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Abstract

Nitrate pollution remains a major problem in some parts of France, especially in the Brittany region, which is characterized by intensive livestock production systems. Although farmers must not exceed a regulatory limit of nitrogen contained in manure per hectare, many farmers in this region exceed this limit. Therefore, they must treat the excess of manure that they produce or export it to be spread in neighbouring farms and/or areas, inducing fierce competition in the land market. Another adaptation strategy consists of modifying production practices or the production system as a whole, *i.e.,* changing the structure of the farm. In this paper, a spatial agent-based model (ABM) has been developed to assess policy options in the regulation of manure management practices. The objective is to highlight the potential effects of these policies on the farmland market and the structural changes that they induce. Our results show that the different policies, which result in similar environmental benefits, induce different changes in the land market and in agricultural structures.

Keywords: farmland market, agent-based model, environmental regulations

JEL classification: Q15, C63, D22

Impacts de politiques environnementales sur le marché foncier et les structures agricoles : un modèle multi-agents appliqué à la Bretagne.

Résumé

Parmi les enjeux environnementaux auxquels fait face l'agriculture bretonne, celui de la gestion et de la maîtrise des effluents domine. Bien que la quantité d'azote organique épandable soit limitée en Bretagne, certains agriculteurs dépassent ce plafond. Ils doivent alors traiter ou transférer leurs effluents en excédent, ce qui crée, dans une région comme la Bretagne, une tension sur le marché foncier. Les agriculteurs peuvent également être amenés à modifier leurs pratiques agricoles et/ou réduire leur cheptel. Dans ce papier, un modèle multi-agent représentant le marché foncier agricole a été développé afin d'évaluer différentes politiques de gestion des effluents d'élevages. L'objectif de ce papier est d'analyser les principaux impacts de ces politiques environnementales sur les échanges de terres et sur les structures agricoles de la région Bretagne. Nos résultats montrent que différents outils de politiques publiques, à bienfaits environnementaux équivalents, ont des conséquences très différentes sur les structures agricoles.

Mots-clés : marché foncier, modèle multi-agents, politiques environnementales

Classification JEL : Q15, C63, D22

The impact of environmental regulations on the farmland market and farm structures: An agent-based model applied to the Brittany region of France

1 Introduction

Nitrate pollution is a major problem in some parts of France. As a result, in 2013, the Court of Justice of the European Union criticized France for not correctly implementing the Nitrates Directive and thus creating a risk of water pollution from nitrogen. This was the second time that the European Commission took action against France regarding nitrate pollution. This litigation concerns mostly the north-western part of France and especially the Brittany region, which is characterized by intensive livestock production systems and has been classified as a vulnerable area since 1994, according to the Nitrates Directive. Although regulations stipulate that farmers cannot exceed the application of 170 kg of organic nitrogen per hectare, in 2010, 20% of farmers in Brittany exceeded this limit. Therefore, these farmers must either treat the excess manure they produce or export it to be spread in neighbouring farms and/or areas, inducing fierce competition in the land market (Letort and Temesgen, 2014). Another adaptation strategy is modifying production practices or the production system as a whole, *i.e.*, changing the farm’s structure.

This paper presents a spatial agent-based model (ABM) developed to assess policy options in the regulation of manure management practices. The objective is to highlight the potential effects of these policies on the farmland market and the structural changes that they may induce. We use the example of the Brittany region, which is strongly concerned with these regulations, but the model can be adapted to other regions by changing the initialization step.

Several studies have examined the role of policies concerning the use of livestock manure. The economic literature largely emphasizes the effects of such regulations on the spatial distribution of animal activities, such as hog production in France (Gaigné *et al.*, 2012) or dairy production in the United States (Isik, 2004). The recent concentration of animal production, which generates non-point pollution, in many countries has certainly motivated economists to address this issue. Innes (2000) proposed an economic model of regional livestock production and regulation that was sufficiently general and simple to highlight the spatial issues of interest. But he acknowledged that his analysis abstracts dynamic processes such as technical change and entry, and the heterogeneity of livestock facilities. In fact, these analytical methods and more traditional simulation models, which require a higher level of aggregation through representative agents, cannot easily integrate the various complex aspects of agricultural systems. Furthermore, they are not adapted to analyse the structural changes proposed by policies (see Matthews and Selman, 2006, for an overview of computational modelling in agriculture and resource economics). These limitations have recently prompted the use of ABMs. An ABM can incorporate some aspects that conventional theoretical studies neglect and can shed significant light on solutions that are difficult to achieve through analytical calculation. For example, Happe *et al.* (2011) focused on the impacts of environmental legislation, including stocking density limitations, on structural changes in agricultural production and on nitrogen emissions in a Danish region. Their study linked an existing farm-based economic model of structural change (AgriPoliS) with an existing model of individual farms' nitrogen loss. The AgriPoliS model, initially proposed by Balmann (1997) and developed by Happe (2004) and Happe *et al.* (2006), is one of the first highly detailed ABMs created to assess the impact of different agricultural policy schemes. Since the late 1990s, several other agent-based systems have been developed to model agricultural and land use issues. Some studies have analysed the use and preservation of natural resources (Filatova *et al.*, 2011), the diffusion of technology (Berger, 2001), the interactions between agricultural land use and environmental and social issues (Bert *et al.*, 2011; Ralha *et al.*, 2013), and spatial patterns of development (Magliocca *et al.*, 2015).

The agent-based modelling community has different opinions about the best way to construct and use an ABM[1]. Some scholars argue that modellers should start with the simplest possible model and only move to a more complex model if needed (Axelrod, 1997), while others believe that modellers should include all variables and mechanisms that appear relevant (Edmonds and Moss, 2005). These choices can be justified depending on the model's objective and thus lead to different interpretations of simulation results. The existing farmland market ABMs vary in their levels of agent and land heterogeneity, realism of land market interactions, and particular features of interest, but their functioning is generally based on very detailed and realistic assumptions. The AgriPoliS model also has these characteristics. First, all production and investment decisions (labour, capital, land) are modelled. The model assumes that farms can adjust their production and investment decisions according to changing market conditions and policy changes. Farms interact with each other in markets, including the land market (which is a local rental market), for production factors. The land supply is determined by unused land, which is free because of the end of a rental contract or the exit of a farm. In the land market, plots are allocated through a bid auction system. A farm first selects a plot that it considers valuable, that is, a plot that minimizes the sum of transportation costs and additional costs. The farm that makes the highest bid for a plot receives it. The rental price is defined as the average rent paid in a region. The maximum amount a farm is willing to pay for a plot is

[1] There are two common design principles for ABMs, KISS (*Keep It Simple Stupid*) models and KIDS (*Keep It Descriptive Stupid*) models.

determined by the shadow price, which represents the marginal utilization of the plot, minus the transportation costs and additional costs for a plot.

In contrast to these aforementioned farmland markets, our model favours simplicity at the expense of realism and is calibrated to reproduce the agricultural structures observed in the Brittany region. This makes it easier to implement, manipulate, check and analyse the model, especially given that agent-based modelling is often criticized because of the lack of common accepted standards on its use; it is also criticized as being a "black box." Our simplified use is conceptually quite similar to traditional simulation, but the use of the agent-based approach has the advantage of more easily allowing the simultaneous consideration of a range of price and policy options, the spatial dimension of agricultural activities and more heterogeneity in agents and landscapes (Axtell, 2000). This feature of our model has two main implications. First, all actions and interactions between farmers take place on the land market. Our model is not coupled with a production choice model, allowing us to focus our analysis on the economic mechanisms occurring on the land market and simplifying our understanding of the simulation results. Second, our strategy for modelling the land market is stylized, as it focuses on the economic behaviour of farmers and does not consider the actual imperfections of the French farmland market (Latruffe *et al.*, 2008). Moreover, similar to other researchers, we do not differentiate the sales market from the rental market; thus, a land exchange may be viewed as a sale or a rental. We assume that all agricultural plots are potentially exchangeable at any time, that these exchanges are based on a bid auction system, and that each farmer's bid is defined according to the net present value maximising model.

In the next section, we describe the ABM that we developed in greater detail. Section 3 documents the calibration of the model. We define policy scenarios and analyse the empirical results in section 4. Section 5 provides concluding remarks.

2. The agent-based model (ABM)

The aim of our ABM is to model the land market to analyze structural changes in various economic or political settings[2]. The model is composed of a set of individual farmers located in an environment in which they interact according to specific rules. This modelling environment has some features that are identical to those of the Brittany region in terms of land use and agricultural structures. Key elements of the model are introduced in this section. A more detailed description, following the

[2] The model was written with Netlogo (Wilensky, 1999).

Overview-Design-Details (ODD) protocol proposed by Grimm *et al.* (2006) and Grimm *et al.* (2010), is available from the authors upon request.

2.1. Agricultural plots and farm agents

The model consists of two types of entities: plots and individual agents. Plots are square pixels of identical size that differ in their agricultural land use. In the model, a plot can be used partially or fully to produce crops and/or for grazing. The Brittany region is characterized by a large diversity of soil types due to the different soil qualities associated with various agricultural activities. The national agricultural statistics (*Ministry of Agriculture, Agreste*) show that nearly 60% of the total agricultural area in the Brittany region in 2010 was occupied by arable fodder crops (including fodder maize and temporary grassland) and permanent grassland, with a particularly high share of fodder maize compared with other French livestock regions.

Agents represent heterogeneous farmers who own or lease and use the plots. In the model, a farmer is characterized by the geographical location of his farmstead in the environment, the list of plots he owns, production technology, and some individual characteristics (see section 2.3). The Brittany region is an important agricultural area mainly characterized by dairy, pig and poultry production. Many farms specialized in pig or poultry production rely on intensive farming systems and have only small amounts of land on which spreading manure. Dairy farms hold nearly two-thirds of the total agricultural area but exhibit various types of farming practices: some of them have a high livestock stocking rate, while others are based on grazing pastures with lower livestock stocking rate. Furthermore, some combine several livestock activities such as dairy and pig production, while others are specialized in one type of livestock. Additionally, although these farms focus on livestock breeding, most of them use a significant share of their area to grow cash crops.

For simplicity, we consider that farmers have two non-joint production activities. On the one hand, they raise animals using one specific variable input that includes all expenditures required for their animals (feed, veterinary care, etc.). On the other hand, they produce cash crops using one specific variable input that includes all expenditures required for crops (fertilizers, pesticides, etc.). Production factors other than land (i.e., labour and capital) are considered fixed in the short run. Technologies can be more or less intensive in terms of stocking density. Farmers' production choices are not derived from an external optimization model, implying no technology change occurs from one period to another at the farm level. This has two consequences. First, farmers apply their specific technology to every plot that they own or acquire. Second, structural change does not result from optimizing the production choices made by existing farms but, rather, from the competition for land among farms with different and fixed technologies. Finally, we focus on technological change within the system as a whole. For example, an overall extensification will be caused by an increase in the share of extensive farms in overall production (at the expense of intensive farms) rather than by a technological shift from intensive farming towards more extensive practices. Thus, even if production technologies are fixed, farmers may increase their levels of animal production by acquiring new plots. When purchasing land, dairy farmers increase their cattle proportionally to the additional fodder area they obtain (i.e., consistent with their specific stocking density rate), while pig and poultry farmers increase their livestock proportionally to the additional cash crop area they acquire (i.e., consistent with their specific feeding capacity).We believe that this modelling strategy is consistent with the overall objective of focusing on interactions in the land market and overall structural change rather than on individual optimizing behaviour; therefore, it enables us a better understanding of the simulation results.

Production is also characterized by diminishing marginal productivity. Increasing variable inputs (animal feed and other animal and crop expenses) and holding fixed factors at a certain level enable to increase production. But further increases in variable inputs will have less effect on output (decreasing marginal returns). Conversely, beyond a certain level, producing one or more units of output will be more costly for a farmer because inputs are used less and less efficiently. This is a result of labour and capital being considered fixed and therefore providing a capacity constraint in the short run. This cost increase is statistically estimated using data from Farm Accountancy Data network (FADN).

2.2. Interactions in the land market

All interactions among farmers take place in the land market. Although this model does not differentiate the sales market from the rental market, it was calibrated such that the simulated land prices are similar to the land prices observed in the sales market of the studied area.

Land market interactions consist of several steps. First, we calculate the farmers' bids for every plot in a given period. Farmers incorporate expectations regarding production increases, which depend on soil usage (see section 2.1), into their decision making. Each plot is then assigned to the farmer who offers the highest bid at a price corresponding to this offer. After the sales are made, each farmer updates the characteristics of his farm: he computes his new total area and the value assigned to each of his plots and deduces the total value of his farm. During an iteration period, land values are calculated by treating the parcels and farmers one by one in random order. This asynchronous processing has no effect on the results of the model (Caron-Lormier, 2008).

The model takes into account the entry and exit of farmers. On the exit side, farmers who have not been assigned any plots at the end of each period are removed from the model and do not participate in the next period. On the entry side, the model provides an opportunity for new farmers to enter the market. Potential new farmers are characterized by randomly chosen production technologies and individual characteristics, but they have no predetermined plots. The first step therefore aims at locating each potential new farmer on the plot i) for which he offers a bid that exceeds any other active farmer's offer and ii) maximizes his own profit. Then, potential new farmers participate in land transfers between all farmers and may become the new owners of several additional plots.

We consider that the land market has reached equilibrium in a given period when land is no longer exchanged or when the number of farmers no longer varies during 20 consecutive iterations. The market equilibrium obtained in the very first period is considered as the reference situation. The only characteristic that then varies from one period to another is the farmers' age, which in turn has an impact on their willingness to pay for agricultural plots (see section 2.3). Finally, policy scenarios are modelled as exogenous shifts in one or several specific parameters of the economic environment.

2.3. Farmers' willingness to pay

The bid per hectare $p_{ij}(T)$ offered by farmer j for plot i in period T corresponds to his willingness to pay and is defined according to the net present value model, as follows (Burt, 1986):

$$p_{ij}(T) = \sum_{t=1}^{\infty} \frac{\alpha_j(T+t)\,\pi_{ij}(T+t) - \tau_{ij}}{(1+r)^t} \tag{1}$$

where $\pi_{ij}(T+t)$ is the per-hectare profit expected by farmer j for plot i in period $T+t$, which is assumed to be constant over t, i.e., $\pi_j(T+t) = \pi_j(T)$. The term r is the discounting rate[3]. We introduce parameter $\alpha_j(T+t)$, which defines the share of the profit used by farmer j at time $T+t$ to acquire an additional unit of land after labour and capital factors have been paid. This type of parameter is also defined in the AgriPoliS model. In fact, Happe *et al.* (2008) assumed that a farmer wants to keep part of the rent as a security mark-up because of the risk associated with the utilisation of the plot or to pay other costs such as taxes or administrative or labour costs. Thus, in our model,

[3] The discounting rate is fixed at 4% in the empirical application.

farmers' willingness to pay for land purchases depends on the weight of other investment decisions that can change during farmers' working life. Indeed, young and new farmers may be forced to invest in capital with high fixed costs at the expense of investments in land. The same applies to older farmers, who may set aside a part of their profit to prepare for retirement rather than investing in land or capital. Consequently, we modelled this parameter as a quadratic function of age:

$$\alpha_j(T+t) = \bar{\alpha}_j\left(1 - \left(\frac{age_j(T) - \overline{age}_j}{age_0 - \overline{age}_j}\right)^2\right) \tag{2}$$

where $\bar{\alpha}_j$ is the maximum share of profit used by farmer j for land investment, $age_j(T)$ is the age of farmer j in period T, $\overline{age}_j$ is the age at which the share of profit used by farmer j reaches the maximum value $\bar{\alpha}_j$, and age_0 is the age at which the share of profit used by farmer j is null.

Finally, the term τ_{ij} is the transportation cost between plot i and the farmstead of farm j. This parameter is defined as the sum of a fixed cost per hectare and a nonlinear term in the distance between plot i and the farmstead of farm j:

$$\tau_{ij} = \tau_0 + \tau_1 \times d_{ij}{}^2 \tag{3}$$

where d_{ij} is the distance in kilometers, and τ_0, τ_1 are parameters that are independent of the plot and the farmer. The quadratic impact of the distance encompasses the additional costs (organizational, time and material costs) associated with isolated and distant plots of land. These costs are discussed in greater detail later (see section 3.1).

Because π_j and α_j eventually do not depend on t, equation (1) simplifies into the following:

$$p_{ij}(T) = \frac{\alpha_j(T)\pi_j(T) - \tau_{ij}}{r} \tag{4}$$

2.4. Economic and political environment

The economic environment reflects the input and output prices observed during the studied period. The environmental regulation in course stipulates that farmers cannot exceed a fixed level of organic manure per hectare. Therefore, farmers must treat or export any surplus manure that they produce, creating an additional cost and, hence, reducing their profit. According to the economics literature, treatment technologies are characterized by economies of scale (*Le* Goffe and Salanié, 2005). In fact, average costs decrease as the amount of treated nitrogen increases given the high investment cost that is sunk in a treatment plant. In this paper, we assume that manure treatment is the only way for farmers who exceed the regulatory quota to comply with the regulation. Thus, we do not account for manure exports (and the corresponding market). The cost of treatment $\rho_j(T)$ for farmer j in period *T* (in Euros per hectare) is defined as following:

$$\rho_j(T) = \bar{\rho} \times \max\left(0, \theta_0 \times \delta_j(T) - \bar{\theta}\right) \tag{5}$$

where $\bar{\rho}$ is the treatment cost per unit of nitrogen surplus, θ_0 is the nitrogen emission by unit of animal, $\delta_j(T)$ is the stocking density by unit of land for farmer *j* in period T and $\bar{\theta}$ is the maximum amount of spreadable nitrogen allowed by the regulation.

3. Empirical application

The model is calibrated using FADN data from the Brittany region in 2010. The input data set contains information on land plots and farm agents that reflects the characteristics of the region and additional information that describes the economic and political context. All the model parameters are reported in Annex A. The model returns information about the farmland market, farm structures, and some economic and environmental indicators. These output variables simulated by the model are compared with the same variables observed in the Brittany region (see section 3.2).

3.1. Model initialization

The number of rows and columns of the workspace are interactively defined by the ABM user. In this paper, we considered 20 rows and 20 columns, that is, 400 plots. Given that the size of each plot was set to 10 hectares, the modelling environment measures a total of 4000 hectares[4]. The portion of fodder area and grassland in each plot was randomly drawn such that the fodder area accounted for 60% of the total area.

We identified 8 types of livestock farms that represent the diversity of structural characteristics and types of livestock holdings in Brittany. The model characterizes these typical farms according to their technological and economic results and the age of their operator. We derived them from the Farm Accountancy Data Network (FADN) database, which contains information on the structure and economic results of a sample of farms observed in the region. These typical farms were obtained using statistical analysis (agglomerative hierarchical clustering) with respect to the criteria of size, intensification level and specialization level. The main animal activities conducted in the Brittany region (dairy, pig and poultry production) are represented in the model. All these farms are more or less intensive depending on their stocking densities and nitrogen loads. Their technical characteristics are described in Table 1.

Table 1: Technical characteristics of farm agents (FADN)

	UAA Acreage	Nitrogen load	Stocking density	Ratio FA/UAA
Dairy farms				
Intensive system	66 ha	140 kgN/ha	2.3 LU/ha	0.78
Extensive maize system	90 ha	86 kgN/ha	1.5 LU /ha	0.68
Grazing system	59 ha	115 kgN/ha	1.9 LU /ha	0.85
Pig and poultry farms				
Intensive system	37 ha	440 kgN/ha	10.0 LU /ha	0.08
Extensive system	56 ha	152 kgN/ha	5.0 LU /ha	0.10
Mixed farms				
Intensive system	57 ha	197 kgN/ha	6.8 LU /ha	0.63
Specialized in pig and poultry	81 ha	172 kgN/ha	4.5 LU /ha	0.41
Specialized in dairy	93 ha	130 kgN/ha	3.5 LU /ha	0.63

Notes : LU = Livestock Unit, FA = Forage Area (including fodder crops and grassland), and UAA = Utilised Agricultural Area.

[4] This modelling environment is not the farmland market of the Brittany region; rather, it is a territory that is similar to Brittany in terms of soil quality and agricultural structures.

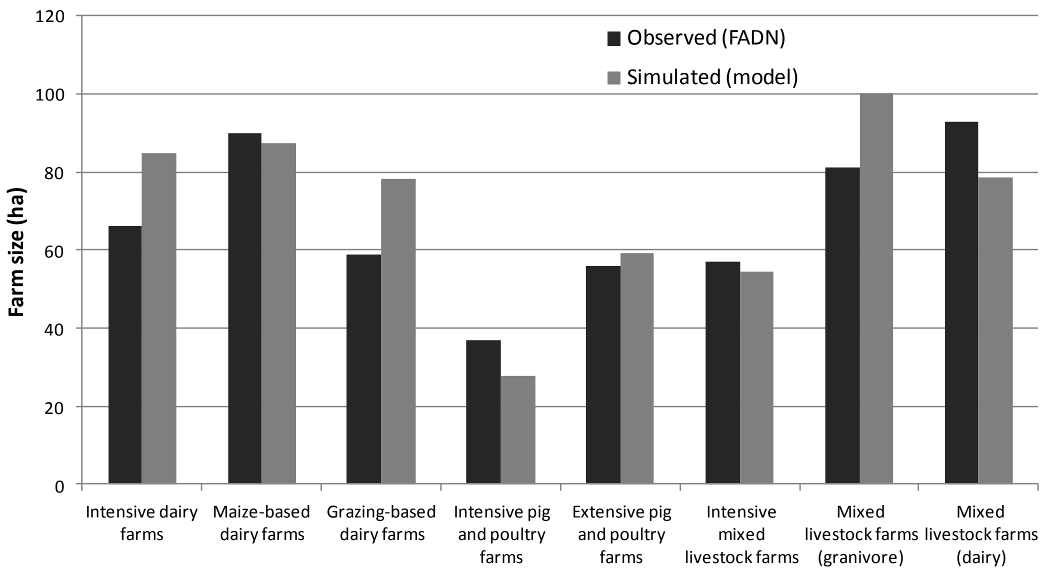
We assumed that each farm agent operates with a fixed quantity of buildings, machinery, and labour that influence the relative remuneration of the land factor. There is considerable variation across farm types, potentially due to differences in the scale of capital investment required for each production activity. For example, the intensive pig and poultry farms use a high proportion of their gross margins to remunerate their capital and labour factors and to repay their debts. By contrast, extensive dairy farms tend to invest more resources in land. These characteristics are indirectly captured in the $\alpha_j(T)$ parameter, which weighs the profit in willingness to pay for land purchases (see equation 1). Given the difficulty of such an evaluation, the maximum share of profit that each farm used for land investment (in equation 2) was manually adjusted in an *ad hoc* manner to reflect its relative remuneration of production factors and to calibrate the initial situation as a realistic land market equilibrium. Finally, farmers' age is a random parameter that was drawn from a uniform distribution. The age of initially present farmers was between 25 and 65, while the potential new farmers' age was between 25 and 40. These two assumptions allowed us to correctly reproduce the age pyramid observed in the studied region in 2010, i.e., 50% of the farmers were over the median age of 45.

Transport and treatment costs were collected from French extension services (Teffène, 2002) or from literature related to France (Djaout *et al.*, 2009). Transport costs include mechanization and fuel expenditures that farmers used for soil preparation and cultivation and for transfer between plots. Therefore, the more distant a plot is from the farmstead, the higher the transport cost and, thus, the more reduced the farmer's willingness to pay for this plot. We also considered the higher transport costs on pig and poultry farms because their crops require more maintenance (fertilizer applications, harvest, reaping…) than does the grassland in dairy farms. Treatment costs include the costs of investing in a treatment plant, operating costs and co-product management costs. The treatment cost of pig manure was set to approximately 5 € per kg of nitrogen, while spreading costs, which were included in transport costs, amounted to approximately 1 € per kg of nitrogen. These treatment costs are characterized by scale economies in the model because the establishment of a treatment plant represents a sunk investment cost. Costs per unit of nitrogen therefore decrease as the number of treated nitrogen units increases because fixed costs are spread out over a larger amount.

3.2. Reference situation

After performing the calibration, we reached a stable initial equilibrium, which was considered as the reference state for the land market. We replicated this situation 300 times, keeping the calibration parameters fixed but varying the random allocation of farmers on plots, random order of farmers processing and random distribution of the stochastic variables (farmers' age). The variability associated with those random draws was evaluated, and the standard errors of output variables showed that the reference situation was only slightly different across replications (Annex B). The robustness of the model is thus confirmed. Figure 1 compares the farm size by farm type observed in reality in the Brittany region and simulated by the model.

Figure 1: Farm size observed in reality and simulated by the model



4. Policy experiments

The baseline scenario represents the reference situation in which all farmers are required to comply with the limit of 170 kg of organic nitrogen per hectare. Then we simulated four different policies aiming at reducing the same environmental impact of livestock activities in terms of reduction in spread organic nitrogen levels. Each scenario began with the same initial land market equilibrium. Then, each policy was implemented for one time period. Simulation results are interpreted in terms of changes in the land market and agricultural structures from the baseline scenario. All the results are defined as the average of the output variables obtained through the 300 replications.

4.1. Policy scenarios

The simulated policy scenarios were inspired by regulatory or incentive tools that the French government used to encourage farmers to adopt best management practices for nitrogen.

The first scenario (“economic incentives”) changes famers’ economic environment through price signals to encourage them to reduce their stocking density. This policy was implemented in the model by increasing the cost of manure treatment, which is equivalent to reducing or even removing treatment subsidies. Since 1994, French farmers have received subsidies for investing in a treatment plant, a policy that favours treatment over other manure elimination options; however, this technology is not profitable for all farmers in the long run.

The second scenario (“regulatory incentives”) tightens the regulatory framework by lowering the allowed nitrogen limit. This regulatory instrument, designed to constrain farmers’ behaviour, may induce administrative and financial penalties and a cut in direct payments according to the eco-conditionality principle of the Common Agricultural Policy (CAP) established in 2000.

The third scenario (“environmental zoning”) defines different levels of the allowed nitrogen limit in several areas. Several zoning designations are in force in the Brittany region to protect environmentally sensitive areas and/or to improve the quality of water used in the production of drinking water. These areas generally have animal stocking densities that result in a nitrogen surplus that exceeds the Nitrate Directive’s limit. Consequently, additional policy measures were implemented in these designated areas exposed to higher environmental pressures from agriculture. The 5th Action Program of the Nitrate Directive, which is currently being prepared by the French government, is intended to simplify and standardize these regulations and zoning. All environmentally sensitive areas will be consolidated into a single zone in which farmers will have to respect an overall nitrogen balance below 50 units of nitrogen per year. Our model does not take into account nitrogen flows; thus, it cannot exactly reproduce this type of policy. Nevertheless, we introduced an environmental zoning policy in which the nitrogen quota was strengthened in consideration of the environmental sensitivity of the area.

Finally, the fourth scenario (“grass payment”) introduces a per-hectare grass payment for farms complying with some conditions regarding the share of corn and grassland in rotation. These conditions are similar to those implemented in French agro-environmental contracts. The payment was designed in several levels depending on the share of grassland in the UAA and the share of corn in the total forage area.

To allow comparability across scenarios, we set the control variables of each specific scenario to reach the same reduction of total organic nitrogen after one year of policy implementation.

In the first scenario, increasing the cost of treatment from 5.22€ to 8.5€ per unit of nitrogen and keeping the nitrogen limit constant induced a 2% decrease in total organic nitrogen. The same reduction could also be achieved in other scenarios, e.g., lowering the nitrogen limit of 170 kgN/ha to 163 kgN/ha and keeping the treatment cost constant (second scenario); lowering the nitrogen limit to 125 kgN/ha in an environmentally sensitive zone corresponding to 45% of the total area (third scenario); and implementing a maximum grass payment of 275€/ha if the share of grassland is more than 70% of the UAA and the share of corn is less than 12% of the total forage area (fourth scenario).

Table 2: Summary of simulated scenarios

	Policies	Policy implementation	Objective
Scenario 1	A rise in the cost of manure treatment	From 5.5 to 8.5 €/kgN for all farms	-2 % spread organic N
Scenario 2	A lowering of the organic nitrogen limit	From 170 to 163 kgN/ha for all farms	-2 % spread organic N
Scenario 3	Environmental zoning	From 170 to 125 kgN/ha in 45% of the area and 170 kgN/ha in the rest of the area.	-2 % spread organic N
Scenario 4	Grass payments	From 0 to 100 or 200 €/ha for farms complying with some conditions regarding the share of corn and grassland in rotation	-2 % spread organic N

4.2. Results

Although the reduction in organic nitrogen levels is, by definition, equal (-2%) across the four simulated policies, the different tested scenarios induce different changes in the land market and agricultural structures. Some economic and environmental indicators were calculated to compare all these scenarios. The main results are presented in Tables 2 and 3; the first column describes the baseline scenario.

The economic incentive (first scenario) leads to a sharp decline in the number and size of specialized pig and poultry farms in favour of dairy farms. Several elements indicate a real extensification. First, the number of farms using treatment to eliminate their surplus manure decreases considerably. Second, the overall share of grassland rises by 2%, indicating an increase in temporary grassland because permanent grassland is fixed. Third, the number of pig and poultry farms decreases by 20%. In this scenario, only farms that exceed the regulatory nitrogen limit are penalized. The increase in treatment costs reduces these farms' profitability with respect to more extensive farms and then encourages them to extensify by buying land for spreading manure or to adjust their livestock downward by selling land. This regulation provides the most significant environmental benefits at the expense of a decrease in the farms' total income and land prices, reflecting a global economic downturn. The rise in the farms' average income is explained by the large decrease in the number of farms.

The regulatory incentive (second scenario) generates a greater disparity across farms. Under this policy, all farm types are potentially affected by the lowering of the nitrogen limit. However, extensive dairy and mixed farms, which remain unconstrained even under this policy, become more profitable. Most farms whose nitrogen load was close to 170 kgN/ha in the reference equilibrium are now required to treat their effluent surplus. More intensive farms have to treat a greater amount of organic nitrogen but also benefit from economies of scale and are, therefore, relatively less affected than less intensive farms. Overall, this policy thus tends to favour the pig and poultry farms at the expense of intensive dairy farms and mixed farms. This policy has very little impact on economic and environmental indicators. In fact, farmers substitute manure spreading with manure treatment, leading to no significant change in agricultural production.

Environmental zoning (third scenario) leads to strong spatial disparity. Dairy farms, particularly grassland dairy farms, become larger in the constrained area, while intensive farms are maintained outside of the area. In contrast to the preceding scenario, this scenario does not demonstrate an increase in treatment use. Mixed farming systems are still penalized. The impacts on other environmental outcomes are quite low, but they are evaluated for the entire area and therefore do not fully reflect the greater benefits in the environmentally sensitive area, where the reduction of organic nitrogen is much more substantial.

Table 2: Simulation results – Structural changes

	Baseline	Economic incentives		Regulatory incentives		Environmental zoning		Grass payments	
Number of dairy farms									
Intensive system	7.68	7.48	-2.60%	7.84	+2.08%	7.63	-0.65%	7.34	-4.43%
Maize system	11.58	12.08	+4.32%	11.67	+0.78%	11.83	+2.16%	11.89	+2.68%
Grazing system	8.64	8.63	-0.12%	8.64	+0.00%	8.77	+1.50%	8.89	+2.89%
Number of pig and poultry farms									
Intensive system	4.33	4.27	-1.39%	0.12	-97.23%	4.38	+1.15%	3.96	-8.55%
Extensive system	8.25	8.07	-2.18%	8.28	+0.36%	7.73	-6.30%	7.89	-4.36%
Number of mixed farms									
Intensive system	7.13	6.92	-2.95%	5.98	-16.13%	6.66	-6.59%	7.09	-0.56%
Specialized in pig and poultry	2.53	2.41	-4.74%	2.61	+3.16%	2.22	-12.25%	2.23	-11.86%
Specialized in dairy production	5.70	5.83	+2.28%	5.75	+0.88%	5.84	+2.46%	5.63	-1.23%
Size of dairy farms									
Intensive system	83.89	84.13	+0.29%	88.24	+5.19%	85.61	+2.05%	80.88	-3.59%
Maize system	86.94	87.51	+0.66%	89.32	+2.74%	89.06	+2.44%	84.44	-2.88%
Grazing system	77.26	78.08	1.06%	80.16	+3.75%	80.43	+4.10%	93.41	+20.90%
Size of pig and poultry farms									
Intensive system	27.19	26.98	-0.77%	16.31	-40.01%	27.3	+0.40%	25.84	-4.97%
Extensive system	58.09	57.47	-1.07%	61.98	+6.70%	56.16	-3.32%	55.50	-4.46%
Size of mixed farms									
Intensive system	54.84	54.1	-1.35%	55.04	+0.36%	53.59	-2.28%	56.02	+2.15%
Specialized in pig and poultry	101.35	99.41	-1.91%	107.63	+6.20%	99.85	-1.48%	97.01	-4.28%
Specialized in dairy production	77.85	78.25	+0.51%	79.96	+2.71%	79.21	+1.75%	75.61	-2.88%

Notes: For each scenario (except the baseline scenario), the first column presents the result in level and the second column is the variation in percent compared with the baseline scenario.

Table 3: Simulation results – Land market, state of environment and overall economy

	Baseline	Economic incentives		Regulatory incentives		Environmental zoning		Grass payments	
Land market									
Total number of farmers	55.83	50.89	-8.85%	55.69	-0.25%	55.06	-1.38%	54.91	-1.65%
Land prices (€/ha)	6,958.69	6,639.84	-4.58%	6,920.13	-0.55%	6,721.84	-3.40%	7,194.30	+3.39%
Number of transactions	799.13	964.40	+20.68%	772.73	-3.30%	850.24	+6.40%	914.10	+14.39%
Environment									
Amount of organic N (1 000 kgN)	573.08	514.04	-10.30%	567.29	-1.01%	562.88	-1.78%	555.51	-3.07%
Amount of spread organic N (1 000 kgN)	511.80	501.16	-2.08%	501.03	-2.10%	501.29	-2.05%	500.83	-2.14%
Amount of treated organic N (1 000 kgN)	61.28	12.88	-78.98%	66.26	+8.13%	61.60	+0.52%	54.68	-10.77%
Grassland area (ha)	2 403.36	2,449.85	+1.93%	2,414.51	+0.46%	2,424.33	+0.87%	2,436.79	+1.39%
Overall economy									
Number of cows (UGB)	5 378.85	5,514.73	+2.53%	5,395.12	+0.30%	5,437.01	+1.08%	5,429.30	+0.94%
Number of pigs and poultry (UGB)	7 679.60	6,104.42	-20.51%	7,460.90	-2.85%	7,203.49	-6.20%	7,109.68	-7.42%
Farms' total income (1 000 €)	10 267.6	9,601.7	-6.48%	10,156.1	-1.09%	9,990.7	-2.70%	10,164.4	-1.00%
Farms' average income (1 000 €)	184.33	189.11	+2.59%	182.75	-0.86%	181.34	-1.62%	185.50	+0.63%
Public cost (1000 €)	1,800.85	1,802.65	+0.10%	1,772.35	-1.58%	1,804.46	+0.20%	2,005.64	+11.37%

The grass payments (fourth scenario) promote dairy farms with a grass-based feeding system and, to a lesser extent, mixed intensive farms, which also receive these premiums. These farms are intensive in terms of animal load but produce a high share of their animal feed on the farm. In fact, they use large areas of pasture to feed cattle to comply with this regulation. By contrast, all farms specialized in pig and poultry productions use their land to grow corn or cereals for animal feed and do not maintain grass on their farm. In this scenario, we observe an increase in farms' average income and in land prices that, in this case, is explained by an increase in the farms' productivity. Environmental effects are far from negligible and are associated with a decrease in the use of treatment technology. The disadvantage of this option is that it is very expensive for the government.

5. Discussion and conclusion

Manure management is a key issue in the French Brittany region because of substantial nitrogen surpluses and water pollution by nitrates. Farmers must look for additional spreading surfaces to avoid reducing their herds, accentuating competition among farmers in the agricultural land market. The objective of this study was to analyse the impact of environmental policies on the land market and on the evolution of agricultural structures. To answer these questions, we first modelled the functioning of a land market using an agent-based modelling framework that accounts for land transactions and farmers' entry and exit. Next, we simulated several environmental policy scenarios inspired by the policy framework currently implemented or under consideration in France. Our model is different from other existing models of farmland market in the sense of its simplicity, which allows us to derive a set of structural, economic and environmental indicators measuring a broad set of impacts for these policies. Simulations confirm that the agent-based approach is useful in studying complex economic processes that cannot be easily addressed by analytical means and in comparing public policy instruments. From the results presented in the previous section, we stress three points that highlight the model's utility.

First, the same environmental benefit can be obtained in several ways. We showed a significant extensification of agricultural practices and the use of new technologies (in this case, the treatment of excess manure). These results are consistent with Gaigné and Ben Arfa's (2011) paper on the effect of nitrogen-related regulations on the location of dairy and pig farms. These authors showed that the spreading stress induced by the Nitrates Directive did not have a dispersive effect on animal production in the western part of France. On the contrary, it encouraged pig farmers to adopt new technologies such as effluent treatment, thus increasing the concentration of farms. The authors concluded that the strengthening of environmental constraints stimulates innovation and technological development, which makes it more effective from an environmental point of view.

Second, none of our simulated policy measures simultaneously improves environmental conditions and maintains the farmers' income, livestock production, and the number of farms with low costs for the global economy. We therefore argue that, more generally, a trade-off is required between economic and environmental priorities. Each of the Member States of the European Union should implement the Nitrate Directive. Our results highlight the reasons why the measures that France has taken are mainly based on nitrogen limitation. In fact, our analysis may reveal that the French government prioritizes small changes in farm structures to maintain agricultural employment despite the relatively limited improvement in environmental quality.

Third, we further note a reduction in land prices due to the increase in manure costs or the additional constraints on the use of spreadable areas. In accordance with economic theory, these political and economic incentives decrease the total wealth of the region and, consequently, the land rents generated by agricultural activities. However, this result may surprise experts on agricultural land markets in the region given that an increase in land prices is observed in the most constrained areas (Letort and Temesgen, 2014). In fact, because of land market regulations, French land prices are artificially low and, thus, far below most farmers' willingness to pay. Therefore, a significant increase in land prices occurs when competition among farmers is high, especially competition in securing spreadable areas for manure (Tesmesgen, 2014).The land market regulations are not considered in the current model and that is why the results show a decrease of land prices in accordance with economic theory, but that may differ with the price evolution observed in practice.

We are currently considering several improvements to our model, especially with respect to the empirical validation of results and sensitivity analysis. The use of ABMs in the literature is growing rapidly and is typically accompanied by an improvement in statistical methods for validating simulation results (Alden *et al.*, 2014). Further improvements to the model may complement the study of other environmental policies, such as setting up a collective treatment plant to study the spatial concentration of farms around such infrastructures or allowing farmers to export and trade their surplus manure. Finally, it would also be interesting to simultaneously model stronger environmental policies together with the abolition of milk quotas, which is likely to further foster competition among farmers on the land market.

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Annex A: Values of model parameters

Parameters	Values
Maximum share of profit used for land investment	
Intensive dairy farms	0.29
Extensive maize dairy farms	0.39
Grazing dairy farms	0.39
Intensive pig and poultry farms	0.10
Extensive pig and poultry farms	0.20
Intensive mixed livestock farms	0.24
Mixed livestock farms specializing in pig and poultry	0.19
Mixed livestock farms specializing in dairy production	0.27
Farmers' age	
Entry age	[25, 70 years]
Age at which the share of profit is at its maximum	[35, 65 years]
Age at which the share of profit is null	[73 years]
Economics	
Actualization rate	4 %
Input and output prices	2010
Transport cost	
Fixed costs – cereals	350 €/ha
Fixed costs – fodder crops	500 €/ha
Fixed costs – grassland	100 €/ha
Nonlinear costs	0.5 €/ha/km²
Environmental policies	
Nitrogen limit	170 kgN/ha
Fixed treatment costs	5.22 €/kgN
Quadratic treatment costs	5.10^{-5} €/kgN²

Annex B: Variability of some output variables simulated by the model

	Means	Standard errors	Confidence intervals
Land prices	6,995 €	290 €	[6 427 €; 7,564 €]
Number of farmers	55.53	3.45	[49; 62]
Number of pigs and poultry	7,788 LU	1,110 LU	[5,612 LU; 9,964 LU]
Number of cows	5,363 LU	290 LU	[4,795 LU; 5,931 LU]

Note : LU = Livestock Unit

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