



**HAL**  
open science

# Pricing manure spreading rights: measure from the land market

Philippe Le Goffe, Julien Salanie

## ► To cite this version:

Philippe Le Goffe, Julien Salanie. Pricing manure spreading rights: measure from the land market. 79th Agricultural Economics Society's annual Conference, Agricultural Economics Society, Jun 2005, Nottingham, United Kingdom. 24 p. hal-02338151

**HAL Id: hal-02338151**

**<https://hal.science/hal-02338151>**

Submitted on 7 Jun 2020

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License

79<sup>th</sup> Agricultural Economics Society's annual Conference, 4-6 April 2005, Nottingham

## Pricing manure spreading rights: measure from the land market<sup>1</sup>

Philippe Le Goffe and Julien Salanié

Agrocampus Rennes  
Department of Rural Economics and Management  
65, rue de Saint Briec - CS 84215  
35042 Rennes cedex - FRANCE

**Abstract** – This paper deals with manure spreading markets in France. We focalise on the capitalisation of the manure spreading rent in the land market. First, the paper summarises the literature on farmland prices. Then we develop a theoretical model based on farm profit maximisation from which we derive inverse demand functions for land and manure spreading rights. We then provide a hedonic application dealing with 7000 individual transactions from the land market of Brittany (western France). Land price is explained by land quality and specialisation, cereal and milk yields. Land price rises when livestock concentration increases. Pig density gets the best results. We conclude making a comparison with the manure market in the Netherlands and dealing with future research.

**Keywords:** land, hedonic pricing, market, demand, manure spreading, manure surplus, nitrogen

**JEL Codes:** Q15, Q24, Q58.

AGROCAMPUS -INRA  
Documentation Economie Rurale  
4 allée Adolphe Bobierre  
CS 61103  
35011 Rennes

<sup>1</sup> The authors thank A. Carpentier, L. Mahé, Y. Surry and D. Vermersch for their comments on a previous version of this paper. The authors also thank O. Jouan and L. Rebuffet for their participation in the early stage of this research. Any remaining errors are of the responsibility of the authors.

## Introduction

The fateful reform of the Water Act illustrates the difficulties to apply the polluter-pays principle to agriculture in France. The project of taxing the nitrogen contained in fertiliser and livestock feed has been dropped, as was the one of taxing nitrogen surpluses under the preceding government. The present system to reduce nitrogen surpluses relies mostly on regulations and subsidies. Thus, the EU Nitrate Directive's second program of actions plans the obligation to process livestock nitrogen surpluses which cost can be subsidised by Water Agencies and local governments. Besides its high cost, this system does not incite to optimise manure spreading via the reduction of mineral fertilisers (Mahé and Le Goffe, 2002). In Brittany, additional measures on livestock farms restructuring create nitrogen quotas per farm. Their environmental and economic inefficiencies have been revealed (Mahé and Ortalo-Magné, 1999). On the opposite, in the Netherlands, dissuasive penalties applied to surpluses in the mineral balance (MINAS) and the absence of subsidies to manure processing have stimulated an effective market for manure spreading rights<sup>2</sup>.

Papers dealing with manure spreading rights markets are rare and recent. Mahé and Ortalo-Magné (1999) described a system of quotas for mineral elements linked to land and that can be negotiated on a market. Rainelli and Vermersch (2000) proposed a microeconomic model for spreading rights markets illustrated with an empirical application of linear programming to typical livestock farms. Vukina and Woosink (2000) deal with the link between spreading rights and land markets. Their microeconomic model shows that the price of hog quotas, expressed in phosphate units, has repercussions on agricultural land prices additional to land productivity. Their hedonic analysis of agricultural land prices in the Netherlands exhibits a positive effects of livestock densities in regions facing surpluses due to restrictions to manure exchange among farmers and that is attenuated over time with production relocalisations. The hedonic study of Pyykkönen (2003) also shows the positive effect of livestock effluents density on farmland prices in Finland. Le Goffe and Vermersch (2004) show the economic advantages of spreading rights markets, with respect to regulations, using market simulation in Structural Surplus Areas<sup>3</sup> (ZES) in Brittany. The price of the spreading right depends on surplus and on the structure of nitrogen reduction costs in the market area.

In this paper, we seek to approach the reality of manure spreading rights markets in our country. The interest is to know if it is already an effective tool in the French case and to compare it to prices observed on the market with those resulting from simulations and in foreign countries. To which extent is the spreading right market representing a significant additional cost inciting to production relocalisation ("automatic stabilisation of livestock concentration")? And to which extent is it inciting to supply spreading lands through mineral fertilisation reduction? We also look at the evolution of the market over time as long as the regulation settles.

It is difficult to directly observe the market because transactions between suppliers and demanders of spreading lands are not always transparent. It particularly takes to the legislation that does not precisely define the status of the manure spreading rent<sup>4</sup>. This is the reason why we look at the capitalisation of the manure spreading rent in the land market. It is measured through the effect of livestock density on agricultural land prices. A spatial hedonic study has been conducted on individual data coming from the farmland transaction file

---

<sup>2</sup> And also livestock reductions.

<sup>3</sup> Zone d'excédent structurel (ZES) in French.

<sup>4</sup> Does it belong to the landowner or to the farmer that rents the land?

notified to the Farmland Development Agency of Brittany over the 1994-2000 period. The first part of this paper summarises the literature on farmland prices. The second part deals with a microeconomic model from which we derive the inverse demand function for land and nitrogen reduction tools chosen by farmers. The third part presents an empirical application to the agricultural land market in Brittany which results are discussed in the fourth part. We then conclude on the needs for future research.

## 1. Factors affecting agricultural land prices

Since Ricardo we know that the price of land corresponds to the discounted sum of the expected gains one can get from it. The three major factors affecting land prices are the rent, the interest rate and the anticipations of economic agents. In rural areas, the rent mostly comes from agriculture, forestry or residential activities. Rents and anticipations are thus dependant on land productivity, the evolutions of the CAP, wood prices and the demand for housing and leisure (Cavailhès, 2002).

Cavailhès and Degoud (1995) have estimated two types of models to explain the evolution of agricultural land prices in France between 1961 and 1993. The first model, called "direct model", is based on Ricardo's capitalisation formula  $P = R/i$ , where  $P$  is the price of land,  $R$  is the rent from land and  $i$  is the interest rate. This classical model has been widely used in the literature. Here, the rent is approached by the gross added value of agriculture but other studies used the agricultural revenue per hectare (e.g. Shi *et al.*, 1997 ; Vukina et Wossink, 2000). The indirect model is stronger from a theoretical point of view because it relies on the profit maximisation process. The demand function for land can be derived and measured because we make the classical assumption that supply is exogenous and inelastic<sup>5</sup>. Land prices are then explained by land quantities (the market volume), input and output prices and the interest rate. However, the adaptive anticipations model can only integrate the information from past and present periods but not the ones made on prospective scenarios. To overcome this limitation and interpret the subsequent abnormal residuals, Cavailhès *et al.* (1996) developed models based on option value.

In their review on agricultural land prices, Weersink *et al.* (1999) show how the classical capitalisation formula has been modified to integrate rent growth, risk, lagged variables, credit rationing and the debt level. It is noted that factors like speculation, discount rate variations over time, non-monetary revenues from land and the variation of the risk premium over time led to put under question the validity of Ricardo's formula.

The theoretical model proposed by Just and Miranowski (1993) restores Ricardo's formula because it explicitly shows the limits of its use in the literature. It differs from Cavailhès and Degoud (1995) in the sense that the producer maximises its expected utility, which is function of its wealth and its consumption. Here, wealth is the algebraic sum of land assets, savings, debt and land sales taxes. It is accounted for savings erosion and debt reductions due to inflation and the opportunity cost of assets. The choice of a functional form for utility allows to determine the derived demand function and the price for farmlands. Empirically, the evolution of land prices in the United-States between 1963 and 1986 is mostly explained by prices anticipations but also by the added value, inflation rate and the opportunity cost of the capital.

---

<sup>5</sup> Supply depends on farmers retirements and not on price.

Finally, it has been shown that rents, according to whether they come from markets or public support schemes, were not capitalised at the same rate (Weersink *et al.*, 1999). Using data for Ontario from 1947 to 1993, and the calculation of land price elasticities with lagged markets revenues and public support, they show that subsidies are capitalised at a lower rate than market revenues. Clearly, farmers consider subsidies as a more stable source of revenue than those from markets over the last 50 years.

Another type of studies tries to explain the spatial differences in farmland prices. The authors use hedonic models to value agricultural characteristics. Palmquist and Danielson (1989) measured, on individual data, the additional value of drainage and of erosion control. They compare them to their respective costs and derive the needs for public support. In France, Michalland (1996) explored the value irrigation possibilities to approach water demand, without any success. Lacking of detailed information on individual transactions, Michalland uses aggregate data for small agricultural areas. Xu *et al.* (1993), Faux and Perry (1999) and Bastian *et al.* (2002) realised studies similar to Michalland (1996.), in the United-States. They got more convincing results, probably because they use micro-data. Goodwin *et al.* (2003) try to explain spatial variations in farmland prices by the value of agricultural and environmental subsidies. Recently, Plantinga *et al.* (2002) and Patton and McErlean (2003) incorporated spatial autocorrelations in farmland prices in the United-States and in Ireland respectively. They find that agricultural land prices are locally correlated because adjacent plots, or close plots, share the same characteristics.

In these studies of farmland prices, the other exogenous variables are the quality of the land, or its productivity (yields), the occupational status of the plot and quotas linked to land ownership. The land rent is not explicitly used, first because these studies seek to explain its composition and second because spatialised data on land rents are hard to obtain. Usually, the interest rate does not enter the hedonic price functions because the models are estimated on cross-section data. Most authors underline the importance of getting individual data to improve estimations results.

Farmland prices are also subject to high urban influence, which are observed far from the cities. Cavailhès and Wavresky (2002) observe the continual decrease in farmland prices as long as one get more far from Dijon (Burgundy). The land price is then the sum of the agricultural rent capitalisation and of the expected capital gain from urbanisation. This one is higher in areas close to the cities because the residential rent is higher and the probability of conversion from agricultural to residential land is also higher. Urban influence is often accounted for in hedonic studies (Palmquist and Danielson, 1989 ; Xu *et al.*, 1993 ; Shi *et al.*, 1997). Shi *et al.* (1997) explain mean farmland prices for counties in Virginia through the use of an urban influence index equal to the population of the closest city divided by the squared distance of this city to the county.

## **2. Microeconomic modelling**

Palmquist (1989) developed a hedonic model that can be applied to a differentiated product such as agricultural land. He distinguishes the characteristics that can be changed by the landowner from those that are exogenous and which price is fixed by demand. Landowners and farmers maximise their profit. The hedonic price function is then the result of farmers' bids and landowners supply. In equilibrium, the farmers' marginal bid and landowners marginal cost, for a marginal increase in farmland characteristics, are equal to the marginal shadow price of the characteristic. Concerning manure spreading, we look at an exogenous

and fixed characteristic: the nitrogen quota per hectare. Its price varies with the situation on local markets with the aggregate manure spreading demand. In our empirical application, hog density is a proxy for the aggregate demand.

Vukina and Wossink (2000) minimise a producer's cost that rents hog quotas to reduce his own farm's phosphate surplus, as it is possible in the Netherlands. Our model maximises a stockbreeder's profit that rents the land from other farms and uses a technology, other than spreading, to resorb nitrogen surpluses (livestock feeding, manure processing). Because it is an exogenous and fixed characteristic, the individual bid functions already give interesting elements to understand the capitalisation phenomena of manure spreading rights. The model writes:

$$\text{Max}_{X,L,M,R,S} \pi = p_1 f(X) + p_2 h(L, M) - cX - wL - mM - g(R) - rS$$

With:  $Y=f(X)$

Subject to:  $\beta Y+M = \alpha(L+S)+R$

The meat output quantity  $Y$  is produced intensively without land using the input  $X$  at unit price  $c$ . The farmed land  $L$ , hired at price  $w$  is used to crop the quantity  $h(L,M)$  also depending on the mineral fertilisation  $M$ . The unit price of mineral nitrogen is  $m$ . Neighbouring farmers put spreading lands  $S$  on the market at price  $r$  per hectare which is set on the local market for spreading lands. To simplify our model, we consider that transportation and spreading costs are insignificant<sup>6</sup>. Other technologies than spreading allow the farmer to resorb  $R$  nitrogen units at cost  $g(R)$ .

The necessary reduction of nitrogen set up in the EU Nitrate Directive is traduced by the model's constraint.  $\alpha$  represents the norm for spread nitrogen per hectare (210 kg, then 170 kg of organic nitrogen).  $\beta$  is the ratio of nitrogen contained in the manure consequently to the production of one kg of meat. It corresponds to the CORPEN<sup>7</sup> norm (i.e. the excretion coefficient for livestock). In fact, the regulatory constraint has been widen in the sense that we accounted for mineral fertilisation because the EU Nitrate Directive aims, in the end, at the equilibrium in the nitrogen balance whatever is the source of fertilisation. We will see that accounting for mineral fertilisation, which is not really effective today in France, induces an elastic supply of spreading rights.

First order conditions (1), (2), (3), (4) and (5), associated with the maximisation problem are solved by the use of a Lagrangean, where  $\lambda$  is the Lagrange multiplier associated to the constraint on the nitrogen used and produced on farm (i.e. nitrogen balance).

$$(1) \quad p_1 \frac{\partial f}{\partial X} - c - \lambda \beta \frac{\partial f}{\partial X} = 0$$

$$(2) \quad p_2 \frac{\partial h}{\partial L} - w + \lambda \alpha = 0$$

<sup>6</sup> They would decrease the demand for spreading rights.

<sup>7</sup> Comité d'Orientation pour la Réduction de la Pollution de l'Eau par les Nitrates.

$$(3) \quad p_2 \frac{\partial h}{\partial M} - m - \lambda = 0$$

$$(4) \quad -\frac{\partial g}{\partial R} + \lambda = 0$$

$$(5) \quad -r + \lambda\alpha = 0$$

(6) is deduced from (2) and (5) :

$$(6) \quad w = p_2 \frac{\partial h}{\partial L} + r$$

The relationship (6) shows that the individual inverse demand for land is the sum of the marginal productivity of land, in value, and the manure spreading rent per hectare. Making equal the aggregate demand and the inelastic global supply would show that the spreading rent is capitalised in farmland prices.

We also have (7) from (1) and (5), and (8) from (4) and (5) :

$$(7) \quad \frac{r}{\alpha} = \frac{p_1 \frac{\partial f}{\partial X} - c}{\beta \frac{\partial f}{\partial X}}$$

$$(8) \quad \frac{r}{\alpha} = \frac{\partial g}{\partial R}$$

(7) and (8) indicate that the producer equalises the marginal profit from input X per unit of nitrogen produced, and the marginal cost of the resorption technology to the price of the spreading right per kg of nitrogen spread. These two relationships represent the individual inverse demand for spreading rights, whether the cheaper alternative for spreading is livestock reduction or the technology to reduce nitrogen surpluses.

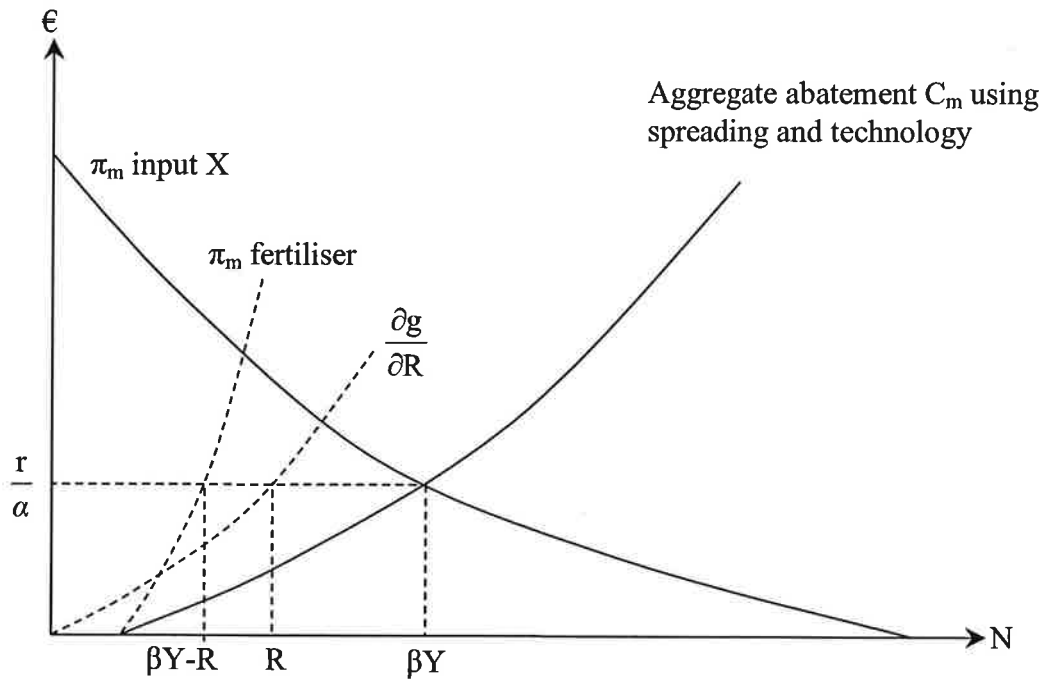
Similarly, (9) is calculated from (3) and (5):

$$(9) \quad \frac{r}{\alpha} = p_2 \frac{\partial h}{\partial M} - m$$

The producer also equalises the fertiliser's marginal profit to the spreading right's price per nitrogen unit. In fact, it is a marginal gain from using fertilisers rather than manure because the model's constraint insures the substitution between mineral and organic nitrogen. This result, as well as the capitalisation of the spreading right, appears if the model is applied to a crop farmer lending is land from manure spreading at price r. This is the individual inverse supply for spreading rights existing for crops and mixed farms. The confrontation on the market of aggregate supply and demand, on local markets to the extent of manure transportation costs, yields the price of the spreading right, which varies spatially and has repercussions in farmland prices.

The figure 1 shows how the producer choose is level of production. The producer has interest in emitting organic nitrogen as long as the marginal profit of the input X per nitrogen unit is greater than the aggregate marginal cost of resorption using technology and mineral fertiliser reduction. Producers having a marginal profit lower than the price of the spreading right have interest in reducing their livestock. If the cost of the technology is artificially lowered by subsidies, the use of the technology and the level of production increase.

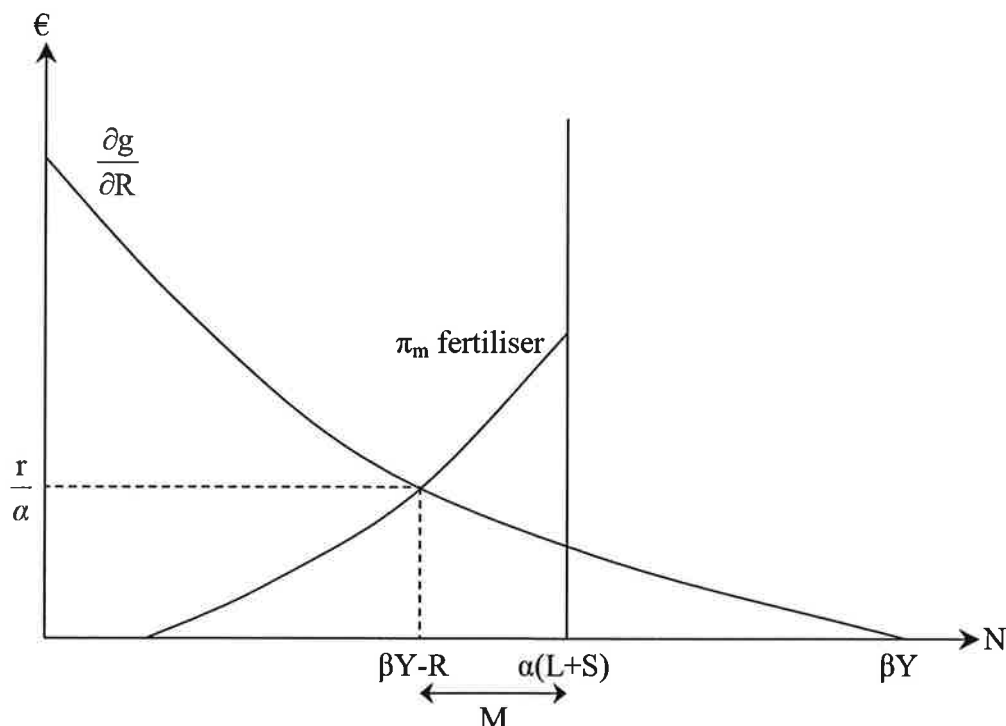
**Figure 1. Determination of the farm's level of production.**



The figure 2 shows the producer's choice between the resorption technology and the reduction of mineral fertilisation. The producer has interest in mineral fertilisation as long as the marginal cost of the technology is less than the marginal gain from using mineral fertilisers rather than manure. Beyond that point, it gets more interesting to spread manure and to reduce mineral fertilisation. When the cost of the technology is subsidised, more mineral fertiliser is used.



Figure 2. Allocation of the nitrogen resorption components at the farm level.



Regulations concerning livestock farms have evolved a lot during the last years. On one hand, the regulatory pressure on livestock farms has increased. The enforcement of Nitrate Directive began in 1996, with the first program of actions and with nitrogen surplus reduction programs. The measures were not very constraining. The Voynet-Le Pensec circular has mandated measures specific to ZES, like the obligation of manure surpluses processing for the biggest farms and limitations on spreading lands. They have been confirmed in 2001 in the second program of actions of the EU Nitrate Directive. During this period, the spreading norm per hectare has been lowered from 210 kg to 170 kg of nitrogen per hectare. Finally, the national pollution tax, planned from 1993 in the PMPOA, has been applied from 1999. On the other hand, technical progresses concerning genetics and feeding reduced livestock nitrogen production. The CORPEN norms for hog and poultry have consequently been reduced<sup>8</sup>.

To show how these evolutions affect farmland prices, we derive the individual demand for land has a function of  $\alpha$  and  $\beta$ . We consider a surplus situation where the nitrogen quantity  $R$ , reduced using the technology, is adjusted to variations in  $\alpha$  and  $\beta$  subject to the nitrogen constraint.

$$(10) \quad \frac{\partial w(\alpha)}{\partial \alpha} = \frac{\partial g}{\partial R} - \alpha(L+S) \frac{\partial^2 g}{\partial R^2}$$

$$(11) \quad \frac{\partial w(\beta)}{\partial \beta} = \alpha Y \frac{\partial^2 g}{\partial R^2}$$

Relations (10) and (11) indicate that the sign of the variation of farmland price depends on the nature of the marginal cost of the resorption technology, which has to be increasing to insure

<sup>8</sup> However, the CORPEN norms for dairy cows have been increased in 2001.

that the second order conditions are verified. Then, farmland prices decrease when the CORPEN norm is relaxed. On the other hand, the sign of the farmland price variation with  $\alpha$  is ambiguous. The marginal cost of the technology needs to be increasing to have increasing farmland prices when tightening the regulatory pressure but it is not a sufficient condition. However, several empirical studies show that manure processing technology is subject to scale economies (Poux and Barbut, 1997). In that case, farmland price would decrease with tightened spreading norms.

### **3. Empirical application: the spreading rent on the agricultural land market in Brittany.**

#### **3.1. Data and models**

The application has been realised on a database from the SBAFER (Briton society for rural land management), which makes the inventory of all farmland transactions (23166 transactions) realised in Brittany between January 1994 and March 2000. Apart from the transaction price and the plot surface area, the database encodes data concerning the seller and the buyer, the predominant cadastral nature of the plot (arable land, grasslands, etc.), the presence of buildings, the nature of the transaction (pre-emption, etc.), the land's destination (farm or other), the presence of an ongoing lease. Because much of factors affecting farmland prices were not easy to control, the following transactions were eliminated from the sample:

- with buildings,
- with uncertain agricultural destination,
- with a cadastral nature different from arable land, grassland, productive moor,
- when agricultural surface area represented less than 95% of the total surface area,
- which were subject to pre-emption,
- when data were subject to statistical secret.

The study was constrained to non-littoral districts, having more than 100 ha in agricultural surface area, on the basis of the rural complement of urban area zoning from INSEE 1997. Similarly, transactions occurring in districts pertaining to small rural areas with atypical productions or agronomic characteristics were excluded. Finally, we excluded observations corresponding to distribution queues for price and plot surface area, keeping 7084 observations for the analysis.

**Table 1. Sample statistics and data sources.**

Variable	Unit	Mean	Std.Dv.	Source
Farmland price	€/ha	2925,8	1405,3	SBAFER 1994 to 2000
Plot surface area	Ha	3,90	3,08	
Arable land	Yes=1/No=0	0,883		
Grasslands	Yes=1/ No=0	0,023		
Moor	Yes=1/ No=0	0,009		
Ongoing lease	Yes=1/ No=0	0,615		
1994	Yes=1/ No=0	0,163		
1995	Yes=1/ No=0	0,192		
1996	Yes=1/ No=0	0,165		
1997	Yes=1/ No=0	0,180		
1998	Yes=1/ No=0	0,149		
1999	Yes=1/ No=0	0,110		
2000	Yes=1/ No=0	0,039		
Vegetables	% TASA	0,031	0,059	RA 2000
Dairy cows density	cows/ha TASA	0,495	0,059	
Irrigation	% TASA	0,017	0,027	
Drainage	% TASA	0,062	0,060	
Wheat high yield	Yes=1/ No=0	0,654		CRAB 2000
Corn high yield	Yes=1/ No=0	0,691		
Corn low yield	Yes=1/ No=0	0,212		
Hog nitrogen pressure	kg/ha TASA	80,39	62,22	MSA 1997
Urban influence index	inhabitants/km <sup>2</sup>	129,57	201,26	INSEE 1999

Note: TASA is the Total Agricultural Surface Area in the district.

We explain net of tax, and net of transaction costs, prices per hectare using three classical functional forms found in the literature on hedonic price studies: linear, semi-log, log-log. These models are estimated using OLS. We also estimated Box-Cox models using MLE. Explanatory variables are divided in two categories: information on individual transactions and district characteristics where the transactions take place (Table 1). The first category comprises the agricultural surface area of the plot, its dominant cadastral nature, the existence of an ongoing lease and the year of the transaction. Although the period studied is short, accounting for the year of the transaction allows to control for market variations due to conjuncture and especially those due to the interest rate. We also tested several agricultural and demographic variables at the district level.

The vegetable proportion represents the probability of actually having this production and its associated rent, which is particularly for that type of crop. The counties cartography for wheat and corn yields has been established on expert's evaluation<sup>9</sup>. The "small agricultural regions" classification dates from the 60s and has little agronomic pertinence. This variable has however been included to account for variations due to geographical localisation. The dairy cows density is a proxy for the probability of having milk quotas associated with land. While being a non-marketed characteristic, it increases the price of the land to which it is linked.

<sup>9</sup> Chambre Régionale d'Agriculture de Bretagne.

Indicators of nitrogen pressure are used to approximate the overall demand for manure spreading lands in the district. Data on livestock have been used to calculate, using the CORPEN norms for nitrogen excretions, the pressure per agricultural land hectare in hog nitrogen, total organic nitrogen and in organic nitrogen beyond the 170 kg/ha limit (notion of nitrogen surplus). The fact that few manure transfers actually occur justifies the need to work at the smallest statistical level, that is the district and not the county, even if manure can come from adjacent districts.

Finally, the district population in 1999, the mean income per capita in 1990 and a synthetic index of urban influence, inspired from Shi *et al.* (1997), are used to appreciate urban influence. The urban influence index is calculated as the population of the closest more than 10 thousands inhabitants city divided by the squared distance between this city and the observation's district. The Table 1 provides the sample statistics for the variables having a significant impact on farmland prices.

### 3.2. Estimations results

Estimations results from linear, semi-log and log-log models are given in Table 2. Only 30% in farmland price variations is explained by these models, which is classical for such an important sample based on individual observations. Palmquist and Danielson (1989) and Pykkönen (2004) get very similar  $R^2$ . For the log-log model, the transformed variables are: the hog nitrogen pressure, hog nitrogen pressure interacted with the ZES and grasslands dummies, the vegetable surface area, the dairy cows density, the urban influence index and the total agricultural surface area of the plot.

The estimates using the maximum likelihood method with Box-Cox transformations, classically used for such hedonic price analysis (Faux and Perry, 1999 ; Patton et McErlean, 2003) are given in Table 3. The dependent variable and hog nitrogen pressure were transformed. The Box-Cox transformed model is described in equation (12).

$$y^{(\lambda)} = \beta x^{(\theta)} + \gamma z + \varepsilon$$

(12)

$$\text{où : } T^{(\delta)} = \frac{T^\delta - 1}{\delta}$$

In that model,  $x(\theta)$  is a vector of identically transformed variables (i.e. using the same Box-Cox parameter) and  $z$  is a vector of non transformed variables.  $\lambda$ ,  $\theta$ ,  $\beta$  and  $\gamma$  are the parameters to be estimated and  $\varepsilon$  is a random error term with the classical properties of zero mean and constant variance. When the Box-Cox coefficients  $\lambda$  and  $\theta$  tend to 1, the model tends to the linear specification. When they tend to 0, the Box-Cox transformation is equivalent to the logarithmic transformation.

The different models were estimated using LIMDEP 8.0. The analysis of the resulting estimations raised two main problems. First, the random errors from the different models violated the homoscedasticity assumption. The heteroscedasticity comes from several variables among which the percentage of vegetables, the percentage of drained lands in the district, the urban influence index and the dummy for on-going lease. Results from OLS estimators were then corrected using White's robust variance-covariance matrix (1980). For the maximum likelihood models (Box-Cox), the variance-covariance matrix was corrected

using a robust "sandwich" estimator (Eicker-White method). We can however notice that the proposed corrections changed the signification of the variables only at the margin.

Second, the abundance of dummies and crossed indicators in the estimated models raised a multicollinearity problem. LIMDEP has a routine to detect high condition numbers, generally used to reveal collinear models. Our estimates do not seem to suffer from this problem but LIMDEP's routine only gives the condition number when it gets to very high extremes (more than  $10^5$ ). For that reason, we also analysed our model using variance inflation factors that are given in Appendix 2. Greene (2002) underlines that variance inflation factors inferior to 10 are generally not problematic. Yet, the interpretation of these factors differs according to several authors for values superior to 10. Some authors indicate that values inferior to 20 or 30 are still acceptable. For our models, the log-log specification is obviously the most problematic one with 4 factors superior to 10 (Appendix 2). For the other models, we consider the absence of multicollinearity.

**Table 2. Hedonic models of farmland prices (OLS).**

<b>Parameter</b>	<b>Linear</b>	<b>Semi-log</b>	<b>Log-log</b>
Constant	1397.11*** (8.791)	7.3015*** (133.91)	7.4789*** (111.00)
Wheat high yield	122.60*** (2.60)	0.0282 (1.57)	0.0650*** (3.67)
Corn high yield	489.00*** (7.72)	0.1744*** (8.55)	0.1725*** (8.55)
Corn low yield	-141.76* (-1.83)	-0.0949*** (-3.34)	-0.0935*** (-3.33)
ZES county	190.78*** (3.74)	0.0876*** (4.39)	-0.0140 (-0.32)
Hog nitrogen pressure	5.960*** (7.60)	0.0023*** (8.29)	<sup>T</sup> 0.0467*** (5.62)
Hog nitrogen * ZES	-2.080** (-2.51)	-0.0009*** (-3.01)	<sup>T</sup> 0.0258** (2.36)
Hog nitrogen * grasslands	-5.936*** (-4.19)	-0.0020*** (-2.88)	<sup>T</sup> -0.0794* (-1.78)
Vegetables	5542.04*** (12.63)	1.5647*** (12.14)	<sup>T</sup> 0.0336*** (7.72)
Dairy cows density	1569.09*** (11.42)	0.5551*** (12.19)	<sup>T</sup> 0.0685*** (3.13)
Urban influence index	0.760*** (5.02)	0.0002*** (5.15)	<sup>T</sup> 0.0801*** (13.09)
Surface area of the plot	11.80** (2.56)	0.0045** (2.34)	<sup>T</sup> 0.0288*** (3.71)
Arable land	188.30*** (4.54)	0.0726*** (4.13)	0.0686*** (3.92)
Grasslands	-279.04** (-2.21)	-0.1936*** (-2.93)	-0.0130 (-0.07)
Moor	-1103.99*** (-8.26)	-0.7052*** (-8.43)	-0.7155*** (-8.57)
Ongoing lease	-201.79*** (-6.69)	-0.0359*** (-3.31)	-0.0323*** (-2.98)
Irrigation	2168.56** (2.56)	0.7665*** (2.96)	1.9727*** (8.57)
Drainage	570.39 (1.57)	0.3027** (2.54)	0.3442*** (2.94)
Adjusted R <sup>2</sup>	0.320	0.323	0.323

Student t-statistics are in parenthesis. \*\*\*, \*\*, \* are for 1%, 5% and 10% signification respectively. <sup>T</sup> identifies the variables transformed using logarithm in the log-log model.

**Table 3. Hedonic models of farmland prices (Box-Cox).**

Parameter	Optimal Box-Cox transformations	
	$\lambda = 0.39 ; \theta = 1$	$\lambda = 0.34 ; \theta = 0.40$
<i>Transformed explanatory variable (<math>\theta</math>)</i>		
Hog nitrogen pressure	0.0493*** (5.97)	0.2733*** (2.98)
<i>Non transformed variables</i>		
Constant	42.237*** (12.27)	32.6395*** (12.90)
Wheat high yield	0.8119** (2.05)	0.6122** (2.25)
Corn high yield	3.9244*** (6.15)	2.6432*** (6.14)
Corn low yield	-1.6623*** (-2.74)	-1.0610** (-2.57)
ZES county	1.7768*** (3.93)	0.4052 (1.50)
Hog nitrogen * ZES	-0.0183*** (-2.80)	0.0022 (0.54)
Hog nitrogen * grasslands	-0.0459*** (-3.68)	-0.0306*** (-3.62)
Vegetables	37.9959*** (7.23)	25.704*** (7.26)
Dairy cows density	12.3121*** (7.20)	7.6377*** (7.01)
Urban influence index	0.0056*** (6.30)	0.0037*** (6.19)
Surface area of the plot	0.1036*** (2.81)	0.0770*** (3.04)
Arable land	1.5627*** (3.68)	1.115*** (3.82)
Grasslands	-3.2886*** (-2.83)	-2.2947*** (-2.89)
Moor	-12.2816*** (-6.86)	-8.6187*** (-6.99)
Ongoing lease	-1.1604*** (-4.35)	-0.7754*** (-4.30)
Irrigation	17.4671*** (3.00)	12.6918*** (3.18)
Drainage	5.7046** (2.10)	4.4176** (2.37)
$\lambda$	0.3936*** (26.46)	0.3449*** (23.36)
$\theta$	-	0.4002*** (3.56)
$\sigma^2$	76.61*** (4.26)	35.56*** (4.31)
$\rho^2$ (McFadden)	0.586	0.630
Log-L at convergence	-25419.4	-22701.5

#### 4. Discussion

The sign of the significant variables is always conform to what was expected and robust when passing from one model to another. Our discussion is based on linear, log-linear and Box-Cox 1 models because the log-log model is the most subject to collinearity problems and because the second Box-Cox specification, while  $\theta$  is significant, holds only for hog nitrogen pressure but not for interaction variables.

The existence of an ongoing lease diminishes the farmland price significantly but only by 4%. The urban influence index increases very significantly the farmland price while the sociodemographic characteristics of the district have no influence. This result is conform to previous studies including that type of indicators (Shi *et al.*, 1997 ; Xu *et al.*, 1993). Arable lands are 27% more expensive than grasslands and the moor lands price is 70% under the reference (unidentified arable lands and/or grasslands). If the probability of having a vegetable land is pushed up to 1 the price is 156% higher than for a conventional land. Differences in corn yields provoke variations of 27% in farmland prices. When the dairy cows density increase by one cow per hectare, the price of the agricultural land increases by 56% which corresponds to a mean price of 0.26 € per kg of milk quota for the average milk yield per cow over the studied period<sup>10</sup>. The global value of the milk quota is probably higher because it is capitalised not only in the land price but also in the value of livestock, buildings and material. An irrigated plot is 77% more expensive than a non-irrigated one. This result is similar to those obtained by Bastian *et al.* (2002) and Faux and Perry (1999) in the United-States. A drained plot is 30% more expensive than a non-drained one. Finally the total surface area positively influences the price of the plot. While this result is opposite to what is found by some authors (Pykkönen, 2004 ; Patton et McErlean, 2003 ; Xu *et al.*, 1993), we believe that this results is not unlikely. These authors justify the negative sign on the total surface area variable because transaction costs are assumed to be smaller for larger plots. However a positive sign can traduce the positive willingness-to-pay for larger plots<sup>11</sup> for which seeding and harvesting marginal costs are probably smaller. Boisvert *et al.* (1997) evoke this possibility to explain results similar to ours.

With a Student t-statistic mostly superior to 6, hog nitrogen pressure belongs to the most significant variables. On average (ZES and no-ZES), farmland price increase by 0.17% per kg of additional hog nitrogen per hectare of total surface area, that is 4.6 €, which represents a difference of 2500€ per hectare between the most pressurised districts and those without hog production. If the farmland price is converted into an annual rent with a 4% discount rate, it represents a leasing value for the manure spreading right of 0.18 € per additional kg of hog nitrogen. It corresponds to a maximum value of approximately 100 € per hectare in the most pressurised districts. Farmland prices being also function of soil quality and crops and milk yields we believe that the hog nitrogen effect captures the rent linked to the constraints of manure spreading. This hypothesis is corroborated by the SBAFER technicians who observe the increase in farmland prices due to hog producers and that has also been evoked by the analysts of the SCEES of Brittany (2003). We have lower Student t when we replace hog nitrogen by total nitrogen or organic nitrogen surplus, while they are strongly correlated. However, this is not surprising because hog and poultry farms are responsible for nitrogen surpluses, and the consequent demand for spreading lands, and because poultry manure is rarely used on site (Thouzeau and Guillemot, 1997 ; Poux and Barbut, 1997).

---

<sup>10</sup> 6000 kg per cow on average.

<sup>11</sup> Especially true in Brittany where farms and plots are small.



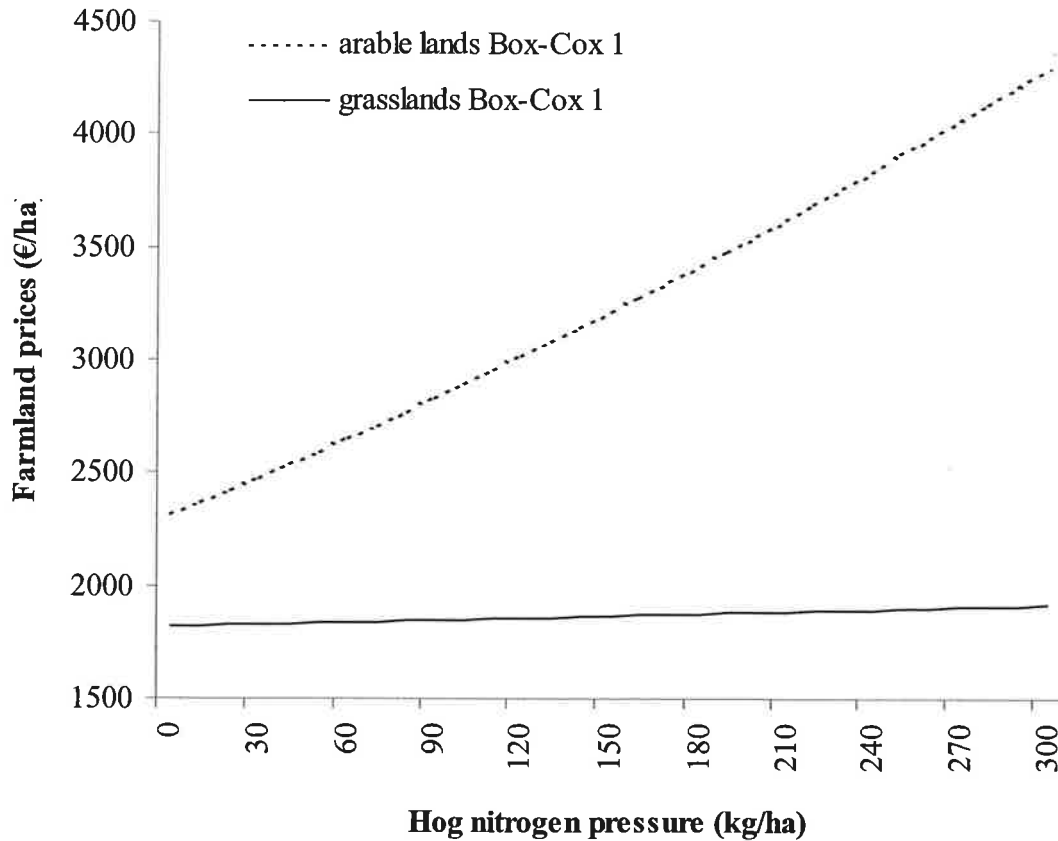
Mean point elasticities (Table 4) are similar for the different models. A 1% increase in the dairy cows density increases land prices by 0.26%. An increase of the same intensity in the urban influence index increases land prices by 0.03%.

**Table 4. Mean point elasticities of land prices with respect to selected variables.**

Model	Hog nitrogen pressure		Dairy cows density	Urban influence index
	Arable lands	Grasslands		
Linear	0,1638	0,0169	0,2656	0,0336
Semi-log	0,1769	0,0161	0,2750	0,0312
Box-Cox 1	0,1712	0,0115	0,2636	0,0316
Box-Cox 2	0,1014	-0,0554	0,2411	0,0304

Knowing that organic nitrogen spreading is concentrated on corn and grasslands (Cébron and Ferron, 2003), we introduced interaction variables for hog nitrogen and soil use (dummies for arable lands and grasslands) into our models. Hog nitrogen pressure impacts farmland prices differently with respect to land use (Table 4 and Figure 3). Indeed, the price elasticity of arable lands with respect to hog nitrogen pressure is 0.17 while it is almost null for grasslands. Grasslands may have a manure spreading value but they have no production value for hog producers that cannot crop neither for hog feeding nor for sale.

Figure 3. Impact of hog nitrogen pressure on arable lands and grasslands.

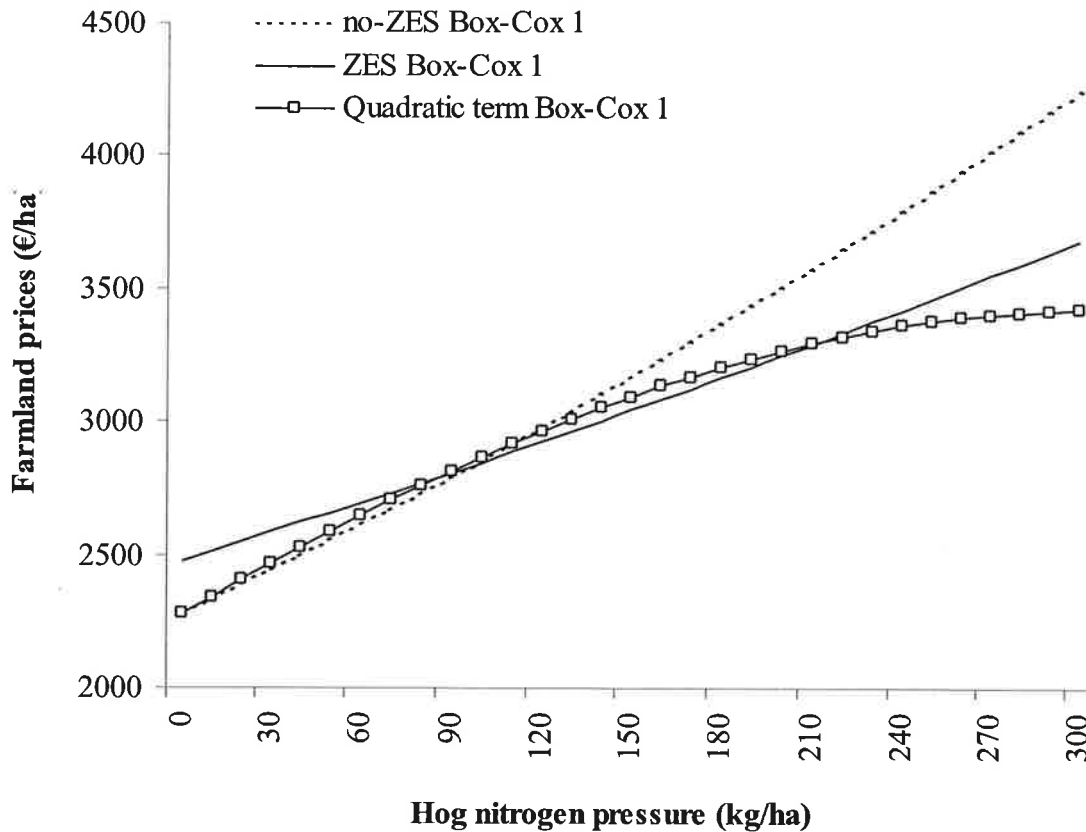


Furthermore, districts with structural surplus (ZES) have been distinguished on the basis of the zoning made in 1994<sup>12</sup>. Farmland prices increase more rapidly with hog manure pressure in districts with low pressure than in those with high pressure (ZES), as shown in Figure 4. In the absence of interaction with the ZES dummy, the introduction of a quadratic term shows that these curves can be interpreted as a slope break. Indeed, including a quadratic term, the model follows the "no-ZES" model for hog manure pressures inferior to 100 kg per hectare and then confounds in the "ZES" model. Thus, as the hog manure pressure increase, the price increases less and less. This result has to be linked with the regulations enforced in ZES districts in 1998 to insure that small farms have access to spreading lands: Compulsory manure surpluses processing imposed to biggest farms, limitation of exchanges through the introduction of limits on spread quantities. These measures and the public subsidies to processing should decrease the tension on spreading right markets in ZES districts<sup>13</sup>. However, these measures appeared only at the end of the period concerned by this study. The boundary reached by farmland prices in ZES is most likely to traduce the limits of the policy's efficiency, which is not respected (see Baron *et al.*, 2001).

<sup>12</sup> This zoning has been revised in 2002 according to the CORPEN norms revision.

<sup>13</sup> To which scale economies on manure processing have to be added.

**Figure 4. Impact of hog manure pressure on farmland prices in ZES and other districts.**



Note : The quadratic form is the following :  $Price = \alpha + 0,06234 * N_{hog} - 0,000098 * N_{hog}^2$ . Student t-statistics for the two terms are 7,31 et -5,11 respectively and  $\alpha$  represents all the other variables at mean.

It is not simple to explain the every-two-years increase in farmland prices we observe (Appendix 1). It is certainly due to an uncontrolled combination of several factors with every single effect being hardly separable. The interest rate has varied over the sampling period with shift-downs in 1995, 1997 and especially in 2000. On the contrary, the Agenda 2000 reform, in 1999, which planned the decrease of agricultural prices, should have had a negative impact on farmland prices. Between 1993 and 1996, the nitrogen quantity produced in Brittany increased by 4% globally and by 13% for intensive farming (Thouzeau and Guillemot, 1997). However, the increase in organic nitrogen pressure has slowed down after 1996. We tested for interactions between the pressure in hog nitrogen and year dummies, or a trend, with the idea that the price evolution could be due to the shocks induced by environmental regulations. These interactions were not significant. The opposite effects of the evolution of the spreading norm and the CORPEN excretion norm can explain this, as shown in the theoretical model. It can also be due to public policy for nitrogen reduction, which stabilises its cost and thus its impact on land prices.

## CONCLUSION

We analysed farmland prices shifting factors in Brittany on a sample of 7000 individual land transactions. The results are very significant for some key variables and conform to what we expected. Farmland price depends on land quality and their productive orientation, as well as crop yields and milk quotas. These results could have been improved with additional individual data on plot attributes.

In accordance to the observations made by Vukina and Wossink (2000), farmland prices increase with livestock density. Microeconomic theoretical and empirical modelling allow to think that it is due to the capitalisation of the nitrogen spreading right price in the price of land. In their simulation, Le Goffe and Vermersch (2004) show that the price of the nitrogen quota increases with the surplus in the local market. Hog density is the best predictor because it is probably the best proxy for the aggregate demand of spreading lands.

In the most densely pressurised areas, the leasing price of the spreading right would represent a resorption cost of 1 € per kg of nitrogen, considering the use of 100 kg/ha of organic nitrogen for fertilisation. This cost is higher than the tax on livestock pollution (0.15 to 0.30 €/kg of nitrogen surplus), but much smaller than the values observed in the Netherlands or in the simulation provided by Le Goffe and Vermersch (2004) which traduces manure processing costs (up to 3 € per nitrogen kg). This means that farmers in Brittany push their resorption effort beyond their strict short-run economic interest. In other words, the regulatory pressure has some efficiency. The gap with the Netherlands comes from the livestock density and environmental taxes, which are higher in this country. In Brittany, the recent regulatory tools and public subsidies induce a strong development of manure processing. With the investment in manure processing plants being subsidised up to 60%, the processing cost perceived by farmers is not very different from the leasing prices we observe for the end of the 90s. If our results are correct, farmland prices should not increase much<sup>14</sup> but the cost for maintaining livestock will rely on collectivity and there will be no incentives for mineral fertilisation reductions.

This work could be completed by the empirical measure of spreading lands supply and demand, which would be useful to evaluate the policies to control livestock pollution. In France, considering the low development level of the market and the opacity surrounding transactions, stated preferences method like contingent valuation could be appropriated. Moreover, bioeconomic integrated models could allow to simulate organic nitrogen transactions according to transportation costs and alternative resorption methods at a regional scale as it has been done in the Netherlands and in Belgium (Helming, 1998 ; Reyns et al., 2000) and sketched out more recently in France (Djaout, 2004).

From the econometric point of view, we acknowledge that we didn't account for spatial autocorrelations in farmland prices. Relying on an approach developed by Anselin (1988 ; 1990), recent studies of farmland price (Plantinga *et al.*, 2002 ; Patton and McErlean, 2003) use models accounting for such correlations of random error using a spatial weights matrix of distance across observations. This correction follows the assumption that adjacent agricultural lands share common characteristics such that farmland prices are not only determined by their characteristics but also reflect the average local prices. Accounting for spatial autocorrelations would allow us to refine our results.

---

<sup>14</sup> The wish of agricultural organisations.

## BIBLIOGRAPHIE

Anselin (L.), 1988 – *Spatial Econometrics : Methods and Models*. Kluwer Academic Publishing, Dodrecht, Pays-Bas.

Anselin (L.), 1990 – Spatial dependence and spatial structural instability in applied regression analysis. *Journal of Regional Sciences*, n° 30, pp. 185-207.

Baron (P.), Barthélémy (F.), Bouvier (M.), Martin (X.), Vogler (J.P.) 2001 – *Elevages et fonctionnement du Conseil Départemental d'Hygiène en Ille et Vilaine*. Ministère de l'aménagement du territoire et de l'environnement, Paris.

Bastian (C.T.), McLeod (D.M.), Germino (M.J.), Reiners (W.A.), Blasko (B.J.), 2002 – Environmental amenities and agricultural land values : A hedonic model using geographic information systems data. *Ecological Economics*, n° 40, pp. 337-349.

Boisvert (R.N.), Schmit (T.M.), Regmi (A.), 1997 – Spatial, productivity, and environmental determinants of farmland values. *American Journal of Agricultural Economics*, n° 5, pp. 1657-1664.

Cavailhès (J.), 2002 – Marché foncier rural : entre l'agriculture et la ville, *Etudes foncières*, n° 100, pp. 20-21.

Cavailhès (J.), Degoud (S.), 1995 – L'évaluation du prix des terres en France. Une application aux effets de la réforme de la PAC, *Cahiers d'économie et sociologie rurales*, n° 36, 49-78.

Cavailhès (J.), Richard (A.), Taverdet (N.), 1996 – Des rentes classiques aux options de rente. Une analyse de l'évolution du prix des terres en France, *Revue économique*, n° 47 (4), pp. 963-981.

Cavailhès (J.), Wavresky (P.), 2002 – Les valeurs foncières dans le périurbain, *Etudes foncières*, n° 97, pp. 14-17.

Cébron (D.), Ferron (R.), 2003 – Excédents azotés : La résorption s'amorce. *Agreste Bretagne*, n° 45, pp. 4-9.

Djaout (F.), 2004 – *Intérêt d'un marché de droits d'épandage des effluents d'élevage en Bretagne : Respecter à moindre coût la directive Nitrate*. Mémoire de fin d'études, Agrocampus Rennes, option Politique Economique de l'Agriculture et l'Espace, sous la direction de M. Tauber et P. Le Goffe, 113p.

Faux (J.), Perry (G.M.), 1999 – Estimating irrigation water value using hedonic pricing analysis : A case study in Malheur county, Oregon. *Land Economics*, n°75 (3), pp. 440-452.

Goodwin (B.K.), Mishra (A.K.), Ortalo-Magné (F.N.), 2003 – What's wrong with our models of agricultural land values ? *American Journal of Agricultural Economics*, n° 85, vol. 3, pp.744-752.

Greene (W.H.), 2000 – *Econometric Analysis*. Prentice-Hall International, Upper Saddle River, New Jersey, Etats-Unis, 4<sup>ème</sup> édition.

Helming (J.F.M.), 1998 - Effects of nitrogen input and nitrogen surplus taxes in Dutch agriculture. *Cahiers d'économie et sociologie rurales*, n°49, pp. 6-31.

Just (R.E.), Miranowsky (J.A.), 1993 – Understanding farmland price changes. *American Journal of Agricultural Economics*, n° 75, pp. 156-168.

Le Goffe (P.), Vermersch (D.), 2004 - Le marché de l'épandage peut-il réduire le coût de la résorption des excédents d'azote ?, *Economie rurale*, n° 279, pp. 20-32.

Mahé (L.P.), Le Goffe (P.), 2002 - *La résorption des excédents d'épandage : principes économiques d'un plan d'action pour la Bretagne*, Rapport à la Préfecture de la Région Bretagne, 63 p.

Mahé (L. P.), Ortalo-Magné (F.), 1999 - CAP and the countryside : proposals for food production and the rural environment, *Economic Policy*, n°28, pp. 89-131.

Michalland (B.), 1996 – Evaluation de la fonction de demande en eau d'irrigation et application de la méthode des prix hédonistes, *Cahiers d'économie et sociologie rurales*, n° 39-40, 199-222.

Palmquist (R.B.), 1989 – Land as a differentiated factor of production : A hedonic model and its implications for welfare measurement. *Land Economics*, n° 65, vol. 1, pp. 23-28.

Palmquist (R.B.), Danielson (L.E.), 1989 – A hedonic study of the effect of erosion control and drainage on farmland values, *American journal of agricultural economics*, février, pp. 55-62.

Patton (M.), McErlean (S.), 2003 – Spatial effects within the agricultural land market in Northern Ireland. *Journal of Agricultural Economics*, n° 54 (1), pp. 35-54.

Plantinga (A.J.), Lubowski (R.N.), Stavins (R.N.), 2002 – The effects of potential land development on agricultural land prices. *Journal of Urban Economics*, n° 52, pp. 561-581.

Poux (X.), Barbut (L.), 1997 - *Etude sur l'insertion optimale des procédés de traitement dans les cantons en excédent structurel*, Association des Sciences de l'Action (AScA), Rapport à l'Agence de l'eau Loire-Bretagne, Ministère de l'environnement.

Pyykkönen (P.), 2004 – *Factors affecting regional differences in farmland prices in Finland*. Conférence annuelle de la Société Finlandaise de Sciences Agricoles, Päivät, 4 p.

Rainelli (P.), Vermersch (D.), 2000 - Gestion foncière des excédents azotés et marché implicite de droits à polluer : application aux élevages intensifs, *Economie et Prévision*, n° 143-144 /2-3, pp. 91-100.

Reyns (L.), Peeters (L.), Veenendaal (P.), 2000 - *Manure in Flanders : assessing the economic consequences of alternative abatement policies*. Document de travail. Agriculture

Economics Research Institute, The Hague (Pays-Bas), Faculty of Applied Economics, Diepenbeek (Belgique).

SCEES Bretagne, 2003 – Prix : terres. *Tableaux de l'Agriculture Bretonne 2003*, AGRESTE – SCEES, Rennes, pp.110-111.

Shi (Y.J.), Phipps (T.T.), Colyer (D.), 1997 – Agricultural land values under urbanizing influences, *Land economics*, n° 73 (1), pp. 90-100.

Thouzeau (A.), Guillemot (P.), 1997 – De plus en plus d'azote d'origine animale, *Agreste Bretagne*, n° 25, pp. 8-12.

Vukina (T.), Wossink (A.), 2000 – Environmental policies and agricultural land values : evidence from the dutch nutrient quota system, *Land Economics*, n° 76 (3), pp. 413-429.

Weersink (A.), Clark (S.), Turvey (C.G.), Sarker (R.), 1999 – The effect of agricultural policies on farmland values. *Land Economics*, n° 75 (3), pp. 425-439.

White (H.), 1980 – A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity, *Econometrica*, n° 48(4), pp. 817-838.

Xu (F.), Mittelhammer (R.C.), Barkley (P.W.), 1993 – Measuring the contribution of site characteristics to the value of agricultural land. *Land Economics*, n° 69 (4), pp. 356-369.

**APPENDIX 1. Parameter estimates for year and PRA dummies.**

Parameter	Linear	Semi-log	Log-log	Box-Cox 1	Box-Cox 2
1995	75,47** (1,75)	0,0021 (1,28)	0,0219 (1,32)	0,5198 (1,46)	0,3545 (1,46)
1996	76,82** (1,71)	0,0192 (1,09)	0,0160 (0,90)	0,5031 (1,36)	0,3152 (1,26)
1997	320,01*** (6,84)	0,0939*** (5,64)	0,0954*** (5,76)	2,24*** (5,01)	1,52*** (5,01)
1998	301,20*** 6,50	0,1034*** (5,92)	0,1064*** (6,07)	2,33*** (5,02)	1,59*** (5,05)
1999	432,82*** (8,10)	0,1413*** (7,59)	0,1358*** (7,30)	3,24*** (5,77)	2,20*** (5,78)
2000	443,72*** (5,65)	0,1300*** (4,37)	0,1267*** (4,23)	3,16*** (4,52)	2,13*** (4,49)
PRA097	-174,74* (-1,73)	-0,0453 (-1,45)	-0,0734* (-2,44)	-1,07 (-1,39)	-0,8060 (-1,54)
PRA103	-524,08** (-2,01)	-0,1248 (-1,20)	-0,2513** (-2,48)	-3,30 (-1,02)	-1,92 (-0,87)
PRA358	-692,14*** (-6,61)	-0,2285*** (-7,35)	-0,2497** (-8,12)	-5,23*** (-5,61)	-3,49*** (-5,56)
PRA359	-714,03*** (-8,02)	-0,2079*** (-8,17)	-0,2755*** (-11,07)	-5,03*** (-6,00)	-3,58*** (-6,15)
PRA360	-635,74*** (-6,50)	-0,1699*** (-4,97)	-0,193*** (-5,65)	-4,27*** (-4,82)	-2,96*** (-4,88)
PRA361	-686,35*** (-6,60)	-0,2565*** (-8,62)	-0,3456*** (-11,13)	-5,53*** (-6,11)	-3,83*** (-6,18)
PRA362	-865,16*** (-9,06)	-0,2876*** (-9,33)	-0,3850*** (-12,11)	-6,47*** (-6,49)	-4,55*** (-6,60)
PRA363	-1109,12*** (-10,87)	-0,4063*** (-12,68)	-0,5055*** (-16,04)	-8,91*** (-7,10)	-6,15*** (-7,17)
PRA364	-1117,16*** (-7,40)	-0,5049*** (-6,70)	-0,4956*** (-6,49)	-10,10*** (-4,98)	-6,66*** (-4,87)

Student t are in parenthesis. \*\*\*, \*\*, \* are for 1%, 5% and 10% signification respectively

**Reference modalities:**

- year : 1994
- PRA : PRA357



**APPENDIX 2. Variance inflation factors for the different models**

<b>Parameter</b>	<b>Linear, semi-log and Box-Cox 1</b>	<b>Log-log</b>	<b>Box-Cox 2</b>
Wheat high yield	2,935	3,012	2,937
Corn high yield	3,165	3,005	3,177
Corn low yield	4,512	4,511	4,504
ZES county	3,308	13,084	2,286
Hog nitrogen pressure	11,641	3,093	3,241
Hog nitrogen * ZES	16,845	18,461	5,291
Hog nitrogen * grasslands	2,279	14,579	2,276
Vegetables	2,046	1,804	2,037
Dairy cows density	1,097	1,277	1,155
Urban influence index	1,286	1,270	1,292
Surface area of the plot	1,031	1,047	1,028
Arable land	1,262	1,328	1,258
Grasslands	2,475	14,774	2,474
Moor	1,094	1,107	1,094
Ongoing lease	1,065	1,068	1,065
Irrigation	1,906	1,516	1,879
Drainage	2,182	2,283	2,159
1995	1,721	1,728	1,721
1996	1,645	1,656	1,647
1997	1,693	1,698	1,692
1998	1,599	1,607	1,599
1999	1,481	1,489	1,481
2000	1,196	1,198	1,196
PRA097	3,054	3,133	3,066
PRA103	1,038	1,056	1,033
PRA358	2,706	2,811	2,690
PRA359	3,964	4,916	4,127
PRA360	2,915	3,179	2,938
PRA361	3,258	3,706	3,275
PRA362	3,732	4,538	3,833
PRA363	2,734	3,490	2,777
PRA364	1,096	1,124	1,096