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Abstract

The Bretagne region is an agricultural area located in the north-west of France. In addition to urban pressure, the competition for farmland is enhanced by strong environmental regulations and incentives. The objective of this paper is to study the determinants of farmland prices and especially the effects of environmental regulations to explain the spatial disparities observed in Bretagne. This paper mainly focuses on environmental policies which are intended to reduce the agricultural pollution of water with nitrates. Several environmental regulations have been implemented in the Bretagne region, which resulted in a complex zoning system with specific measures. To account for this local characteristic, we use the hedonic pricing model and take into account the potential spatial dependencies between farmland prices. For empirical application, we use a dataset of individual transactions in Bretagne from 2007 to 2010. The estimation results show an increase or a decrease in farmland prices in environmentally sensitive areas depending on the types of regulations applied in these areas. The results also emphasize the importance of spatial interaction in the farmland market.

Keywords: environmental policies, hedonic price function, spatial econometrics

JEL classifications: Q51, Q11, C21

Impacts des politiques environnementales sur le prix des terres agricoles en Bretagne

Résumé

La Bretagne est une importante région agricole située au nord-ouest de la France. En plus de la pression urbaine, les concurrences sur le marché de la terre agricole sont accentuées par les incitations publiques, qui sont très fortes en Bretagne pour la protection de l'environnement et de la qualité de l'eau. Cet article vise à mettre en évidence les différents facteurs qui influencent le prix de la terre agricole en Bretagne, et particulièrement les effets des régulations environnementales mises en place pour lutter contre les pollutions de l'eau par les nitrates d'origine agricole. Ces politiques ont abouti à la création de différentes zones environnementales sensibles soumises à différents types de mesures réglementaires ou incitatives. Un modèle de prix hédonique tenant compte des potentielles dépendances spatiales entre les prix est estimé à partir de données concernant toutes les transactions de terres agricoles notifiées par les notaires réalisées en Bretagne de 2007 à 2010. Les résultats obtenus montrent une augmentation ou une diminution du prix des terres agricoles dans ces zones environnementales sensibles en fonction du type de régulation appliquée. Les résultats montrent également l'importance des interactions spatiales sur le marché de la terre agricole.

Mots-clés : politiques environnementales, fonction de prix hédonique, économétrie spatiale

Classification JEL : Q51, Q11, C21

Influence of environmental policies on farmland prices in the Bretagne region of France

1 Introduction

The Bretagne region is an agricultural area located in the northwest of France[1]. Agricultural land covers approximately 65% of this region's total land area, which is higher than the French average (53%). This region has faced serious water pollution that can mainly be attributed to agricultural activities. Since 2001, a part of the Bretagne region has been in European litigation for failure to comply with the Directive of 1975 concerning the quality requirement for surface water that is intended for the abstraction of drinking water. In 2009, an enormous algal bloom was observed on the beaches of Bretagne, and this phenomenon intensified the recurring debate on the water quality in Bretagne and the ineffectiveness of the environmental policy measures in the agricultural sector. Nitrogen discharges associated with animal effluent and fertilizer were believed to be the main cause for the proliferation of the algal bloom, as algae decomposition on beaches produces toxic gases. The death of wild boars in one of the famous bays as a result of toxic gas further stimulated the public debate and the tensions between the agricultural and environmental lobbies. In 2012, the European Commission decided to refer France to the European Court of Justice for failure to comply with the Nitrates Directive of 1991. The case in question involves 39 water basins which are located in Bretagne, and the nitrate regulation that was allegedly violated limits organic fertilization. Farmers with excess manure must seek additional areas in which to spread manure to maintain or increase their herd size, which leads to increased competition between farmers which may increase the price of farmland.

In addition to the land pressure due to environmental regulations, the competition for farmland is intensified by strong urbanization effects, which are partly induced by the regional demographic dynamism. The non-agricultural use of farmland is common in those areas that surround major cities and peri-urban areas. Nearly half of the municipalities of Bretagne are located in an urban area. Furthermore, the region is bordered by 2,800 km of coastline. The regional urban development encourages investors to buy farmland in the most coveted areas in anticipation of a future conversion from agricultural use to residential use.

[1] According to the European nomenclature of regional levels (NUTS), Bretagne is one of the 22 NUTS2 regions of metropolitan France. The different levels of territorial units for the Bretagne region are presented in Annex A.

Consequently, these double-edged demands for farmland resources naturally increase the market clearing price.

However, the trend of farmland prices in France has remained relatively stable over time compared with other European countries (Ciaian *et al.* 2010, 2012). This relative stability is a result of land-market regulations which involve the French government and farmers' organizations. Indeed, the farmland market in France is governed by a set of laws and legal institutions, and regional land offices operate in farmland markets according to agricultural policy objectives or environmental concerns or to ensure infrastructure development. The relevant French legislation's main mission and responsibilities are to regulate the farmland market in every French region, to improve farmland accessibility for young farmers, to assist the smallest farms in enlarging their farms and to moderate land sale prices. In addition, farmland rental rates are constrained by administered boundaries, and the law limits the rights of landowners to protect farmers' access to farmland. These regulations often induce under-the-table payments in farmland transactions which are not registered as part of their observed prices.

The objective of this paper is to study the determinants of farmland prices and especially the effects of environmental regulations to explain the spatial disparities observed in Bretagne. This paper mainly focuses on environmental policies which are intended to reduce the agricultural pollution of water with nitrates. Several environmental regulations have been implemented in the Bretagne region, which resulted in a complex zoning system with specific measures. To account for this local characteristic, we use the hedonic pricing model and take into account the potential spatial dependencies between farmland prices.

The remainder of the paper is organized as follows: the first section briefly outlines the theoretical background of this study; the second section provides a brief description of the hedonic approach and its specification and; the third section discusses both the spatial autocorrelation problems and related econometric solutions. For empirical application, we use a dataset of individual transactions in Bretagne from 2007 to 2010 described in the fourth section. Results are presented and discussed in the fifth section.

2 Theoretical background

In response to environmental issues, there are several political tools which can be used to constrain farmers or induce them to change their behavior. We focus exclusively on policy instruments for water protection against pollution by nitrates from agricultural sources. In the first part of this section, we briefly present the environmental regulations which have been implemented in the Bretagne region, which resulted in complex zoning designed to protect environmentally sensitive areas. In the second part of this section, we use the theoretical framework developed by Bonnieux *et al.* (1998) to illustrate the expected effects of these environmental zoning regulations on farmland values.

Environmental policy instruments

In agricultural legislation, compulsory regulations are often used, especially to prevent water pollution caused by nitrates from agricultural sources. In 1991, the implementation of the nitrate directive was designed to improve water quality by promoting better management of animal manure and chemical nitrogen fertilizers. All of the member states of the European Union (EU) were required to draw up action programs applicable to areas with a high nitrate concentration. In 1993, the regional authorities identified and classified nitrate vulnerable zones (NVZ) according to the nitrate concentration of surface water. In such zones, the permitted organic manure cannot exceed 170 kg of nitrogen per hectare per year. In 1996, additional measures were implemented in designated areas (the French acronym is ZES for '*Zones d'Excédent Structurel*') which had higher environmental pressure from agriculture. These designated areas have animal densities resulting in a nitrogen surplus which exceeds the limit of the nitrate directive. In this case, farmers are forced to process or export their manure and are encouraged to reduce their herd of livestock. In 2001, the nitrate directive also motivated the creation of areas with complementary actions (the French acronym is ZAC for '*Zones d'Actions Complémentaires*') to improve the quality of water used in the production of drinkable water. These complementary actions are primarily intended to cover arable land. It is prohibited to spread more than 210 kg of nitrogen per hectare of livestock manure and mineral fertilizers. In addition, schedules define different periods when the application of fertilizers and manure is prohibited, and these schedules depend on the type of crops and fertilizers. The entire Bretagne region is classified as a nitrate vulnerable zone. Nearly half of the NUTS4[2] regions in Bretagne were ZES in 2006, and nearly one-third of the water basins are under the obligations of a ZAC. All of these environmental zones are constrained by different regulations, and furthermore, disregarding these regulations results in a financial penalty and a cut in direct payments following the eco-conditionality principle, which was established in 2005.

Other political schemes provide some incentives for farmers to voluntarily adopt agricultural practices which are more environmentally friendly. In return for changing their practices, farmers are supported financially to enable them to invest in farm equipment, or compensated for the loss of gains that is associated with the new practices. These economic incentives based on farmers' voluntary compliance are implemented in environmentally sensitive zones in the Bretagne region; indeed, these incentives are in place in the territories which are concerned about green algae proliferation, as described in the introduction. A national action plan was prepared in 2010 for eight designated water basins corresponding to bays and which are most strongly affected by algal blooms. The action plan aims to reduce nitrate flows by 30% to 40% before 2015, and this plan includes both curative and preventive measures which are no more stringent than those measures already existing in the ZES. In addition, this plan proposes voluntary measures to encourage the development of grassland-based production systems.

If no improvement in water quality is observed in these areas, then these measures, which were initially voluntary, may become compulsory for all farmers, as was the case for those areas which were concerned with the first European litigation. In 2007, nine water basins in the Bretagne region were still affected by the first European dissensions, which started in 2001. Following this, the French government decided in 2008 to strengthen its regulations and to prohibit the application of livestock manure and mineral fertilizers in amounts exceeding 140 kg or 160 kg of nitrogen per hectare per year (depending on the agricultural production). A specific payment, which decreases over five years, is then paid to farmers to compensate them for their resulting income losses and to finance the costs associated with manure management. In 2010, the European Commission stopped the legal process against France, as France had implemented its action plan and had largely complied with the regulations.

In summary, there are three specific areas with different policy instruments which can be used in France to limit the amount of nitrogen used by farmers. Farmers are constrained to respect

[2] The different levels of territorial units for the Bretagne region are presented in Annex A.

this limitation in ZAC. In territories concerned by green algae proliferation, the limitation is voluntary and is associated with financial compensation. Finally, although the regulation is compulsory for farmers in contentious areas, they receive a specific payment in return for complying with it. From a theoretical point of view, we analyze the effects of these different political instruments.

Modeling farmer's behavior

We examine these three cases of pollution regulations based on a constrained input. The theoretical model used is based on the model built by Bonnieux *et al.* (1998), which considers a farm's profit maximization problem with one constrained factor. In their study, they analyzed the behavior of farmers facing an environmental regulation and modeled their willing-to-accept to enter the environmental scheme. This corresponds to our second case. We calculate and analyze the results for the two others.

Let $x=(x_i,\, i=1,...I)$ be the vector of variable inputs, let $y=(y_j,\, j=1,...J)$ be the vector of outputs and let $z=(z_k,\, k=1,...K)$ be the vector of quasi-fixed factors such as land z_l, labor and equipment. The price vectors w and p are associated with the vectors x and y. The farm's profit maximization program is defined by:

$$\begin{cases} \max\limits_{x,y} p'y - w'x \\ F(x,y,z)=0 \end{cases} \tag{1}$$

where the function $F(.)$ represents the production technology. This profit function is continuous, non-decreasing in p, non-increasing in w, homogenous of degree one and convex in (p,w). The maximization of this problem leads to the optimal farm's demand x^* and supply y^*. We can rewrite the profit function derived from this problem so that it distinguishes the variable input which generates external effects x_c from the other effects x_{-c}. Then, the price vector w_{-c} is associated with the vector x_{-c}. We obtain the following reference total profit function:

$$\Pi\left(p,w,z\right)=\Pi R\left(p,w_{-c},x_c^*,z\right)-w_c x_c^* \tag{2}$$

where $\Pi R\left(p, w_{-c}, x_c^*, z\right) = \left[\max_{x,y} p'y - w_{-c}'x_{-c}; F(x_{-c}, x_c^*, y, z) = 0\right]$ and x_c * denotes the optimal value (without any constraint imposed by regulations) of the input x_c.

Case 1: Compulsory regulation

First, we consider the case where the factor x_c is constrained and $\overline{x}_c$ is the upper bound which is imposed by environmental policy. We have $\overline{x}_c < x_c$ *, which occurs when a compulsory regulation limits the use of nitrogen per hectare from livestock manure and mineral fertilizers. The farm's profit maximization problem is defined by:

$$\begin{cases} \max_{x,y} p'y - w'x \\ F(x, y, z) = 0 \\ x_c \leq \overline{x}_c \end{cases} \tag{3}$$

The resolution of this program leads to the following total profit function:

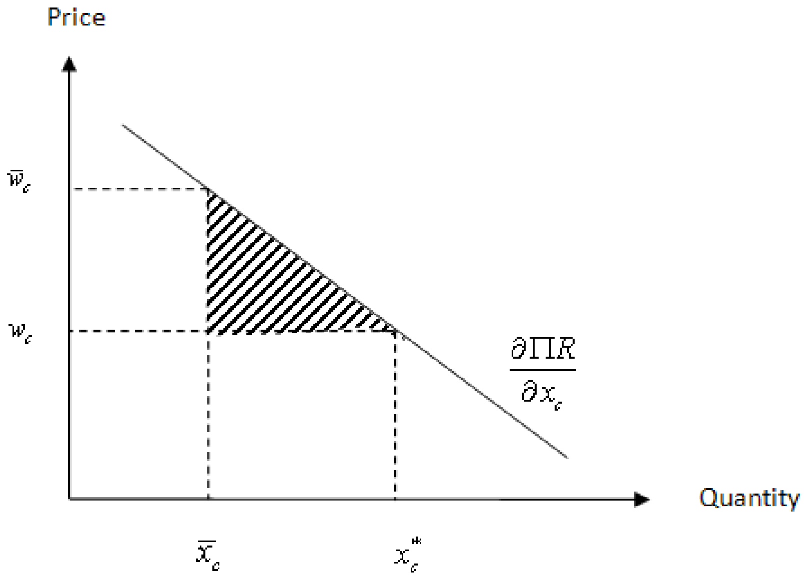
$$\Pi\left(p, w, \overline{x}_c, z\right) = \Pi R\left(p, w_{-c}, \overline{x}_c, z\right) - w_c \overline{x}_c \tag{4}$$

with the restricted profit function $\Pi R\left(p, w_{-c}, \overline{x}_c, z\right)$ obtained from the optimization problem (3); this function equals $\left[\max_{x_{-c}, y} p'y - w_{-c}'x_{-c}; F(x_{-c}, \overline{x}_c, y, z) = 0\right]$. Given that $\overline{x}_c < x_c$ *, any solution which deviates from the optimum leads to a loss of profit defined by the difference between (2) and (4), which is as follows:

$$\Delta\Pi_1 = \left[\Pi R\left(., x_c^*\right) - \Pi R\left(., \overline{x}_c\right)\right] - w_c\left[x_c^* - \overline{x}_c\right] \tag{5}$$

This loss of profit is due to the regulation and illustrated by the hatched area in Figure 1; this loss equals the producer's surplus variation, which is due to the decrease in the use of x_c relative to $\overline{x}_c$. The price $\overline{w}_c$ is the virtual price associated with the bound imposed by the environmental policy (Lau 1976). It corresponds to the price which would lead the allocation of $\overline{x}_c$ as input level maximizing the profit.

Figure 1: The loss of profit (case 1) and the willingness-to-accept (case 2)



Case 2: Voluntary adoption in return for financial compensation

In the second model, farmers may accept or refuse a limitation of nitrogen use. Farmers who participate in this environmental scheme receive financial compensation. A farmer voluntarily changes his practices and limits his use of nitrogen to a level $\bar{x}_c$ if the perceived subsidy ρ adequately compensates him for the loss of profit that is generated by the constrained factor (and vice versa). In accordance with Bonnieux *et al.* (1998), we suppose that a continuous choice is available to farmers and that the subsidy or premium is a decreasing function of the above upper bound $\bar{x}_c$ of x_c. The second farm-behavior model is defined by:

$$\begin{cases} \max\limits_{x,y} p'y - w'x + \rho(\bar{x}_c)\, z_l \\ F(x,y,z) = 0 \\ x_c \leq \bar{x}_c \end{cases} \qquad (6)$$

The total profit derived from this optimization problem has the following form (see Bonnieux *et al.* (1998) for more details and a proof):

$$\Pi\left(p, w, \bar{x}_c, z\right) = \Pi R\left(p, w_{-c}, \bar{x}_c, z\right) - w_c \bar{x}_c + \rho(\bar{x}_c) z_l \qquad (7)$$

where the restricted profit function $\Pi R\left(p, w_{-c}, \overline{x}_c, z\right)$ is obtained from the optimization problem (6); this function equals $\left[\max_{x_{-c}, y} p' y - w_{-c}' x_{-c} ; F(x_{-c}, \overline{x}_c, y, z) = 0\right]$.

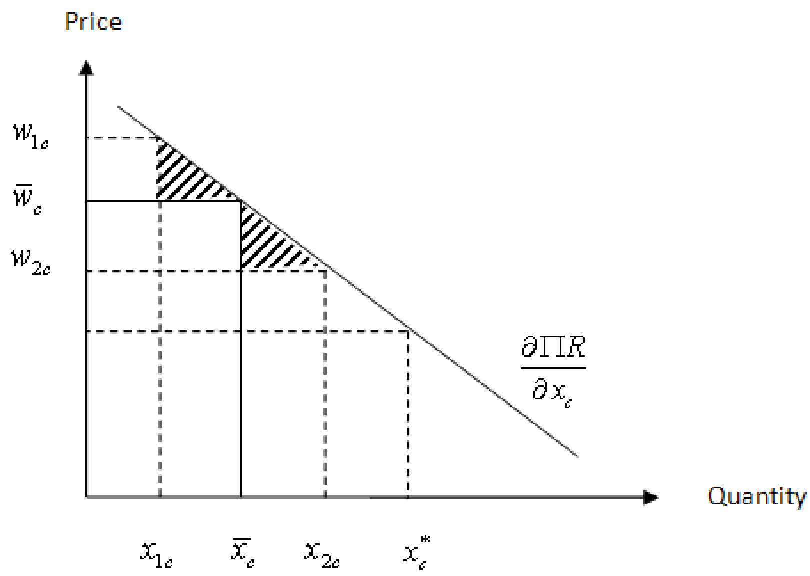
Farmers have an interest in participating in the environmental program if the subsidy is greater than the loss of profit, which is defined by $\Delta\Pi_1$ (5). As illustrated in Figure 1, in this case, the hatched area corresponds to the minimum willingness to accept limiting the use of x_c.

Case 3: Compulsory regulation compensating farmers with subsidies

In the third case, farmers are constrained to respect the regulation, but they receive a subsidy to compensate their resulting profit loss. The government has no interest in overcompensating farmers. In theory, the government may compensate exactly for the profit loss of each farmer, with compensatory payments equaling $\Delta\Pi_1$ (5). This is not usually what is observed in practice. Several factors can explain deviations.

Given the heterogeneity of farmers and of their agricultural practices, the government may provide the same average compensation to all farmers, because it lacks information at the individual farmer level or in order to reduce its administrative costs. Consequently, some farmers will be under-compensated and others over-compensated. On the one hand, if the average payment may compensate a farmer for a decrease in his input use from x_c^* to x_{1c} and if $x_{1c} < \overline{x}_c$, then the producer's surplus variation is more than offset by subsidies and, hence, this farmer can gain profit; this occurrence is illustrated by the hatched area in Figure 2. On the other hand, this same payment may compensate a farmer only for a decrease of the input use from x_c^* to x_{2c}, with $x_{2c} > \overline{x}_c$. In this case, the farmer faces a profit loss, which corresponds to the second hatched area in Figure 2. Consequently, the empirical effect of this political instrument can be positive for some farmers and negative for others but will be zero on average.

Figure 2: The gain and loss of profit (case 3)



This static model does not take into account dynamic processes and uncertainty. These limitations of the model can lead to biased results, if the regulations affect the farmers' income variability or future productivity opportunities.

In most situations, such biases will not change the hierarchy of the expected profit effect across these different regulations. The voluntary regulation stays more favorable for risk averse farmers because it replaces an uncertain gain of last input units by a certain public payment and farmers may opt out if better market or technical opportunities occur. In contrast, command and control regulations are not reversible.

The value of farmland depends on the expected future stream of earnings of this land. Hence an increase (respectively, a decrease) in the agricultural profit associated with the characteristics of a particular farmland results in the increase (decrease) in this particular farmland price. Consequently, we can expect to obtain a decrease in the farmland prices in areas constrained by compulsory regulations without compensations as in ZAC, and stable or decreasing prices in EU contentious areas; furthermore, we can expect stable or increasing prices in areas which are concerned with green algae proliferation, where voluntary measures may provide additional profit to some farmers.

3 Methodology

The main objective of this paper is to examine whether there are price differences between farmland inside and outside the environmental zones which are imposed by policies, and to control for any other factors influencing this value. For this purpose, we use the hedonic pricing model to analyze the factors which affect farmland values. First, we give a short literature review on the empirical studies which have applied the hedonic approach and methods to evaluate how public policies affect land values.

Literature review

There are two primary approaches to studying the determinants of land prices. The first approach is based on the discounted value of farmland and is known as the net present value (NPV) model. These models of farmland price are considered to be theoretically sound and are the most cited models in the literature on farmland prices (see, among others, Alston (1986) and Burt (1986)); they are based on the theoretical and empirical developments of the Ricardo capitalization formula. The present value of the land is established as the discounted sum of the future expected revenues that will be provided by the farmland. This approach is often used to explain the temporal evolution of the price of land in relation to macroeconomic variables or to study the influence of agriculture-supporting policies on farmland prices (Guyomard *et al.*, 2004; Ciaian *et al.*, 2012; Feichtinger and Salhofer, 2011).

The second approach, which was chosen for this study, relies on the construction of a hedonic price model. The theoretical foundation of the hedonic price method was developed by Lancaster (1966). In his seminal work, he observed that consumption goods are heterogeneous and that comparisons between them are difficult. Lancaster assumed that consumer utility is not directly derived from the consumption good but is derived from the characteristics or attributes of such a good. This decomposition of any heterogeneous consumption good into its homogenous attributes facilitates the comparison between goods. The hedonic price method estimates the implicit price of each attribute by regressing a good's price over its attributes. Rosen (1974) used the theoretical framework of Lancaster to analyze the functioning of the housing market and estimated a hedonic price function based on the characteristics of houses. The hedonic-price-function estimates were used to measure the implicit price of each house characteristic and to calculate the willingness to pay of consumers for each marginal change. Following this work, several problems were identified, including the potentially simultaneous choice between the house price and the quantities of certain characteristics as well as the correlation between the explanatory variables and the residuals (Epple, 1987).

This method was applied to the price of farmland by Palmquist (1989), who showed how to derive the bid function for a plot of farmland. Different plots of farmland are endowed with different characteristics in terms of soil quality, climate, irrigation potential and infrastructure. We assumed that a person buys a particular plot for its attributes and its location and that the price of this plot of land is determined by the willingness to pay of buyers for these specific characteristics. In addition, we assumed that no individual is able to influence the hedonic price equation, as the market clearing price would eliminate the excess supply and demand for each type of farmland. This approach has been widely used in the literature to study the prices of agricultural land in different countries, such as Georgia (Elad *et al.*, 1994), the United States (Bastian *et al.*, 2002), Northern Ireland (Patton and McErlean, 2003), France (Le Goffe and Salanié, 2005) and Finland (Pyykkönen, 2005). For example, Plantinga *et al.* (2002) showed how parcel characteristics and urban factors influence farmland sale prices in the United States. Similarly, Cavailhés and Wavresky (2003) analyzed the urban influence in the southern part of France. In addition, researchers' attention has also been devoted to the characteristics of buyers and sellers (see, among others, Harding *et al.* (2003) and Cotteleer *et al.* (2008)).

However, few empirical studies have addressed environmental policies and regulations. Le Goffe and Salanié (2005) analyzed the effect of the implementation of the Nitrate Directive in Bretagne from a hedonic price function for the 1994-2000 period. This implementation consists in a limit of 170 kg of organic nitrogen per hectare per year. The theoretical approach of their paper assumes that farms above this limit either buy the right to spread manure from farms that operate below the limit or buy additional land for the same purpose. Their analysis focused on pig production. In their empirical investigation, the authors showed that in regions characterized by high densities of pigs, the equivalent land rents increased by 1 € per kg of nitrogen[3]. This cost is higher than the farm-pollution tax rate (which is between 0.15 and 0.30 € per kg of excess nitrogen) but much lower than the estimated cost of manure treatment in dedicated plants (3 € per kg of nitrogen). These authors conclude that the regulation has

[3] This result considers organic nitrogen fertilization at a rate of 100 kg per hectare.

had some effect on farmland prices, which may reflect the fact that pig farmers were forced to deviate from their unconstrained profit-maximizing behavior.

Most of the economic studies which assess public policies focus on non-farm development in agricultural areas and on policies which are implemented to reduce urban sprawl. In particular, these studies analyze the effects of urban-development restrictions imposed by agricultural zoning on land values. Jaeger and Plantinga (2007) give a literature review of the economic and empirical studies on the effects of land-use regulations on property values in the United States (especially in the counties of Oregon). The hedonic price method is applied in the majority of these studies, as it can be used to identify the effects of policies on farmland prices. Furthermore, this method is often used to estimate the relationship between farmland values and environmental amenities. For example, Netusil (2005) examines whether there are price differences in Oregon between properties inside and outside environmental zones and controls for other factors which influence value. He uses a hedonic price method to examine how the proximity to environmental amenities is related to the sale price of a piece of land

The economists who investigate these issues have mostly relied on hedonic price models which include regulatory variables as right-hand-side determinants of property value. Furthermore, they include a dummy variable to distinguish parcels inside and outside a specific zoning area. In most hedonic studies, land-use regulations are assumed to be exogenous attributes of land parcels. However, many parcel characteristics which determine property values may plausibly be said to influence the local government's decision about how to implement its own regulations. Failure to control for these variables in a hedonic regression can bias the estimated effects of regulations. A few earlier studies recognized this problem and used the following econometric methods to address the endogeneity of regulations: propensity score matching, double difference, instrumental variables, or regression discontinuity (see Imbens and Wooldridge (2009) or Fougère (2010) for a review of the policies which are evaluated with econometric methods). For example, Lynch *et al.* (2007) examine the impact of agricultural easements on farmland sale prices in Maryland during 1994-1997 using both hedonic regression and propensity-score approaches. Landowners may have entered farmland preservation programs because the market value of their parcel was lower than that of other parcels. In that case, the authors were confronted to a sample selection problem and had to use an adapted econometric method.

The hedonic pricing model

Although our work is inspired by the work of Le Goffe and Salanié (2005), it differs from it in several respects. With respect to the environmental-policy factors, we focus on the effects of environmental zoning on farmland prices. The national and regional authorities have identified different environmental protection zones according to the nitrate concentration of the surface water or the nitrogen surplus. Each area is regulated by means of specific political tools. Farmers can be constrained by additional mandatory measures in one zoning area and encouraged to change their agricultural practices in exchange for financial support in another one. From an econometric point of view, our specification accounts for the potential spatial dependence of our observations.

We used different sets of explanatory variables to characterize the land and estimate its price. The variables describe the characteristics of the land, such as the size of a plot or the soil quality. These factors affect the productivity of the land, and therefore, the expected income from it. All of the supporting policies which are bound to the agricultural area of production, such as the manure-spreading rights and dairy quotas, can be capitalized on the land and were included in this model. In addition, variables which include the proximity of a coastline or a location in an urban-rural fringe area can represent the intensity of non-agricultural demand for land. Our model includes two additional sets of variables: i) variables which indicate the tenancy status of a plot of land (land under a tenancy contract or farmland without an ongoing tenancy contract) and; ii) variables which represent the environmental situation of the municipality of the transacted farmland. The simpler hedonic price function applied to the individual land-price observations is linear and encompasses the preceding sets of variables. This function can be written as follows:

$$P = \alpha + \beta X + \gamma Z + \zeta S + \delta F + \eta E + \varepsilon \qquad (8)$$

In the above function, P is the vector of observed prices of transacted plots of farmland, X is the matrix of agricultural characteristics of the plot, Z is the matrix of its non-agricultural characteristics, S is the array of policy instruments which are related to the farmland, and F and E describe the institutional and environmental situations of the plots of farmland, respectively. The stochastic error term is represented by ε.

Several functional forms can be used in hedonic studies. The functional form of the hedonic regression equation can be linear, semi-logarithmic, or log-log. The most common specification is the semi-logarithmic form, and in this form, each parameter estimate directly provides the percentage of the price which depends on the corresponding characteristics. In addition, each parameter measures the relative change of the price following a unit change in the respective characteristic. Furthermore, we also chose the semi-log specification for its implementation simplicity[4].

With respect to the environmental regulations, we simply include a dummy variable to distinguish parcels inside and outside each environmental zoning area. The environmental zoning area is considered an exogenous determinant of land prices; this assumption is needed for unbiased estimation of the parameters in the model. We assume that the government does not consider land values in making zoning decisions and that nothing differentiates environmental zones in other areas except for their water-quality indexes. In this case, the use of specific econometric methods is not required, even if they allow a more flexible model.

4 The econometric strategy

This section presents econometric issues. Some of them are specific to the hedonic pricing model, others are related to spatial databases. The estimation method we used is described and justified.

Standard econometric issues

Although multicollinearity is often an issue in hedonic pricing models, no definitive rules exist for determining whether it is a serious problem or not. We can make a judgment by checking related statistics, such as variance inflation factors (VIF), eigenvalues and condition indices. The VIF criterion shows how multicollinearity has increased the instability of the coefficient estimates[5]. In addition, multicollinearity can be detected using eigenvalues and condition indices[6]. An eigenvalue of zero means that there is perfect collinearity among the independent variables, and very small eigenvalues imply severe collinearity, which indicates that small changes in the data values may lead to large changes in the estimates of the

[4] The Box-Cox transformation is frequently used because of its flexibility. Three reasons motivated the choice of the log-linear form: the interpretation of the results is simpler, it is easier to adapt to spatial autocorrelation, and several studies have shown that the results change little between the two models (Le Goffe and Salanié, 2005).

[5] According to Kennedy (1985), a VIF greater than 10 indicates the presence of this problem.

[6] Values greater than 15 indicate a possible problem with collinearity while values greater than 30 indicate a serious problem.

coefficients. The condition indices are computed as the square roots of the ratios of the largest eigenvalue to each successive eigenvalue. In our analysis, all of these criteria suggest that there is no serious multicollinearity problem.

In general, individuals simultaneously choose the price of a plot of land and its attributes, which generates an endogeneity problem (Epple, 1987). This problem is especially prevalent in the housing market, as a buyer simultaneously chooses the price and the size of his house. In this case, instrumental variables are needed to obtain unbiased estimates. For example, individual characteristics of buyers and sellers can be used as valid instrumental variables (Rosen, 1974). However, this endogeneity problem is less obvious in the farmland market. We assume that a farmer has not necessarily made the choice of the parcel size, which is therefore considered an exogenous variable in our model.

Problems of spatial autocorrelation

When data have a spatial dimension, two specific issues must be considered: spatial heterogeneity and spatial autocorrelation. The municipalities in Bretagne are highly heterogeneous, and part of this heterogeneity is controlled by the inclusion of the following municipality characteristics in the set of explanatory variables: the population density; whether the municipality is located in a suburban area or not and; the proximity to the coastline. If unobserved spatial heterogeneity remains, then we are faced with a problem of heteroskedasticity and/or the instability of the model parameters which vary systematically with respect to location (Le Gallo, 2000b). This unobserved heterogeneity can be accounted for by correcting for possible heteroskedasticity and/or using standard econometric methods (*e.g.*, random parameter models).

In contrast to the treatment of spatial heterogeneity, the treatment of spatial autocorrelation requires specific econometric methods. Spatial autocorrelation is defined as the correlation of a variable with itself according to the geographical pattern of observations. This correlation can consist in spatial dependence between the observations of the endogenous variable, spatial dependence between observations of exogenous variables or spatial dependence between the error terms. This problem is typically caused by omitted variables which have spatial dependence. In our case, the sale price of farmland may be affected by the value given to the surrounding farmland and by these surroundings' attributes. Location factors, such as the demographic pressure and the urban geographical structure of the area, are the primary factors which influence the price of farmland in addition to its production value. Spatial autocorrelation destroys the independence of observations which is assumed to exist in the usual econometric methods, such as ordinary least squares (OLS). Therefore, it is necessary to detect the presence of such correlations.

There are strong and complex links between spatial dependence and spatial heterogeneity. Poor model specification or the omission of explanatory variables can cause heteroskedasticity and lead to spatial autocorrelation in the error terms (Le Gallo 2000a, 2000b, 2002). Therefore, it is difficult to distinguish between the effects of autocorrelation and heterogeneity. Similarly, the correction of a problem which is linked to the spatial dimension of the data is likely to have side effects on other potential problems. For example, the inclusion of explanatory variables in the model to control for spatial heterogeneity is likely to reduce or eliminate the spatial autocorrelation of errors. In addition, an autoregressive model specification with a spatially lagged endogenous variable is likely to capture the influence of the omitted variables on the dependent variable and reduce the presence of the spatial autocorrelation of the error terms. As a result, it is difficult to detect a specific dependence effect in the presence of different forms of spatial dependence and heterogeneity.

The standard methods for testing and accounting for spatial autocorrelation were developed in the late 1970s. Since 2000, these methods have been improved and applied to various empirical studies. In parallel, new theoretical approaches have been developed, such as economic geography; in addition, the availability of spatial data has significantly increased. To test and capture the spatial interdependence between observations, we must consider the geographical position of the farmland. Although we have information on the municipalities in which sales occur, we do not know the exact position of the transacted land in each municipality. Thus, we began with the assumption that the spatial interaction between two farmland sales depends on the distance between the municipalities in which the farmland is located. A spatial weight matrix is used to represent this interaction. A weight matrix enables the connection of each observation with the other observations according to their relative geographical locations. If y is a spatial variable and W is the weight matrix, then we can measure the intensity of the overall effect of the *i*th observation's values in space using:

$$[Wy]_i = \sum_{j=1}^{N} w_{ij} y_j \tag{9}$$

This notion of spatial lag is important because it allows introducing the effects of spatial autocorrelation in the econometric models. The weight matrix can be written in different ways. The most frequently used technique in the literature (Patton and McEarlen, 2002; Pyykkönen, 2005) consists in inserting the inverse of the squared distance for each pair of geographical locations into the matrix to represent how the municipalities are spatially connected. Because we lacked the precise location of farmlands within their municipalities, we used the municipalities' areas to calculate the distance between two hypothetical plots of farmland which are randomly located in the same municipality. Above a certain distance between two municipalities, we assumed that the spatial interaction is zero. The choice of this distance threshold depends on the size of the farmland market in our studied area. By convention, the diagonal elements of the matrix are equal to 0. These matrices are often normalized such that the sum of each row is set to 1.

The spatial lag autoregressive model (the SAR model), which is characterized by the autocorrelation of the endogenous variable, is written as follows:

$$P = \alpha + \rho WP + \mu Q + \varepsilon \qquad (10)$$

where Q includes all of the characteristics' variables. This specification accounts for the interactions which may exist between neighbors in determining the selling price of farmland. The second term of the right-hand side of (10) is the spatially lagged term, which should be treated as an endogenous variable. OLS is not appropriate for this model because such an estimator would be biased and inefficient. The specification of the spatial error model (the SEM model) with the spatial autocorrelation of the error terms is written as follows:

$$\varepsilon = \lambda W\varepsilon + v \qquad (11)$$

The error term is split into the $\lambda W\varepsilon$ term and the v term, which refers to the true independent homoskedastic residual term with zero mean and constant variance. In this case, the OLS estimator is unbiased but inefficient. The details of both models were developed in the work of Lesage and Pace (2009). In addition, there is a model which combines both a lagged endogenous variable and the spatial correlation of error terms; this model is known as the spatial auto-correlation model (the SAC model).

The spatial Durbin model (the SDM model), which is characterized by a spatial lag of the dependent variable and a spatial lag of the explanatory variables, is written as:

$$P = \alpha + \rho WP + \mu WQ + \varepsilon \qquad (12)$$

Since 2000, those farmland-market studies which use the hedonic price approach have focused on the potential spatial interactions between neighboring transactions. Elad *et al.* (1994) segmented the land market into different local submarkets to measure spatial heterogeneity by estimating a specific hedonic price function for each submarket. Furthermore, Patton and McErlean (2003) introduced advanced spatial econometrics to estimate a hedonic price model for Northern Ireland farmland. Their results showed that there are many spatial interactions in this market: spatial heterogeneity and spatial dependence exist among the observations of the endogenous variable. Because ignoring these effects could lead to biased estimates, these results suggest that it can be difficult for an owner to identify the value of his own farmland's characteristics and to establish the appropriate price. In this case, potential sellers of farmland set prices according to the historic sale prices of nearby plots even if these plots have different characteristics. This mimetic behavior introduced direct influence of one transaction on other neighboring transactions.

The literature contains various tests for spatial autocorrelation which are based on the Moran test and the statistical test of the Lagrange multiplier (LM); these tests can detect the presence of several forms of spatial dependence. The methodology and explanation of these tests are largely presented in the works of Le Gallo (2000) and Lesage and Pace (2009). In situations in which both types of dependence exist, Anselin and Rey (1991) proposed to retain the model which corresponds to the highest statistical test value. Pyykkönen (2005) and Patton and McErlean (2003) followed this rule and estimated a model with lagged endogenous variables to describe the farmland market.

Econometric methods

Maximum likelihood (ML) is consistent for spatial models. The first step in the adapted ML approach is to estimate part of the first-order conditions. In the second step, the solutions of the first step are introduced into the log-likelihood function, which is 'concentrated' because it depends on fewer parameters (see Le Gallo (2000, 2002) for the spatial models' specification and estimation within the ML method). Much of the spatial econometrics literature has focused on ways to avoid maximum likelihood estimation because of computational difficulty. Patton and McErlean (2003) estimated this model using an instrumental variable method based on the White estimator of the variance-covariance matrix, which is robust for any form of heteroskedasticity. However, it was shown that tests for heteroskedasticity are not always reliable in the presence of the spatial autocorrelation of error terms (Anselin and Griffith, 1988). Lagged explanatory variables are generally used as instruments (Kelejian and Robinson, 1992). Pyykkönen (2005) compared an adapted maximum likelihood (ML) estimator with the preceding instrumental variable (IV) method to estimate a model with lagged endogenous variables which were applied to the Finnish farmland market. He found that the results of these two approaches are similar.

There is no implementation of maximum likelihood (ML) estimation for the likelihood functions of spatial autocorrelation models with normal but heteroskedastic disturbances, although Anselin (1988) has derived these likelihood functions. Thus, less efficient methods based on instrumental variables (IV) must be applied if the disturbance terms might be heteroskedastic. The heteroskedasticity of spatial autoregressive models has led to several discussions (Anselin, 1988; Kelejian and Prucha, 2007; Lesage and Pace 2009). Yokoi (2010) confirms the efficiency of ML estimation in cases with heteroskedastic disturbances using Monte Carlo simulations. Furthermore, some authors, such as Lesage and Pace (2009), have recently provided a new approach to reduce computational tasks and to construct maximum likelihood estimates in only a matter of minutes.

Bayesian regression methods implemented with diffuse *a priori* information can replicate maximum-likelihood-estimation results. The parameters are considered to be random variables with a distribution. Some extensions are available with this Bayesian approach, and they are especially ideal for dealing with heteroskedastic disturbances (see Lesage (1997, 1999) and Lesage and Pace (2009) for a description of the Bayesian spatial autoregressive models). Dantas *et al.* (2010) used this method to analyze the spatial effects of zoning on housing prices on the French coast. In this paper, heteroskedasticity is corrected using the Bayesian simulation methods proposed by Lesage and Parent (2006) and Lesage and Pace (2009). These methods do not require specifying an arbitrary form of heteroskedasticity. Furthermore, they have the advantage of supporting the uncertainty on both a weight matrix which is exogenously fixed and the explanatory variables which are used in the model (Lesage and Fisher, 2007).

In this paper, we estimate several models: the spatial models SAC, SEM, SAR and SDM are estimated by both the maximum likelihood method and the Bayesian approach with heteroskedastic disturbances. The estimation quality for these models is compared by means of several criteria and presented in the following section.

5 The empirical model

All of the information on farmland transactions in Bretagne was derived from the Perval database. This dataset gathers all transactions of farmland sales which were reported by the notaries in Bretagne from 2007 to 2010. We selected observations of farmland with no buildings or forested land and farmland purchased by farmers. After eliminating transactions which correspond to the tails of the distribution of prices, we obtained a total of about 4,000 observations from 2007 to 2010 to use in the analysis. Additional variables describing the location of the traded farmland were obtained from several databases. The descriptions and summary statistics of these variables and databases are presented in Table 1.

The price of farmland is defined in euros per hectare after excluding the transaction costs (trading costs) and notary fees[7]. The nominal price was deflated by the producer price index (with base 100 in 2005). The total size of the traded farmland was used as an explanatory variable in the model, and the agronomic quality of the soil was approximated by several variables. Furthermore, the "potentiality for irrigation" was considered. The variables indicate whether the sold farmland has a system of irrigation infrastructure, a drainage facility or a retention pond. An index of soil quality was built at the NUTS5 level, indicating whether the soil is primarily clay, silty clay or sandy. The climatic conditions of a municipality are approximated by the level of precipitation, the average temperature and the radiance. Finally, the proportion of vegetable farms in the utilized agricultural area (UAA) of the municipality in which the farmland sale is located approximates the agronomic quality of land.

The geographic location of farmland is another important factor. Therefore, we considered the following four variables: a variable representing the geographical proximity to the coast; a variable identifying whether the parcel is located in an urban area[8]; the distance between the farmland and the nearest urban center and; the population density. These variables approximate the competition-based effects of urbanization and tourism.

[7] In accordance with the practice of most agricultural economists, we estimate the price of land per hectare to eliminate the size effect. This is not an important constraint given that each traded fund is relatively homogenous (because it lacks housing and forest). Moreover, it allows limiting the potential heteroskedasticity problems.

[8] A municipality is considered to be in an urban area if it belongs to an urban area (a center which offers at least 10,000 jobs and is not located in the midst of another urban center) or a suburban area (all of the municipalities in the urban area excluding the pole).

Table 1: Descriptive statistics of the variables

Variables	Unit	Level	Mean	Std. err.	Source
Prices of the sold farmland plots	€/hectare	Plot	4016	2974	Perval
Agricultural Factors					
Area of the plot	hectare	Plot	6.85	10.08	Perval
Possibility of irrigation	yes=1/no=0	Plot	0.01	-	Perval
Vegetable share in municipality UAA	%	Municipality	0.06	0.15	AC 2000
Soil quality (reference: other soil quality)			-	-	
Clay soils	yes=1/no=0	Canton	0.38	-	GIS-Sol
Silty clay soils	yes=1/no=0	Canton	0.31	-	GIS-Sol
Sandy soils	yes=1/no=0	Canton	0.01	-	GIS-Sol
Grassland	yes=1/no=0	Plot	0.28		Perval
Climate index					
Total precipitation	mm	Municipality	986.38	157.82	Météo-France
Atmospheric radiation	J/cm²	Municipality	104.10^4	2.32	Météo-France
Average temperature	°C	Municipality	11.47	0.37	Météo-France
Non-Agricultural factors					
Urban zone	yes=1/no=0	Municipality	0.50	-	Built variable
Coastline proximity	yes=1/no=0	Canton	0.24	-	Built variable
Influence density	inhab/km²	Municipality	81.12	108.86	INSEE 2008
Distance between land and urban pole	km	Plot	21.66	10.71	Built variable
Agricultural Policy factors					
Milk quota	1000 litre/ha	Municipality	2.82	0.99	AC 2000
Single farm payments	€/ha	Canton	291.99	40.31	DRAAF
Farmland Policy factors					Perval
Rented land	yes=1/no=0	Plot	0.57	-	
Environmental Policy factors					
Total nitrogen load	kg N/ ha	Municipality	117.83	43.95	AC 2000
Green algae areas	yes=1/no=0	Municipality	0.03	-	Built variable
Contentious areas	yes=1/no=0	Municipality	0.08	-	Built variable
ZAC areas	yes=1/no=0	Municipality	0.56	-	Built variable
Others variables					
Temporal dummy 2008	yes=1/no=0	Plot	0.27	-	Built variable
Temporal dummy 2009	yes=1/no=0	Plot	0.25	-	Built variable
Temporal dummy 2010	yes=1/no=0	Plot	0.21	-	Built variable

*Note: the agricultural census (AC) was conducted in 2000 and 2010 but the authors did not have access to the 2010 data. INSEE (*Institut National de la Statistique et des Etudes Economiques*) provides the general census of the French population, which was conducted in 2008. DRAAF (*Direction Régionale de l'Alimentation, de l'Agriculture et de la Forêt*) is the agricultural local authority which implements the policy defined by the national government and the European Union in the region. The specific databases GIS-Sol and Météo-France provide indexes on pedo-climatic conditions.*

Source: various databases (see note) – authors' calculation

Agricultural-policy factors must be considered in the course of explaining farmland prices. For example, milk quotas or payment entitlements transferred with farmland are likely to have a positive effect on land prices. The milk quota at the municipality level was included to approximate the probability that the exchanged land is associated with a milk quota. The average single-farm-payment entitlements at the NUTS4 level, which were provided by the local authorities, are also included in the model.

Another important characteristic of a plot of land is its rental status. If land is sold while still rented, we can suppose that it will be sold more cheaply (Lefebvre and Rouquette, 2011). In this case, there are two possible situations: firstly, the farmland was purchased by the farmer who rented the land before the transaction, and because he has the right of preemption on this land, the sale price will likely be lower; secondly, the owner wants to sell his land but it is already rented by a farmer who does not want to buy it. In this case, the land is less attractive to potential buyers because, except for those who want to invest in land rather than occupy it, they won't be able to farm the plot themselves before the already existing rental contract terminates.

With respect to the environmental-policy factors, the demand for manure spreading on farmland was measured by the nitrogen-pressure indicator at the municipality level, as designed by Le Goffe and Salanié (2005). Data on the nitrogen load which results from the total animal production were directly calculated based on the 2000 agricultural census (AC) of the French agriculture ministry database[9].

The demand for farmland was expected to vary in environmentally sensitive areas. Three dummy variables indicate, respectively, a location in one of the bays which are targeted by the national plan against algal blooms, a location in one of the areas covered by environmental litigation, and a location in one of the ZAC. Furthermore, these variables are crossed with the total nitrogen load to account for the fact that the impacts of these regulations are even more important than the strength of the nitrogen pressure.

Finally, temporal dummies are integrated in the model to account for temporal variation.

The choice of the model was based on statistical tests. As a first step, the model was estimated using OLS. From the obtained results, tests based on the Lagrange multiplier and the likelihood ratios were performed to detect autocorrelation. Another test was performed from the SAR model to confirm the presence of spatial-error dependence. All of these statistical tests, which are presented in Table 2, provide evidence of spatial correlation in the residuals and in the dependent variable (see Annex B for a description of the properties of the coefficient estimates in cases of misspecification).

[9] This AC 2000 variable can be assumed to be exogenous in our regression without any problem.

Table 2: The statistical tests for spatial autocorrelation

Test	Model	Value	Probability	Chi-squared
Moran test	OLS	5.04	<0.001	-
LR test	OLS	19.93	<0.001	6.635
Wald test	OLS	63.48	<0.001	6.635
LM test	OLS	22.85	<0.001	17.611
LM test	SAR	25.59	<0.001	6.635

Source: authors' calculation

Given the large number of binary variables, it did not seem useful to introduce a lag in the explanatory variables and estimate an SDM model. Thus, three estimates were performed: the SAR model defined by (10), the SEM model defined by (11) and the SAC model (without the specification of two different weight matrices). All of the spatial models were estimated using the maximum likelihood method and the Bayesian approach. All of the utilized codes were developed by Lesage in Matlab and are available on his website[10].

We set the weighting matrix elements to 0 if the distance between the two corresponding municipalities is greater than 10 km. For larger distances, we assumed that there was no spatial interaction between the endogenous variables. Various estimates were performed using different threshold distances. Our choice was based on R^2 and log-likelihood results. However, it must be emphasized that the results appear to be insensitive to the choice of this threshold distance if it is between 10 km and 30 km.

The estimated coefficients from the three methods are shown in Tables 3 and 4. Note that Pace and Lesage (2006) distinguished between direct and indirect effects. In instances in which the model contains spatial lags of the explanatory or dependent variables, the interpretation of the parameters is more complicated. In fact, a change in the explanatory variable for an observation can potentially affect the dependent variable in all other observations. The average direct effect represents the average response of the dependent variable according to the independent variables. This interpretation is similar to the typical interpretations of regression coefficients, and it measures the effects of change on the *i*th observation of Q on P_i. In contrast, the average indirect effects measure the effects of changes in the *i*th observation of Q on P_j for $j \neq i$. Lastly, the average total effects measure how changes in a single observation influence all observations. For the continuous variables,

[10] http://www.spatial-econometrics.com/

the parameters were multiplied by 100 to provide the percentage of the change in price which results from a unit increase in the quantity of the attribute. Similarly, for the binary variables, the parameters were also multiplied by 100 to provide the percentage of the change in price which results from the introduction of characteristics relative to the baseline.

6 Results

Table 3 presents the average direct effects which are estimated from the spatial models by ML and the Bayesian approach. Table 4 presents the average indirect (spillover) effects. The average total effects are obtained by adding the direct and indirect effects.

The estimation quality, the coefficient estimates and the inference of the parameters are relatively similar between the models and econometric methods used. Nevertheless, we can note some differences. The main difference between the SAC and SAR models is that the indirect effects are more important for the SAR model because of the higher parameter ρ (which is associated with the lag-dependent variable). Although the parameter ρ is not significantly different from zero in the SAC model estimated by ML, the parameter λ which is associated with the lag error term is highly significant. There is little difference between the coefficients estimated by ML and the Bayesian approach, except for the estimation of certain parameters in the SAC model, which is especially true for the spatial parameters and the parameter associated with environmental zoning. According to the log-likelihood value and the R^2 value, the SAC model seems to be the best model.

The pedo-climatic conditions have important effects on farmland prices. Clay and silty clay soils are more expensive by about 8% and 11%, respectively, than others soils if we consider only direct effects. Similarly, clay and silty clay soils are 6% and 13% more expensive if we consider the total effects, respectively. Grassland is less expensive than cropland by about 5%. In addition, lands located in wetter and colder areas are *ipso facto* cheaper. The location of farmland also influences its price. On average, the most expensive lands are found near the coast or near an urban pole. This increase can be explained by the fact that some individuals bought farmland which was well-located at higher prices for speculation, as they expected a conversion into residential or industrial use.

Table 3: Coefficient estimates. Average direct effects

Variables	SAR model		SEM model		SAC model	
	ML	Bayesian	ML	Bayesian	ML	Bayesian
Model selection criteria						
R^2 criteria	0.2795	0.2701	0.2865	0.2842	0.2878	0.3166
Log-likelihood	-768.9527	-	-764.8453	-	-764.5311	-
Parameter ρ	0.1440***	0.1500***	-	-	-0.0660	-0.8688***
Parameter λ	-	-	0.2200***	0.2204***	0.2760***	0.7137***
Constant	6.5472***	7.0255***	7.6143***	7.9900***	8.1221***	14.9385***
Agricultural Factors						
Area of the plot	0.0007	0.0006	0.0008	0.0007	0.0008	0.0006
Possibility of irrigation	0.0243***	0.0632	0.0211	0.0450	0.0235	0.0402
Vegetable share in UAA	1.3603***	1.4293***	1.3997***	1.4393***	1.4097***	1.5073***
Soil quality						
Sandy soils	-0.0275	-0.0154	-0.0242	-0.0111	-0.0191	0.0313
Clay soils	0.0869***	0.0770***	0.0843***	0.0791***	0.0845***	0.0821***
Silty clay soils	0.1090***	0.1009***	0.1067***	0.1036***	0.1071***	0.1072***
Grassland	-0.0546***	-0.0394***	-0.0568***	-0.0502***	-0.0572***	-0.0511***
Climate index						
Total precipitation	-0.0005***	-0.0005***	-0.0005***	-0.0005***	-0.0005***	-0.0005***
Atmospheric radiation	<0.0001***	<0.0001***	<0.0001***	<0.0001***	<0.0001***	<0.0001
Average temperature	-0.1105***	-0.1327***	-0.1018***	-0.1207***	-0.0995***	-0.1032
Non-Agricultural factors						
Urban zone	-0.0040	0.0155	0.0046	0.0088	-0.0047	0.0156
Coastline proximity	0.0724***	0.0759***	0.0776***	0.0779***	0.0771***	0.0701*
Influence density	0.0005***	0.0004***	0.0004***	0.0004***	0.0005***	0.0005***
Distance to an urban pole	-0.0065***	-0.0059***	-0.0066***	-0.0062***	-0.0067***	-0.0064***
Agricultural Policy factors						
Milk quota	0.5000***	0.5500***	0.5400***	0.5600***	0.5500***	0.6000***
Single farm payments	0.0007***	0.0007***	0.0007***	0.0006***	0.0007***	0.0007
Farmland Policy factors						
Rented land	-0.1296***	-0.1570***	-0.1299***	-0.1448***	-0.1298***	-0.1416***
Environmental Policy factors						
Total nitrogen load	0.0019***	0.0019***	0.0019***	0.0020***	0.0019***	0.0021***
ZAC areas	0.0640	0.0270	0.0660*	0.0482*	0.0672	0.0678
ZAC areas * nitrogen load	-0.0005	-0.0004*	-0.0005**	0.0012**	-0.0006*	-0.0006
Green algae areas	-0.1895**	-0.0615	-0.1785*	-0.1188*	-0.1729*	-0.1120
Green algae areas * nitrogen load	0.0009***	0.0004***	0.0008	0.0006	0.0007***	0.0006
Contentious areas	-0.1572*	-0.0904*	-0.1546*	-0.1146*	-0.1548*	-0.0587
Contentious areas * nitrogen load	0.0016	0.0010	0.0016***	0.0020***	0.0016*	0.0008
Others variables						
Temporal dummy 2008	0.0436***	0.0386***	0.0449***	0.0414***	0.0451***	0.0448
Temporal dummy 2009	0.0358*	0.0436***	0.0411***	0.0440***	0.0428***	0.0529
Temporal dummy 2010	0.0514***	0.0490***	0.0544***	0.0535***	0.0549***	0.0548

*Note: ***, **, and * mean that the coefficient estimates are statistically significant at the 1%, 5% and 10% levels, respectively.*

Source: authors' calculation

In our sample, only 50% of the sold farmland was already leased (*i.e.*, there was an ongoing tenant contract at the time of the sale). As expected, nearly 90% of this farmland was purchased by the tenant farmer who rented the land before the sale. A study on the French farmland market from 1997 to 2010 (Lefebvre and Rouquette, 2011) showed that leased farmlands were sold at a 15% less expensive price than non-leased farmlands. This effect was partly caused by the French legal status of agricultural tenancy, which gives an automatic priority to tenants who choose to buy the land which they farm and thus reduces the competitive mechanisms. Our results confirm that land sold to its former tenant farmer is less expensive than other land (indeed, such land is between 13% and 16% cheaper if we consider only direct effects, and it is between 15% and 19% less expensive if the spillover is included).

Table 4: Coefficient estimates. Average indirect effects

Variables	SAR model		SEM model		SAC model	
	ML	Bayesian	ML	Bayesian	ML	Bayesian
Agricultural Factors						
Area of the plot	0.0001	0.0001	-	-	<0.0001	-0.0003
Possibility of irrigation	0.0040	0.0112	-	-	-0.0014	-0.0185
Vegetable share in UAA	0.2309***	0.2533***	-	-	-0.0891	-0.6915***
Soil quality						
Sandy soils	-0.0048	-0.0029	-	-	0.0011	-0.0143
Clay soils	0.0145***	0.0136***	-	-	-0.0055	-0.0377***
Silty clay soils	0.0183***	0.0179***	-	-	-0.0069	-0.0492***
Grassland	-0.0093***	-0.0070***	-	-	0.0036	0.0234***
Climate index						
Total precipitation	-0.0001***	-0.0001***	-	-	<0.0001	0.0002***
Atmospheric radiation	<0.0001*	<0.0001*	-	-	<0.0001	<0.0001
Average temperature	-0.0185*	-0.0235*	-	-	0.0064	0.0472
Non-Agricultural factors						
Urban zone	-0.0008	0.0027	-	-	0.0002	-0.0071
Coastline proximity	0.0121***	0.0134***	-	-	-0.0049	-0.0321*
Influence density	0.0001***	0.0001***	-	-	0.0000	-0.0002***
Distance to an urban pole	-0.0011***	-0.0011***	-	-	0.0004	0.0029***
Agricultural Policy factors						
Milk quota	0.5900***	0.1000***	-	-	-0.0300	-0.2800***
Single farm payments	0.0001	0.0001	-	-	<0.0001	-0.0003
Farmland Policy factors						
Rented land	-0.0220***	-0.0278***	-	-	0.0082	0.0648***
Environmental Policy factors						
Total nitrogen load	0.0003***	0.0003***	-	-	-0.0001	-0.0010***
ZAC areas	0.0109	0.0049	-	-	-0.0043	-0.0311
ZAC areas * nitrogen load	-0.0001	-0.0001	-	-	<0.0001	0.0003
Green algae areas	-0.0316	-0.0109	-	-	0.0109	0.0512
Green algae areas * nitrogen load	0.0001	0.0001	-	-	<0.0001	-0.0003
Contentious areas	-0.0269	-0.0162	-	-	0.0099	0.0268
Contentious areas * nitrogen load	0.0003	0.0002	-	-	-0.0001	-0.0004
Others variables						
Temporal dummy 2008	0.0074	0.0068	-	-	-0.0029	-0.0205
Temporal dummy 2009	0.0061	0.0077	-	-	-0.0027	-0.0243
Temporal dummy 2010	0.0087*	0.0087*	-	-	-0.0035	-0.0251

*Note: ***, **, and * mean that the coefficient estimates are statistically significant at the 1%, 5% and 10% levels, respectively.*

Source: authors' calculation

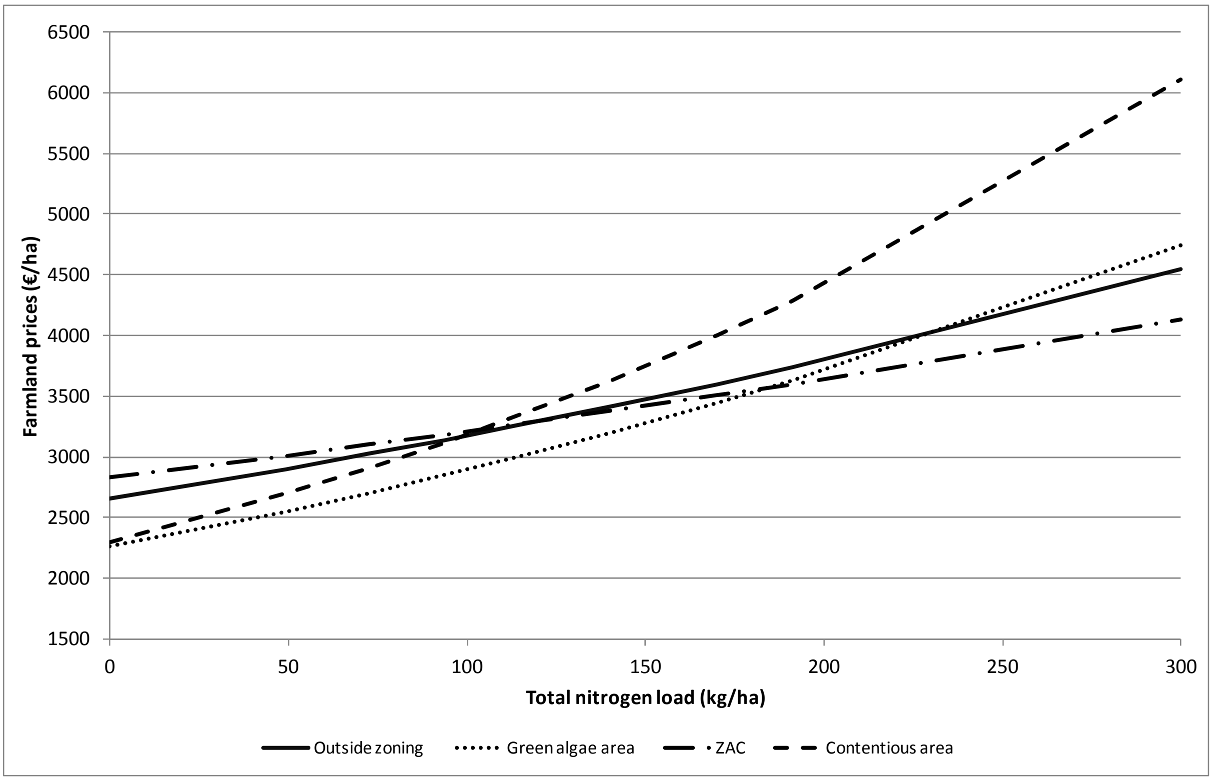
With respect to the influence of agricultural policies, it can be assumed that farmland values will increase with the associated production entitlements. As expected, the milk quota and the CAP payment entitlements have positive and significant effects on farmland prices regardless of the model and the estimation method used. The results for the organic nitrogen load were not dependent on the type of model or method used for estimation either. Previously, Le Goffe and Salanié (2005) reported a price increase of 4.4 € per kg of nitrogen of porcine origin. They interpreted this increase in farmland prices by the rising demand from farmers who must meet the manure-spreading regulations. In addition, this price increase illustrates the intensification of pig production in the Bretagne region. Our results show that the farmland price increases by about 6.50 € per kg of additional total nitrogen per hectare[11].

In 2010, 115 farmland plots were exchanged within eight water basins that were affected by an enormous algal bloom, which primarily occurred on the north coast of the Bretagne region. From 2007 to 2010, 584 farmland plots were exchanged within areas covered by environmental litigation zoning. More than half of the exchanged land belongs to an area with complementary actions (*i.e.*, a ZAC). Three binary variables were included in the model, and they equal 1 when the land belongs to one of these environmental zoning areas that were created by regulations and 0 otherwise. In addition, we include three additional variables in the model by crossing these binary variables with the organic nitrogen load to analyze the effects of these environmental zoning areas on farmland prices at different levels of nitrogen loading. Figure 3 presents the impact of the nitrogen load on land prices in the three environmental areas (namely, ZAC, green algae areas, and contentious areas) and the area outside these zones, as obtained by the SAR model estimated with ML.

The trends of these curves are the same regardless of the model and the method used. We observe that farmland prices increase as the nitrogen pressure increases, which may be explained by the higher profitability in areas characterized by higher livestock density. In the regulation, municipalities were categorized as highly loaded if they had more than 50 kg per hectare of organic nitrogen associated with pig production. In the sales data, 95% of the transactions belong to a municipality with more than 50 kg of nitrogen per hectare. The average amount of animal nitrogen is approximately 115 kg per hectare in the Bretagne region.

[11] Our calculation applies to all animals and not only to pigs, as in Le Goffe and Salanié (2005). This distinction can explain the differences observed between the price increases.

Figure 3: The impacts of nitrogen loading on land prices in environmentally sensitive areas (SAC model estimated by ML)



Source: authors' calculation

The profitability of livestock density increase depends on the different policy applied in each area as well as production conditions. Compared to the outside zoning areas, the results obtained for ZAC and areas affected by green algae proliferation are consistent with our theoretical background. In ZAC, we observed a smaller increase in the farmland prices. Farmers in these areas are constrained to comply with the limitations on their nitrogen use per hectare, which leads to decreases in their profits. On the contrary, in areas affected by green algae, we observed a higher increase in the farmland prices. Farmers in these areas have not yet been forced to change their agricultural practices. They would do so only if the offered payments overcompensated their loss of profit. The result obtained for areas under litigation contradicts our theoretical expectation. Farmland prices are expected to decrease sharply because this area is characterized by the highest regulatory constraint: the total use of mineral and organic nitrogen fertilizers is limited to 140 kg or 160 kg per hectare. On the contrary, we observe the highest price increase with the animal density.

This non-expected effect might be explained by imperfections in the farmland market. If perfect competition between farmers prevails on the farmland market, the land price equals its net present value, which depends on the expected future revenues provided by this farmland. In practice, the French land market is imperfect, since it is constrained by land institutions and regulations limiting and controlling competition. Farmers can rent farmland at a relatively low price which is constrained by administrated boundaries. Furthermore, the law limits the rights of landowners to protect farmers' access to farmland, and the tenants have a legal priority to buy the land they rent. If there is no competition between farmers, the farmland price equals the capitalized rental price. Dupraz and Temesgen (2012) have shown that the French arable farmland price lies between its capitalized rental income and its capitalized marginal agricultural profit. In this context of imperfect market, the environmental regulation may induce a price increase due to an increase in competition between farmers. To ensure the existence of their livestock farm under the new regulation, the farmers need a higher registered area for manure spreading. Although the registered spreading area of one farmer may be owned and/or farmed by other people and provided by dedicated agreements, buying the corresponding land is the most secure way for keeping it under control. Hence, despite the decrease in land profitability due to the regulation, the farmland price may increase because of an increased competition between farmers on the land market, since a large enough gap initially separates the capitalized rental price from the capitalized farmland agricultural profits.

7 Conclusion

In this paper, we use a spatial hedonic pricing model for the valuation of farmland prices in the Bretagne region. The main contribution of this paper is its empirical application. We try to understand and evaluate the farmland price effects of different environmental policies which are intended to reduce the agricultural pollution of water with nitrates. Our results highlight two important points.

First, our results and tests prove the existence of spatial interaction in the farmland market in Bretagne. In addition, there is likely a 'spillover' effect between farmland sales, although it is difficult to interpret this effect because of the spatial data. Sellers are likely influenced by transactions which have occurred in their neighborhood, and this influence could be intensified by a lack of information or asymmetric information. Consequently, sellers rely on sales information which is available near the location of their farmland. Thus, it is advisable to better understand the differences observed in the results obtained by the models. Such an understanding may help us better define the spatial effects and better analyze their influence on the results, especially on the environmental factors.

Second, our results show that the effects of environmental policies on farmland prices depend on the types of regulations and economic incentives. There are different zoning areas in the Bretagne region which have specific measures limiting the amount of nitrogen spread per hectare. This zoning explains the significant variations in farmland prices in more environmentally sensitive areas, as ZAC and in the areas concerned by the proliferation of green algae. On the contrary, we cannot explicitly understand how the policy in the areas affected by European litigation affects farmland prices. For this, it would be interesting to test our assumption of an increased competition between farmers for farmland due to the stringent regulation resulting in opposite effects of land market regulations and environmental regulations on farmland price. In a first step a counterfactual method would be useful to better disentangle the regulation effects from other determinants of farmland price.

This notion of the effectiveness of environmental policies arises as government policies have begun to reflect the simplification and relaxation of regulations and environmental constraints. Since 2011, a decree has extended the total farmland area which is considered when the usable surface for manure spreading is calculated. According to a French environmental association[12], this decree will increase the amount of nitrogen applied to the soil by 20%. In addition, the government plans to remove the ZES and ZAC in 2013. Thus, the recent changes and the potential future changes are intended to relax constraints on farmers and encourage them to modernize and better control their nitrogen load on their own.

[12] '*Eau et Rivière'*, whose objectives are the protection of water and natural environments.

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Annex A – Nomenclature of territorial units for statistics for the Bretagne region

	Level of division	Size of division
NUTS2	Region	Bretagne
NUTS3	Departments	4 NUTS3: *Ille-et-Vilaine*, *Côtes d'Armor*, *Finistère*, and *Morbihan*
NUTS4	Cantons	171 NUTS4
NUTS5	Municipalities	1270 NUTS5

Annex B – Properties of the coefficient estimated by spatial models

The Table B1 below describes the properties of the coefficient estimates obtained by the four models (SEM, SAR, SAC and SDM models) in cases of misspecification. For cases in which the true data generating process (DGP) has spatial dependence in disturbances and includes spatial lag dependence, the SAR, SAC and SDM models will produce unbiased coefficient estimates. The SDM model is the only model which will produce unbiased coefficient estimates under all four data-generating process (James and Lesage, 2009).

Table B1. Properties of coefficient estimates depending on the true data generating process (DGP)

True DGP	SEM model	SAR model	SAC model	SDM model
SEM	-	biased/inefficient	biased/inefficient	unbiased/inefficient
SAR	unbiased/inefficient	-	unbiased/inefficient	unbiased/inefficient
SAC	biased/inefficient	unbiased/efficient	-	unbiased/inefficient
SDM	biased/inefficient	biased/inefficient	biased/efficient	-

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