Economic tools aiming at nitrogen use reduction by the European agro-system

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Abstract

Mineral fertilizers are often used by agriculture, all around Europe. Crops require nitrogen for their metabolism and these fertilizers may strongly increase the yields. However, mineral fertilizers, when they are used excessively, may be the cause of several environmental problems. For instance, nitrates, that are seeping into the ground, until groundwaters or steams, can deplete the quality of water. Nitrous oxide, a powerfull green-house gas, which may contribute significtancly to global warming. For these reasons, public authorities need to have tools to controle better the quantity of fertilizers that is spread.

Through AROPAj, a technico-economic model of the supply side of the European Agriculture, an increase of the price of mineral fertilizers (until 200 % of the initial price) was implemented in 6 years, from 2007 to 2012. The purpose of this study is to analyse farmers' behaviour, concerning mineral fertilizing demand, land use or green-house gas emissions when they face the introduction of a tax on fertilizers price, other things being equal.

Results show that an increase in fertilizers price may reduce their consumption but also reduce the green-house gas emission from the agricultural sector in the European Union. More precise simulations for France, in 2009, show that some regions are more affected by a tax on nitrogen fertilizers price than others. These simulations also show that the part of land allocated for cereal crops may decrease, in favor of permanent pasture and

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wasteland.
Keywords: AROPAj, mathematical programming, agri-environmental policy, taxes, mineral fertilizers, land use

JEL: Q50, C61, C63

1. Introduction

Nitrogen fertilizers are nowadays commonly used around Europe. Instead of their crucial need for crops, they produce environmental externalities [5]. Their effects on the environment come from three different molecules : nitrates, nitrous oxide and ammonia. Nitrates (NO_3^-) pollutes water, by contaminating aquifers and streams [1]. NO_3^- can be responsible for diverse health problems, for instance, the blue baby syndrome or the stomach cancer [18]. NO_3^-, also causes eutrophication when it leaches the soil [11]. Nitrous oxide (NO_2) contributes to global warming [29] and to deplete the ozone layer [28]. Ammonia (NH_3) can induce acid rains [32].

Public policies are widely concerned by these issues, the European Commission adopted in 2000 a water framework directive [2] that aims to preserve water quality in Europe by targeting nitrogen pollution which comes from the agricultural sector (mineral and organic fertilizers). The report also highlights some agricultural practices more environmental friendly, particularly concerning lowers N-inputs consumption. In 2010, the European Union also decided to reduce total greenhouse gas emissions by 10 % between 2005 and 2020.

In economics, nitrogen pollution is considered as a nonpoint source (NPS) pollution. It means there is a lack of information (due to technical or economic barriers) between the final pollution and the polluters. There is no single point of emission but the pollution comes from diverse and diffuse sources and it is not possible to know precisely who created this negative externality. In the case of nitrogen pollutions, the final pollution is well known (water that contains nitrates, nitrous oxide emissions, etc...) but, because there is a large amount of farmers, it is impossible to know who used the biggest quantity of fertilizers and who contributed the more to pollute. There is also a part of natural origins of nitrates that is very hard to distinguish from the anthropogenic emissions, or a time lapse between farmers' losses and the pollution linked to it [16]. For all these reasons, first-best instruments (for instance, a Pigouvian tax on nitrates or emission quotas) are not efficient to controle the nitrate pollution [17] and the spatial heterogeneity could lead to a choice of the right instrument to use for the purpose of controlling this type of NPS pollution [31].

Facing an environmental problem such as nitrates pollution, the goal of public policies is to maximise the social welfare. In other terms, public deciders have to find a way to internalize the environmental externality. The ultimate aim of a policy may be to reach a Pareto equilibrium where the social marginal damages are compensated by the polluter's marginal deficit. But, in fact and most of the time, the social damage function is very expensive and hard to construct, that is why the goal of a policy maker, instead of achieving a Pareto Optimum, may be to reach environmental standards at lowest costs in an "Environmental Pricing and Standards" (EPS) scheme [6].

2. Litterature Review

Given this context, several authors tried to find the best way of controlling nitrate pollution. Martinez et al. [26] showed in 2007 that a tax on nitrogen fertilizers or a quota on the quantity used may be a quite good second-best control instrument. However, dynamics have to be taken into consideration in order to not to be mistaken on the choice of the right instrument. They also highlighted that differential control measures have to consider the diversity of soil types, for the purpose of maximising welfare gains.

In 2007, Semaan et al. [30] coupled an agronomic model with a mathematical multi-objective programming model to analyse the effects of three agricultural policies (irrigation water pricing, subsidies to adopt improved management levels and taxation on the use of nitrogen fertilizer were examined) on nitrate leaching. They showed that a tax on nitrogen fertilizers is more efficient than water pricing for reducing nitrate leaching.

Then, Gómez-Limón and Gallego-Ayala [15] tried to compare the different instruments that may exist for mitigating nitrate pollution. They implemented the Common Agricultural Policy (CAP) reform of 2003 with several policy instruments for reducing nitrate pollution. The results were that the CAP reform (partial decoupling of subsidies) itself lead to a real decrease of nitrate pollution.

Clother than what it is trying to do in this study, Berntsen et al. [7] suggested in 2003 an evaluation of several taxation scenarios using the dynamic whole farm simulation model FASSET. The different scenarios were a tax on nitrogen in mineral fertiliser, a tax on nitrogen in mineral fertiliser and imported animal feedstuff, and a tax on the farm nitrogen surplus. These policies were applied on four farm types : arable on sandy soil, arable on loamy soil, pig production on sandy soil and pig production on loamy soil. They finally conclude that none of the taxation policies was the most cost-effective for all farm types, for instance, a tax on mineral fertilizers favours pig producers instead of a tax on nitrogen surplus that favours arable farms. They also established that the social abatement cost of reducing nitrate leaching varied between 1 and 9 €.kgN^{-1}.

Jayet and Petsakos [23] submitted in 2013 another evaluation of the efficiency of a uniform N-Input tax under two policy scenarios and at different scales. The policy scenarios were corresponding to post Agenda 2000 and 2003 Luxembourg reforms of European Union's CAP and the analysis was based on a bioeconomic approach that coupled STICS (a crop model) with AROPAj (an economic model). Results were that the efficiency of such a uniform N-tax changes regarding the geographical scale and the type of farming. They also found in this study that these policies may lead to perverse effects which have to be taken into account if they are implemented. For instance, some farms may adapt their land use and choose more pollutant crops, crops that do not need a lot of nitrogen fertilizers but crops that reject more nitrogen because they do not store it so much.

In this study, the goal is to observe farmers' behaviours facing the implementation of a tax on mineral nitrogen fertilizers, in terms of land use adaptation, nitrogens fertilizers consumption or water consumption. An analysis for the whole european union (UE-27) will be provide.

3. The Model

3.1. The Agro-Economic Model

The mathematical programming model used in this study is the model AROPAj, a supply-side model of the EU agricultural sector [24]. This model is made of a set of independent, mixed integer and linear-programming models (MILP). Each model describes the economic behavior of a representative farmer, that is represented by a "farm type" and denoted by k. Farms are grouped into these "farm types" respecting to the type of farming (TF), the number of animals, the animal feeding, the crop area allocation, the eligible crops, the economic size, the region and the altitude class. Each farm type is assumed to choose the supply level and the input demand (x_k) that maximize its total gross margin (π_k). It is also noteworthy that each farm types is considered to be price-taker. This model can be written as follows, for its general form [12]:

$$\begin{cases} \max\limits_{x_k} \pi_k(x_k) = g_k \times x_k \\ \text{s.t. } A_k \times x_k \leq z_k \\ x_k \geq 0 \end{cases} \tag{1}$$

– x_k is the n-vector of producing activities for farm type k
– g_k is the n-vector of gross margins
– A_k is the $m \times n$ - matrix of the coefficients associated with the n producing activities and defining the m constraints
– z_k is the m-vector of the right-hand size parameters

It is to note that x_k includes the area and output for each crop (24 crop farming are modelled), crop production can be either directly sold in the market or used to feed animals (forage, pastures, feed grains). x_k also includes the quantity of purchased animal feeding, milk and meat production, and animal numbers in each animal category (concerning livestock there are 31 categories represented in the model, 27 for cattle plus sheep, goats, swine and poultry). g_k includes all gross margins corresponding to each producing activities : revenue (yield multiplied by price) plus subsidies, minus variable costs. A_k and z_k contains the constraints that limit the production, in terms of technically feasible production but also in terms of CAP requirements.

Total land area (split into crops and grasslands) is bounded by the European land area. There are also constraints on the crop rotations. Animal numbers are bounded by the place, but, with the purpose of reflecting the real nature of livestock-related capital which almost does not change, animal numbers are allowed to vary in a very limited range. In the model, it is assumed that the animal number may vary into a +-15% of the initial animal number in each category of animals.

Constraints on animal feeding are also developed by the model. Farmers can use crop and forage production or purchased concentrates. There are four types of purchased concentrates and this differentiation enables to make the distinction between energy-rich and protein-rich concentrates, then, farmers have to reach the minimal digestible needs, in terms of proteins and energy, for each animal category. The maximal digestible quantity of ingested matter and the requirements in proteins or in energy for each category of animals were taken from Jarrige [21].

Another set of constraints concerns the CAP measures. These constraints may be for instance quotas in milk production or a maximum amount of organic fertilizers that can be applied (170 kg.ha^{-1}).

Then, the implementation of the parameters defining A_k, z_k, g_k and x_k takes three steps, the first one is the selection and the grouping of sample farms into farm groups, the second one is the estimation of the parameters of the model and the third one is the calibration.

The Farm Accounting Data Network (FADN) is the main source of data. The 2007 -

2012 FADN provides accounting data (revenues, variable costs, prices, yields, crop area, animal numbers, support received, type of farming) for more than 80,000 farms. A bit more than 70,000 farms are part of the model (horticulture and permanent crops such as vineyards or orchards are not considered by the model), grouped into 1802 farm types, which represents more than 3.7 millions of European full-time farmers. Data is available at a regional level (approximately 130 regions in the EU-27).

Then, the selected farms are grouped into farm types regarding three main criterions, the region (134 regions in the EU-27), the average elevation (3 classes : 0 - 300 m, 300 - 600 m and above 600 m) and the main type of farming (14 types of farming in the FADN classification). It is important to quote that the number of sample farms, grouped into farm types, has to be large enough to deal with the confidentiality policy of the FADN (at least 15 sample farms in a farm type) but also to provide a certain robustness to the estimations. Nevertheless, the number of farm types has also to be large in order to reduce the aggregation bias at the regional level.

To summarize, a farm type is an aggregation of sample farms that are located in the same region, have the same elevation and the same type of farming. Each farm type follows the model described in (1).

Other sources of information are also used when the FADN is not competent. The Intergovernmental Panel on Climate Change provides climate data [3], information on feeding products and livestock requirements are also from technical reports [21]. Experts knowledge may also be used when there is no statistical or technical source on the field.

The calibration of the parameters is the last step before doing the simulations. In this phase, initial values of the parameters are re-computed with the aim of minimizing the distance between the observed value x_k^0 and the optimal one x_k^* [13].

3.2. Spatialization

Even if the region of farm types is known, the exact geographical location of farm types is unknown due to the FADN privacy policy. That is why the AROPAj results are spatialized according to a method based on an econometric model [10] which was first developped by Cantelaube et al. [9]. This method has to follow three steps. The first one is to estimate the crop location by considering the physical data at a very fine level of resolution. The second one is to refine the crop location probabilities (with a cross entropy method). The third one is to estimate the location of farm groups by combining FADN data with the high-resolution crop allocation.

AROPAj outputs may be distributed all over France thanks to this spatialization method. Each farm group on each cell of the grid contributes to give the regional agricultural activity. On the map, each variable is represented by a polygon that satisfies the following equation.

$$V_{polygone} = \frac{\sum_k v_k}{\sum_j s_{jk}} \times p_k \tag{2}$$

– $V_{polygone}$ is the volume of the polygon
– v is the variable
– s is the surface
– p_k is the crop location probability
– k is the farm type
– j is the culture

The spatialization makes sense for analysing the results, not only to know at a very fine level which areas are the most affected by the tax but also because of the degree of locality of the pollution caused by the use of mineral fertilizers. For instance, the spatialization might be usefull to know where the tax is the most efficient to tackle nitrate pollution.

3.3. Simulating N-input Taxes

Assuming that farmers' behaviour is lead by rational choices, the gross margin has to be maximize by the farmers. The maximum value of the gross margin is reached when the marginal productivity of fertilizers is equal to the ratio between fertilizer prices and the production price.

However, nitrogen fertilizers might have negative effects on the quality of environment, that is why public policies try to find a way of reducing their use in order to enhance ambient quality. A tax may be a good tool for the regulator, even if the social acceptability of this type of policy is sometimes questionable. Indeed, the implementation of a tax on fertilizer prices changes the gross margin function for farmers, the maximum value of the gross margin may be reached only if the marginal productivity of fertilizers is equal to the ratio between fertilizer prices plus the tax on these fertilizer prices and the production price.

The FADN provides 6 independant sets of data, one for each year from 2007 to 2012. Then, a uniform tax on the mineral nitrogen fertilizers is implemented. This tax starts with 0% of the initial fertilizer prices and goes, with a step of 20%, until 200% of the initial mineral nitrogen fertilizer prices. It means there is an amount of 11 simulations for each set of data (2007-2012).

It is important to add that the year 2009, for France, is more precise because of the use of dose-response functions [19]. Instead of using observed economic data given by the FADN, those dose-response functions, extracted from the crop model STICS [8] are able to give the yield of a crop for an amount of nitrogen fertilizer and irrigation water.

This protocole provides informations to analyse farmers' behaviour when they face to an introduction of a tax on mineral nitrogen fertilizer prices.

At a European scale, other things being equal, how can evolve the farmers' gross margin, the land use and the mineral nitrogen fertilizers and water consumption ?

4. Results

4.1. European Union (UE-27)

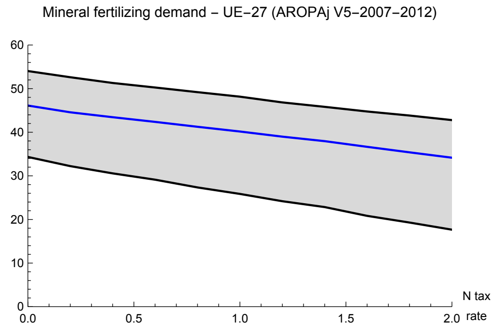

Figure 1: Mineral fertilizing consumption for UE-27 for 2007-2012 in function of the N-tax rate

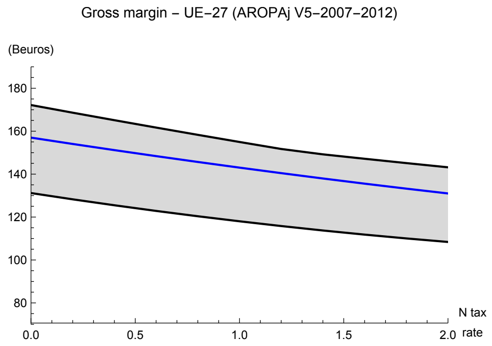

Figure 2: Gross margin for EU-27 for 2007-2012 in function of the N-tax rate

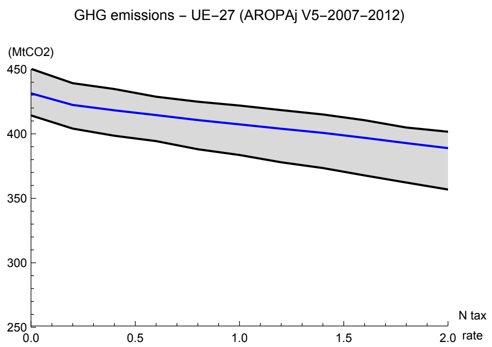

Figure 3: GHG emissions for EU-27 for 2007-2012 in function of the N-tax rate

4.1.1. Nitrogen Fertilizers Consumption

The mineral fertilizing demand (in millions of tons) is represented in figure 1 in function of the tax rate on the price of mineral nitrogen fertilizers. It means the price of the fertilizers vary between the initial price (0.0 on the scale of the N tax rate) and 300% of the initial price (2.0 on the scale of the N tax rate). The all 6 years are in the grey zone which is bordered by the minimum and the maximum. This zone is build with the 6 curves (2007-2012) obtained with AROPAj simulations. The blue curve is the mean value of the 6 simulations. The 6 simulations used to construct this graph are presented in annex A.

The figure 1 presents the mineral fertilizing demand for the EU-27 in function of the N-tax rate. When the fertilizers' price is multiplied by 3, their consumption goes down from 46.2 MT to 36.5 MT. For an increase of 200% of the price of mineral fertilizers, the demand decreases of 21%. It means there is an elasticity of the mineral fertilizers of -0.11 for the European Union from 2007 to 2012.

N.B.: The minimum is the year 2009 because the prices of fertilizers were high (so their consumption was weak, even before the implementation of a tax on the fertilizers). For 2009, the demand decreases of 45% for an increase of 200% of the price, so the elasticity of fertilizers is -0.23.

4.1.2. Gross Margin

In the European Union (UE-27), the figure 2 shows that an increase of the price of nitrogen fertilizers may have a negative impact on the gross margin. The use of mineral fertilizers is a production cost for a farmer so it is easily understandable that if production costs increase without increasing crops yield, the gross margin decreases.
The elasticity of the gross margin is in average of -0.07 for the period 2007-2012.

4.1.3. GHG Emissions

According to the figure 3, a tax on the price of mineral nitrogen fertilizers causes a reduction of green-house gas emissions (GHG emissions). The GHG emissions from the European Union may decrease of 8.6% when the price of fertilizers is multiplied by 3.

This result is probably directly due to the decline of the consumption of mineral fertilizers.

The use of mineral fertilizers induces the release of nitrous oxide (NO_2), a gas that has 298 times the atmospheric heat-trapping ability of carbon dioxide (CO_2) [14]. So, a reduction of the use of chemical fertilizers may logically reduce the GHG emissions.

4.2. France

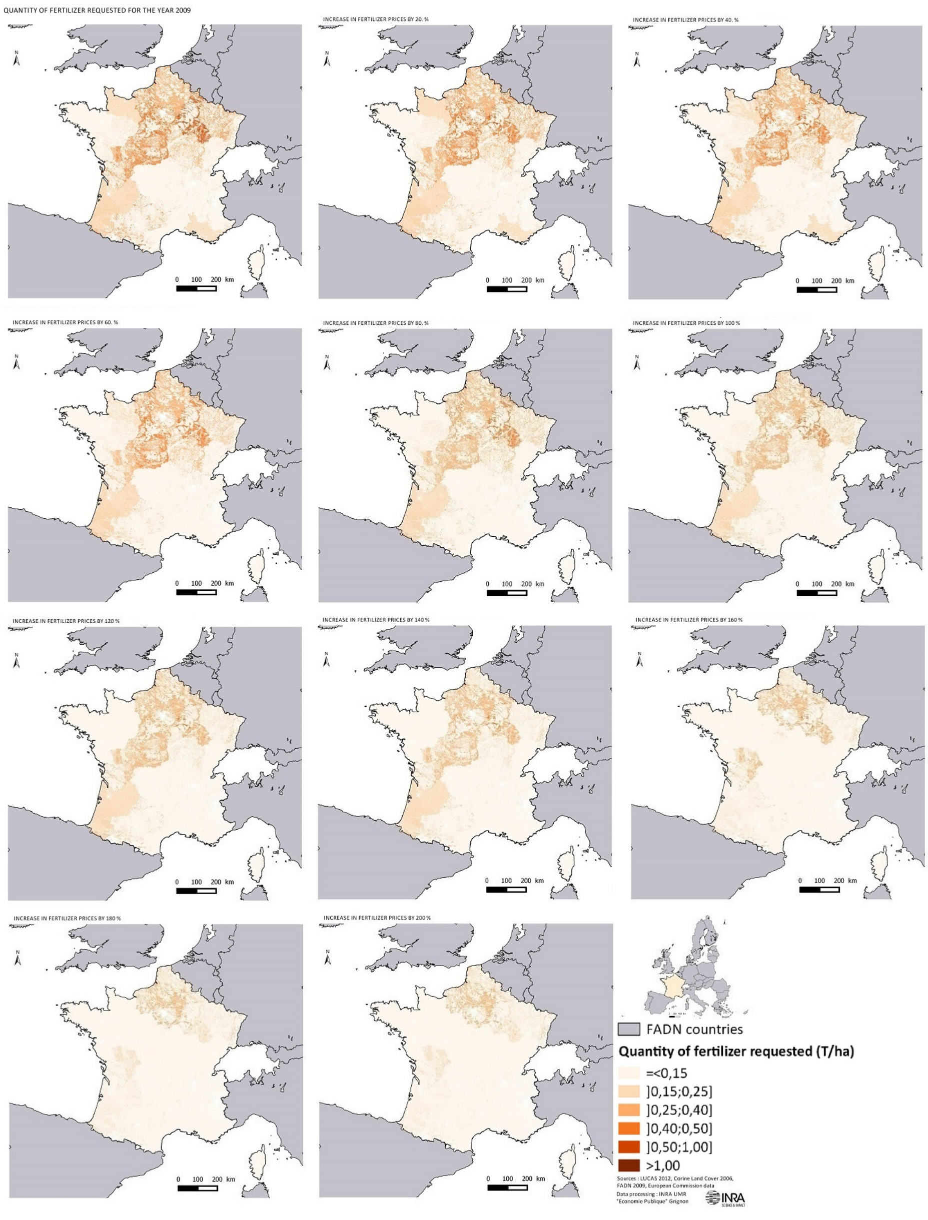

Figure 4: French mineral fertilizing consumption under an N-tax rate, 2009

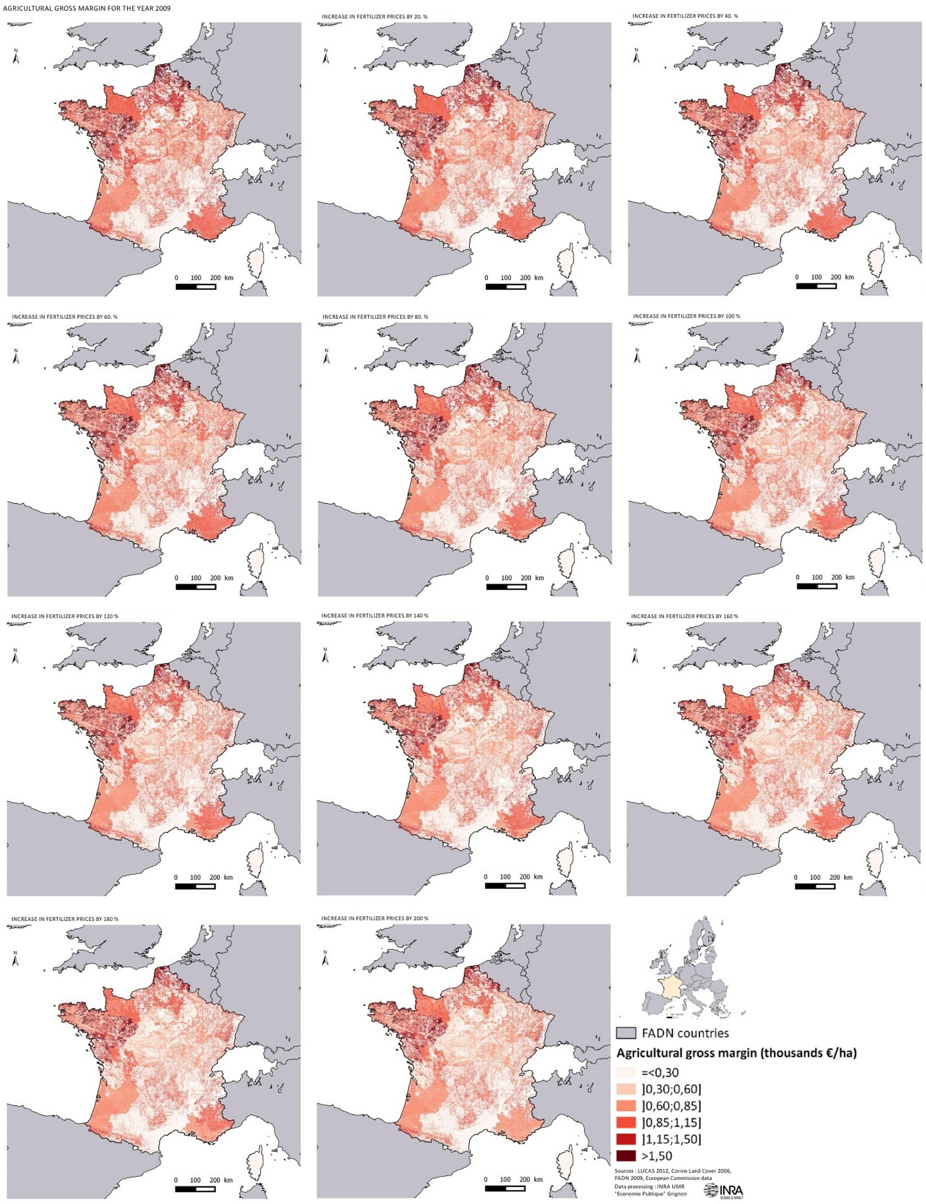

Figure 5: French agricultural gross margin under an N-tax rate, 2009

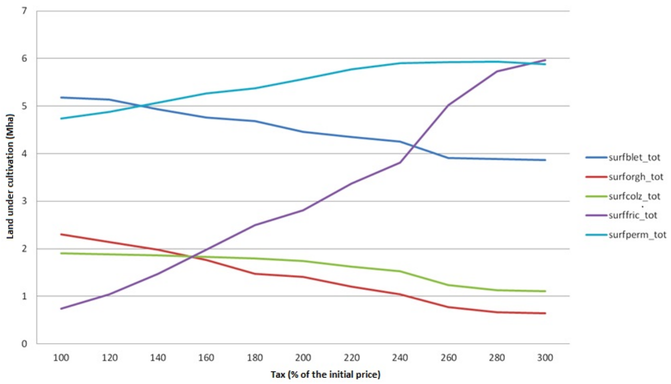

Figure 6: Land Use in function of the N-tax rate for France, 2009

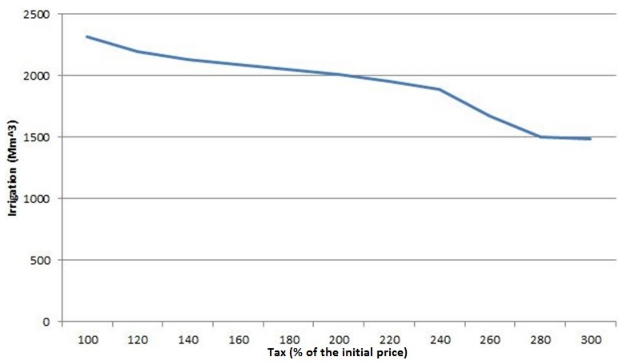

Figure 7: Irrigation in function of the N-tax rate for France, 2009

4.2.1. Nitrogen Fertilizers Consumption

The figure 4 presents spatialized results of the french mineral fertilizing consumption when the price of fertilizers goes to 300 % of the initial price, with a step of 20 %. The regions that are the biggest consumers of mineral fertilizers are Picardie, Centre and the south of Champagne-Ardenne. It is quite coherent with the fact that these regions are the biggest producers of cereal crops in France. The consumption of mineral fertilizers is low in dairy farming area (Bretagne, Normandie) or in mountain regions where pasture are dominant (Massif Central, Alps, Pyrenees).Before the implementation of the tax, some areas of the region Centre or of Champagne-Ardenne are consuming more than 1 ton of fertilizers per hectare. Picardie is also a big consumer (between 0,5 and 1 ton per hectare). Champagne-Ardenne and Centre are more affected than Picardie by the implementation of the tax on mineral fertilizers. When the price of fertilizers is doubled, their consumption in these regions is between 0,4 and 0,5 ton per hectare and when the price is multiplied by 3, the consumption is lower than 0,15 ton per hectare whereas the consumption is roughly between 0,15 and 0,4 ton per hectare for the region Picardie.

These results may be put in relation with the results on the gross margin. Regions that are the most affected by the tax (South of Champagne-Ardenne, Centre) have a gross margin that is always inferior to the farmers' gross margin of Picardie. It is reasonably possible to make the hypothesis that farmers from Picardie do not reduce their consumption that much because they still have an important gross margin, even when the price of fertilizers increases.

This is also probably due to the fact that it is not exactly the same crops that are produced in these several regions [4]. While the region Center and the south of Champagne-Ardenne are big producers of wheat, barley and canola, Picardie is a good producer of wheat, beetroot and potato. wheat and canola crops require more nitrogen fertilizers than beetroot and potato crops [25]. Another explanation may be the different sensitivity to nitrogen fertilizers of these crops. Perhaps, there is no interest in reducing fertilizing for farmers which produce potatoes because the yield may decrease too much.

4.2.2. Gross Margin

The figure 5 presents the evolution of the gross margin in France, for 2009, when the tax on the price of nitrogen fertilizers increases. Before the implementation of the tax, regions that have the biggest gross margin are the north of France, Bretagne and Normandie (more than 1500 €.ha^{-1}) but also Champagne-Ardenne and Centre (850 - 1 500 €.ha^{-1}). Normandie and Bretagne are not affected that much by the tax on the price of nitrogen fertilizers. This can be explain by the fact that these regions are mainly dairy areas, they do not produce a lot of cereal crops that require nitrogen fertilizers. In the case farmers produce cereal crops, in these regions with livestock husbandry, they probably can use organic fertilizers instead of mineral fertilizers. Then, the north of France, Picardie, Champagne-Ardenne and Centre are big producers of cereal crops, but the implementation of the tax affects more severely Champagne-Ardenne and Centre than Picardie. This result could be put in relation with the maps on the evolution of mineral fertilizing demand when the price of fertilizers rises. It is also possible to see on these maps that Champagne-Ardenne and Centre are more reducing their fertilizer consumption than Picardie. This could be explain by the fact that crops which are produced in these regions are not exactly the same. Champagne-Ardenne and Centre are big producers of wheat, colona and barley, whereas Picardie and the North are good producers of wheat, potato and beetroot.

4.2.3. *Land Use*

For France, in the year 2009, the figure 6 shows that the increase of the mineral nitrogen price causes the decline of the cereal crops. On the one hand, the wheat falls to 3,9 Mha from 5,2 Mha when the mineral fertilizers price is multiplied by 3. The sharpest decrease concerns the barley that falls of 74% (from 2,3 Mha to 0,6 Mha) when the price of fertilizers is multiplied by 3. On the other hand, the part of permanent pasture and wasteland increases strongly. From 0,7 Mha, the wasteland may reach 6 Mha, which represents an increase of 757%.

Even if the decline of cereal crops, that need an important amount of nitrogen fertilizers to grow, seems to be quite logical, the strong increase of wasteland is not so instinctive. Farmers don't make the choice of growing crops that require less nitrogen fertilizers. For instance, the part of pulses and legumes (faba beans, lucerne) don't increase. This is probably due to the fact that these crops are not very often directed to the human consumption but to cattle. However, it is assumed in the model that the number of animals may not vary of more than 15% (in order to well reflect the real world). So if the number of animals can't increase that much, farmers do not have interests in producing crops for animal feeding [20].

4.2.4. *Irrigation*

For the year 2009, the amount of water used for agriculture is better estimated by AROPAj than in other years because of the presence of dose-response functions that link the crops yield to water and nitrogen fertilizers requirements [19]. The figure 7 shows that when the price increases of 200%, the water demand for irrigation decreases of 36%, so the elasticity of the water demand is 0.18.

This result is in tune with the result on land use, The part of crop cultures decreases with the tax on fertilizers' price, so does the water demand for irrigation. The less crops there are, the less it is necessary to water.

The result is also coherent with the shape of dose-response functions. If the dose of nitrogen fertilizer decrease, the dose of water supplied to the crops also has to decrease in order to reach the optimal yield.

5. Conclusion & Discussion

Along this study, it has been shown that a tax on the price of nitrogen fertilizers may really affect the agricultural gross margin and the consumption of fertilizers, all around the European Union. An increase in fertilizers price might also decrease the green-house gas emissions from the agricultural sector.

A focus on France, for the year 2009, was made possible because of the use of dose-response functions for crops yield. At first, It has been shown that the implementation of a tax on nitrogen fertilizers may not affect the gross margin in dairy areas (Normandie, Bretagne) where the mineral fertilizers consumption is low. Regions that are good producers of crop cereals are more affected by the tax, especially Centre and Champagne-Ardenne which produce a lot of wheat, barley and colona, crops that require a big amount of nitrogen fertilizers. Picardie and the north of France are doing quite well for cereal producers, probably because they produce in a large part potato and beetroot crops, two crops that need less nitrogen fertilizers than wheat or colona.

Last but not least, it is also shown that the implementation of a tax on the price of mineral fertilizers might deeply change the land use. The part of areas covered by wheat or barley decreases whereas areas of permanent pasture and wasteland increase.

The implementation of such a tax may be discussed. Even if nitrogen fertilizers produce environmental problems, this is not really conceivable of multiplying their price by 3, for economic reasons but also for food safety reasons. This tax has not that much chances to be socially accepted.

It would also be interesting to see how fruit and vegetable production is affected by the tax.

The model does not take into account these producers, that are though, big consummers of mineral nitrogen fertilizers.

Another possible interest could be to put these results in relation with a model that can evaluate the local pollution (such as the one caused by nitrates). It could allow to better know what the regions very polluted and where this tax is efficient to fight the nitrate pollution. This question on the problem of local pollution leads to think that it could also be usefull to controle organic fertilizers and not only mineral fertilizers. The region Bretagne is well touched by the problem of nitrates pollution, with the increasing number of green algae [27], but a tax on the price of mineral fertilizers is not efficient for this region. Indeed, the nitrate pollution in this region essentially comes from livestock. A creation of a market of organic fertilizers may be add to this study to know if it is possible to make a link between nitrogen rich regions (Bretagne, Normandie) and nitrogen poor regions (Centre, Champagne-Ardenne) that need to import mineral fertilizers. A market of organic nitrogen fertilizers has already been imagined by Jayet et al. [22] and it has an ecological sense because it might permit to recycle the N cycle.

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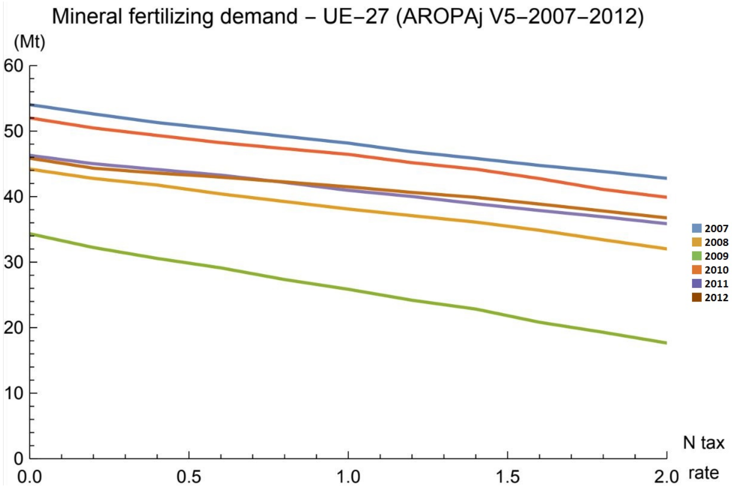
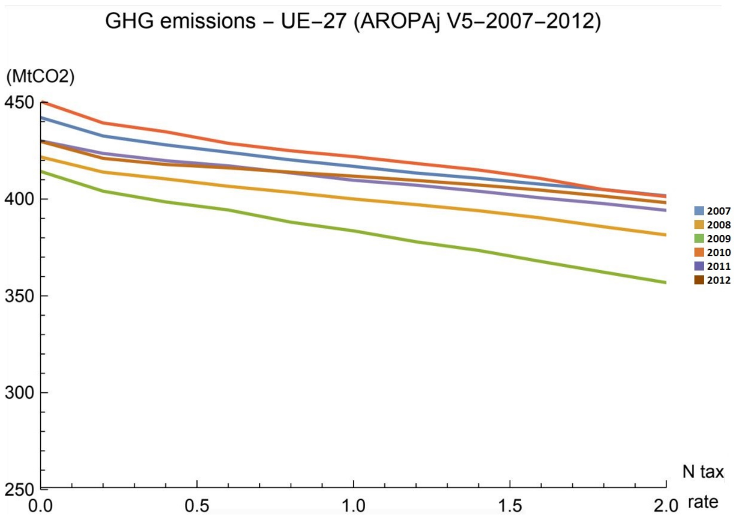
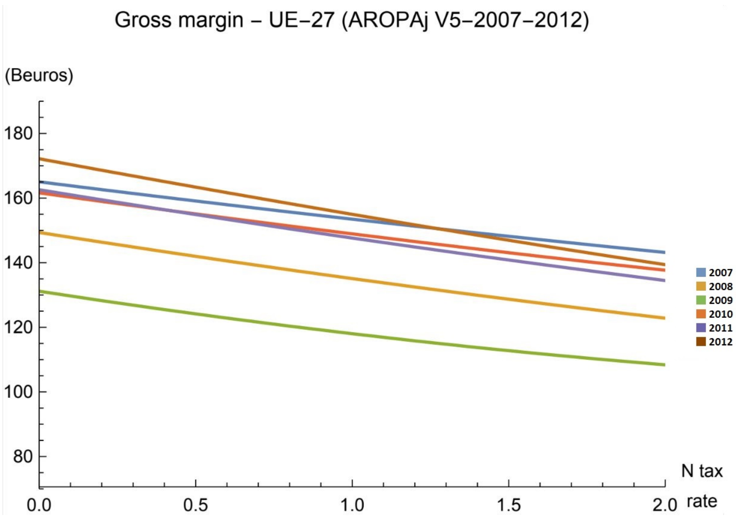
Annex A


Mineral fertilizing demand – UE-27 (AROPAj V5-2007-2012)
(Mt)
60
50
40
30
20
10
0
0.0
0.5
1.0
1.5
2.0
N tax
rate
2007
2008
2009
2010
2011
2012


GHG emissions – UE-27 (AROPAj V5-2007-2012)
(MtCO2)
450
400
350
300
250
0.0
0.5
1.0
1.5
2.0
N tax
rate
2007
2008
2009
2010
2011
2012


Gross margin – UE-27 (AROPAj V5-2007-2012)
(Beuros)
180
160
140
120
100
80
0.0
0.5
1.0
1.5
2.0
N tax
rate
2007
2008
2009
2010
2011
2012