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## Improvement of water quality as a joint production of milk when dairy farms are heterogeneous<sup>1</sup>

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### Abstract

We present the impact of the farms heterogeneity on the promotion of non-commodity outputs on a French case study. We show first that the large heterogeneity of the ratio of the amount of non-commodity and commodity outputs supplied by the farms can be captured by a one-dimensional parameter: the type of the farm. Second, using the relationship between the amount of non-commodity and commodity outputs supplied by the farms and their types, a regulator can design an optimally differentiated policy to promote the supply of the non-commodity output without weakening too much the supply of the commodity output and the farmers' revenue.

keywords: joint production, farms heterogeneity, linear regulation, differentiated regulation

### 1 Introduction

The consequences of the diversification of the amounts of commodity and non-commodity outputs supplied by farms on the cost of policies promoting agro-environmental measures have been analyzed for space (Ancev, *et al.*, 2003) or time variations (McSweeney and Shorite, 1990, Mapp, 1994). But the farms also use production factors that are not differentiated spatially and evolve slowly in time, like the management skills of the farmer, the genetic value of the herd, or the ability for the farm to use low cost machinery, for example. As a consequence, the same technical choice on two different farms may result in the supply of different amounts of commodity and non-commodity outputs, without any simple relation to the localization of the farm.

This heterogeneity of the farms induces distortions when a regulator chooses linear instruments to promote agro-environmental measures. These distortions are sometimes reported to be of low importance (Helfand and House, 1995), but much often the induced distortion is high enough to considerably modify the cost of the regulating policy (Wu and Babcock, 2001, Khanna, *et al.*, 2002). Differentiated regulations including lots of information usually overcome undifferentiated policies, most often largely (Flemmings and Adams, 1997, Carpentier, *et al.*, 1998, Claassen and Horan, 2001). Thus, before promoting any agro-environmental measure, it is of utmost importance for a regulator to analyze the variation of the ratio between the commodity and non-commodity outputs supplied by the regulated farmers and to determine whether this variation requires the design of a differentiated policy.

In this paper, we present on a case study the impact of the farms heterogeneity on the promotion of non-commodity outputs by a regulator, on a French region. We show first that the large heterogeneity of the ratio of the amount of non-commodity and commodity outputs supplied by the farms can be captured by a one-dimensional parameter: the type of the farm. This one-dimensional parameter is built as a combination of several qualitative variables that are perfectly mastered by the farmers. Second, once the regulator has determined a relationship between the amount of non-commodity and commodity outputs supplied by the farms and their types, she can design an optimally differentiated policy to promote the supply of the non-commodity output without weakening too much the supply of the commodity output and the farmers' revenue.

The paper is organized as follow: section 2 describes the concepts and theories that have been mobilized. The section 3 presents the methods used for building the model and provides the data of the empirical application. The main results are displayed in section 4 and the section 5 concludes.

### 2 Concepts and theories

When designing a policy, a regulator has to make choices on how he will distribute the non-commodity production effort among the producers, when they are heterogeneous. The effort repartition will depend on the variation of the ratio between the amount of the commodity and non-commodity outputs supplied among the farms. The regulator needs to include in the design of the policy some information on the range of the heterogeneity of the farms. Even though the models describing the physical consequences of the farmers' economic decisions greatly developed for the last years, a regulator can not acquire all the information she would need to design first best regulations.

<sup>1</sup> We acknowledge financial support from EU through the AgriBMPWater project (5th PCRD).



For the regulator, designing such a policy means choosing two different things. First the regulator has to determine which instrument is to be regulated. The choice of the instrument base can significantly influence the cost-effectiveness of the agro-environmental policy. The regulated instrument can be an estimation of the individual amount of non-commodity output provided, or some input related with this amount, or some specific production technique or input which is supposed to be related to the amenities provided, or the production level.

Second the regulator has to define the method of applying the policy: will she content herself with a uniform regulation or does she need an optimally differentiated one? She can either built regulations with several instruments which compensate their mutual distortions (Vatn, et al., 1997, Ipe, et al., 2001, Kampas and white, 2003, Horan, et al., 2002), or include incentive constraints in the regulation (Wu and Babcock, 1996, Goldsmith and Basak, 2001, Peterson and Boisvert, 2001).

We shall focus here on the promotion of good quality water production when this production is joined with dairy production, but when the degree of junction depends on the farm. Most of the possible sets of policies for this promotion have been designed and analyzed through the non-point source (NPS) pollution literature, which focuses on two basic frameworks. The first framework assumes that the soils, climate or farm locations are of great importance for both farmers' profit and pollutant transfers to water. The models resulting from this approach are generally soil-management based. They are often combined with a hydrological model to describe water and pollutants transfers through a watershed, and are coupled with a simple economic model of some technically defined types of farms. The coupling of the physical and economic models allows a cost-efficiency analysis of different policies. This framework led to several important advancements: there are large differences in emission levels from one farm to another, especially when their productions, like pigs, milk or cereals differ (Schou et al., 2000); management decisions interact with soil and climate conditions with significant consequences on profit and emissions (Kampas et White, 2003). Thus, a regulating option can be of high value for some types of farms in one given watershed and of no interest elsewhere (Polman et Thijssen, 2002).

The second framework goes further and focuses on the description of the heterogeneity of the farms along a watershed or a country. The modeling designs policies that are differentiated among the producers. Usually, regulation strategies including lots of information out-perform uniform regulations and in most cases with a large margin (Claassen and Horan, 2001). But because the regulator can not access all the informations she would need to design such a regulation, she has to add some incentive constraints during the design. These constraints are costly but they ensure that each producer chooses the instruments that have been designed for him. The model developed in this paper belongs to this set of literature, according to Laffont (1994) who applied the economical Agency theory to pollution problems. Laffont (1994) showed that as soon as a regulator can correctly characterize the possible polluters, she is able to efficiently distribute the de-polluting effort, or similarly the non-commodity output production effort, among the producers (Laplana, et al., 2004).

### 3 Method used

#### 3.1 Study area

The Don watershed (71 706 ha) is located in the western part of France, in "Pays de la Loire" region. Farm production is mainly cattle breeding (dairy and meat productions), where cereals are grown for both grain and forage. Indoor breeding is still of low importance, but the number of pig and poultry farms is increasing. Grasslands, associated with dairy production, account for around 50% of total agricultural area. Cereals represent 18% and corn 15% of the total area. The average size of farms was 74 ha in 1999. The weather is typically oceanic, with cool wet winters and warm drier summers. The Don watershed is covered by brown soils resulting from the alteration of the underlying schist rock. The watershed being quite flat and soil hydraulic conductivities rather low, these thin soils (60 to 90 cm deep) are frequently hydromorphic. The water coming from the Don watershed is connected to two pumping stations for drinking water, supplying around 150,000 people. The "Departmental Council of Loire Atlantique" monitors water flows and nitrate concentrations at the "Conquereuil" station (draining 59 306 ha of the whole Don watershed).

In the Don watershed, the nitrate concentration regularly reached or exceeded the EU guidelines of 50 mg/l at the "Conquereuil" pumping station in the mid-nineties when a recovery program was elaborated by local extension services. Cropping, fertilising and manuring advice have been proposed to the farmers who could voluntary choose to adopt them or not. For several years, no change in water quality has been noticed, so the attention focused to the rate of adoption of the "best practices" that had been promoted on this watershed.

The population of farms in this watershed was initially surveyed by an extension service in 1999. This inventory was used to stratify the whole population of 820 farms with production system criteria. The stratification of the population was based on both the production system and on the balance between grazed (mostly pastures) to harvested (mostly corn) areas. A sample of 82 farms was randomly selected from these *strata* (with sample size proportional to each stratum size) and surveyed in more details. The aim of the more detailed survey was to describe the stages of decision making by the farmers faced with environmental questions (Ölmer et al., 1998), i.e. problem detection, problem definition, analysis and choice (observation and searching for options, analysis tools) and eventually the implementation of action. Special attention has been paid to the evolution of these ideas for the last five years. A precise description of the fertilisation practices for each crop in each rotation has been collected for the last ten years. For the farmers who accepted it, gross and net output, production costs have been collected for the last three years.

### 3.2 Relationship between the amount of commodity and non-commodity outputs supplied

Bontems *et al.* (2003) proposed a regulation framework for heterogeneous dairy farms, optimally differentiated on the dairy production level, which results in the joint production of good quality water along to improving the farmers' income. Their framework relies on the relationships between commodity and non-commodity outputs production functions of the farms. We shall focus in this paper on this relationship.

Individual emissions have been estimated using the SWAT model. This model -Soil and Water Assessment Tool- is a semi-distributed watershed model with a GIS interface (DiLuzio *et al.*, 2002) that outlines the sub-watersheds and stream networks from a digital elevation model and calculates daily water balances from meteorological, soil and land-use data. SWAT simulates each sub-basin separately according to the soil water budget equation taking into account daily amounts of precipitation, runoff, riverbed transmission losses, percolation from the soil profile, and evapotranspiration. For the surveyed farms, there is no clear relationship between the supply of the commodity output, milk and the non-commodity output, N-nitrate emitted to the river (see Figure 1).

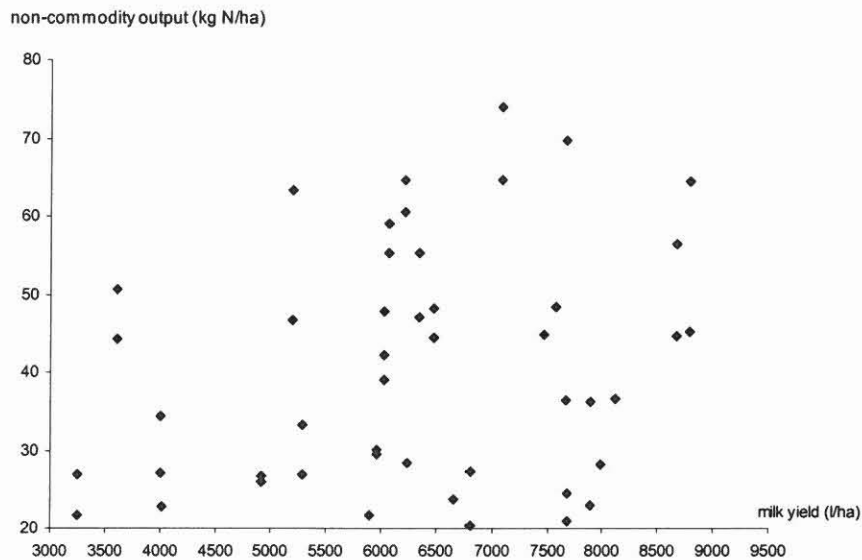


Figure 1: Supply of commodity (milk) and non-commodity (N-nitrate in water) outputs by the surveyed dairy farms on the don watershed

Bontems *et al.* (2003) reduced the heterogeneity of the farms along two dimensions, their ability to transform inputs into final production and the available area they possess. Productive ability is private information to the farmers while available area and final production are observable characteristics. The ability parameter, denoted  $\theta$ , is estimated by combining the technical variables that capture differences across farms and, in our case, describes 43% of the whole variability among the farms (Turpin, et al., 2003). The qualitative variables concern the quality of the land, the repartition of the fields around the farm buildings, the managements skills of the farmer, the genetic value of the herd. In the short-term, it is reasonable to consider these levels as being fixed, so that  $\theta$  is exogenous. In our case, this parameter represents the farmer's ability to transform feed crops into the production of milk : we considered farmers whose commodity output,  $y$  (milk), is produced from a quantity  $s$  of land devoted to feed crops and a polluting input (such as fertilizers), with production costs  $c(y,\theta)$  per unit of land. We make the following assumptions<sup>2</sup>:  $c_y > 0$ ,  $c_{yy} \geq 0$ ,  $c_\theta < 0$  and  $c_{y\theta} < 0$ . The two latter assumptions mean that we normalize the set of types by assuming that the variable cost is decreasing in the ability parameter and that the marginal cost of producing milk is also decreasing with the ability (the so-called single-crossing conditions). In other words, a more efficient farmer is also associated with lower optimal rates of input use (see Figure 2).

<sup>2</sup> The properties of the cost and emission functions have been derived from the analysis of a sample of farms from the Don watershed (700 km<sup>2</sup> in Loire Atlantique, France).

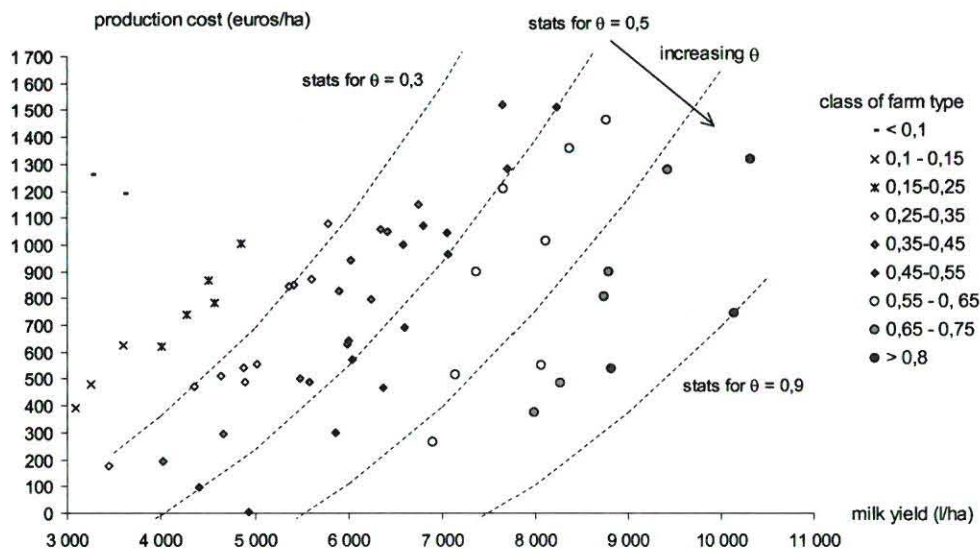


Figure 2: dairy production costs depending on the milk yield and the type of farm for surveyed farms on the Don watershed (with statistics for some values of  $\theta$ ).

The type-dependent emissions have been determined from the individual estimations, using a quadratic function and a constrained maximum likelihood method and are described as an emission function per hectare of land, denoted  $g(y, \theta)$ . Note that because the more efficient farmers tend to produce with higher yields, there is no homothetic relationship between the  $\theta$ -type parameter and either the production cost or the individual emissions. Moreover, on the Don watershed, the ratio profit/emissions is not monotonous in  $\theta$  for the laissez-faire situation, but the use of the  $\theta$  parameter is sufficient enough to reduce the overall heterogeneity of this ratio profit/emissions for the surveyed farms.

### 3.3 Design of a differentiated policy

To examine how the existence of the farms heterogeneity may hamper the supply of both the commodity and the non-commodity outputs let us consider the problem of the regulatory (utilitarian) agency. She seeks to maximize a social welfare function, written as the sum of the taxpayers surplus weighted by the social cost of public funds  $(1+\lambda)$ , the farmers total surplus and the environmental damage  $D$ . We assume that the social cost of pollution  $D$  depends on total pollution emitted  $E$ , with  $D$  increasing and convex in the total pollution.

Once the cost, emission and damage functions have been described and their parameters estimated (see Bomters, *et al.*, 2003, for details), the regulation design is an optimization problem: the regulator's objective is to maximize a welfare function, and the feasible allocations are constrained by the information set of the regulator. We also introduce acceptability constraints as part of the constraints that the regulator has to take into account. Basically, the regulator has to satisfy a given proportion of farmers through his intervention and a farmer is satisfied if he does not loose from regulation compared to the *laissez-faire* situation.

Two types of policies have been tested within this framework:

1. first we considered policies which are optimally differentiated and take into consideration the heterogeneity of farms on their cost and emission functions. The regulator proposes a contract to the farmers and designs this contract by maximizing his own welfare function. The program requires the farmer to declare both the level of production and the area he chooses and then receive the associated subsidy (or pay the associated tax).
2. then we compared the differentiated policies with standard economic instruments, such as taxes or quotas applied on inputs or outputs. On the Don watershed a tax on the amounts of mineral N used by the farms, a quota of mineral N applied, and a linear extensification (decrease of milk yield per hectare) have been tested.

For each policy, the level of the instrument (the tax, the subsidy) is determined by the model while maximizing the welfare function of the regulator. Thus, the commodity and the non-commodity levels are not fixed by the regulator as an objective but it is endogenously determined as a result of the maximization process.

## 4 Main results

### 4.1 Supply of fresh water

The emission function per hectare of land,  $g(\cdot, \cdot)$ , is increasing with  $y$  and decreasing with  $\theta$  (see Figure 3). Thus, a more efficient farmer also pollutes less at the margin *ceteris paribus*.

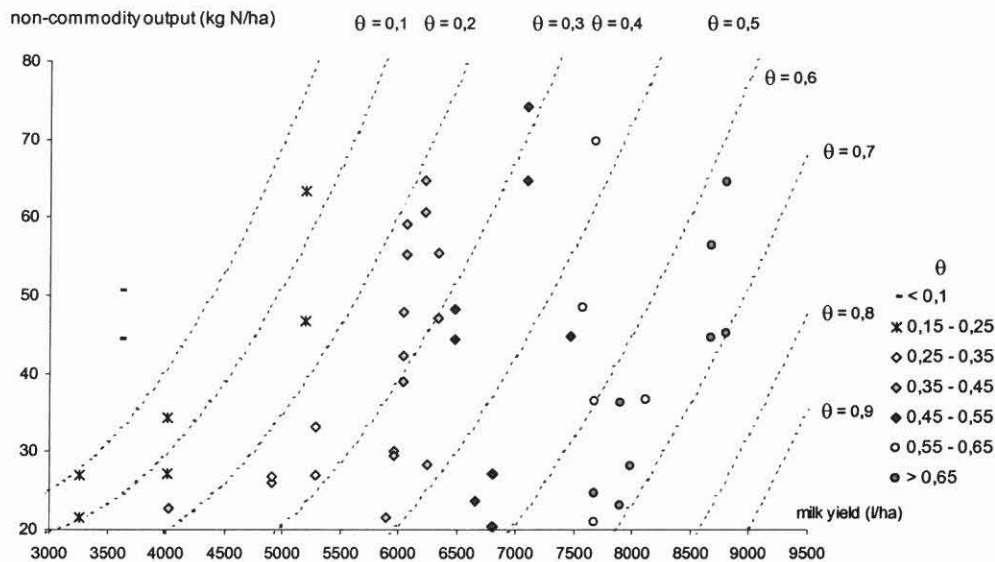


Figure 3: non-commodity output depending on the milk yield and on the farm type for a sample of surveyed farms on the Don watershed (statistics for some values of  $\theta$ ).

But in the baseline scenario, the more efficient farmers are induced to produce with higher milk yields per hectare than the less efficient ones. As a consequence, in the baseline scenario, the more efficient farmers also pollute more than the less efficient ones (see Figure 4).

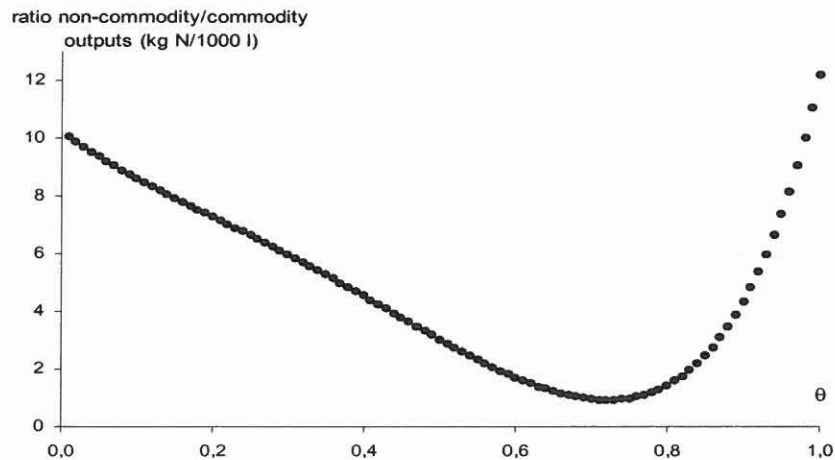


Figure 4 : variation of the ratio between the amounts of non-commodity (N-nitrate) and commodity (milk) outputs supplied by the dairy farms on the Don watershed, depending on their  $\theta$ -type

### 4.2 Supply of other amenities

It is worthwhile noting that the  $\theta$ -type which is of interest to considerably reduce the set of variables which can describe the relationship between the amount of milk and nitrate supplied per hectare is of no help for the joint supply of other amenities by the farms: we found no relationship between the value of the  $\theta$ -type, the milk yield and the adoption by the farmers on the watershed of any agro-environmental measure that has been proposed to the farmers.

### 4.3 Regulation patterns

The optimally differentiated policy induces the farmers to decrease their milk yield, the more efficient farmers decreasing it less than the less efficient ones. But because they pollute less *ceteris paribus*, the policy leads to a high decrease of emissions per hectare for efficient farmers (see Figure 5). In our application case, the non-commodity output (fresh water) is mostly provided by the more efficient farmers.

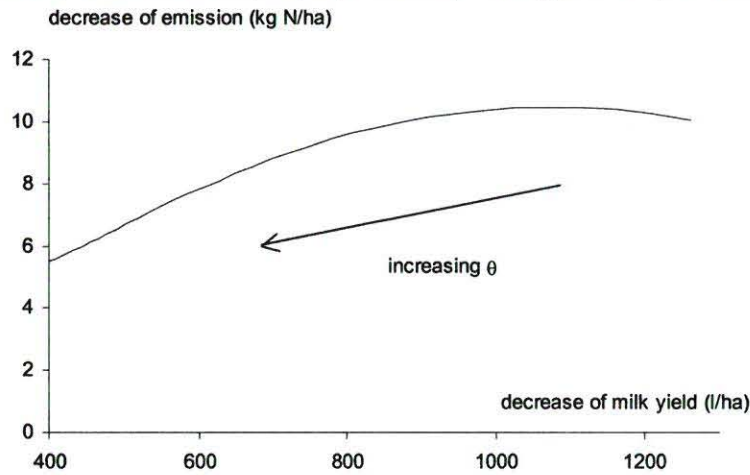


Figure 5: decrease of milk yield (commodity output) and of N emissions to water (non-commodity output) for farm cropping 25 ha after the optimally differentiated policy which benefit to no farmers.

The situation is totally different for the linear instruments. For the tax on the N input and the linear extensification, the more efficient farmers are induced to decrease their milk yield more than the less efficient ones, and this results in a larger variation of the ratio emissions/milk for the higher  $\theta$ -type farmers (see Figure 6). Mandating a quota of N input use per hectare would induce only the less efficient farmers to provide the non-commodity output.

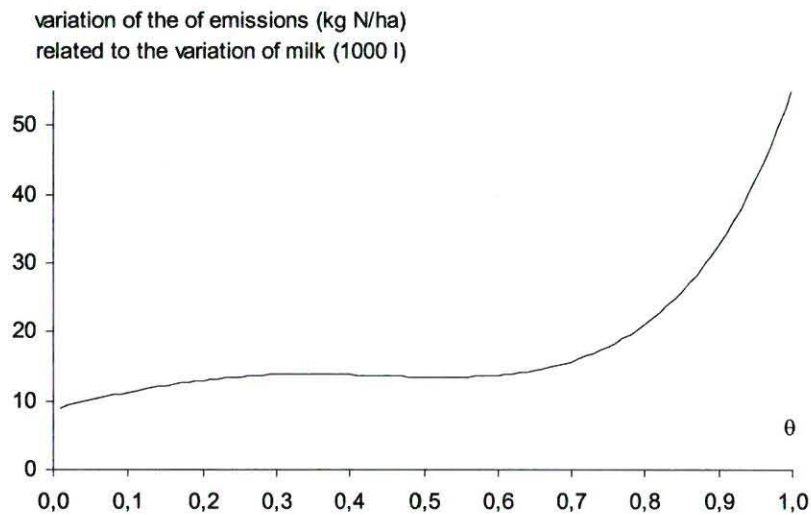


Figure 6 : variation of the ratio emissions/milk supplied by the farms subject to a tax on the fertilizer input

It is worthwhile noting that some policies lead to a quality of water below the EU threshold of 25 mg NO<sub>3</sub>/l taken as a standard of good quality for water (see Figure 7). These policies do not induce the farmer to lower their dairy production enough to reach a good quality standard.

Last, the regulator can use the money she collects with the agro-environmental regulation and distribute it so that farmers do not suffer from a high decrease of their revenue. While doing this, the regulator can choose the proportion of farmers who do not lose money and thus should not complain from the regulation. As a consequence, optimally differentiated policies can benefit to a large range of farms, perform with an increase of welfare, and allow the EU standard for water quality to be reached until 55% of the farmers benefit from the regulation (see Figure 7).

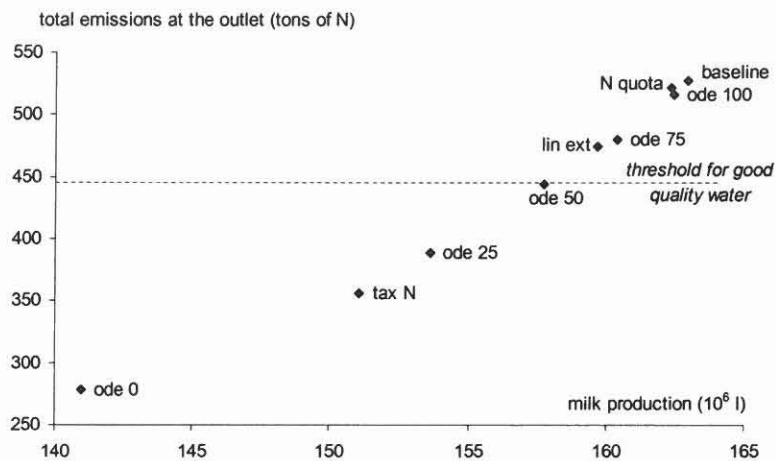


Figure 7: commodity (milk) and non-commodity (nitrates) outputs for the Don watershed depending on a set of potential policies.

legend for this Figure:

ode x: optimally differentiated extensification benefiting to x% of the farmers

tax N: tax on the amount of nitrogen fertilizers inputs

lin ext: linear extensification

N quota: quota on the amount of N input per hectare.

## 5 Conclusion

Compensating farmers who adopt costly but environmentally friendly practices is an idea that is supported by an increasing number of both farmers and environmentalists, and has already been tested in many areas in Europe. But stewardship compensation programs must overcome many difficulties, the most important being enforcements problems when the practices are not easily observed. In this case, the promotion of the agro-environmental framework can be designed on the basis of a small set of variables that are common knowledge. This paper presents the regulation of nonpoint source pollution from a population of farmers when the level of production is easily observed. We assume that the farmers have more information about their own resource setting than the regulator but that this information can be summarized into a one-dimensional parameter, the farmer's type, which is not observed. Private information makes self-selection necessary. We assume that the relationship between pollution, profits production level and farmer's type is known, which allows the design of a payment scheme. The program requires the farmer to declare both the level of production and the area he chooses and then receive the associated subsidy (or pay the associated tax). Adjusting subsidies or taxes depending on the farmer's type has not yet been widely developed by policy makers, with an exception for adjustments according to the size of the farm. But because within the Water Framework Directive (2000/60/EC, hereafter WFD) EU Member States have to ensure a program of measures to mitigate water pollution, they need to select the most cost-effective measures among the set of potential ones. In our application case, the loss of welfare related to private information is lower than the cost of information required to implement the first best production levels and obviously such a program with adjusted subsidies is cost-effective to implement the WFD.

The design of policies to mitigate NPS pollution from farms with a differentiated framework induces a better allocation of the abatement effort between farms: the empirical application on the Don watershed suggests that this abatement effort is mostly borne by the farms having the lower ratio profit/emissions, and, given this ratio, by the more efficient farmers.

The model that we described here can be widely refined. The farm model can be fitted to farms with multiple productions because the farmers can switch one production with another when the relative profitability changes. Parameterizing such a model with data from the European Farm Accountancy Data Network (FADN) could provide a European wide farm model which captures the type of farming, the size and location of the farms and the density in each class of farmer's ability. European wide hydrological model are still not available but should be provided within a few years and thus a Decision Support System for implementing the WFD could be designed. Moreover, we have only considered here the nitrate pollution of water but phosphorus, sediments, metals or bacteria emission should be taken into consideration too. Regulating water quality through production may hence provide multiple environmental benefits. Last, the characterization of the  $\theta$ -type can be improved to capture other agro-environmental amenities also.



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