint source water pollution (Shortle et al. 2012). For instance, economic incentives alone do not account for changes in farming practice that improve water quality because of a dual, self and others interests (Czap et al. 2012, Sheeder & Lynne 2011). Barnes et al. (2013) highlight a vicious circle of regulation of water pollution: coercive behaviour due to regulation creates a negative perception of water pollution issues and, ultimately, leads to a greater need for regulation.

Information instruments imply a voluntary commitment of farmers to adopt practices in favour of water quality. They include public education and information campaigns. The concept of nudge, developed in behavioural economics, refers to the provision of information that influences the decision-making of individuals without changing the structure of economic incentives or restricting their available options. For example, Kuhfuss et al. (2016) found a positive effect of information on a social norm as a behavioural nudge on the maintenance of practices promoted by agri-environmental schemes. The information may be used in a complementary way to enhance the effect of an economic instrument. Barnes et al. (2013) also found that nudges play a positive role in the implementation of regulatory policies targeting water quality. An optimal mix of policies can lead to positive effects on water quality.

Villamayor et al. (2019) highlighted that information-based policies can be based on either: (1) providing information in a relatively neutral way or (2) providing an appropriate interpretation of the information to guide behaviour in a particular direction. For example, the authority in charge of water management can monitor the concentration of pollutants in water and inform farmers about it. An alternative action is to provide information about the consequences of this pollution in order to raise awareness. According to Lastra-Bravo et al. (2015) and Okumah et al. (2021), training, awareness-raising and information for farmers are key elements that promote eco-friendly practices. Awareness-raising of the environmental consequences of farming is generally considered a necessary step towards the adoption of practices that improve water quality (Blackstock et al., 2010; Ervin & Ervin, 1982; Prokopy et al., 2008). Blackstock et al. (2010), based on a literature review, highlighted that raising awareness amongst farmers can alone be effective in persuading farmers to adopt favourable water practices.

The information provided to improve water quality can concern different aspects such as the behaviour of others, the environmental consequences of farming, or the level of degradation of the resource. We focus particularly on the information on the water resource.

2.2. Influence of water quality on the decision-making process in the adoption of farming practices promoted by environmental policies

In the field of drinking water management, the level of water contamination by nitrates and/or pesticides was found to play an important role in stakeholders' incentives to cooperate in the protection of drinking water catchments (Lubell et al. 2002, Bosc and Doussan 2009). Several studies have shown how the threat of applying regulatory measures when the level of pollution is high may stimulate the involvement of agricultural stakeholders in collective action to protect water catchments and watersheds (Hardy and Koontz 2010, Grolleau and McCann 2012, Amblard 2019). By contrast, some studies have noted that the good quality of the water resource, i.e., the absence of water pollution, can constitute an impediment to agricultural stakeholders' involvement (Garin and Barraqué 2012, Amblard 2019). The good quality of the water resource appears to be an obstacle to the participation of farmers who question the legitimacy of undertaking costly changes in their farming practices in the absence of any observed pollution (Amblard 2019).

Moreover, the concern of farmers for the environment impacts their adoption of sustainable practices (Toma and Mathijs 2007, Best 2010, Jaeck and Lifran 2013). D'Souza et al. (1993) found that farmers who are aware of on-farm environmental issues are more likely to implement sustainable practices.

Floress et al. (2017) found a positive relationship between awareness of water quality problems and farmers' willingness to adopt actions to improve water quality in Indiana. Identically, Michel-Guillou and Moser (2006) showed that farmers who have adopted pro-environmental practices feel more involved in this problem than farmers who have maintained traditional practices. Indeed, while some farmers may recognise the impact of agricultural practices on water quality (e.g., Ward et al. 1995, Hu and Morton 2011), other farmers may not be aware of these consequences (e.g. Popp and Rodrigez 2007). Moreover, some farmers may have a negative opinion of the environmental benefits of water management (e.g. Barnes et al. 2009, Morton et al. 2017, Inman et al. 2018).

This brief review highlights the importance of information-based instruments in environmental management, which constitutes the main motivation for our modelling approach. We focus on information about the state of the water body and, therefore, we developed a model involving actors whose decision-making process partially depends on the state of the water body, in a context where a mix of policies includes information instruments.

3. A SOCIAL-ECOLOGICAL MODEL INTEGRATING THE IMPACT OF INFORMATION-BASED INSTRUMENTS

We extend an agent-based model of a social-ecological system (SES) from a previous study (Bourceret et al., 2022). This model, representing a water catchment area, uses the Theory of Planned Behaviour (TPB). This theory has been frequently applied for predicting human behaviour, more particularly to understand farmers' behaviour in a voluntary policy context (Sok et al., 2021). First, we present the core elements of the model previously developed (Section 3.1). Second, we present the adaptations made to the model to analyse the effect of an information policy on farming practices (Section 3.2). See Appendix 1 for the Overview Design concepts and Details (ODD) protocol description. The code is available here : <https://github.com/ABourceret/behaviouralDynamicsInSES.git> (modeleInformationInstruments.nlogo).

3.1. Existing TPB-based model of a drinking water catchment as a SES

In the existing model (Bourceret et al. 2022), individual farmers are connected in a social network, and their decision of whether or not to join a catchment protection programme (and thus to practice low-input farming promoted by the programme) is based on the TPB (Ajzen 1991). Each farmer has an intention to change to low-input practices, i.e., a level of motivation to adopt a low-input practice,

based on three independent factors: the attitude, subjective norm and perceived behavioural control. Following different studies (Defrancesco et al. 2007, Mettepenningen et al. 2013, Falconer 2000), we described the attitude as the financial and environmental judgement about the desirability of adopting the low-input farming practice. The considerations about the influence and opinions of others on the behaviour of interest define the subjective norm (Ajzen 1991). Farmers' decisions are influenced by the practices of farmers belonging to their social network. The perceived behavioural control is the aggregation of past experiences, knowledge and qualification (Ajzen 1991). Farmers with an intention higher than a personal threshold will change to low-input farming.

3.1.1. Water body

The water used for drinking water production is extracted from a water body. The water body sub-model is a linear reservoir model whose storage law and discharge law vary linearly as a function of the water level. We consider that the quantities of water feeding and leaving (natural flow and extracted water) the water body system are equal and constant over time. The concentration of pollutants in water ($C(t)$), in mg/L, is used as a proxy to measure water quality. We assume that diffuse pollution from agricultural activities is the only source of water body pollution and that only high-input farming practices lead to residual pollutants in the water body.

3.1.2. Actors

3.1.2.1. Decision process

The intention to change to low-input farming practices, $I_i(t)$, is a linear function of the three basic factors.

$$I_i(t) = s_i(t) + a_i(t) + p \quad (1)$$

where,

- $s_i(t)$ is the subjective norm, linked to the behaviour of others,
- $a_i(t)$ is the attitude, i.e., the judgement of farmer i on the desirability of changing to low-input farming practices, and on the consequences of this change,
- p is the perceived control of behaviour, representing the beliefs of the farmer on his or her ability to adopt the low-input farming practice,

Depending on the level of $I_i(t)$, and on a behavioural threshold, the farmer will choose whether or not to change their farming practices ($B_i(t)$).

$$\text{If } I_i(t) \geq \Omega_i \text{ then } B_i(t+1) = 1 \quad (2)$$

The value of the behavioural threshold (Ω_i) is distributed among the population according to a normal law. Thus, it is different for each simulation. This distribution is chosen to represent the diversity among individuals and the fact that the intention, although relatively good at predicting behaviour, is not a perfect predictor.

3.1.2.2. Factors

Subjective norm

The subjective norm is the agent's perception of what the other people who are important to the agent (the farmers in the network of the agent) think the agent should or should not do. Each farmer has its own network. Farmers in a network can communicate about their farming practices. We assume that what the farmer believes that the other important people think the agent should or should not do is equivalent to what the other important people do. Thus, the subjective norm is equal to the share of low-input farmers in the network of the farmer. This factor is dynamic and evolves during the simulation (dotted line in Figure 1).

We represent the farmer's network as partly based on spatial criteria of proximity following the literature and partly random (e.g. Schmidtner et al., 2012; Laple and Kelley, 2015). We used the algorithm of the “Small Worlds” model developed in NetLogo by Wilensky (2015). We set the parameters to fit our case in terms of number and characteristics of initial connections and rewiring probability (see Appendix 2 for the clustering coefficient and the average shortest path length). Farmers are initially located randomly on a lattice for each simulation. At the initialization of the network of the farmers' network, each farmer is connected to his neighbors located on nearby plots ($x_i \pm 1; y_i \pm 1$), i.e. maximum eight neighbours. Then, each connection has a 50% probability of being rewired to another random farmer. The farmers with whom the farmer is connected represent its network. Therefore, a farmer's network is on average composed for half of farmers in his neighborhood ($x_i \pm 1; y_i \pm 1$) and for half by randomly located farmers.

Perceived behavioural control

The perceived behavioural control is the perception of the ease and difficulty of performing the behaviour. This factor is static and the same for all farmers. In the model, we represent the perceived behavioural control as the initial aggregation of past experiences, knowledge and qualification and new knowledge acquired with the protection programme. We assume that the initial perceived behavioural control is zero and the same for all farmers.

Attitude

The attitude, $a_i(t)$, comprises two components: a financial component, f , and an environmental component, $e_i(t)$ (3).

$$a_i(t) = e_i(t) * w_i + f * (1 - w_i) \quad (3)$$

$$f = (\pi^l - \pi^h + \varphi) / (\pi^h - \pi^l) \quad (4)$$

The financial attitude towards the protection programme and its implementation, f , is the difference between the low-input farming and high-input farming gross margins, normalized (4). The costs of change can be a barrier to the intention of changing farming practices. π_h and π_l are, respectively, the gross margin of the high-input farming practice and of the low-input farming practice. Compensation (φ) can be provided to farmers depending on the protection programme. $e_i(t)$ is the environmental component of the attitude (i.e., the perception of the concentration of pollutants and the awareness of the consequences of the farming practices and of pollution). Its calculation is described in Section 3.2.

Following several authors, we use the term “preference” to describe the relative weight of the components of the attitude, and more specifically “environmental preference” to describe the relative weight of the environmental component of the attitude (w_i) (e.g. Verwaart et al. 2011, Robinson and Ray 2015, Muelder and Filatova 2018).

3.2. Integrating a dynamical environmental component of the attitude and information measures

3.2.1. Environmental component of the attitude

Based on the existing model, we developed the conceptual foundations for explaining the attitude of agents towards the environment ($e_i(t)$). The purpose of the proposed agent-based model is to explore how the choice by farmers, who are connected in a network, to join a protection programme (and thus to practice low-input farming promoted by the programme) (see Figure 1) is influenced by the environmental component of the attitude. The agent-based model is implemented in NetLogo (version 6.0.3) (Wilensky, 1999). All parameters, value ranges, and sources of values can be found in Appendix 3.

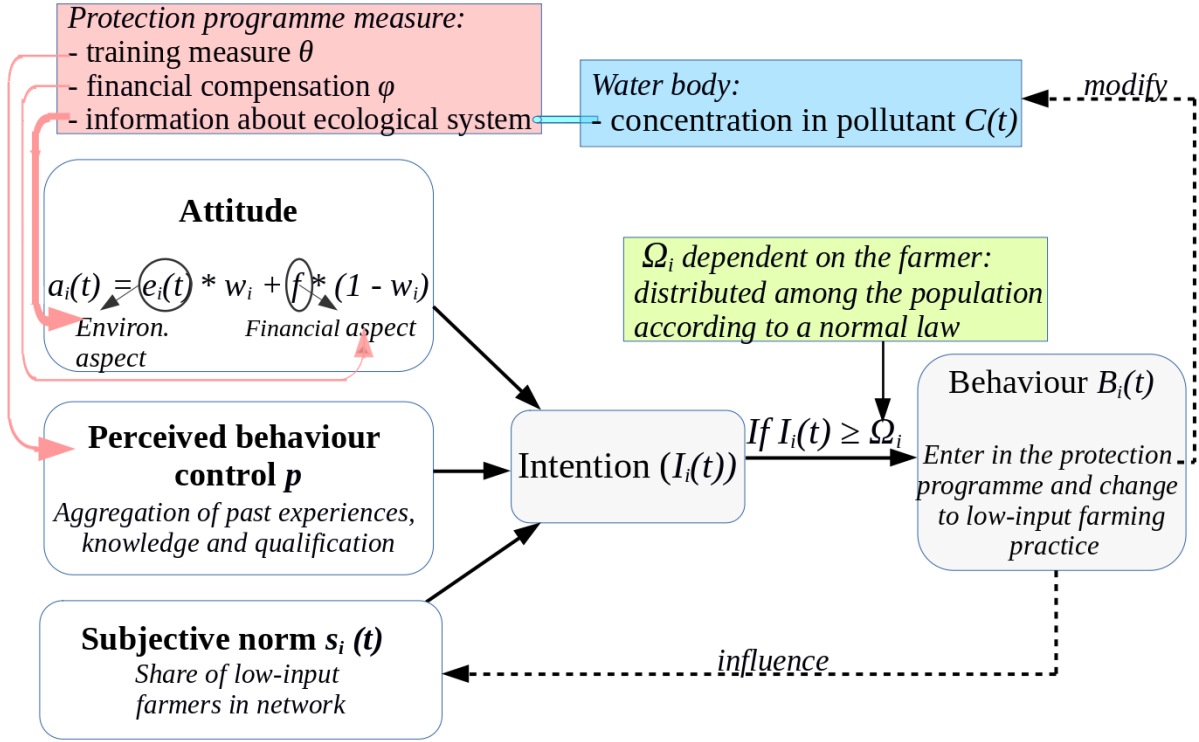


Figure 1: Decision model schema based on the TPB (source: Ajzen 1991), adapted from Bourceret et al., 2022. The pink box represents the protection programme measures. Squircles represent the process of the decision. The individual threshold (Ω) is shown in green. Dashed lines represent the feedback from the behaviours 1) of the social network of the farmer i that *influence* the subjective norm of this farmer and 2) of all famers that *modify* the concentration in pollutant in the water body. The blue box represents the influence of the water body on the attitude through the information measure.

$e_i(t)$ is the environmental component of the attitude, a_i , which is the judgement of farmer i on the desirability of changing to low-input farming practices. Thus, $e_i(t)$ is the judgement of farmer i on the environmental desirability of changing to low-input farming practices. The environmental component of the attitude depends on three parameters: (1) the perception of the concentration of pollutants ($C_i(t)$); (2) an individual awareness threshold (α); (3) a sensitivity to this awareness threshold (q). Following Mathias et al. (2020), we chose a function based on a sigmoid shape (s-shaped). If farmers perceive a good water quality, they judge that there is no environmental desirability for them to change to low-input farming practices. The perception of a high concentration of pollutants implies a belief in the importance of changing practices that contribute to increasing the environmental component of the attitude.

$$e_i(t) = C_i(t)^q / (C_i(t)^q + \alpha^q) \quad (5)$$

α is the awareness threshold for a favourable attitude, and it corresponds to the environmental attitude inflection point (see Figure 2). Around this awareness threshold, the environmental attitude increases quickly. If $C_i(t) = \alpha$, $e_i(t) = 0.5$. q is the degree of sensitivity to change in the environmental attitude. If q is high, then the farmer will have a rapid change in environmental attitude and if q is low then the change in environmental attitude will be more gradual. We set $q = 5$, which implies a relatively high rate of environmental attitude change. Note that other high values of q – yielding sudden perception change – will not change the results qualitatively.

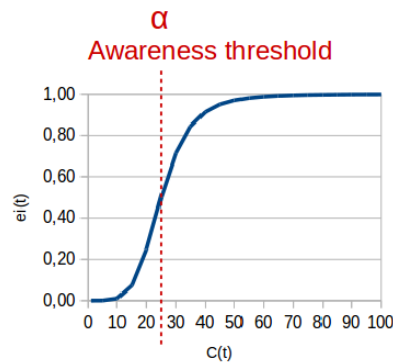


Figure 2: Environmental component of attitude depending on concentration for $q = 5$ and $\alpha = 25$.

$C_i(t)$ can be informed by the authority in charge of water quality management or can be the belief of the farmers if they do not have any information about the pollution level.

- If the farmer receives the information about the concentration of pollutants in the water, then $C_i(t) = C(t)$. This information received depends on a parameter of the system of governance (see below).
- If the farmer receives no information about the concentration of pollutants in the water, then $C_i(t) = C_i$. We assumed that, on average, farmers in our model, at the initialisation of the model, if they do not have information about the concentration of the water, perceive the concentration of pollutants in the water to be lower than in reality. Indeed, we followed Gachango et al. (2015), who found in their study that farmers, on average, perceive the water quality to be above the effective water quality ($C_i(t=0) < C(t=0)$). The belief is distributed at the initialisation of the model and is different for each simulation. The belief regarding the concentration is distributed among the population according to a normal law and is stable during the simulation. .

3.2.2. Information measures

A protection programme aiming at protecting the drinking water catchment is implemented. The farmer may or may not choose to participate in the programme. If the farmers enter the programme, they must change their farming practices to low-input farming. The protection programme is based on a combination of the following measures: financial compensation, training and information. The duration of the programme is 5 years. The financial compensation and training measures are fixed for all simulations. They are considered as fixed parameters in the programme in order to study the impact of information-based measures. The financial compensation and the training influence the calculation of the financial component of attitude and the perceived behavioural control (more details about the specific results on Bourceret et al. 2022).

- *Financial compensation (fixed measure in what follows)*. This measure is based on agri-environmental schemes of the Common Agricultural Policy (CAP) of the European Union. Farmers voluntarily commit to adopting eco-friendly farming practices in return for financial compensation. This compensation aims at covering the costs and income losses resulting from the change as well as transaction costs. It influences the economic profits associated with a farming practice, hence the financial aspect of the attitude. The compensation is annual for 5 years. In the following analysis, we fixed the amount of compensation φ at 300€/year, which covers exactly the difference between the gross margins of low-input and high-input farming practices (π_h and π_l). This implies that the financial component of the attitude is equal to zero.
- *Training (fixed measure in what follows)*. Technical support and individual training are individual support measures to farmers when they change their practices (e.g. technical advice, meetings, technical tests, experiments). In the model, this measure affects the perceived control by increasing farmers' knowledge about a farming practice. Knowledge persists in time. In the following analysis, the training intensity θ is fixed at 0.75.

We focus on two information measures that influence the environmental component of attitude:

- *Information measure about the pollution level*. The information given to the farmers is the monitored concentration of pollutants in the water body. This measure can target all farmers or a certain share of farmers depending on the intensity of information diffusion (m). When a farmer is concerned by the information measure, she receives information about the pollutant concentration at each time step (one year). The information modifies $C_i(t)$ in the calculation of the environmental component of attitude (equation 4).

- *Information measure about the negative consequences of water pollution on health, economy and biodiversity (termed “awareness-raising measure” in what follows).* The objective is to lower the awareness threshold of farmers. Therefore, the information will modify α in the calculation of the environmental component of attitude (equation 4). The modification of the awareness threshold for a farmer is permanent.

3.3. Simulations

The impact of information measures on farmers’ behaviour and thus on water quality was explored by realizing three sets of simulations (see Table 1 for the parameters of simulations). All simulations were performed 1000 times to give representative results on average (see Appendix 4 for standard deviations of the results).

In the first and second sets of simulations, we explored the effect of the information measures in the context of two specific groups of farmers gathering 50% of farmers with similar environmental preferences (EP) within each group: the *eco-friendly* and *economicus* groups. The *eco-friendly* farmers place more emphasis on the environment than do the *economicus* farmers, who attach more importance to economic profits. Hence, the EP for the *eco-friendly* farmers ($w_i = 0.5$) is higher than the EP for the *economicus* farmers ($w_i = 0.1$).

In the first set of simulations, we analysed the impact of both information-based measures on the evolution of farmers’ practices by considering the *eco-friendly* and *economicus* groups of farmers. First, we tested the impact of the information measure about the level of pollution on the evolution of low-input practices and on the concentration of pollutants in water. Then, we analysed the effect of targeting farmers according to their EPs. Finally, we tested the effect of the combined measures of providing information about the pollution level and information about the consequences of pollution (awareness-raising measure).

In this first set of simulations, we assume that the initial concentration of pollutants corresponds to a stationary state before the implementation of the protection programme. All farmers initially practice high-input agriculture and, consequently, the initial concentration of pollutants in water is equal to 50 mg/L. However, we suppose that the initial concentration may change the intention of farmers to practice low-input farming.

In order to analyse how this influences policy effectiveness, we tested the effect of different initial concentrations of pollutants in the water in a second set of simulations. To simplify the analysis, we

keep the assumption about the composition of the population (half of the farmers are eco-friendly and half are economicus).

In a third set of simulations, we consider a more general case with two groups of the same size whose EPs may vary. Indeed, in the first and second simulations, we investigate the case of a moderate EP for the eco-friendly farmers and a low EP for the economicus farmers. We now consider the general case where the population is still split into two equal-sized groups, and within each group, all individuals exhibit the same EP, denoted w_1 for farmers of group 1 and w_2 for farmers of group 2. We expect that different EP combinations between groups may lead to changes in the effectiveness of the information measure about the level of pollution targeting all farmers.

Table 1: Parameters of simulations

Name	Symbol	Domain	Reference value
Initial concentration	$C_0(t)$	[0, 100]	50
Percentage of farmers affected by the information measure about the water pollution level	m	[0, 100]	0
Individual awareness threshold modified by the awareness-raising measure	α	[0, 100]	25
Relative weight of the environmental component of the attitude of farmers of group 1	w_1	[0, 1]	0.5
Relative weight of the environmental component of the attitude of farmers of group 2	w_2	[0, 1]	0.1

4. RESULTS

In this section, we present the results of the simulations aimed at exploring how information measures and farmers' EPs influence water quality. Section 4.1. presents how information-based measures impact the evolution of farmers' practices and water pollution levels. We then present the results obtained regarding the influence of the initial pollution level on policy effectiveness (Section 4.2). Finally, how the heterogeneity in farmers' EPs impacts the effectiveness of the information measures is detailed in Section 4.3.

4.1. Information-based measures enhance farmers' participation in protection programmes

4.1.1. Policy effectiveness depends on the share of farmers concerned by the information measure

We assume that policy makers can choose the intensity of information dissemination (e.g. the amount of money allocated to the information measure) which translates in the model into the percentage of farmers affected by the information measure about the water pollution level. The final share of low-input farmers increases with the share of farmers targeted by the information measure: approximately linearly from 29% to 40% (see Figure 3). The concentration of pollutants also follows a linear decrease.

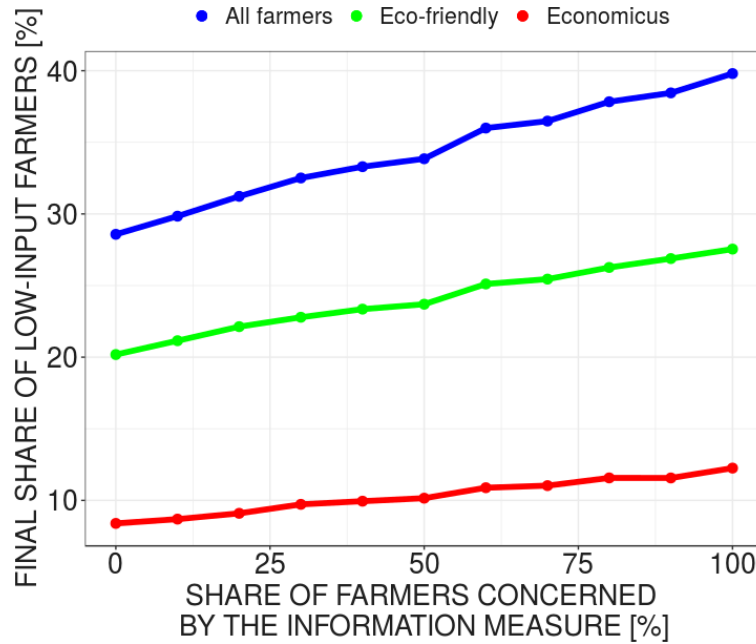


Figure 3: Final share of low-input farmers depending on the share of farmers informed. The points are representative on average. The standard deviations (not reported in the figure for clarity but described in the Annexe 3) are almost always the same, from 4.8 to 5.9 for the final share of low-input economicus farmers, from 6.6 to 7.1 for the final share of low-input eco-friendly farmers and from 10.9 to 12.1 for the final share of low-input farmers (see Appendix 4 for the detail of standard deviations).

In both eco-friendly and economicus farmers' groups, the final share of low-input farmers increases with the share of farmers affected by the information measure. Nevertheless, whatever the informed farmers' share, the final share of low-input eco-friendly farmers is higher than the final share of low-input economicus farmers. That is because the subjective norm and the perceived behavioural control are the same for both groups and only the attitude, which is different between groups, is higher for eco-friendly farmers. Due to a financial compensation set as the difference in profit between the two farming practices (see Section 3.2.3), the financial component of attitude is equal to zero.

Consequently, only the environmental component of attitude plays a role in the attitude, which is higher for eco-friendly farmers.

4.1.2. Targeting farmers according to their environmental preference

In addition to choosing how many farmers are affected by the information measure on the concentration of pollutants, policy makers can select which groups of farmers (according to their EP) will be targeted by the information measure. Indeed, depending on how the information is disseminated, it could affect different groups of farmers. For example, information can be disseminated through a cooperative that gathers the same type of farmer, through an agricultural magazine read by a certain type of farmer, or through a network to which only one type of farmer belongs (e.g., the DEPHY network in France brings together farmers, committed to a voluntary approach for reducing the use of pesticides, thus likely to have higher EPs (Lapierre et al. 2018)).

We compared four different policies in relation to the targeting of farmers: (1) only eco-friendly farmers are informed (i.e., 50% of the total number of farmers); (2) only economicus farmers are informed (i.e., 50% of the total number of farmers); (3) all farmers are informed; (4) 50% of randomly selected farmers are informed; (5) no information is provided to farmers (see Figure 4).

When only eco-friendly farmers are targeted for information dissemination, more farmers change their farming practice than when only economicus farmers are targeted and when half of the farmers are randomly targeted. Even if they do not receive information, there are more eco-friendly farmers adopting low-input practices when economicus farmers are informed than when no farmers are informed due to the diffusion of behaviour through the subjective norm. This highlights the two drivers of the model: an individual driver through the attitude $a_i(t)$ and a social driver through the subjective norm $s_i(t)$. For the economicus farmers, the diffusion through the subjective norm (social driver) has a higher impact than the effect of information on the attitude (individual driver), as seen when comparing the cases where economicus farmers are informed and where half of the farmers are informed. The eco-friendly farmers are more receptive to the information through the attitude (individual driver) than to the subjective norm (social driver).

Thus, for the same share of 50% of farmers informed, an information policy targeting the group of farmers with higher EPs is more effective than no targeting. For a constant cost of information dissemination, targeting farmers according to their EP is more efficient. However, if the objective is to involve as many farmers as possible in the programme, the most effective programme is the one where all farmers are affected by the information measure.

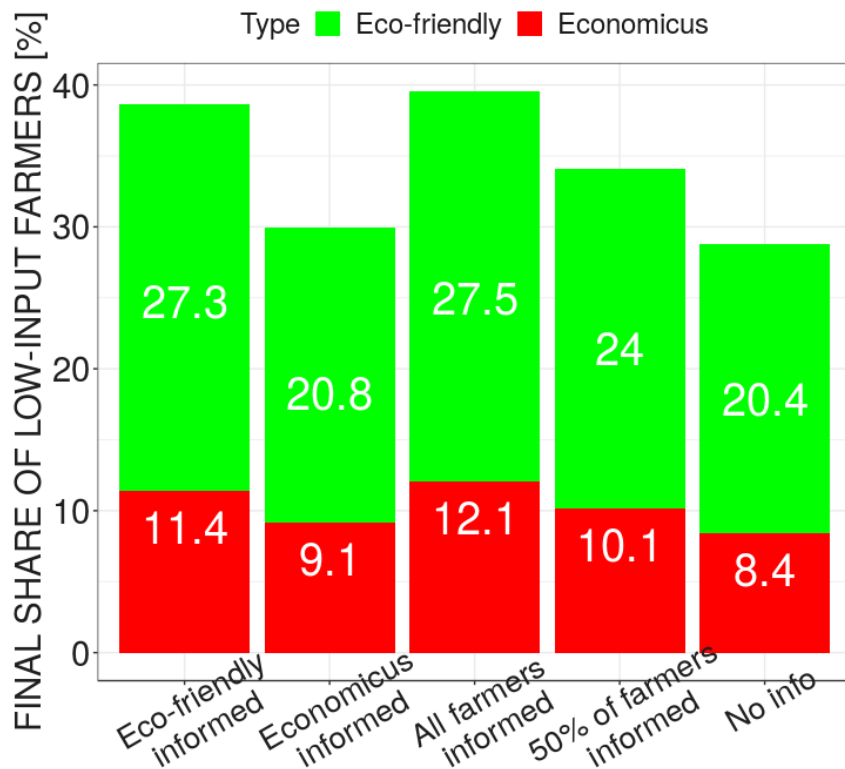


Figure 4: Final share of low-input farmers depending on information providing. Information is provided to: (1) all eco-friendly farmers (i.e., 50% of total number of farmers); (2) all economicus farmers (i.e., 50% of total number of farmers); (3) all farmers; (4) 50% of random farmers; (5) no information.

4.1.3. Policy effectiveness depends on farmers' awareness threshold

The environmental component of attitude depends on the information about the pollutant concentration in water. We now consider the provision of information about the consequences of the pollution (awareness-raising measure) that lowers the awareness threshold. We suppose that an awareness-raising measure may improve the effectiveness of the protection programme because it increases the environmental component of attitude, and its effect is higher when combined with the provision of information about the pollutant concentration.

The concentration of pollutants can vary from 0 to 50 mg/L. A concentration of 50 mg/L corresponds to the concentration where all farmers have high-input practices, and is the initial situation. Nevertheless, without information, the farmers perceive on average a concentration equal to 35 mg/L. The lower the awareness threshold, the lower the final concentration of pollutants and the higher the final share of low-input farmers. Three sets of awareness thresholds emerge. Considering only the awareness-raising measure (dotted lines in Figure 5):

- Set 1a: awareness thresholds from 0 to 20 mg/L. Whatever the thresholds, the final share of low-input farmers is high. In this situation, at $t = 0$, the environmental component of attitude is equal to 1. In this range of initial thresholds, an awareness-raising measure does not have any effect on the final share of low-input farmers and on the pollutant concentration. Therefore, if the initial awareness threshold is low, it is not necessary to invest in a policy measure targeting the awareness threshold.
- Set 2a: awareness thresholds from 20 to 50 mg/L. The environmental component of attitude decreases from 1 to 0 and consequently the final share of low-input farmers decreases.
- Set 3a: awareness thresholds higher than 50. The environmental component for an awareness threshold of 50 and a perceived pollutant concentration of 35 (initial and fixed perceived pollutant concentration in the case of no information about the pollutant concentration) is approximately equal to 0. Thus, there is no difference between awareness thresholds higher than 50. They correspond to a significantly light involvement of farmers. In this set, an awareness-raising measure has to set the threshold at least below 50mg/L in order to trigger an increase of final share of low-input farmers.

With the two information measures combined (information about concentration and awareness-raising) (solid lines in Figure 5) the final share of low-input farmers is higher whatever the awareness threshold. Moreover, there are still three sets of awareness thresholds, nevertheless they have shifted:

- Set 1b: awareness thresholds from 0 to 25 mg/L. The awareness-raising measure has no effect. The range of thresholds where the measure has no effect has been expanded compared to set 1a. Thus, the information measure increases the threshold at which investing in an awareness measure has an effect on the final share of low-input farmers.
- Set 2b: awareness thresholds from 25 to 65 mg/L. An awareness-raising measure has a greater impact when the awareness threshold is medium, with or without information on pollutant concentrations. Nevertheless, the set of awareness threshold where there is a high impact of the awareness-raising measure has shifted and has been extended to 65 mg/L. Thus, the information about pollutant concentrations allows the awareness-raising measure to have an impact on farmers with higher awareness thresholds.
- Set 3b: awareness thresholds higher than 65mg/L. The set where the awareness-raising measure has to be important has shifted on the right. Thus, the information measure about the pollutant concentration permits to improve the effect of awareness-raising measure for farmers with a high awareness threshold.

Finally, the awareness-raising measure has the greatest effect for a population with a medium sensitivity threshold. Moreover, when the two measures are combined, the information measure on the pollution level being the domain of low-threshold populations for which there is no need to invest in the awareness measure, and it improves its effect for populations with a high threshold (grey intervals in Figure 5).

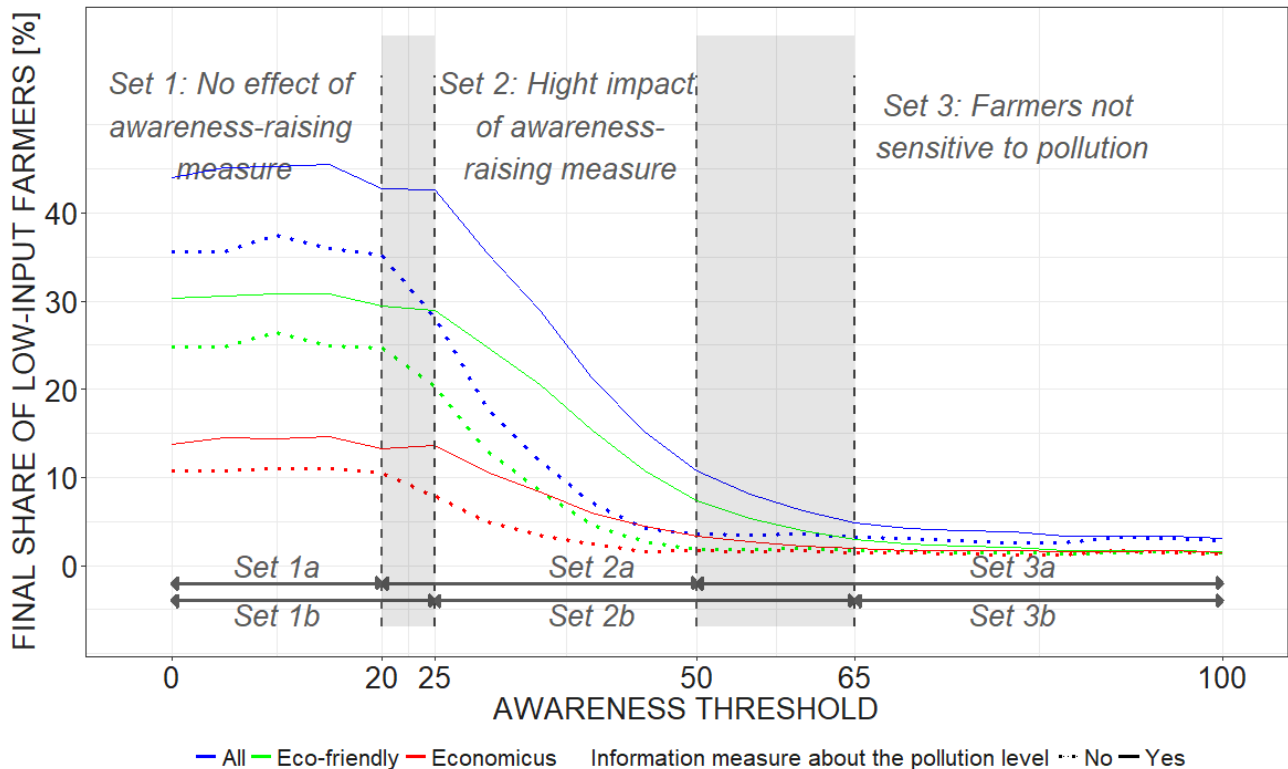


Figure 5: Final share of low-input farmers depending on the awareness threshold without information about the pollutant concentration (dotted line) and with all farmers informed about the concentration of pollutants in water (solid line), for all farmers (in blue), eco-friendly (in green) and economicus (in red). Grey intervals represent the shift of sets. The points are representative on average. The standard deviations (not reported in the figure for clarity but described in the Annexe 3) are, from 1 to 6.9 for the final share of low-input economicus farmers, from 1 to 8.1 for the final share of low-input eco-friendly farmers and from 1.7 to 14.2 for the final share of low-input farmers (see Appendix 4 for the detail of standard deviations).

4.2. Impact of the variation in the initial level of pollution

The second set of simulations shows that the final share of low-input farmers increases with the initial concentration of pollutants (see Figure 6). Below a certain level of initial concentration, the final

share of low-input farmers and the final concentration are the same. Then, farmers' involvement increases steadily with the initial concentration. Finally, above a certain initial concentration, the share of low-input farmers is quite stable.

A high initial concentration leads to a higher involvement of farmers in the protection programme from the start of its implementation. Then, other farmers are involved due to the subjective norm, and even if the concentration decreases (final concentration lower than initial concentration), the subjective norm maintains the level of farmers' involvement. When the pollutant concentration is lower, the farmers get involved later, when the concentration increases.

For more details on the transition pathway of the share of low-input farmers depending on the concentration for different initial concentrations, see in Appendix 4 an example for a low initial concentration (0 mg/L), a medium initial concentration (34 mg/L) and a high initial concentration (50 mg/L).

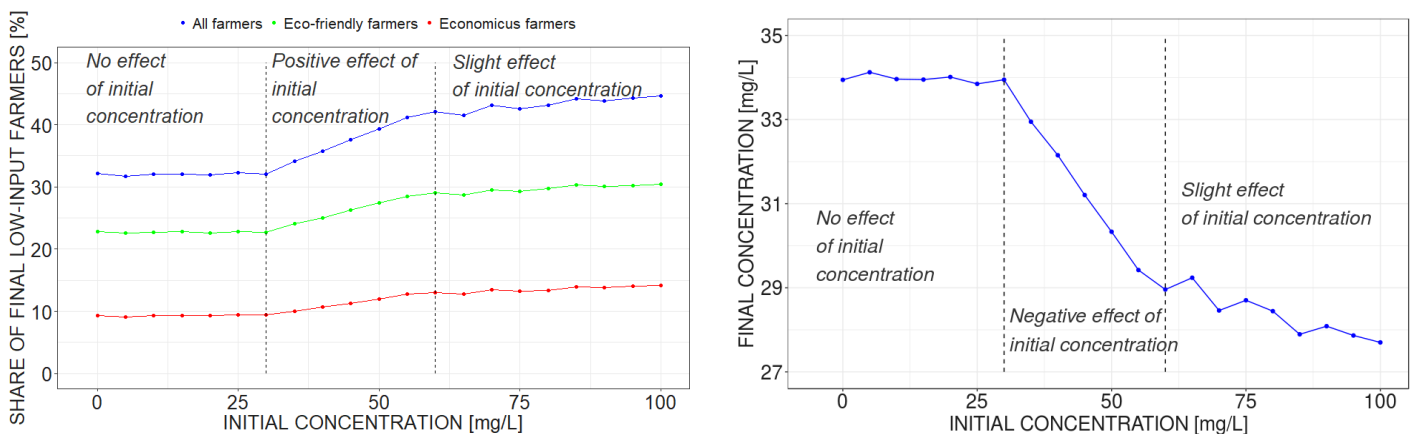


Figure 6: Final share of low-input farmers (left graph) and concentration (right graph) according to the initial concentration. The points are representative on average. The standard deviations (not reported in the figure for clarity but described in the Annexe 3) are almost always the same, from 4.1 to 6.4 for the final share of low-input economicus farmers, from 5 to 7 for the final share of low-input eco-friendly farmers, from 8.5 to 12.7 for the final share of low-input farmers and from 5.3 to 7.9 for the final concentration in pollutants (see Appendix 4 for the detail of standard deviations).

4.3. Influence of heterogeneity in farmers' environmental preferences on the impact of information measures

4.3.1. Influence of different combinations of EPs: uniform population versus highly heterogeneous population

We test different combinations of values of EPs for the two groups of the population with EPs (w_1 , w_2) varying between 0 and 1. Figure 7a displays the final share of low-input farmers depending on w_1 and w_2 , and Figure 7b shows different sections of 7a. For both groups, the environmental component is higher than the financial component (see Section 4.1.1). Therefore, the higher are the EPs, the higher is the final share of low-input farmers.

First, let us analyse the results in the case of a *uniform population* where the EPs of the groups are equal, i.e., all farmers have the same EP ($w_1 = w_2$). This corresponds to the dashed lines (cross-section b) in Figure 7.a and 7.b. For a uniform population, the higher are the EPs, the higher is the final share of low-input farmers. In this section, the EPs are the same and equal the average of EPs, i.e., $a = (w_1 + w_2) / 2$.

Second, we consider the case of an *heterogeneous population*. We called “the heterogeneity of the population” the difference in EPs between the groups i.e., the higher is the difference, the more heterogeneous is the population. The *heterogeneous population* is the population with the highest heterogeneity. For this purpose, we fix an EP to one population (0 or 1) and we vary the EP of the second population from 0 to 1, leading to a EP difference between 0 (uniform population) and 1 (highest heterogeneous population). It corresponds to the purple solid lines in Figure 7.a, i.e., the first part of the curve is *if* $a \in [0; 0.5]$, $w_1 = 2 * a$ and $w_2 = 0$ (cross-section a1) and the second part is *if* $a \in [0.5; 1]$, $w_1 = 1$ and $w_2 = 2 * a - 1$ (cross-section a2). The average of EPs increases along these lines. For the *heterogeneous population*, the results are the same than the *uniform population*, the higher the EPs, the higher the final share of low-input farmers. Therefore, for both types of populations, the increase of EPs has a similar effect.

Third, we now compare the results with both populations according to the average of EPs. The average of EPs can vary from 0 to 1. We plotted the evolution of two types of populations in Figure 8b in purple: a dashed line for the *uniform population* ($w_1 = w_2$) and a solid line for the *heterogeneous population*. This latter corresponds to the two cross-sections of a1 and a2 from Figure 7a. As expected, the final share of low-input farmers increases with the average of EPs. The final share of low-input farmers is higher with the *heterogeneous population* when the average of EPs is low and is higher with the *uniform population* when the average of EPs is high.

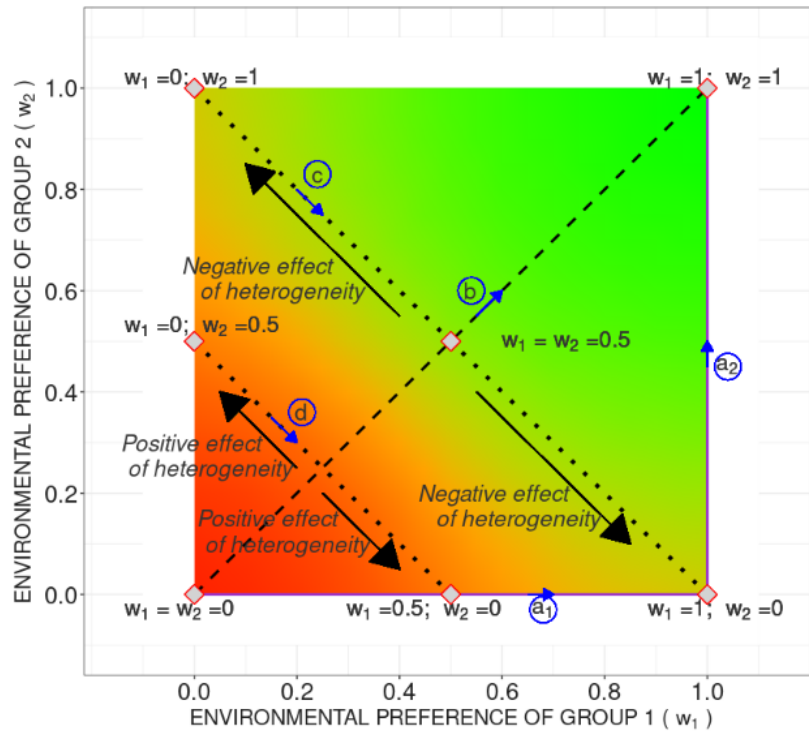
4.3.2. Individual and social drivers of the influence of heterogeneity in farmers' environmental preferences

Let us analyse the results in the case of a *fixed average population* where the average EPs of groups is fixed (i.e., $(w_1+w_2) / 2 = a$). For example, a population with a fixed average of 0.5 (thus $w_1 = 1 - w_2$) and a population with a fixed average of 0.25 (thus $w_1 = 0.5 - w_2$) correspond to the dotted lines in Figure 7a and 7b (cross-section c and d), respectively. For these two cases, the final share of low-input farmers for a population with a fixed average of EPs depends on the difference between the EPs of the groups. For the population with a fixed average of 0.5 (cross-section c in Figure 7), the closer are the EPs (i.e., at the centre of the figure), the higher is the final share of low-input farmers. By contrast, the further are the EPs, i.e., the more heterogeneous is the population, the lower is the final share of low-input farmers. The opposite holds true for the population with a fixed average of 0.25 (cross-section d in Figure 7).

The c- and d-sections highlight that the effect of the heterogeneity of the groups depends on the average of EPs and underline the two drivers of the model. First, the individual driver acting through the environmental component of attitude has a different weight depending on the farmers' groups (EPs). Second, the social driver acting through the subjective norm (SN) has the same weight for all farmers. When the fixed EP average is equal to 0.5, the driver leading to more changes in low-input farming is the individual driver. When the fixed EP average is equal to 0.25, the driver leading to more changes in low-input farming is the social driver.

The threshold above which the individual driver becomes more important than the social driver is the intersection between the two types of populations in figure 7b. Above this point, it means that the individual driver is sufficient on average to encourage farmers to change their practices. Below this point, the individual driver is not sufficient and the social driver becomes more important.

a) Final share of low-input farmers depending on EPs



Final share of low-input farmers (%): ■ 25 ■ 50 ■ 75

—●— Cross-section

- - - Uniform population

· · · Population with fixed average of EPs

($w_1 = w_2$)

$a=0.5$ and $a=0.25$

b) Final share of low-input farmers depending on EP of group1 and on average of EPs

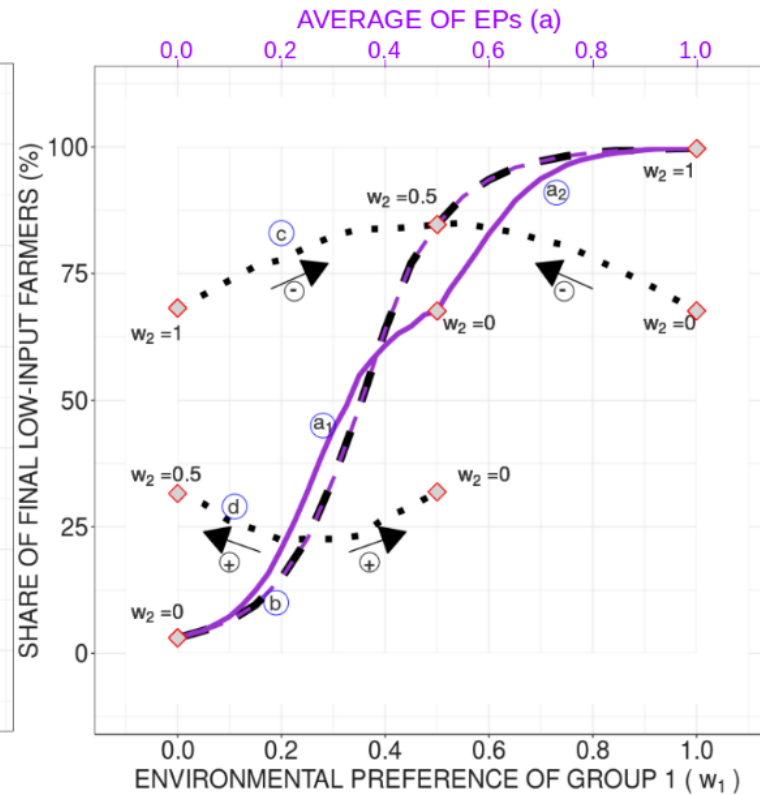


Figure 7: 7.a) Final share of low-input farmers for all farmers depending on the environmental preferences (EPs) w_1 and w_2 of both groups (group 1 and group 2 represent respectively 50% of the population). 7.b) Cross-sections from Figure 7.a: cross-section a1 and a2 (solid lines) correspond, respectively, to $w_2 = 0$ and $w_1 = 1$; cross-section b (dashed line) corresponds to the evolution of the uniform population; cross-sections c and d (dotted lines) correspond to the population with a fixed average of EPs for, respectively, an average of 0.5 and 0.25. The points are representative on average. The standard deviations (not reported in the figure for clarity but described in the Annexe 3) are ranged 0.3 to 7.8 for the final share of low-input economicus farmers, from 0.3 to 7.7 for the final share of low-input eco-friendly farmers and from 0.4 to 14.9 for the final share of low-input farmers (see Appendix 4 for the detail of standard deviations).

5. DISCUSSION AND CONCLUSIONS

5.1. Contributions and policy implications

Water pollution is a major environmental concern, and improving water quality is one of the main management goals at both national and supra-national scales. Our study explored the role of information measures in programmes designed to protect water quality. In the literature, the role of information has been explored through the analysis of social learning processes (e.g., Shaijumon and James 2018; BenYishay and Mobarak 2019; Baggio and Hillis 2019), the study of the imitation strategies (e.g., Efferson et al. 2007; Baggio et al. 2018; Rebaudo and Dangles 2015) or the assessment of expected value (e.g. Davis et al. 2019). Previous research has also focused on the water resource (e.g. Kaiser et al. 2020). Nevertheless, to our best knowledge, no study has dealt with information in the specific context of water quality management. Moreover, although the literature recognises that information-based policies are of interest in the context of environmental policies (e.g. Blackstock et al., 2010; Ervin & Ervin, 1982; Prokopy et al., 2008), the decision-making mechanisms involved are not yet well-understood.

The first contribution of this paper is therefore to formalise the role of information about the ecological system in farmers' decision-making processes. Our results showed that the involvement of farmers in protection programmes depends on the information given about water pollution and about the consequences of this pollution. In addition, the difference between environmental preferences in the farmers' population affects the diffusion of low-input farming practices. The higher are the farmers' environmental preferences on average, the more farmers will adopt practices favourable to water quality. Heterogeneity in farmers' preferences is a factor fostering the adoption of eco-friendly practices when the average preference is sufficiently low, whereas it hinders adoption when the average preference is high. Thus, the difference in environmental preferences between farmers has to be taken into account in the choice of public policies. This is in line with the study by Garforth et al. (2003), who found that an important point in the provision of information and advice is to recognise the diversity of the motivations of land managers. It is important to recognise the heterogeneity of those managing land–water relationships and to tailor advice to the different farming contexts and cultures. Finally, different initial concentrations are also a determinant of the involvement of farmers. Farmers' participation increases with the initial pollution level. Nevertheless, these conclusions are to be interpreted in light of two caveats. First, we suppose that there is no irreversibility in the water quality problems. Second, the time during which the policy is not implemented and during which the

concentration of pollutants increases could have negative consequences such as an increase in the cost of depolluting to produce drinking water or an increase in health-related costs.

The second contribution of this article is methodological. Our model is an illustration of an agent-based complex system described by An et al. (2021) using the concept of an information instrument and its impact on the decision-making process. The operationalisation and implementation in a mathematical model of this concept contribute to the debates on the definition of it and use. The role of information has already been studied in models using the TPB but only with regard to the financial motivation of behaviour (Muelder and Filatova 2018; Verwaart and Valeeva 2011) and, to the best of our knowledge, it has not been implemented in the context of an environmental factor.

More specifically, in terms of implementation, our work contributes toward integrating ecological dimensions in the conceptualisation of the attitude factor of the TPB coupled with the use of information. We propose a formalisation of the environmental component of attitude using an awareness threshold and the state of the water body. This differs from the modelling of environmental attitudes in previous studies, such as the use of the CO₂ emission-saving of solar panels (Muelder and Filatova 2008), environmental friendliness of energy conservation behaviours (Raihanian Mashadi and Behdad 2018) or the environmental productivity of a farming practice (Xu et al. 2018).

5.2. Limitations and perspectives

We formalised the role of information in farmers' decision-making process through a dynamical model. We identify five avenues for future work concerning the heterogeneity of farmers, the environmental component of attitude, the change in environmental preferences, the network dynamics, and the possibility to return to high-input farming practices.

First, we considered only two homogeneous groups of farmers with different environmental preferences. Nevertheless, we may explore the influence of having more groups or including variations in the groups. For example, Broch and Vedel (2012), using a survey, analysed the heterogeneity in farmers' preferences for agri-environmental schemes and identified four groups with divergent preferences regarding their willingness to accept compensation and to engage in groundwater and biodiversity protection.

Second, the conceptualisation of the environmental component of attitude could be improved. The influence of the concentration of pollutants is the same during the simulation; nevertheless, the variation in concentration could be linked with the behaviour of the farmer or of the farmer's network. For example, if the farmer sees as a consequence of the changes in practices in her network a decrease in the pollution level, he or she is more likely to change their behaviour than if they see no change.

Indeed, slower changes in water quality may result in farmers being less motivated to adopt low-input practices (Okumah et al. 2021). Additionally, the process could be moderated as a function of the trust in public authorities. The trust in public authorities has been shown to have a positive effect on the participation in agri-environmental schemes (Arnaud et al. 2007, Lastra-Bravo et al., 2015).

Third, a process of change in environmental preferences could be considered. The information about the consequences of water pollution could also change farmers' environmental preferences in addition to changes in the awareness threshold. In this case, the provision of information will have consequences not only on the behaviour of the farmers but also on their decision-making process, with a longer-term change.

Fourth, the conceptualisation of the social component can be improved, both by including dynamics of the social network or by adding other cognitive and affective processes. The social network might evolve in time according to farmers' choices and/or their environmental preferences for instance. This would create a feedback between the governance component, the social component and the choices of farming practices. Moreover, the social component correspond to a conformist network where the farmer has a tendency to follow the majority. We could further integrate a tendency to imitate success (e.g. Efferson et al. 2007) or to be mavericks (e.g. Efferson et al. 2008).

Finally, we did not include in our model the possibility to revert to the original farming practices after a few years of entering the protection programme. However, in Europe the agri-environmental contracts end after 5 years and the farmers are free of any contractual commitment concerning their land management choice. They can therefore revert to their previous practices. The introduction of a reversion process could be interesting in order to highlight the influence of economic and information instruments on the longer term. For example, Khufuss et al. (2016) show that information about what other farmers intend to do can greatly influence a farmer's decision in maintaining the practices after the end of agri-environmental contracts.

5.3. Concluding remarks

We investigated the role of information measures in the change in farming practices and thus their impact on water pollution. The extension of an agent-based model of a drinking catchment area allowed us to explore the impact of the information about pollution and the consequences of pollution, the effect of the diversity of environmental preferences among farmers and the influence of the initial level of pollution. Our contributions are methodological and theoretical. First, the implementation of information in an agent-based model and the description of the environmental attitude contribute to debates on the use of these concepts in computer models. Second, we highlighted that targeting

farmers who have higher environmental preferences is more effective than no targeting when half of the population can be subject to the information campaign. Moreover, when this measure is combined with the awareness-raising measure, once a certain threshold of public awareness is reached, there is a synergy between them. Furthermore, the heterogeneity between farmers in terms of environmental preferences has an influence on the involvement of farmers in the programme depending on the average environmental concern. Finally, under certain conditions in terms of information and population characteristics, the higher is the initial pollution, the higher is the involvement of farmers in the environmental programme.

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Appendix 1: ODD+D protocol

After the ODD+D protocol for describing human decisions in agent-based models (Müller et al. 2013).

This appendix contains the description of the model of the article of Bourceret et al. (2022) in which we have added the new elements of the article's model in bold.

List of abbreviations:

TPB: theory of planned behaviour

		Guiding questions	Own ODD+D Model description
Overview	I.i Purpose	I.i.a What is the purpose of the study?	To explore how the choice by farmers, with either financial or environmental orientation, who are connected in a network, for whether or not to join a protection programme (and thus to practice low-input farming, the farming practice promoting by protection program) and the consequences in terms of drinking water quality are influenced, on the one hand, by different behavioural specifications and, on the other hand, by different characteristics of a protection programme.
		I.ii.b For whom is the model designed?	For scientists of different disciplinary backgrounds, particularly those interested in natural resource governance.

	I.ii Entities, state variables, and scales	I.ii.a What kinds of entities are in the model?	<p><u>One ecological entity:</u> A groundwater with a certain concentration of nitrate.</p> <p><u>Two types of social entities:</u> Farmers and governance.</p> <p>Dozens of agents represent farmers whose farming practices have the unintended consequence of releasing pollutants into groundwater. They decide to enter or not in the protection programme (which is whether or not to practice low-input farming promoting by the protection programme).</p> <p>Governance is represented by an agent and its function is to encourage farmers to become involved in the proposed protection programme, which aims to ensure that farmers practice low-input agriculture.</p>
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		<p>I.ii.b By what attributes (i.e. state variables and parameters) are these entities characterized?</p>	<p><u>Ecological entity</u>: The groundwater has a certain quantity of water (Q). There is a natural flow that feeds (E) the groundwater and a quantity that exits (D) the groundwater. The concentration of pollutants in water ($C(t)$), in mg/l, is used as a proxy to measure water quality, i.e. the quantity of pollutant ($N(t)$) relative to the quantity of water in the groundwater (Q).</p> <p><u>Farmers (one agent represents one farmer (i)) are characterized by</u>: a location, a farming practice ($B_i(t)$), which can be low-input (l) or high-input (h), low-input farming practice is more favourable to water quality than the high-input practice but less economically profitable, a residual pollutant affecting the groundwater ($R_i(t)$) of the agent i depending on her practice, a social network (S_i), a behavioural type: economicus or eco-friendly, a decision model and a set of decision parameters, a behavioural threshold to change (Ω_i), a financial preference (w_i), an intention factors preferences ($\gamma_a \gamma_s \gamma_p$), a set of knowledge and past experiences about farming practices p.</p> <p><u>Governance is characterized by these variables</u>: an amount of compensation (φ), an intensity of training practice (θ), Information measure about the pollution level ($C_i(t)$) and information measure about the negative consequences of water pollution on health, economy and biodiversity (α) (termed “awareness-raising measure” in what follows).</p>
		<p>I.ii.c What are the exogenous factors / drivers of the model?</p>	<p>Nothing</p>

		I.ii.d If applicable, how is space included in the model?	N/A
		I.ii.e What are the temporal and spatial resolutions and extents of the model?	One time step equals to one year and the simulations were run at two time horizons: at 10 years that corresponds to policy time scale and at 500 years to evaluate ecological equilibrium. Rectangular grid 10*10 represented a water catchment area.
	I.iii Process overview and scheduling	I.iii.a What entity does what, and in what order?	<u>Step 1</u> : Governance - Update of the protection program <u>Step 2</u> : Farmers - Choice to enter or not in the protection programme and therefore switch or not their farming practice <u>Step 3</u> : Ecological system - Update of watershed (concentration of pollutants)

<p style="text-align: center;">Design Concepts</p>	<p style="text-align: center;">II.i Theoretical and Empirical Background</p>	<p>II.i.a Which general concepts, theories or hypotheses are underlying the model's design at the system level or at the level(s) of the submodel(s) (apart from the decision model)? What is the link to complexity and the purpose of the model?</p>	<p>The ecological submodel is a linear reservoir model whose storage law and discharge law vary linearly as a function of the water level. "The linear reservoir model, in its simplest form, appears well adapted to quite variable situations ranging from small, highly urbanized watersheds to watersheds of several hundred hectares." (Ministère de la transition écologique et solidaire 2020).</p> <p>The governance submodel is a choice of a protection programme that can include the following measures: information measure about the pollution level and awareness-raising measure (financial compensation, individual training and technical support fixed measures). The choice is about the farmers targeted by the measures and about the level of the awareness threshold.</p> <p><i>Financial compensation:</i> They are based on agri-environmental scheme that are EU Common Agricultural Policy's instruments. Farmers voluntary commit to adopt low-input farming practices in return for a financial compensation. This compensation aims at covering the costs and income losses resulting from the change as well as transaction costs. It influences the economic profits associated with a farming practice, hence the economic component of the attitude. The compensation is provided annually for five years.</p> <p><i>Training:</i> Technical support and awareness raising are individual support measures to farmers in their changes of practices (e.g., technical advice, meetings, technical tests, experiments). According to Paineau et al. (1998) and Lastra-Bravo et al. (2015), training and information for farmers are key</p>
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		<p>elements that promote a greater respect for the environment. In the model, this measure affects the perceived control by increasing farmers' knowledge about a farming practice. Knowledge persists in time.</p> <p><i>Information measure about the pollution level:</i> The information given to the farmers is the monitored concentration of pollutants in the water body. This information measure can target all farmers or a certain share of farmers depending on the intensity of information diffusion. When a farmer is concerned by the information measure, she receives information about the pollutant concentration at each time step (one year). The information modifies $C_i(t)$ in the calculation of the environmental component of attitude (equation 4).</p> <p><i>Awareness-raising measure:</i> The objective is to lower the awareness threshold of farmers. Therefore, the information will modify α in the calculation of the environmental component of attitude (equation 3). The modification of the awareness threshold for a farmer is permanent.</p>
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		<p>II.i.b On what assumptions is/are the agents' decision model(s) based?</p>	<p>We adapt the theory of planned behaviour (TPB) (Ajzen 1991). In this framework, the intention towards a behaviour, considered as a trustworthy predictor as whether or not the behaviour will be performed, is influenced by three global variables: judgment about the desirability of the behaviour and its consequences (attitude towards behaviour); considerations about the influence and opinions of others on that behaviour (subjective norm); and beliefs about the individual's ability to succeed in the behaviour (perceived behavioural control). The attitude comprises two components: a financial component and an environmental component (equations 3 and 4).</p>
		<p>II.i.c Why is a/are certain decision model(s) chosen?</p>	<p>One of the most frequently used approach to understand farmers' decision-making with regard to agri-environmental policies is the theory of reasoned action developed by Ajzen and Fishbein (Ajzen and Fishbein 1980; Toma and Mathijs 2007; Falconer 2000) who was later extended to the TPB (Ajzen 1991).</p>
		<p>II.i.d If the model / a submodel (e.g. the decision model) is based on empirical data, where does the data come from?</p>	
		<p>II.i.e At which level of aggregation were the data available?</p>	

	II.ii Individual Decision Making	II.ii.a What are the subjects and objects of decision-making? On which level of aggregation is decision-making modeled? Are multiple levels of decision making included?	Farmers decide if there are involved in the protection programme and accordingly apply low-input farming practice. Governance give information about the pollution level and about the negative consequences of water pollution on health, economy and biodiversity and target some farmers for its measures.
II.ii.b What is the basic rationality behind agents' decision-making in the model? Do agents pursue an explicit objective or have other success criteria?		Farmers act if their intention exceeds a threshold. This intention is a function of their beliefs about the behaviour in term of attitude, subjective norm and perceived behavioural control.	

		<p>II.ii.c How do agents make their decisions?</p>	<p>If the farmer is not in the protection programme (and thus do not practice low-input farming), she compares her intention to be involved in the programme ($I_i(t)$) and her behavioural threshold (Ω_i). If the behavioural threshold is exceeded, she enters in the programme and change to low-input farming.</p> <p>1. Calculation of intentions ($I_i(t)$), which is a linear function of the following factors weighted ($\gamma_a \gamma_s \gamma_p$) by their contribution in the intention:</p> <ul style="list-style-type: none"> - attitude (a_i): weighted sum of a comparison between profit and environmental component - subjective norm ($s_i(t)$): percentage of low-input farmers in networks - perceived behavioural control (p): knowledge and past experiences <p>2. Compare intentions with behavioural threshold (Ω_i)</p> <p>Attributes of farmers concerning the decision-making process are: a weight of the importance of attitude in intention, a weight of the importance of perceived behavioural control in intention and a weight of the importance of subjective norm in intention, a weight of the importance of the financial component of the attitude, a weight of the importance of the environmental component of the attitude, behavioural threshold (it indicates when the intention becomes a behaviour).</p>
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		II.ii.d Do the agents adapt their behavior to changing endogenous and exogenous state variables? And if yes, how?	Yes, attitude is modifying by the information given in the protection programme.
		II.ii.e Do social norms or cultural values play a role in the decision-making process?	Yes, a social norm represented by the percentage of low-input farmers in an agent's network constitutes the subjective norm.
		II.ii.f Do spatial aspects play a role in the decision process?	No
		II.ii.g Do temporal aspects play a role in the decision process?	Yes, the farmers communicate to others their farming practice from the last year
		II.ii.h To which extent and how is uncertainty included in the agents' decision rules?	

	II.iii Learning	II.iii.a Is individual learning included in the decision process? How do individuals change their decision rules over time as consequence of their experience?	No
		II.iii.b Is collective learning implemented in the model?	
	II.iv Individual Sensing	II.iv.a What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous?	Individuals sense characteristics of protection programme, profit of different farming practices and information given. No process erroneous.
		II.iv.b What state variables of which other individuals can an individual perceive? Is the sensing process erroneous?	Farmers know the farming practices of other farmers. No process erroneous.
		II.iv.c What is the spatial scale of sensing?	Networks

		II.iv.d Are the mechanisms by which agents obtain information modeled explicitly, or are individuals simply assumed to know these variables?	Farmers are assumed to know these variables.
		II.iv.e Are costs for cognition and costs for gathering information included in the model?	No
	II.v Individual Prediction	II.v.a Which data uses the agent to predict future conditions?	Data from the protection programme (change the expected profit of farming practices and expected control).
		II.v.b What internal models are agents assumed to use to estimate future conditions or consequences of their decisions?	Farmers' attitude is the judgement about the desirability of their behaviour and consequences. This attitude is divided in a financial and an environmental component. The financial component of the attitude use the expected income from the farming practice and the environmental component use the output effect of farming practice on watershed.

		<p>II.v.c Might agents be erroneous in the prediction process, and how is it implemented?</p>	<p>No, they are not erroneous.</p> <p>For the financial component, they calculate the difference normalized between the expected income of actual farming practice and the other farming practice.</p> <p>The environmental component is the judgement of farmer i on the environmental desirability of changing to low-input farming practices. It depends on the perception of the concentration of pollutants ($C_i(t)$) and on an individual awareness threshold (α). If farmers perceive a good water quality, they judge that there is no environmental desirability for them to change to low-input farming practices. The perception of a high concentration of pollutants implies a belief in the importance of changing practices that contribute to increasing the environmental component of the attitude.</p>
	II.vi Interaction	<p>II.vi.a Are interactions among agents and entities assumed as direct or indirect?</p>	<p>Direct interactions through communication about farming practices</p>
		<p>II.vi.b On what do the interactions depend?</p>	<p>Social network (based on links with farmers which are in one of the 8 patches around the farmer that are randomly renewed with other farmers - based on the “Small Worlds” model of Wilensky (2015) which is an adaptation of a model proposed by Watts and Strogatz (1998))</p>
		<p>II.vi.c If the interactions involve communication, how are such communications represented?</p>	<p>Communication about farming practices</p>

		II.vi.d If a coordination network exists, how does it affect the agent behaviour? Is the structure of the network imposed or emergent?	N/A
	II.vii Collectives	II.vii.a Do the individuals form or belong to aggregations that affect, and are affected by, the individuals? Are these aggregations imposed by the modeller or do they emerge during the simulation?	Individuals are affected by the practice of farmers in their network.
		II.vii.b How are collectives represented?	N/A
	II.viii Heterogeneity	II.viii.a Are the agents heterogeneous? If yes, which state variables and/or processes differ between the agents?	There are two types of farmers, <i>eco-friendly</i> and <i>economicus</i> . Differences are in the decision-making process, in the weight of finance component in calculation of attitude (a_i).

		II.viii.b Are the agents heterogeneous in their decision-making? If yes, which decision models or decision objects differ between the agents?	They are heterogeneous in their decision-making. They don't have the same weight of the importance of the financial component of the attitude. <i>Eco-friendly</i> farmers place more emphasis in environment than in profit in the calculation of attitude. <i>Economicus</i> on the contrary place more emphasis in profit.
	II.ix Stochasticity	II.ix.a What processes (including initialization) are modeled by assuming they are random or partly random?	Stochasticity is in part in initialisation only. Location, type, social network and the behavioural threshold are assigned randomly to farmers. The random distribution of the behavioural threshold follows the normal law. The social network is random.
	II.x Observation	II.x.a What data are collected from the ABM for testing, understanding, and analyzing it, and how and when are they collected?	Number of farmers entering in protection programme. Evolution of factors attitude, subjective norm and perceived behavioural control in function of farmers' types and farming practices. Evolution of intention in function of farmers' types and farming practices. Costs of protection programme. Concentration in nitrates.
		II.x.b What key results, outputs or characteristics of the model are emerging from the individuals? (Emergence)	Number of farmers involved in the protection programme and concentration in nitrates depend on behavioural characteristics and measures of the protection programme.
- Details	II.i Implementation Details	III.i.a How has the model been implemented?	Netlogo version 6.0.3
		III.i.b Is the model accessible and if so where?	

	III.ii Initialization	III.ii.a What is the initial state of the model world, i.e. at time $t=0$ of a simulation run?	80 farmers, 50% type economicus / 50% type eco-friendly, all in high-input farming <i>See below for details of initial data.</i>
		III.ii.b Is initialization always the same, or is it allowed to vary among simulations?	
		III.ii.c Are the initial values chosen arbitrarily or based on data?	The initial values for the watershed have been estimate based on data (groundwater body, withdrawn) from the catchment area of the Allier (Amblard and Reynal 2015 ; Chambre d’Agriculture de L’Allier, 2015) Data for farmers are assumed.
	III.iii Input Data	III.iii.a Does the model use input from external sources such as data files or other models to represent processes that change over time?	No
	III.iv Submodels	III.iv.a What, in detail, are the submodels that represent the processes listed in ‘Process overview and scheduling’?	For this following processes see below: Calculation of intention Decision Update concentration
		III.iv.b What are the model parameters, their dimensions and reference values?	<i>See below</i>

		III.iv.c How were submodels designed or chosen, and how were they parameterized and then tested?	<i>See text below</i>
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Appendix 2: Coefficients of the networked

Average for 1000 initialisations of the clustering coefficient and the average shortest path length, according to Wilensky (2015) and Watts and Strogatz (1998).

L_{actual}	L_{random}	L_{regular}	C_{actual}	C_{random}	C_{regular}
2.537	2.570	3.480	0.111	0.077	0.428

Appendix 3 - Values of parameters

Number of simulations: 1000 / set of parameters

Agent-farmer's parameters

Name	Agent parameters	Initial value	Scale
	Grid size	10*10	
n	Number of farmers	80	-
$B_i(0)$	Farming practice of farmer i at $t = 0$	high	-
Ω_i	Behavioural threshold of the farmer i	N(0.5; 0.125)	-
S_i	Social network		
p_0	Initial aggregation of past experiences, knowledge and qualification	0	-
w_1	Relative weight of the environmental component of the attitude of eco-friendly farmers	0.5	[0, 1]
w_2	Relative weight of the environmental component of the attitude of economicus farmers	0.1	[0, 1]
α	Individual awareness threshold	25	[1, 100]

Name	Farming practices	Value
π_l π_h	Gross margin	low: 600 high: 900 [€/ha/an]
$R(k_i)$	Residual pollutant affecting the groundwater	low: 0 high: 3 [w.u.]

Ecological system parameter

Name	Description	Initialisation	Scale
$C_0(t)$	Initial concentration	0	[0, 100]

Appendix 4: Standard deviation of the simulations

Table A3.1: Standard deviation of the simulation in Figure 3

Share of farmers concerned by the information measure	Final share of low-input economicus farmers	Final share of low-input eco-friendly farmers	Final share of low-input farmers	Standard deviation of the final share of low-input economicus farmers	Standard deviation of the final share of low-input eco-friendly farmers	Standard deviation of the final share of low-input farmers
0	6.72	16.15	22.86	4.88	6.87	11.09
10	6.96	16.92	23.87	4.82	6.74	10.93
20	7.28	17.70	24.98	4.97	6.69	10.99
30	7.78	18.23	26.01	5.47	7.09	11.89
40	7.96	18.68	26.64	5.42	6.94	11.73
50	8.12	18.96	27.08	5.07	6.96	11.40
60	8.71	20.09	28.80	5.69	7.13	12.15
70	8.83	20.36	29.19	5.31	6.59	11.15
80	9.26	21.01	30.27	5.52	6.87	11.68
90	9.25	21.51	30.76	5.31	6.80	11.41
100	9.80	22.04	31.84	5.86	6.76	11.89

Table A3.2: Standard deviation of the simulation in Figure 5

Awareness threshold	Final share of low-input economicus farmers	Final share of low-input eco-friendly farmers	Final share of low-input farmers	Standard deviation of the final share of low-input economicus farmers	Standard deviation of the final share of low-input eco-friendly farmers	Standard deviation of the final share of low-input farmers
0	11.940	25.380	37.320	6.992	7.883	14.213
5	8.630	19.830	28.460	6.229	8.080	13.483
10	8.840	21.180	30.020	5.694	7.368	12.412
15	8.770	19.970	28.740	6.120	6.801	12.337
20	8.420	19.760	28.180	6.032	7.818	13.340
25	6.260	16.210	22.470	4.426	6.742	10.481
30	3.930	10.430	14.360	3.169	4.831	7.373
35	2.780	6.740	9.520	2.043	4.069	5.381
40	2.000	3.650	5.650	2.010	2.772	4.200
45	1.270	2.140	3.410	1.362	1.688	2.353
50	1.400	1.490	2.890	1.385	1.418	2.247
55	1.310	1.440	2.750	1.261	1.373	2.071
60	1.390	1.520	2.910	1.490	1.439	2.483
65	1.200	1.380	2.580	1.378	1.245	1.996
70	1.170	1.330	2.500	1.223	1.101	1.883
75	1.090	1.130	2.220	1.083	1.070	1.685
80	0.960	1.130	2.090	1.063	1.186	1.682
85	1.000	1.110	2.110	1.119	1.118	1.711
90	1.390	1.140	2.530	1.392	1.181	2.096
95	1.200	1.230	2.430	1.263	1.317	2.036
100	1.090	1.130	2.220	1.120	1.292	1.779

Table A3.3: Standard deviation of the simulation in Figure 6

Initial concentration	Final share of low-input economicus farmers	Final share of low-input eco-friendly farmers	Final share of low-input farmers	Final concentration	Standard deviation of the final share of low-input economicus farmers	Standard deviation of the final share of low-input eco-friendly farmers	Standard deviation of the final share of low-input farmers	Standard deviation of the final concentration
0	7.425	18.266	25.691	33.943	4.199	5.162	8.473	5.295
5	7.304	18.099	25.403	34.124	4.297	5.016	8.498	5.310
10	7.491	18.171	25.662	33.961	4.306	5.238	8.680	5.425
15	7.435	18.245	25.680	33.950	4.056	5.327	8.552	5.345

20	7.477	18.104	25.581	34.012	4.223	5.241	8.633	5.396
25	7.550	18.293	25.843	33.848	4.285	5.402	8.851	5.532
30	7.515	18.170	25.685	33.947	4.382	5.609	9.219	5.762
35	8.023	19.260	27.283	32.948	4.881	6.033	10.095	6.309
40	8.524	20.034	28.558	32.151	5.270	6.491	11.104	6.940
45	9.003	21.069	30.072	31.205	5.365	6.623	11.264	7.040
50	9.557	21.912	31.469	30.332	5.553	6.594	11.397	7.123
55	10.182	22.744	32.926	29.422	5.923	6.763	11.957	7.473
60	10.399	23.268	33.667	28.958	5.791	6.929	11.990	7.494
65	10.247	22.972	33.219	29.238	6.020	7.049	12.376	7.735
70	10.814	23.651	34.465	28.460	6.053	6.907	12.218	7.636
75	10.608	23.468	34.076	28.703	6.110	7.035	12.436	7.772
80	10.694	23.796	34.490	28.444	6.146	6.900	12.315	7.696
85	11.123	24.248	35.371	27.894	6.386	6.883	12.572	7.857
90	11.029	24.033	35.062	28.087	6.358	7.019	12.647	7.904
95	11.210	24.206	35.416	27.866	6.221	6.927	12.456	7.785
100	11.305	24.375	35.680	27.701	6.172	6.842	12.259	7.662

Table A3.4:

Environmental preferences of group 1 w1	Environmental preferences of group 2 w2	Final share of low-input economic farmers	Final share of low-input eco-friendly farmers	Final share of low-input farmers	Standard deviation of the final share of low-input economic farmers	Standard deviation of the final share of low-input eco-friendly farmers	Standard deviation of the final share of low-input farmers
0	0	1.232	1.207	2.439	1.251	1.243	1.985
	0.05	1.691	1.220	2.911	1.511	1.278	2.266
	0.1	2.305	1.325	3.630	1.931	1.347	2.698
	0.15	3.163	1.496	4.659	2.314	1.455	3.160
	0.2	4.296	1.684	5.980	2.766	1.568	3.749
	0.25	5.773	2.011	7.784	3.298	1.794	4.535
	0.3	7.606	2.303	9.909	4.023	2.132	5.532
	0.35	10.342	3.005	13.347	4.952	2.542	6.852
	0.4	13.016	3.652	16.668	5.680	2.993	7.979
	0.45	16.404	4.359	20.763	5.866	3.282	8.448
	0.5	19.816	5.448	25.264	6.273	3.796	9.331
	0.55	23.777	7.054	30.831	6.018	4.419	9.650
	0.6	26.849	8.345	35.194	5.558	4.691	9.377
	0.65	29.751	9.754	39.505	4.947	5.003	9.088

	0.7	32.089	11.044	43.133	4.236	5.161	8.436
	0.75	34.004	12.346	46.350	3.524	5.406	8.014
	0.8	35.540	13.311	48.851	2.851	5.047	6.986
	0.85	36.574	14.041	50.615	2.396	5.178	6.789
	0.9	37.550	14.856	52.406	1.927	5.215	6.361
	0.95	38.097	15.084	53.181	1.708	5.042	5.983
	1	38.624	15.923	54.547	1.296	4.926	5.481
0.05	0	1.338	1.716	3.054	1.420	1.631	2.527
	0.05	1.735	1.860	3.595	1.698	1.673	2.791
	0.1	2.420	1.899	4.319	1.950	1.732	3.083
	0.15	3.369	2.032	5.401	2.478	1.797	3.705
	0.2	4.278	2.269	6.547	2.913	1.977	4.275
	0.25	6.048	2.667	8.715	3.916	2.305	5.589
	0.3	7.851	3.114	10.965	4.255	2.586	6.235
	0.35	10.809	3.828	14.637	5.360	3.130	7.816
	0.4	13.493	4.603	18.096	5.851	3.583	8.783
	0.45	17.547	6.106	23.653	6.555	4.215	10.056
	0.5	20.904	7.363	28.267	6.602	4.680	10.572
	0.55	24.510	9.054	33.564	6.020	5.200	10.452
	0.6	27.883	10.610	38.493	5.824	5.593	10.614
	0.65	30.725	12.433	43.158	4.568	5.635	9.426
	0.7	32.867	13.768	46.635	4.094	5.706	8.923
	0.75	34.729	15.090	49.819	3.330	5.614	8.017
	0.8	36.046	15.748	51.794	2.702	5.411	7.291
	0.85	37.032	16.905	53.937	2.330	5.455	6.954
	0.9	37.793	17.520	55.313	1.895	5.607	6.796
	0.95	38.396	18.244	56.640	1.493	5.300	6.067
	1	38.769	18.526	57.295	1.249	5.388	5.965
0.1	0	1.296	2.325	3.621	1.286	1.855	2.624
	0.05	1.883	2.374	4.257	1.670	1.969	3.059
	0.1	2.493	2.620	5.113	2.037	2.101	3.478
	0.15	3.424	2.760	6.184	2.425	2.246	4.023
	0.2	4.482	2.919	7.401	3.029	2.315	4.693
	0.25	6.399	3.582	9.981	4.021	2.956	6.359
	0.3	8.629	4.407	13.036	4.772	3.353	7.484
	0.35	11.021	5.018	16.039	5.434	3.794	8.571
	0.4	14.603	6.302	20.905	6.289	4.565	10.141
	0.45	18.149	7.702	25.851	6.635	5.098	11.009

	0.5	21.940	9.649	31.589	6.560	5.510	11.383
	0.55	26.088	11.884	37.972	6.427	6.167	11.883
	0.6	28.866	13.587	42.453	5.370	6.042	10.614
	0.65	31.756	15.324	47.080	4.630	6.028	9.826
	0.7	33.715	16.572	50.287	3.763	5.857	8.751
	0.75	35.522	18.392	53.914	2.976	5.704	7.886
	0.8	36.583	19.244	55.827	2.502	5.875	7.608
	0.85	37.389	19.755	57.144	2.086	5.713	7.017
	0.9	38.143	20.791	58.934	1.755	5.700	6.717
	0.95	38.538	20.953	59.491	1.392	5.316	5.996
	1	38.928	21.692	60.620	1.167	5.372	5.920
0.15	0	1.552	3.113	4.665	1.460	2.320	3.198
	0.05	2.040	3.284	5.324	1.853	2.549	3.800
	0.1	2.681	3.350	6.031	2.241	2.469	4.080
	0.15	3.712	3.934	7.646	2.792	2.906	5.043
	0.2	5.205	4.368	9.573	3.294	3.230	5.873
	0.25	6.979	4.993	11.972	4.299	3.631	7.312
	0.3	9.416	5.841	15.257	5.249	4.188	8.805
	0.35	12.345	7.231	19.576	6.309	4.931	10.673
	0.4	15.845	8.316	24.161	6.653	5.397	11.400
	0.45	19.273	10.378	29.651	7.045	6.102	12.456
	0.5	23.562	12.378	35.940	6.608	6.297	12.236
	0.55	26.774	14.293	41.067	6.171	6.612	12.052
	0.6	30.203	16.858	47.061	5.290	6.552	11.083
	0.65	32.772	18.779	51.551	4.255	6.322	9.821
	0.7	34.648	20.000	54.648	3.435	6.191	8.824
	0.75	35.839	21.163	57.002	2.825	6.023	8.077
	0.8	37.015	22.383	59.398	2.316	5.673	7.223
	0.85	37.855	23.310	61.165	1.788	5.603	6.625
	0.9	38.355	23.236	61.591	1.610	5.692	6.558
	0.95	38.745	24.011	62.756	1.364	5.330	6.035
	1	39.126	24.158	63.284	1.072	5.239	5.683
0.2	0	1.670	4.137	5.807	1.540	2.709	3.642
	0.05	2.411	4.526	6.937	2.134	2.977	4.543
	0.1	3.108	4.917	8.025	2.501	3.288	5.146
	0.15	4.247	5.158	9.405	2.891	3.181	5.414
	0.2	5.984	5.888	11.872	3.858	3.796	7.052
	0.25	8.009	6.925	14.934	4.986	4.514	8.844

	0.3	10.229	7.662	17.891	5.798	5.017	10.200
	0.35	13.760	9.311	23.071	6.568	5.974	11.859
	0.4	16.957	11.053	28.010	7.176	6.364	12.903
	0.45	21.408	13.508	34.916	7.048	6.882	13.258
	0.5	25.122	15.550	40.672	6.932	7.245	13.463
	0.55	28.384	17.593	45.977	5.817	6.744	11.837
	0.6	31.298	19.776	51.074	4.976	6.675	10.879
	0.65	33.562	21.828	55.390	3.934	6.143	9.293
	0.7	35.329	23.344	58.673	3.192	6.001	8.442
	0.75	36.560	24.358	60.918	2.568	5.794	7.580
	0.8	37.283	24.901	62.184	2.261	5.500	7.010
	0.85	38.028	25.604	63.632	1.863	5.222	6.441
	0.9	38.620	26.551	65.171	1.333	5.156	5.840
	0.95	38.906	26.293	65.199	1.210	5.140	5.702
	1	39.260	26.981	66.241	0.945	4.993	5.375
0.25	0	1.932	5.726	7.658	1.776	3.401	4.573
	0.05	2.643	5.979	8.622	2.216	3.534	5.154
	0.1	3.608	6.392	10.000	2.751	3.904	6.048
	0.15	4.871	6.923	11.794	3.321	4.170	6.848
	0.2	6.374	7.669	14.043	4.247	4.766	8.489
	0.25	9.014	9.070	18.084	5.258	5.141	9.743
	0.3	11.906	10.290	22.196	6.255	5.974	11.632
	0.35	15.352	12.346	27.698	6.857	6.559	12.754
	0.4	19.347	14.517	33.864	7.452	7.307	14.151
	0.45	23.251	17.077	40.328	7.193	7.249	13.771
	0.5	26.901	19.218	46.119	6.488	7.157	12.988
	0.55	29.702	21.136	50.838	5.487	6.930	11.679
	0.6	32.736	23.398	56.134	4.329	6.358	9.980
	0.65	34.563	24.980	59.543	3.652	5.942	8.883
	0.7	35.756	25.671	61.427	2.951	5.603	7.809
	0.75	37.083	27.126	64.209	2.299	5.360	6.946
	0.8	37.799	28.023	65.822	1.907	5.018	6.214
	0.85	38.350	28.246	66.596	1.604	4.941	5.893
	0.9	38.858	28.947	67.805	1.299	4.880	5.570
	0.95	39.141	29.302	68.443	1.100	4.470	4.997
	1	39.377	29.748	69.125	0.879	4.591	4.955
0.3	0	2.296	7.621	9.917	2.119	4.227	5.769
	0.05	3.149	7.897	11.046	2.580	4.317	6.249

	0.1	4.280	8.654	12.934	3.235	4.642	7.253
	0.15	5.741	9.405	15.146	4.004	5.179	8.541
	0.2	7.741	10.329	18.070	4.909	5.554	9.834
	0.25	10.667	12.205	22.872	6.009	6.293	11.698
	0.3	13.797	13.754	27.551	7.017	6.888	13.255
	0.35	17.084	15.525	32.609	7.551	7.599	14.570
	0.4	21.476	18.325	39.801	7.653	7.549	14.655
	0.45	24.976	20.497	45.473	6.959	7.273	13.551
	0.5	28.897	23.325	52.222	6.031	6.942	12.280
	0.55	31.258	24.732	55.990	5.028	6.647	10.972
	0.6	33.560	26.682	60.242	4.012	5.959	9.290
	0.65	35.128	27.831	62.959	3.319	5.353	7.938
	0.7	36.658	29.297	65.955	2.503	4.852	6.581
	0.75	37.491	29.627	67.118	2.175	4.833	6.311
	0.8	38.211	30.540	68.751	1.684	4.329	5.400
	0.85	38.627	30.715	69.342	1.466	4.451	5.299
	0.9	39.015	31.195	70.210	1.148	4.310	4.935
	0.95	39.288	31.454	70.742	0.940	4.065	4.497
	1	39.507	31.878	71.385	0.795	4.046	4.405
0.35	0	2.763	9.895	12.658	2.559	4.990	6.884
	0.05	3.886	10.619	14.505	3.135	5.242	7.730
	0.1	5.295	11.338	16.633	3.915	5.544	8.791
	0.15	6.570	12.008	18.578	4.437	5.819	9.548
	0.2	9.412	13.665	23.077	5.851	6.747	11.987
	0.25	12.561	15.423	27.984	6.742	7.123	13.256
	0.3	15.913	17.387	33.300	7.361	7.221	13.983
	0.35	19.327	19.476	38.803	7.408	7.517	14.315
	0.4	23.262	21.704	44.966	7.050	7.351	13.804
	0.45	27.305	24.357	51.662	6.406	6.859	12.636
	0.5	30.102	26.416	56.518	5.840	6.329	11.545
	0.55	32.683	28.118	60.801	4.691	5.944	10.033
	0.6	34.546	29.227	63.773	3.761	5.534	8.658
	0.65	36.210	30.798	67.008	2.873	4.747	6.930
	0.7	37.209	31.233	68.442	2.218	4.316	5.891
	0.75	37.900	31.912	69.812	1.963	4.121	5.438
	0.8	38.451	32.605	71.056	1.543	3.920	4.827
	0.85	38.822	32.701	71.523	1.271	3.755	4.509
	0.9	39.225	33.388	72.613	0.995	3.501	3.958

	0.95	39.435	33.438	72.873	0.858	3.555	3.934
	1	39.567	33.540	73.107	0.715	3.544	3.826
0.4	0	3.615	12.945	16.560	2.917	5.537	7.835
	0.05	4.877	13.757	18.634	3.681	5.894	8.900
	0.1	6.504	14.892	21.396	4.543	6.261	10.106
	0.15	8.287	15.690	23.977	5.313	6.792	11.375
	0.2	11.119	17.116	28.235	6.438	7.137	13.007
	0.25	14.601	19.313	33.914	7.132	7.331	13.856
	0.3	18.263	21.296	39.559	7.783	7.654	14.862
	0.35	22.007	23.641	45.648	7.422	7.173	13.995
	0.4	25.628	25.537	51.165	7.117	7.011	13.556
	0.45	28.543	27.540	56.083	6.153	6.248	11.753
	0.5	31.814	29.617	61.431	5.128	5.724	10.200
	0.55	33.680	30.637	64.317	4.182	5.102	8.631
	0.6	35.311	31.774	67.085	3.371	4.377	7.079
	0.65	36.561	32.683	69.244	2.662	4.332	6.357
	0.7	37.687	33.579	71.266	2.027	3.779	5.232
	0.75	38.257	33.802	72.059	1.752	3.612	4.752
	0.8	38.700	34.006	72.706	1.443	3.595	4.484
	0.85	39.092	34.618	73.710	1.138	3.178	3.789
	0.9	39.294	34.765	74.059	0.951	3.292	3.767
	0.95	39.521	35.069	74.590	0.772	2.952	3.302
	1	39.631	35.085	74.716	0.685	3.038	3.312
0.45	0	4.405	16.360	20.765	3.422	5.966	8.737
	0.05	5.979	17.212	23.191	4.340	6.343	9.933
	0.1	7.987	18.678	26.665	5.044	6.636	10.983
	0.15	10.563	19.918	30.481	6.048	7.032	12.397
	0.2	13.537	21.462	34.999	6.655	7.121	13.120
	0.25	16.922	22.919	39.841	7.381	7.245	14.044
	0.3	20.574	25.046	45.620	7.282	6.969	13.642
	0.35	24.348	27.179	51.527	6.968	6.380	12.736
	0.4	27.587	28.925	56.512	6.380	6.071	11.848
	0.45	30.718	30.910	61.628	5.171	5.047	9.526
	0.5	32.878	31.717	64.595	4.481	4.909	8.780
	0.55	34.733	32.585	67.318	3.569	4.348	7.232
	0.6	36.106	33.675	69.781	2.952	3.922	6.262
	0.65	37.140	34.567	71.707	2.330	3.434	5.119
	0.7	37.941	34.955	72.896	1.882	3.176	4.406

	0.75	38.558	35.566	74.124	1.475	2.980	3.859
	0.8	38.889	35.592	74.481	1.291	2.934	3.652
	0.85	39.176	35.815	74.991	1.074	2.723	3.306
	0.9	39.480	36.133	75.613	0.785	2.671	3.000
	0.95	39.606	36.277	75.883	0.674	2.492	2.784
	1	39.697	36.512	76.209	0.599	2.483	2.695
0.5	0	5.617	19.890	25.507	3.867	6.256	9.393
	0.05	7.624	21.020	28.644	4.989	6.425	10.672
	0.1	9.682	21.957	31.639	5.584	6.440	11.333
	0.15	12.762	23.743	36.505	6.568	6.894	12.756
	0.2	15.897	25.093	40.990	6.887	6.652	12.849
	0.25	19.598	27.106	46.704	7.238	6.332	12.890
	0.3	22.831	28.710	51.541	7.032	6.057	12.438
	0.35	26.408	30.357	56.765	6.620	5.739	11.726
	0.4	29.219	31.649	60.868	5.740	5.161	10.252
	0.45	31.957	32.959	64.916	4.627	4.329	8.361
	0.5	33.865	33.882	67.747	4.214	4.148	7.773
	0.55	35.641	34.934	70.575	3.073	3.321	5.733
	0.6	36.708	35.373	72.081	2.644	3.233	5.325
	0.65	37.508	35.813	73.321	2.153	2.985	4.509
	0.7	38.196	36.267	74.463	1.720	2.552	3.734
	0.75	38.731	36.561	75.292	1.387	2.431	3.261
	0.8	39.087	36.747	75.834	1.133	2.311	2.862
	0.85	39.359	36.986	76.345	0.931	2.230	2.751
	0.9	39.491	37.124	76.615	0.777	2.136	2.487
	0.95	39.685	37.309	76.994	0.595	2.141	2.348
	1	39.786	37.366	77.152	0.510	2.003	2.166
0.55	0	7.024	23.653	30.677	4.458	6.030	9.714
	0.05	9.072	24.714	33.786	5.144	6.107	10.410
	0.1	11.894	26.135	38.029	6.004	6.222	11.452
	0.15	14.654	27.070	41.724	6.796	6.374	12.397
	0.2	17.811	28.421	46.232	6.761	5.830	11.893
	0.25	21.541	30.164	51.705	6.853	5.514	11.684
	0.3	25.193	31.485	56.678	6.542	5.244	11.153
	0.35	27.657	32.504	60.161	6.031	4.732	10.137
	0.4	30.930	34.018	64.948	4.865	3.925	8.150
	0.45	33.135	34.849	67.984	4.359	3.577	7.313
	0.5	34.795	35.479	70.274	3.458	3.043	5.882

	0.55	36.039	36.131	72.170	2.770	2.819	4.931
	0.6	37.193	36.642	73.835	2.211	2.469	4.093
	0.65	37.934	37.009	74.943	1.844	2.302	3.540
	0.7	38.453	37.113	75.566	1.598	2.272	3.341
	0.75	38.895	37.465	76.360	1.274	2.071	2.823
	0.8	39.204	37.501	76.705	1.000	1.986	2.487
	0.85	39.400	37.672	77.072	0.896	1.873	2.291
	0.9	39.598	37.981	77.579	0.700	1.717	1.995
	0.95	39.724	37.973	77.697	0.583	1.825	2.059
	1	39.791	38.045	77.836	0.468	1.703	1.854
0.6	0	8.303	27.088	35.391	4.701	5.545	9.405
	0.05	10.798	27.958	38.756	5.622	5.628	10.470
	0.1	13.523	28.836	42.359	6.193	5.558	10.928
	0.15	16.726	30.142	46.868	6.596	5.336	11.197
	0.2	19.916	31.306	51.222	6.677	5.051	11.014
	0.25	23.618	32.762	56.380	6.552	4.598	10.501
	0.3	26.558	33.680	60.238	5.890	4.136	9.316
	0.35	29.212	34.521	63.733	5.364	3.720	8.362
	0.4	31.786	35.373	67.159	4.524	3.300	7.160
	0.45	33.753	36.083	69.836	3.855	2.825	6.060
	0.5	35.251	36.408	71.659	3.126	2.672	5.156
	0.55	36.676	37.265	73.941	2.487	2.226	4.042
	0.6	37.413	37.423	74.836	2.146	2.091	3.647
	0.65	38.203	37.769	75.972	1.765	1.920	3.100
	0.7	38.710	37.942	76.652	1.328	1.799	2.610
	0.75	39.092	38.124	77.216	1.196	1.781	2.509
	0.8	39.330	38.320	77.650	0.935	1.592	2.108
	0.85	39.542	38.455	77.997	0.768	1.497	1.903
	0.9	39.634	38.406	78.040	0.659	1.508	1.795
	0.95	39.746	38.541	78.287	0.565	1.418	1.642
	1	39.811	38.486	78.297	0.462	1.514	1.684
0.65	0	9.453	29.605	39.058	4.739	4.911	8.816
	0.05	12.161	30.457	42.618	5.757	4.823	9.785
	0.1	14.840	31.208	46.048	6.182	4.526	9.844
	0.15	18.345	32.411	50.756	6.340	4.280	9.843
	0.2	21.904	33.540	55.444	6.381	4.049	9.739
	0.25	25.112	34.561	59.673	5.974	3.552	8.815
	0.3	27.873	35.344	63.217	5.514	3.262	8.117

	0.35	30.458	36.052	66.510	4.798	2.821	6.961
	0.4	32.565	36.659	69.224	4.128	2.616	6.078
	0.45	34.452	37.210	71.662	3.369	2.292	5.052
	0.5	36.036	37.631	73.667	2.772	1.996	4.173
	0.55	36.984	37.928	74.912	2.293	1.888	3.582
	0.6	37.779	38.175	75.954	1.981	1.684	3.146
	0.65	38.375	38.367	76.742	1.618	1.604	2.729
	0.7	38.783	38.519	77.302	1.360	1.490	2.390
	0.75	39.192	38.633	77.825	1.000	1.464	2.007
	0.8	39.382	38.675	78.057	0.890	1.463	1.912
	0.85	39.554	38.802	78.356	0.750	1.268	1.615
	0.9	39.689	38.881	78.570	0.620	1.191	1.484
	0.95	39.793	38.894	78.687	0.488	1.218	1.403
	1	39.860	39.024	78.884	0.375	1.133	1.251
0.7	0	11.387	32.520	43.907	5.042	3.837	8.021
	0.05	13.699	32.895	46.594	5.660	4.023	8.767
	0.1	16.668	33.651	50.319	6.027	3.809	9.044
	0.15	19.537	34.460	53.997	6.407	3.698	9.277
	0.2	23.095	35.227	58.322	6.105	3.337	8.709
	0.25	26.083	35.942	62.025	5.679	2.961	7.845
	0.3	28.740	36.545	65.285	5.201	2.583	7.095
	0.35	31.527	37.169	68.696	4.456	2.388	6.173
	0.4	33.282	37.555	70.837	3.823	2.122	5.302
	0.45	35.152	38.006	73.158	3.089	1.871	4.337
	0.5	36.394	38.333	74.727	2.640	1.683	3.778
	0.55	37.246	38.486	75.732	2.148	1.522	3.121
	0.6	37.991	38.715	76.706	1.850	1.421	2.767
	0.65	38.558	38.855	77.413	1.510	1.297	2.330
	0.7	38.869	38.880	77.749	1.253	1.239	2.043
	0.75	39.218	38.997	78.215	0.971	1.176	1.740
	0.8	39.406	39.067	78.473	0.859	1.116	1.553
	0.85	39.574	39.077	78.651	0.720	1.171	1.490
	0.9	39.727	39.134	78.861	0.602	1.092	1.378
	0.95	39.817	39.166	78.983	0.449	1.070	1.223
	1	39.872	39.225	79.097	0.384	1.061	1.194
0.75	0	12.439	34.001	46.440	5.268	3.552	7.983
	0.05	14.868	34.631	49.499	5.652	3.239	8.046
	0.1	18.074	35.380	53.454	5.841	3.015	8.015

	0.15	20.914	35.880	56.794	6.145	2.902	8.287
	0.2	24.396	36.562	60.958	5.837	2.659	7.789
	0.25	27.367	37.061	64.428	5.378	2.365	7.038
	0.3	29.726	37.519	67.245	4.859	2.111	6.303
	0.35	31.906	37.890	69.796	4.448	1.941	5.787
	0.4	33.975	38.180	72.155	3.532	1.731	4.722
	0.45	35.194	38.482	73.676	3.097	1.652	4.187
	0.5	36.708	38.780	75.488	2.509	1.307	3.293
	0.55	37.421	38.908	76.329	2.177	1.227	2.887
	0.6	38.102	39.058	77.160	1.719	1.136	2.391
	0.65	38.664	39.164	77.828	1.390	1.006	1.977
	0.7	38.997	39.246	78.243	1.137	1.031	1.727
	0.75	39.311	39.258	78.569	0.905	1.032	1.512
	0.8	39.445	39.299	78.744	0.823	0.942	1.403
	0.85	39.645	39.415	79.060	0.647	0.823	1.164
	0.9	39.735	39.381	79.116	0.561	0.903	1.130
	0.95	39.827	39.419	79.246	0.439	0.861	1.019
	1	39.886	39.453	79.339	0.345	0.818	0.923
0.8	0	13.056	35.597	48.653	5.036	2.787	6.895
	0.05	16.088	36.075	52.163	5.507	2.674	7.311
	0.1	19.035	36.553	55.588	5.765	2.432	7.418
	0.15	22.036	36.933	58.969	5.776	2.280	7.314
	0.2	25.014	37.421	62.435	5.490	2.062	6.843
	0.25	28.076	37.706	65.782	5.164	1.925	6.392
	0.3	30.495	38.215	68.710	4.658	1.731	5.786
	0.35	32.682	38.541	71.223	3.861	1.461	4.709
	0.4	34.197	38.752	72.949	3.438	1.439	4.286
	0.45	35.628	38.923	74.551	2.859	1.255	3.557
	0.5	36.651	39.117	75.768	2.440	1.062	2.992
	0.55	37.691	39.226	76.917	1.885	1.005	2.390
	0.6	38.203	39.249	77.452	1.622	0.977	2.088
	0.65	38.712	39.372	78.084	1.316	0.884	1.784
	0.7	39.064	39.457	78.521	1.126	0.809	1.476
	0.75	39.319	39.456	78.775	0.959	0.832	1.367
	0.8	39.547	39.548	79.095	0.737	0.741	1.130
	0.85	39.700	39.581	79.281	0.598	0.708	1.009
	0.9	39.773	39.554	79.327	0.540	0.760	0.993
	0.95	39.836	39.591	79.427	0.428	0.675	0.836

	1	39.884	39.620	79.504	0.367	0.645	0.782
0.85	0	13.797	36.731	50.528	5.101	2.366	6.642
	0.05	16.969	37.064	54.033	5.512	2.120	6.846
	0.1	20.009	37.364	57.373	5.729	2.039	6.948
	0.15	22.768	37.762	60.530	5.396	1.813	6.490
	0.2	25.754	38.059	63.813	5.424	1.773	6.560
	0.25	28.405	38.358	66.763	4.681	1.575	5.588
	0.3	31.031	38.654	69.685	4.360	1.393	5.155
	0.35	33.073	38.960	72.033	3.670	1.160	4.283
	0.4	34.568	39.062	73.630	3.287	1.086	3.846
	0.45	35.773	39.224	74.997	2.897	1.043	3.466
	0.5	36.935	39.386	76.321	2.364	0.884	2.791
	0.55	37.752	39.377	77.129	1.875	0.908	2.317
	0.6	38.383	39.517	77.900	1.605	0.739	1.964
	0.65	38.820	39.578	78.398	1.269	0.735	1.628
	0.7	39.152	39.600	78.752	1.036	0.687	1.306
	0.75	39.404	39.648	79.052	0.841	0.647	1.149
	0.8	39.534	39.676	79.210	0.767	0.611	1.079
	0.85	39.691	39.734	79.425	0.590	0.560	0.881
	0.9	39.782	39.761	79.543	0.490	0.537	0.758
	0.95	39.852	39.700	79.552	0.408	0.600	0.752
	1	39.900	39.735	79.635	0.313	0.561	0.688
0.9	0	14.352	37.311	51.663	5.164	2.015	6.358
	0.05	17.559	37.680	55.239	5.389	1.874	6.494
	0.1	20.462	38.120	58.582	5.333	1.715	6.353
	0.15	23.254	38.302	61.556	5.493	1.616	6.481
	0.2	26.396	38.537	64.933	5.005	1.495	5.863
	0.25	28.782	38.773	67.555	4.777	1.333	5.485
	0.3	31.208	39.012	70.220	4.061	1.154	4.676
	0.35	33.132	39.188	72.320	3.561	1.051	4.070
	0.4	34.831	39.274	74.105	3.170	0.998	3.657
	0.45	35.943	39.428	75.371	2.646	0.832	3.002
	0.5	37.094	39.549	76.643	2.194	0.756	2.524
	0.55	37.913	39.597	77.510	1.955	0.685	2.232
	0.6	38.435	39.639	78.074	1.451	0.653	1.734
	0.65	38.883	39.683	78.566	1.164	0.599	1.418
	0.7	39.113	39.711	78.824	1.067	0.577	1.310
	0.75	39.405	39.775	79.180	0.864	0.496	1.079

	0.8	39.581	39.745	79.326	0.718	0.550	0.957
	0.85	39.719	39.798	79.517	0.569	0.487	0.782
	0.9	39.781	39.818	79.599	0.493	0.446	0.681
	0.95	39.872	39.830	79.702	0.379	0.442	0.621
	1	39.906	39.782	79.688	0.318	0.486	0.617
0.95	0	15.419	38.044	53.463	5.150	1.608	6.021
	0.05	17.926	38.388	56.314	5.230	1.512	5.986
	0.1	21.122	38.545	59.667	5.551	1.395	6.317
	0.15	24.078	38.726	62.804	5.179	1.357	5.914
	0.2	26.937	38.954	65.891	5.023	1.184	5.661
	0.25	29.388	39.100	68.488	4.596	1.094	5.088
	0.3	31.797	39.253	71.050	4.057	0.981	4.526
	0.35	33.436	39.477	72.913	3.598	0.834	3.946
	0.4	35.013	39.480	74.493	3.132	0.796	3.523
	0.45	36.210	39.562	75.772	2.614	0.720	2.881
	0.5	37.170	39.675	76.845	2.150	0.634	2.375
	0.55	37.986	39.687	77.673	1.787	0.581	2.022
	0.6	38.532	39.760	78.292	1.513	0.494	1.637
	0.65	38.915	39.785	78.700	1.240	0.491	1.412
	0.7	39.240	39.801	79.041	0.972	0.481	1.142
	0.75	39.402	39.810	79.212	0.881	0.456	1.037
	0.8	39.590	39.818	79.408	0.693	0.455	0.893
	0.85	39.736	39.860	79.596	0.576	0.390	0.742
	0.9	39.810	39.861	79.671	0.465	0.376	0.625
	0.95	39.867	39.874	79.741	0.379	0.374	0.555
	1	39.907	39.879	79.786	0.323	0.369	0.510
1	0	15.580	38.512	54.092	5.374	1.436	6.113
	0.05	18.682	38.856	57.538	5.193	1.260	5.813
	0.1	21.430	38.903	60.333	5.367	1.212	5.938
	0.15	24.151	39.081	63.232	5.286	1.076	5.811
	0.2	27.101	39.225	66.326	4.936	1.018	5.377
	0.25	29.458	39.369	68.827	4.514	0.853	4.833
	0.3	31.959	39.533	71.492	3.962	0.723	4.257
	0.35	33.753	39.576	73.329	3.624	0.725	3.912
	0.4	35.339	39.662	75.001	2.981	0.671	3.239
	0.45	36.330	39.706	76.036	2.428	0.549	2.610
	0.5	37.374	39.795	77.169	1.984	0.515	2.180
	0.55	38.072	39.819	77.891	1.739	0.482	1.880

	0.6	38.546	39.823	78.369	1.486	0.442	1.632
	0.65	38.944	39.854	78.798	1.217	0.416	1.365
	0.7	39.242	39.868	79.110	1.019	0.388	1.134
	0.75	39.405	39.883	79.288	0.861	0.365	0.975
	0.8	39.635	39.885	79.520	0.659	0.340	0.786
	0.85	39.770	39.903	79.673	0.521	0.319	0.625
	0.9	39.822	39.898	79.720	0.443	0.331	0.581
	0.95	39.878	39.922	79.800	0.365	0.290	0.475
	1	39.916	39.931	79.847	0.298	0.265	0.412

Appendix 4 – Transition pathways of the share of low-input farmers

In Section 4.2., we presented the effect of initial concentrations on the final share of low-input farmers. To go further, we analysed the transition pathway of the share of low-input farmers depending on the concentration for different initial concentrations. We chose three initial concentrations with different effects to illustrate our analysis (see Figure A.2): (1) a low initial concentration (0 mg/L); (2) a medium initial concentration (34 mg/L); (3) a high initial concentration (50 mg/L). We compare the pathway with the equilibrium states depending on fixed shares of low-input farmers. These equilibrium states correspond to the balance between the quantity of pollutant exiting the water body and the quantity of pollutant entering through the high-input practices of farmers (dashed lines in Figure A.2).

1) In the first case, there is a low initial pollution. Since at the beginning of the simulation, all farmers practice high-input agriculture, the concentration will naturally increase. And, even if there are some low-input farmers thanks to the protection programme, as long as the share of low-input farmers remains low, i.e., below the equilibrium states (dashed line in Figure A.2), the concentration of pollutants increases despite the increase in the share of low-input farmers. Close to the equilibrium states there is a slight decrease in the concentration.

2) When the initial concentration is medium, first, the concentration of pollutants increases despite the increase in the share of low-input farmers, and then it decreases. Indeed, while the quantity of pollutants entering the system is higher than the quantity exiting, the concentration increases. It corresponds to a concentration lower than the concentration at the equilibrium state for the same share of low-input farmers. After a few steps, when the concentration is higher than the equilibrium, the concentration of pollutants decreases until reaching equilibrium. This is due to the time it takes for the groundwater body to react.

3) The last case represents the cases where the concentration decreases during the entire simulation. In this simulation, the initial concentration is higher than the concentration of pollutants entering the system; at each further step, the concentration in water is still higher than the concentration entering, until the equilibrium. Thus, the concentration decreases with the share of low-input farming.

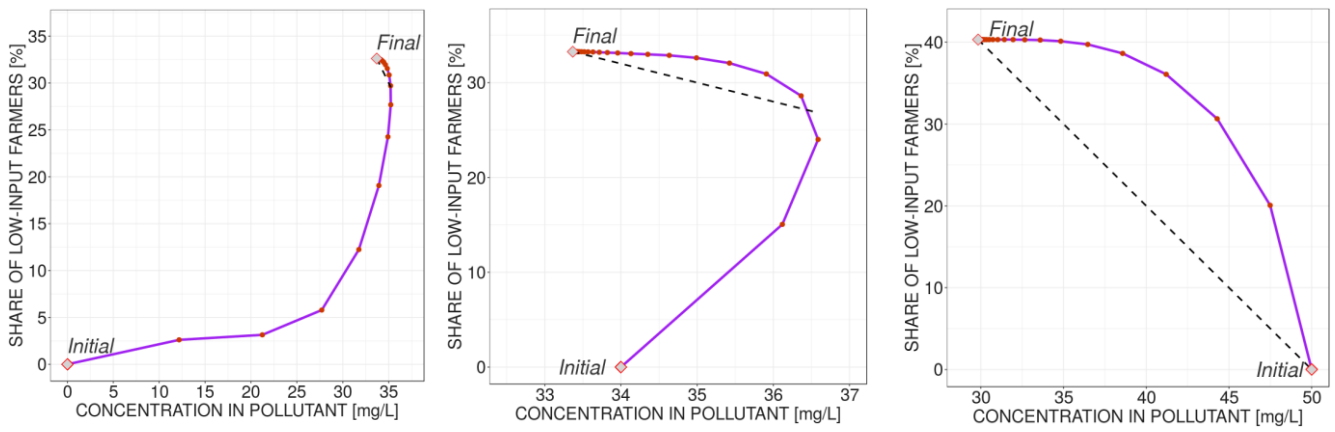


Figure A.2. Share of low-input farmers depending on the concentration of pollutants for three initial concentrations: (1) low initial concentration (0 mg/L); (2) medium initial concentration (34 mg/L); (3) high initial concentration (50 mg/L). Dashed lines are equilibrium states.