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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 of prices observed in Bretagne. Several environmental regulations policies have been implemented in the Bretagne region, which resulted in a complex zoning system with specific measures. To take into account this local characteristic, we use the hedonic pricing model and focus our attention on 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.*

Keywords: *environmental policies, hedonic price function, spatial econometric model, land market, price determinants*

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

Résumé – La Bretagne est une région fortement agricole située au nord-ouest de la France. Outre la pression urbaine, la compétition pour les terres agricoles est renforcée par les fortes contraintes environnementales présentes dans cette région. L'objectif de ce papier est d'étudier les déterminants du prix des terres agricoles et en particulier les effets de ces contraintes environnementales. La mise en place des politiques environnementales a abouti à un zonage complexe de la région caractérisé par différentes mesures réglementaires. Pour tenir compte de ces caractéristiques locales, nous utilisons un modèle de prix hédonique et nous nous intéressons aux potentielles dépendances spatiales entre les prix des terres. Pour l'application empirique, des données concernant les transactions de terres agricoles réalisées en Bretagne de 2007 à 2010 sont utilisées. Les résultats montrent une augmentation ou une diminution du prix des terres dans les zones environnementales sensibles selon le type de mesures politiques mises en œuvre dans ces zones.

Mots-clés : politiques environnementales, fonction de prix hédonique, modèle économétrique spatial, marché de la terre, déterminants des prix

JEL Classification: Q51, Q11, C21

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 drinking water abstraction. 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 of 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 that are located in Bretagne, and the nitrate regulation that was allegedly violated limits organic fertilization. Farmers with excess manure must seek additional areas to spread manure in order to maintain or increase their herd size, which leads to increased competition between farmers and then may increase the farmland price.

In addition to the land pressure that is 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 a common practice in peri-urban areas and in areas that surround major cities. Nearly half of the municipalities of Bretagne are located in an urban area. Furthermore, this region is bordered by 2,800 km of coastline. This 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. 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 b). This relative stability is a result of land-market regulations that involve the French government and farmers' organizations. The farmland market in France is governed by a set of laws and legal institutions. Moreover, regional land offices operate in farmland markets according to

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[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 Appendix A.

agricultural policy objectives, environmental concerns and infrastructure development enhancement. The relevant French legislation's main mission and responsibilities are (i) to regulate the farmland market in every French region, (ii) to improve farmland accessibility for young farmers, (iii) to assist the smallest farms in enlarging their farms and (iv) to moderate land sale prices. In addition, farmland rental rates are constrained by administered boundaries, and laws limit the landowners rights to protect farmers' access to farmland. These regulations often induce bribe payments in farmland transactions that 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 that 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 take into account this local feature, we use the hedonic pricing model and focus our attention on the potential spatial dependencies between farmland prices.

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 and the results are presented and discussed in the fifth section.

1. Theoretical background

In response to environmental issues, several political tools can be used to constrain farmers or induce them to change their behaviour. 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 that have been implemented in the *Bretagne* region, which resulted in complex zoning that is 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.

1.1. 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. Every member states of European Union were required to draw up action programs that are applicable to areas with a high nitrate concentration. In 1993, the regional authorities identified and classified nitrate vulnerable zones (NVZ) (the French acronym is ZES) according to the nitrate concentration of surface water. In such a zone, permitted organic manure cannot exceed 170 kg of nitrogen *per* hectare *per* year. In 1996, additional measures were implemented in designated areas that had higher environmental pressure from agriculture. These designated areas have animal densities that result in a nitrogen surplus that 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) to improve the water quality that is 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 from 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 classified in ZES area in 2006, and nearly one-third of the water basins are under the obligations of a ZAC classification regulation. All of these environmental zones are constrained by different regulations, that may induce financial penalties and a cut in direct payments following the eco-conditionality principle, which was established in 2005.

Other political measures provide some incentives for farmers to voluntarily adopt agricultural practices that are more environmental friendly. In return for changing their practices, farmers are supported financially to enable them to invest in farm equipment or farmers are compensated for the loss of gains that is associated with the new practices. These economic incentives that are based on farmers' voluntarily compliance are implemented in environmentally sensitive zones in the Bretagne region. Indeed, these incentives are implemented in the territories concerned about green *algae* proliferation, which was described in the introduction. A national action plan was prepared in 2010 for eight designated water basins that correspond to bays and that are the 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 that are no more stringent than the measures that already exist in the ZES. In addition, this plan proposes voluntary measures to encourage the development of grassland-based production systems.

If no improvement of water quality is observed in these areas, then these measures, which were initially voluntary, may become compulsory for

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

all farmers, as was the case for those areas that were concerned with the first European litigation, which are also described in the introduction. 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 that exceed 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 that can be utilized to limit the amount of nitrogen used by farmers. Farmers are constrained to respect this limitation in ZAC. In territories concerned by green *algae* proliferation, the limitation is voluntarily 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 obeying it. From a theoretical point of view, we analyze the effects of these different political instruments.

1.2. Modeling farmer behaviour

We examine these three cases of pollution regulations based on a constrained input. The theoretical model that we 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 this study, they analyzed the behaviour of farmers facing an environmental regulation and modeled their willingness-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, labour 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 that is derived from this problem such that it distinguishes the variable input that 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:

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

where $\Pi R\left(p, w_{-c}, x_c^*, z\right) = \left\{ \max_{x,\, y} p'y - w_{-c}{}'x_{-c};\ F\left(x_{-c}, x_c^*, y, z\right) = 0 \right\}$ 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 in which the factor x_c is constrained and $\bar{x_c}$ is the upper bound that is imposed by environmental policy. We have $\bar{x_c} < x_c^*$, 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:

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

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

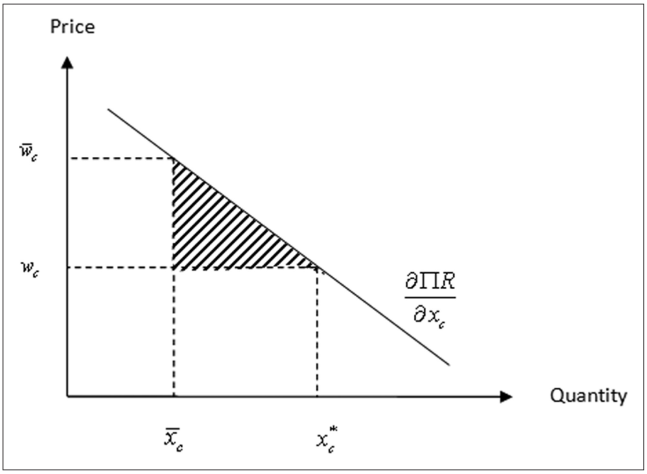
$$\Pi\left(p, w, \bar{x_c}, z\right) = \Pi R\left(p, w_{-c}, \bar{x_c}, z\right) - w_c \bar{x_c} \qquad (4)$$

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

$$\Delta\Pi_1 = [\Pi R(., x_c^*) - \Pi R(., \bar{x_c})] - w_c[x_c^* - \bar{x_c}] \qquad (5)$$

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 $\bar{x_c}$. The price $w - c$ is the virtual price associated with the bound imposed by environmental policy (Lau, 1976). It corresponds to the price that would lead the allocation of $\bar{x_c}$ 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-behaviour model is defined by:

$$\begin{cases} \max\limits_{x,y} p'y - w'x + \rho(\bar{x_c})z_1 \\ F(x, y, z) = 0 \\ x_c \leq \bar{x_c} \end{cases} \quad (6)$$

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

$$\Pi\,(p, w, \bar{x_c}, z) = \Pi R\,(p, w_{-c}, \bar{x_c}, z) - Wc\bar{x_c} + \rho\,(\bar{x_c})\,z_1 \quad (7)$$

where the restricted profit function $\Pi R(p, w_{-c}, \bar{x_c}, z)$ is obtained from the optimization problem (6); this function equals $\left[\max\limits_{x_{-c},y} p'y - w_{-c}{}'x_{-c};\ F(x_{-c}, \bar{x_c}, y, z) = 0\right]$. Farmers have an interest in participating in the environmental program if the subsidy is superior to the loss of profit, which is defined by $\Delta\Pi_1$ (equation 5). As illustrated in Figure 1, in this case, the hachured area corresponds to the minimum willingness-to-accept limiting the use of x_c

Case 3: Compulsory regulation compensates farmers with subsidies

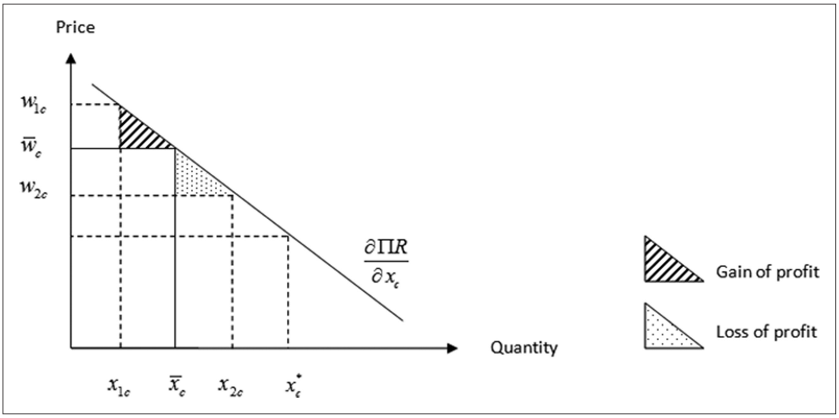
In the third case, farmers are constrained to respect the regulation, but they receive a subsidy to compensate their resulting profit loss. The government has no interest in overcompensating farmers. He may choose to compensate exactly for the profit loss of each farmer, with compensatory payments equaling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

Given the heterogeneity of the farmers and their agricultural practices, the government may provide the same average compensation to all farmers, because it lacks information on the individual farmer level or in order to reduce its administrative costs. Consequently, some farmers will be under-compensated and others over-compensated. If the average payment compensates a farmer for a decrease of its input use from x_c^* to x_{1c} and if $x_{1c} < \bar{x}_c$, 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 hachured area in Figure 2. In another hand, this same payment can compensate a farmer only for a decrease of the input use from x_c^* to x_{2c}, with $x_{2c} > \bar{x}_c$. In this case, the farmer faces a profit loss, which corresponds to the second hachured 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.[3]

The value of farmland depends on the expected future stream of earnings of this land. Hence an increase/a decrease in the agricultural profit associated to the characteristics of a particular farmland results in the increase/decrease of 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 contentious European areas. Furthermore, we can expect stable or increasing prices in territories that are concerned with green *algae* proliferation, where voluntary measures may provide additional profit to some farmers.

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

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



2. Methodology

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

2.1. Literature review

There are two primary approaches to studying the determinants of land prices. The first approach is based on the actualized 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 a; and 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, Lancaster observed that consumer goods are quite 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 two 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 propose a theoretical structure for hedonic regression. The hedonic-price-function estimates were used to measure the implicit price of each commodity characteristic and to calculate the willingness of consumers to pay for each marginal change. Following this work, several problems were identified, including the potentially simultaneous choice between the commodity 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 of buyers to pay 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 the United States (Elad *et al.*, 1994; Bastian *et al.*, 2002), Northern Ireland (Patton and McErlean, 2003), France (Le Goffe and Salanié, 2005) and Finland (Pyykkönen, 2005). For example, Plantiga *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; 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 of 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[4]. 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

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

the estimated cost of manure treatment in dedicated plants (3 € *per* kg of nitrogen). These authors conclude that the regulation has had some effect on farmland prices, which may reflect the fact that pig farmers were forced to deviate from their unconstrained profit-maximizing behaviour.

Most of the economic studies that evaluate public policy focus on non-farm development in agricultural areas and on policies that are implemented to reduce urban sprawl. In particular, these studies analyze the effects of urban-development restrictions that are 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 that influence value. The author uses a hedonic price method to examine how the proximity to environmental amenities is related to a piece of land's sale price.

The economists who investigate these issues have mostly relied on hedonic price models that 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 that 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 that 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 their parcel's market value was lower than other parcels' values. In that case, they are confronted with a sample selection problem and must use an adapted econometric method.

2.2. The hedonic pricing model

Although our work is inspired by the work of Le Goffe and Salanié (2005), it differs from their work 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 that 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. Dairy quotas are not exchanged on a market, but their transfer is permitted with the associated land. Some studies have reported evidence that dairy quotas are capitalized into farmland prices (Barthélemy and Boinon, 2001). This capitalization also applies to single farm payments; since 2006, farmers have been allowed to transfer such payments with farmland transactions. Several studies have shown that policies offering agricultural supports, especially direct payments to farmers, are either fully or partially capitalized into the farmland price, depending on the modalities of their implementation (Guyomard *et al.*, 2004; Ciaian *et al.*, 2012 and Feichtinger and Salhofer, 2011). In addition, variables that 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 that indicate the tenancy status of a plot of land (land under a tenancy contract or farmland without an ongoing tenancy contract) and (ii) variables that represent the environmental situation of the municipality of the transacted farmland. The simpler hedonic price function that is applied to the individual land-price observations is linear and encompasses the preceding sets of variables. This function can be written as follows:

$$p = \alpha + \beta X + \gamma Z + \xi S + \delta F + \eta E + \varepsilon \tag{8}$$

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 that are related to the farmland, and F and E describe the institutional and environmental situations of the plots of farmland, respectively. We simply include a dummy variable to distinguish parcels inside and outside each environmental zoning area[5]. 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 measures the relative change of the price following a unit change in the respective characteristic, and provides an approximation of the percentage of the price that depends on corresponding characteristics. Furthermore, we also chose the semi-log specification for its simple implementation[6].

3. The econometric strategy

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

3.1. 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. 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[7]. In addition, multicollinearity can be detected using eigenvalues and condition indices[8]. An eigenvalue of zero means that there is perfect collinearity among the independent variables, and very small eigenvalues imply severe

[5] We do not take into account the possible endogeneity of zoning areas. This could be done in the future work of this research. However, these environmental zoning areas can be considered as exogenous determinant of land prices, because they are predetermined. The ZAC and contentious zoning areas are defined by scientists who rely on environmental *criteria* in 2001 and then, long before the period of the study (2007-2010). By cons, the green *algae* areas are created in 2010. The farmland prices may influence the production decisions of farmers and the level of agricultural intensification that have repercussions on water quality. This source of endogeneity is nevertheless strongly moderated by the topological and geographical characteristics of the areas that are exogenous. In fact, the areas affected by green *algae* proliferations are not necessary the most intensive areas.

[6] 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).

[7] According to Kennedy (1985), a VIF greater than 10 is an indicator of the presence of this problem.

[8] Whereas values greater than 15 indicate a possible problem with collinearity, values greater than 30 indicate a serious problem.

collinearity, which indicates that small changes in the data values may lead to large changes in the estimates of the 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's values suggest that there is not a serious problem of multicollinearity.

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 estimators; for example, individual characteristics of buyers and sellers can be used as valid instrument 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 as an exogenous variable in our model.

3.2. 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, a location in a suburban area, and the coastline proximity. If unobserved spatial heterogeneity remains, then we are confronted with a problem of heteroskedasticity and/or the instability of the model parameters that 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 model parameters).

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 of 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 that have spatial dependence. In our case, the sale price of farmland may be affected by the value that is 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 that influence the price of farmland in addition to its production value. Spatial autocorrelation destroys the independence of observations that 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 of 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 that 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 expression (9):

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

This notion of spatial lag is important because it allows us to introduce the effects of spatial autocorrelation in the econometric models. The weight matrix can be written in different ways. The technique used very often in the literature (Patton and McEarlen, 2003; Pyykkönen, 2005) consists of 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 the precise location of farmlands within their municipalities is a missing information, we used the municipalities' areas to calculate the distance between two hypothetical plots of farmland that 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 at 1.

The spatial lag autoregressive model (the SAR model), which is characterized by the autocorrelation of the endogenous variable, is written as (10):

$$P = \alpha + \rho W P + \mu Q + \varepsilon \tag{10}$$

where Q includes all of the characteristics' variables. This specification accounts for the interactions that may exist between neighbors in determining the farmland selling price. 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 (11):

$$\varepsilon = \lambda W \varepsilon + \nu \tag{11}$$

The error term is split into the $\lambda W \varepsilon + \nu$ term and the v term, which refers to the true independent homoskedastic residual term that has a mean of zero 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 that combines both a lagged endogenous variable and the spatial correlation of error terms; this model is known as the spatial auto-correlation model (*i.e.*, the SAC model).

Since 2000, those farmland-market studies that 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 for it. 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 behaviour introduced direct influence of one transaction on other neighboring transactions.

The literature contains various tests for spatial autocorrelation that 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 a and b) and Lesage and Pace (2009). In situations in which both types of dependence exist, Anselin and Rey (1991) proposed retaining the model that 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.

3.3. 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 a and b and 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 difficulties. Patton and McErlean (2003) estimated this model using an instrumental variable method that is based on the White estimator of the variance-covariance matrix, which is robust for any heteroskedastic form. 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 that 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 has derived these likelihood functions (Anselin, 1988). 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 few 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, 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 that were proposed by Lesage and Parent (2006) and Lesage and Pace (2009). These methods do not require to specify an arbitrary form of heteroskedasticity. Furthermore, they have the advantage of supporting the uncertainty on both a weight matrix that is exogenously fixed and the explanatory variables that are used in the model (Lesage and Fisher, 2007).

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

4. The empirical model

All information on farmland transactions in Bretagne was derived from the *Perval* database. This dataset gathers the whole transactions of farmland sales that were reported by the notaries in Bretagne from 2007 to 2010. We selected observations of farmland with no building or forested land and farmland purchased by farmers. After eliminating the farmland that corresponds to the tails of the distribution of prices, we obtained a total of 3,500 observations from 2007 to 2010 to use in the analysis. Additional variables that describe 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[9]. The nominal price was deflated by the producer price index (which was 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 of 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, and this index indicates 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,

[9] In accord 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 to limit the potential heteroskedasticity problems.

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 these lands.

The geographic location of farmland is another important factor. Therefore, we considered the following four variables: a variable that represents farmland with a geographical proximity to the coast, a variable that identifies whether farmland is located in an urban area[10], the Euclidian distance between the farmland and the nearest urban center, and the population density. These variables approximate the competition-based effects of urbanization and tourism.

Agricultural-policy factors must be considered in the course of explaining farmland prices. For example, milk quotas or payment entitlements that are transferred with farmland are likely to have a positive effect on land prices. The milk quota at the municipality (NUTS5) 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 regional level, which are 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 cheaper. In this case, there are two possible situations: first, 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; second, the owner wants to sell his land but it is already used by a farmer who does not want to buy it. In this case, the land is less attractive to potential buyers (except for those who want to invest in land rather than occupy it).

With respect to the environmental-policy factors, the demand for manure spreading on farmland was measured by the nitrogen-pressure indicator at the municipality (NUTS5) level, which was designed by Le Goffe and Salanié (2005). Data on the nitrogen load that results from the total animal production were directly calculated based on the 2000 agricultural census of the French Agriculture Ministry database[11].

The demand for farmland was expected to vary in environmentally sensitive areas. Three dummy variables indicate a location in one of the bays that is 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. These three zoning areas are affected by political instruments that limit the amount of nitrogen used by farmers. Furthermore, these variables are crossed

[10] A municipality is considered to belong to an urban area if it belongs to an urban pole that offers at least 10,000 jobs, or to a municipality in which at least 40% of the resident labour force works in the urban pole.
[11] The nitrogen load is calculated from the composition of herds in the year 2000 and is used to explain the land price from 2007 to 2010. The variable used is predetermined and then exogenous from a statistical point of view.

Table 1. **Descriptive statistics of the variables**

Variables	Unit	Level	Average	Standard errors	Database
Prices of the sold farmland plots	**€/hectare**	**Plot**	3722	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 UAA	/ha SAU commune	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/cm^2	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	-	Build variable
Coastline proximity	yes=1/no=0	Canton	0.24	-	Build variable
Influence density	$inhab/km^2$	Municipality	81.12	108.86	INSEE 2008
Distance between land and urban pole	km	Plot	21.66	10.71	Build 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	-	Build variable
Contentious areas	yes=1/no=0	Municipality	0.08	-	Build variable
ZAC areas	yes=1/no=0	Municipality	0.56	-	Build variable
Others variables					
Temporal dummy 2008	yes=1/no=0	Plot	0.27	-	Build variable
Temporal dummy 2009	yes=1/no=0	Plot	0.25	-	Build variable
Temporal dummy 2010	yes=1/no=0	Plot	0.21	-	Build variable

A note about the databases: The agricultural census (AC) was conducted in 2000 and 2010, whereas the census of the French population (which is available in the INSEE database) was conducted in 2008. The authors do not have access to the agricultural census data of 2010. The Institut National de la Statistique et des Études Économiques (INSEE) analyzes and diffuses the official statistics in France. In addition, the local authority DRAAF (Direction Régionale de l'Alimentation, de l'Agriculture et de la Forêt) implements the policy defined by the government and the European Union in the region. The specific databases GIS-Sol and Météo-France provide some indexes of the pedo-climatic conditions.

with the total nitrogen load to take into account 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 the presence of autocorrelation. Another test was performed from the SAR model to confirm the presence of spatial-error dependence. All these statistical tests, which are presented in Table 2, provide evidence of spatial correlation in the residuals and in the dependent variable.

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

Three estimates were performed: the SAR model defined by equation (10), the SEM model defined by equation (11) and the SAC model (without the specification of two different weight matrices). All the spatial models were estimated using the maximum likelihood method and the Bayesian approach. All the codes used were developed by Lesage in Matlab and are available on his website[12].

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 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. 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 Table 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

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

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 every other observations. For the continuous variables, the parameters were multiplied by 100 to provide the percentage of the change in price that 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 that results from the introduction of characteristics relative to the baseline.

5. Results

Table 3 presents the average direct effects that are estimated from these spatial models by ML and the Bayesian approach. Table 4 presents the average indirect (spillover) effects. Naturally, 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 that are 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 that 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 econometric tests, 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 in an urban area. This increase can be explained by the fact that some individuals bought farmland that was well-located at higher prices for speculation, as they expected a conversion into residential or industrial use.

In our sample, only 50% of the sold farmland was leased (*i.e.*, an ongoing tenant contract exits at the time of the sale). As expected, nearly 90% of this farmland was purchased by tenant farmers who rented the land before the sale.

A study on the French farmland market from 1997 to 2010 (Lefebvre and Rouquette, 2011b) showed that leased farmlands were sold at a price that was 15% less expensive 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 buy the land that they farm and thus reduces the competitive mechanisms. Our results confirm that land that is sold to its former tenant farmers is less expensive than other land (indeed, such land is between 13% and 16% less expensive if we consider only direct effects, and it is between 15% and 19% less expensive if the spillover is included).

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. Previously, Le Goffe and Salanié (2005) reported a price increase of 4.4 € *per* kg of porcine nitrogen. 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 farmland price increases by about 7.10 € *per* kg of additional total nitrogen *per* hectare[13]. This corresponds to an increase in land prices from about 1,200 €/ha in the municipalities characterized by a total nitrogen load superior to 130 kg of nitrogen *per* hectare (more than 30% of the transactions). This may be explained by the need for farmers to buy additional plots to spread the manure and thus comply with environmental constraints.

In 2010, 115 farmland plots were exchanged within eight water basins 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 pertinent environmental litigation. 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

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

areas) and the area outside these zones was obtained by the SAR model estimated with ML. The trend of theses curves are the same regardless of the model and the method used. These curves associated to the three environmental areas are not significantly different when the confidence intervals are calculated[14]. However the parameters associated with these zoning are significantly different from 0, except in the model SAC estimated with the Bayesian approach. Then the results should be interpreted with caution and we cannot conclude from our theoretical model.

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 that was 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. About 5% of the transactions belong to a municipality with more than 190 kg of nitrogen *per* hectare.

The profitability of livestock density increase depends on the different policy applied in each area as well as production conditions. 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 it only if the offered payments over-compensated their loss of profit. On the other side, farmland prices are expected to decrease sharply in areas under litigation because this area is characterized by the highest regulatory constraint: the total use of mineral and organic nitrogen fertilizers is limited at 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 the imperfection of 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 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 is between its capitalized rental income

[14] For the sake of clarity, confidence intervals are not shown on the graph.

Table 3. Coefficient estimates - The 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 between land and 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***

Table 3. **Coefficient estimates - The average direct effects *(continued)***

	SAR model		SEM model		SAC model	
Variables	ML	Bayesian	ML	Bayesian	ML	Bayesian
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 dummy2008	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

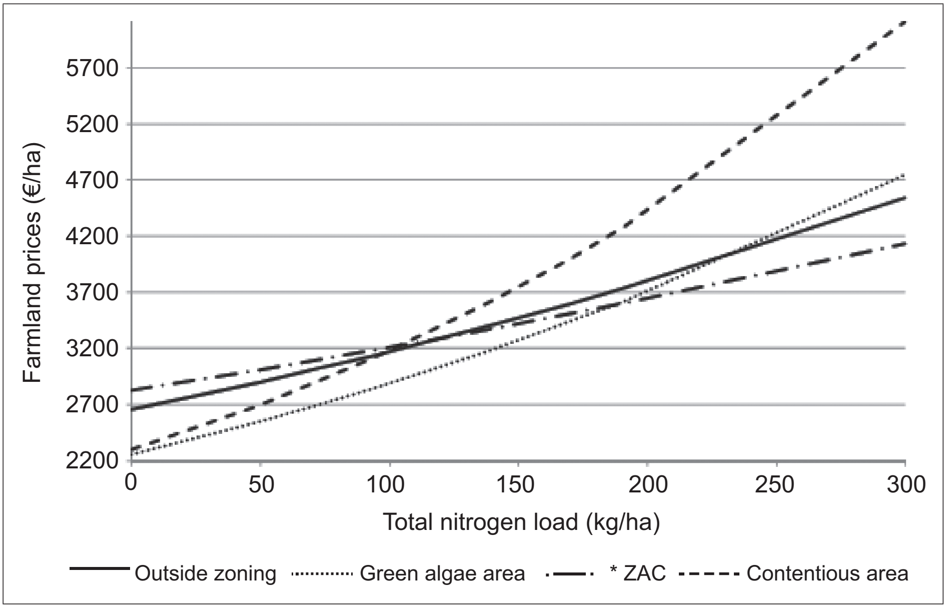
***, **, and * imply that the coefficient estimates are statistically significant at the 1%, 5% and 10% levels, respectively.

Table 4. **Coefficient estimates - The average indirect effects**

	SAR model		SEM model		SAC model	
Variables	**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 between land and 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

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

Figure 3. **The impacts of nitrogen loading on land prices in environmentally sensible areas – The SAC model estimated by ML**



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 increase competition between farmers on the land market, since a large enough gap initially separates the capitalized rental price from the capitalized farmland agricultural profits.

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 that are intended to reduce the agricultural pollution of water with nitrates. Our results highlight two important points.

First, the results and tests in this study proved 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 that have occurred in their neighborhoods, and this influence could be intensified by a lack of information or asymmetric information. Consequently, sellers rely on sales information that is available near the location of their farmland. Thus, it is advisable to better understand the differences that were 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 that have specific measures that limit the amount of nitrogen spread *per* hectare. This zoning explains the 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. To improve the significance of the results, it would be necessary to improve the empirical model and the method used. In a first step, a counterfactual method would be useful to better disentangle the regulation effects from other determinants of farmland price. It would be also 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.

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 that is considered when the surface that is usable for manure spreading is calculated. According to a French environmental association[15], 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.

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[15] This French association is *Eau et Rivière*, whose objectives are the protection of water and natural environments.

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Appendix A – Nomenclature of territorial units for statistics

	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