How cost-effective is a mixed policy targeting the management of three pollutants from N-fertilizers?

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Summary

This paper assesses the cost-effectiveness of a mixed policy in attempts to curb three nitrogen pollutants: NO\textsubscript{3}, N\textsubscript{2}O and NH\textsubscript{3}. The policy under study combines an N-tax on nitrogen input and incentives promoting perennial crops assumed to require low input. We show that opting for a perennial crop subsidy, in addition to an N-tax, significantly increases tax effectiveness in the case of NO\textsubscript{3}. A quantitative analysis provides an assessment of impacts in terms of land-use, farmers’ income and N losses throughout France and at the river-basin scale.

Keywords: Cost-effectiveness; mixed policy; N-input tax; Land-use policy; nitrogen pollutants; bio-economic model; mathematical linear programming.

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1 Introduction

The use of nitrogen fertilizers is a major source of three environmental pollutants: nitrates (NO$_3$), nitrous oxide (N$_2$O), and ammonium (NH$_3$). NO$_3$ pollutes water, causing soil eutrophication and human health problems, such as the baby-blue syndrome and stomach cancer (Addiscott, 1996). N$_2$O contribute to global warming. NH$_3$ plays a role in acid rain. Policies have been addressing these issues on a pollutant-by-pollutant basis. For example, the Water Framework Directive (2000/60/EC), adopted by the European Commission, deals with water quality conservation by preventing nitrogen pollution arising from the agricultural sector (mineral fertilizer and livestock manure) through a set of good agricultural practices (especially in terms of N-input consumption).

More recently, the European Commission decided to reduce total EU greenhouse gas emissions, from the sectors currently not covered by the ETS$^2$, by approximately 10% in 2020, relative to 2005 levels (European Union, 2009).

In the field of economics, nitrogen pollution is characterized by the fact it is a non-point source pollution (NPS). First-best emission instruments are therefore inappropriate in attempts to regulate it. Helfand and House (1995). Second best policies include various mechanisms, mainly land-use policy, the regulation of ambient concentration and input tax, as reviewed in Shortle and Horan (2001). Most studies have focused on these mechanisms one at a time. For example, in case of land-use, it has been shown that perennial crops dedicated to bioenergy can have positive impacts on the environment (Lankoski and Ollikainen, 2008, 2011). These authors studied the environmental impacts of biofuel policy in Finland and showed that contrary to rape seed and cereals, when they are dedicated to the production of biodiesel or ethanol, only reed canary grass is unambiguously desirable, because it requires low doses of fertilizer. Consequently, they recommended a subsidy for this crop in order to restore the social optimum.

Ambient concentration mechanisms and input tax are policy instruments whose limits have been shown. Studies focusing on the application of an ambient concentration mechanism found it difficult because of problems in terms of measuring discharges from individual farms and/or implementation and as well as in terms of legally attributing any random or collective penalties. Studies focusing on input tax found that equals the marginal profit of fertilizer use across heterogeneous land but not the marginal pollution control cost, the land-use reallocation does not necessarily favored the environment (extensive margin effects). Moreover, a single-tax policy is not sufficient regarding the Water Framework Directives and, for example, an increase in grassland or an introduction of catch crops can appear more cost effective (Lacroix et al., 2005).

Given this context, cost-effective management of pollution arising from the use of fertilizers requires accounting for both intensive (input regulation) and extensive margin (land-use regulation) effects (Shortle et al., 1998; Goetz et al., 2006). However, few studies have taken into consideration both these aspects at the same time. Aftab et al. (2010) did

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1 According to the latest greenhouse gas (GHG) inventories by the European Environment Agency (2010), agricultural emissions represent about 10% of total EU emissions.

2 Emission Trading Scheme
combine managerial measures (farm land retirement and a reduction in livestock stocking density reduction) with an input tax. Goetz et al. (2006) combined a tax/subsidy on each crop with an input tax. These studies, focusing on one pollutant (NO$_3$), reported the superiority of a mixed approach in terms of cost effectiveness. However, the introduction of multi-crop instruments or managerial measures in order to regulate the extensive margin would likely lead to a rise in enforcement costs and it would be difficult to implement. Moreover, the relatively small areas and the limited number of crops taken into account can fail to capture the inherent heterogeneity among real-world farms and thus, can bias the estimation (Balana et al., 2011). There is clearly a need for a better comprehension of gains, in terms of cost effectiveness, if a well-specified mixed policy would to be adapted. In addition, there are numerous land-use policies. Which one would be well adapted, to add to an N-tax in a mixed policy approach, is still being debated.

In this paper, we raise the following question: How cost effective a mixed policy targeting the management of three pollutants arising from N-fertilizers? We combine a common N-input tax and a subsidy for a perennial bioenergy crop. Miscanthus is chosen thanks to high nitrogen, energy and land-use efficiencies at all N fertilizer and energy input levels compared to other perennial crops, especially reed canary grass (Lewandowski and Schmidt, 2005). To tackle this question, we provide an integrated economic and agronomic approach. A supply agricultural model is combined with a crop model in order to capture the soil and crop heterogeneities in fertilizer response (in terms of yields and emissions) as well as compute nitrogen pollutions.

We show that a mixed policy increases the pollutant-abatements compared to the N-tax. Moreover, a mixed policy is cost-effective in the case of the NO$_3$ while the single tax is cost-effective for gas emissions. Another interesting advantage of a mixed policy is the possibility of choosing the couple of instruments which grants the largest abatement for a given agricultural income loss and maximizing the abatement for a given revenue. Particularly, for example, for a given revenue between 0.6 and 0.8 M€ for the social planner, the abatement range is between 7 and 35 % in the case of NO$_3$ and between 16 and 50% in the case of N$_2$O Moreover, the soils, crops and emissions being very heterogeneous following the give region considered, we provide an analysis by river basin. First of all, we show that these heterogeneities are reflected in the abatement cost curves. Then, we show that the mixed policy, and especially the land-use policy, should be adapted per basin in order to improve the cost-effectiveness of regulation.

The paper is organized as follows. The model is explained in section 2. Results for France and per river basin are given in section 3. In section 4, results are discusses in terms of land-use, crop area allocation and emission functions.

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3Respectively, eastern Scotland and the aquifer in the watershed of Lake Baldegg, Switzerland.
4Respectively 4 and 5.
2 The Model

2.1 The agro-economic model

The investigation undertaken here relies on an updated version of the economic model, AROPAj, initially presented by De Cara et al. (2005) and now described by Gallo and Jayet (2011). In short, the overall model consists of a set of 1,074 independent mixed integer linear-programming models (MILP). Each model describes the annual supply choices of a representative farmer (or a 'farm group') who optimizes crop and livestock production with respect to a set of technical and economic constraints. AROPAj covers the main annual crops and animal categories relevant to European agriculture. Farmers are grouped into farm types according to: the farm techno-economic orientations within the region, the farm economic size, and the farm altitude class. These farms are statistically representative of the different production systems at the regional level thanks to the Farm Accountancy Data Network (FADN). Each farm group is assumed to maximize its total gross margin. The set of constraints includes; (i) crop rotation and agronomic constraints; (ii) CAP-related constraints; (iii) restrictions concerning animal demography and nutritional requirements, and (iv) restrictions concerning quasi-fixed production factors (land and livestock).

FADN data overcome the problems of data confidentiality and improve the representation of farm heterogeneity in comparison to many bioeconomic models (e.g., Aftab et al. (2010), Aftab et al. (2007)). For a more detailed and technical description of model structure, the set of constraints and the main features, see De Cara et al. (2005). For this investigation, we have introduced the changes in agricultural policy that were put into action in 2005, more specifically the decoupling schemes triggered by the implementation of the 2003 CAP reform (Galko and Jayet, 2011).

Balana et al. (2011) note that a large number of agri-environmental studies, which are based on a 'stylized' farm, may fail to capture the inherent heterogeneity of real-world farms, thereby sending wrong signals to the decision-making process. They suggest the use of actual farm data instead of 'stylized' farms. Our methodology retains the advantages of these two approaches. Indeed, on the one hand, our farm groups are representative at the regional scale thanks to the use of FADN data, and, on the other hand, the functional form of a farm group allows us to take into account changes in environmental and economic constraints.

Coupling the economic model AROPAj with the agronomic crop model STICS (Brisson et al., 1998, 2003) captures the heterogeneity more precisely by taking into account the wide-range of soil characteristics, the impact of soil nitrogen supply on nitrogen plant uptake, farm practices, and the climate. This also allows us to deal with most of the crops relevant to EU agriculture. This coupling involves the replacement of average 'point N-Yields' with a Mitscherlich-response function of nitrogen dependent on physical (climatic and soil) and economic (price and economic policy) factors for crops in each farm.

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In the case of the V2 version based on the EU-15 which, for this study, was adapted to France.

Following De Cara et al. (2005), we assume in our central set of simulations that livestock numbers are allowed to vary within $\pm 15\%$ of the values reported in the FADN database.

Accounting for xx crops, including soft and hard wheat, maize and colza.
group. This improves the representations because the farmers can adapt their nitrogen fertilizer practices to physical constraints and the economic context (For a more detailed technical description, see Godard et al. (2008)). This leads to the transformation of AROPAj from an LP to a NLP model, with respect to nitrogen. Moreover, the nitrogen-yield function response improves the impact assessment regarding price scenarios like a nitrogen taxation, better than relying on arbitrary uniform changes in practices (e.g.; 20 % less fertilizers, Lacroix et al. (2005)). Finally, after coupling, the AROPAj model determines the most profitable land and nitrogen allocation to each farm group as well as animal numbers, animal feeds consumption, output, and gross margin. We can note that livestock waste is accounted for as a source of fertilizer (and nitrate) and a substitute for mineral fertilizers.

In addition to the amount of fertilizers, the STICS crops model provides us with the leaching associated with each type of soil and crops as well as climatic conditions and application date. Similar to Aftab et al. (2010), the leaching functions are derived by regressing STICS outputs within a reasonable range of nitrogen applications.

2.2 Introduction of the perennial bioenergy crop into the AROPAj model

*Miscanthus x Giganteus*[^8] is a rhizomatous grass which originated in the tropics and subtropics, but is found under different species throughout a wide range of climate in eastern Asia (Greef and Deuter, 1993). The remarkable adaptability of miscanthus to different environments (Numata, 1974) makes it suitable for growth under European and North American climatic conditions (Lewandowski et al., 2000). Physiologically, miscanthus, like maize, is a $C_4$ species, fixing carbon by multiple metabolic pathways with a high water use efficiency (Koshi et al., 1982; Moss et al., 1969). Miscanthus roots can penetrate to a depth of around 2 meters, which can provide a good protection against soil erosion. Field trials have shown the high biomass yield potential, 15 to 20 tons dry matter per hectare, in comparison to other herbaceous crops (Clifton-Brown and Jones, 1996; Jorgensen, 1997; Lewandowski et al., 2000). Despite its high biomass yield potential, this crop requires small amounts of input and can therefore decrease the risk of ground water pollution by pesticides and nitrates.

To introduce miscanthus into the AROPAj model, two main elements must first be calculated for each farm-group: the Average Net Present Value ($NPV^*$) and the average yield ($Y$), both corresponding to the optimal rotation ($T^*$). The determination of $NPV^*$ is based on a Faustmann’s dynamic optimization over time, used in the case of a perennial crop harvested annually, and a function in terms of growth is used to compute $Y$. The growth function used at this level is calibrated on some data available from the work of Miguez et al. (2008), Clifton-Brown et al. (2007), and Christian et al. (2008), and adjusted to the average yield of a common annual crop. Indeed, miscanthus yields are not available in the FADN database, and knowing that miscanthus have been recently introduced in France, yield information for the full rotation period (15-20 years) is not

[^8]: *Miscanthus x Giganteus* is a sterile hybrid between *M. Sinensis* and *M. Sacchariflorus*.

provided as well. So, we suppose that miscanthus yield increases with the quality of the
ting. Wheat is considered to be a common crop, present in four-fifths of the French farm-group in AROPAj.

3 Results of the mixed policy abatement

We aim to assess the impacts of a mixed policy in terms of cost-effectiveness given three
main N-pollutants: NO$_3$, N$_2$O and NH$_3$. The abatement cost curves in function of
abatement for the three pollutants are evaluated for a range of subsidies varying from
0 to 250€/ha by increments of 25€/ha and for a range of tax values from 0% to 100%
of the N-price by increments of 10%. The tax receipt and the subsidy payment being
monetary transfers between the farmers and the social planner, this value is subtracted
from the abatement costs in order to estimate net social welfare (omitting the other
indirect economics effects). Thereby, the abatement costs represent the loss (in value) of
production for the farmers due to both the lower yields and the area reallocation between
crops induced by both the tax and the subsidy. The following sections present the results
in the case for France.

3.1 French impact assessment

![Figure 1](image1)

**Figure 1:** These curves illustrate abatement costs
when (1) only N-tax is implemented (the main
curves), (2) the mixed policy is implemented (branching
ing off from the main curves)

![Figure 2](image2)

**Figure 2:** These curves illustrate abatement costs
when (1) only N-tax is implemented (the main
curves), (2) the mixed policy is implemented (branching
ing off from the main curves)

Figures 1 and 2 describe the abatement cost curves (in % of gross margin) in function of pollutant abatement. The bold curves illustrate the results obtained when a single
N-input tax is applied. The other curves, branching off from the single tax curves,
correspond to the additional abatement when subsidies are added to the tax.

Regardless the tax and subsidy combinations, the abatement costs concerning the gas
pollutants are lower than cost for the NO$_3$ pollutant. For a given abatement cost, and
in the case where only a single N-tax is implemented, the abatement obtained for the

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Wheat yield data are provided by the FADN database.
gas pollutants is twice as important as for the N03 pollutants. This result is in line with the numerous studies (ref) referring to difficulties in water pollution management in the case of N-tax implementation. When a land-use policy is added to a single N-tax, these effects are lessened. Indeed, when the maximum tax and subsidy levels are reached, the abatement gain of the mixed policy is lower than 10 points for the gas emissions whereas the abatement increases to half (from 24% to 36%) for NO3. Even when the land-use policy increase abatement of the three pollutants is added, the mixed policy is only cost-effective in the case of NO3. As shown in figures[1] and [2], adding a miscanthus subsidy sharply decreases the abatement cost of NO3 (in comparison with the tax alone) and slightly increases the abatement costs of gas pollutants (N2O and NH3).

Indeed, for a given abatement target, a mixed policy is less costly in a case of NO3 whereas the single tax is less costly in a case of the gas pollutants. For example, a target of a 20% abatement leads to a decrease in cost of 0.8 points (from 2.8% to 2% of gross margin) for t N03. In other words, for a given N03 abatement target, we can find a couple (tax, subsidy) less costly than a single tax. This is noteworthy because N03 is the pollutant for which the abatement costs are the highest and the abatement range (with a tax alone) is restricted.

3.2

We have seen that a mixed policy can improve the cost-effectiveness of regulation. Another interesting advantage of a mixed policy is the possibility of choosing the couple which grant the best abatement without exceeding a given agricultural income loss. Indeed, the social planner has to face social reality (and farmers' lobby) and meet environmental objectives. This can lead the social planner to look for the best abatement for a given agricultural income loss. The following graphs draw a parallel between these two aspects. For example, in the first graph, if the social planner self-imposes not to exceed a loss of 1.5% percent of agricultural income, we see that the possible N03 abatement is between 16 and 20%, and the possible N2O abatement is between 22 and 30%. In the similar way, we can fix a target for one of the two pollutants and look for the tax/subsidy combination which maximizes the second pollutant abatement. The second graph displays the income received by the social planner associated with each tax/subsidy combination. For a given revenue (between 0.6 and 0.8 M€), a wide-range of possible abatements exists. The third figure shows the symmetric characteristics when the gas pollutants are under consideration. Indeed, if we focus only on the gas pollutants, we see that the mixed policy does not lead a flexibility on the abatement levels.
3.3 Impact assessment at the river-basin scale

We have shown that the cost-effectiveness of a mixed policy depends on both the given kind of pollutants and the possibility of replacing some existing crops with miscanthus. However, the nature of these two aspects is very heterogeneous, depending on the region under consideration. On the one hand, the crops and various constraints (soils, animal localization) are strongly heterogeneous given the river basin. On the other hand, the potential miscanthus area is not equally spatially distributed no matter the basin. Moreover, the emission function can vary in intensity according to the river basin. A cost-effective policy must therefore be adapted to the given river-basin characteristics.

In France, the basin agencies are in charge of water pollution management (six for metropolitan France), ensuring consistency between the scale of pollution and the area falling under the control of the agency.

We assess below the cost-effectiveness of a mixed policy between the various river basin.
The graphs for each basin reflect heterogeneity in terms of abatement costs. For two basins (Seine and Artois basin), the gains associated with a mixed policy in terms of both abatement and abatement costs are very important. In the Seine basin, for an NO$_3$ abatement target of 20 %, the abatement costs are divided by 2.5 (2.5% to 1% of gross margin) and the range of possible abatement increases from 25% to 45% (for the given values of tax and subsidy). For the Artois basin, we see that an abatement increase based on only a tax is very expensive (compared to other basins) and limited (about 15% for a N-tax of 100%). However, the mixed policy increases the possible NO$_3$ abatement from 15 to 35 % and divides the cost by 3 to reach an abatement of 15%. Regarding N$_2$O, the additional abatement related to a mixed policy decreases with the level of N-tax.

For the Rhin and Rhone basin, we find the same results as for the above two basins: the mixed policy is only cost-effective in the case the NO$_3$. However, there is less to gain when a mixed policy is adapted. For an NO$_3$ abatement target of 20 %, the abatement costs are decrease of 0.5 and 0.6 points (respectively 1.3% to 0.8% and 1.8% to 1.2 % to of gross margin for the Rhin and Rhone basin )

This can be explained by the fact that the abatement costs in the case of a N-tax policy are lower: respectively 1.2 % and 1.8% of gross margin to reach a NO$_3$ abatement of 20 % in comparison to 2.5% and > 3 % for the Seine and Artois basins. It is 1.6% to reach 40% of N$_2$O abatement for the Rhone and Rhin basins whereas abatement costs are 2.6% and 3.2% for the above basins and the same target.

Graph shows that even if the mixed policy always increases the abatement range it cannot be cost-effective in the case the NO$_3$ in the Adour-Garonne basin. For the Loire-Bretagne basin, the benefits of a mixed policy in the case N0$_3$ is negative, except for the highest level of N-tax.

Figure 3: Abatement costs (% of revenue) in function of NO$_3$ and N$_2$O abatements in mixed policy in the Seine basin

Figure 4: Abatement costs (% of revenue) in function of NO$_3$ and N$_2$O abatements in mixed policy in the Artois basin
The abatement costs with a single N-tax being relatively high for the Loire-Bretagne basin, (like those for the Seine and Artois basins), one would have expected stronger results in the case of a mixed policy. To explain the extent of this difference, let us now discuss the impact of a mixed policy on land use.

4 Discussion

Natural N-losses, when there is no N-input, are greater in the case of NO$_3$ than in the case of N$_2$O and NH$_3$ (see Table 1). This fact plays an important role in the cost-effectiveness of a mixed policy. Indeed, when the emission functions are not linear[10], an input tax is not sufficient to restore the optimal crop area allocation[11]. Moreover, this optimal allocation depends on the given pollution. The constant ($\beta$) for the gas pollutant is low (cf ??), so an N-input tax policy leads to a crop area allocation close to the optimality for these pollutants.

[10] We call linear, the functional form: emission = $\alpha$ + fertilizers. In this paper, the emissions are interpolated as follows: emission = $\beta + \alpha$.*

[11] This is the subject of an article in progress. The proof can be provided on request.
The cost effectiveness of a mixed policy for the NO₃ pollutant is mainly due to the extensive margin effects: This is to say that the land is reallocated in favor of miscanthus (for which we assumed $\beta = 0$) due to the N-input tax and subsidies. In addition, since the natural losses ($\beta$) for the other pollutants are low for commonly found crops (especially soft wheat), the land reallocation in favor of miscanthus leads to fewer additional abatement in comparison to the N-fertilizer tax alone.

Indeed, as shown in (figure 9), the implementation of the tax alone leads to a moderate decrease in crop areas (about 6% of Utilizer Agricultural Area (UAA)) in favor mainly of grassland. Miscanthus, which is close to zero if the tax is null (lower profitability) can cover one third of these abandoned lands at the maximum of tax (1.9 % of UAA). At the maximum subsidy level (and without N-tax), miscanthus can cover up to 4.6 % of UAA. At the maximum level of two instruments, miscanthus can cover up to 11% of UAA. This concave characteristic makes a mixed policy more interesting in the cases of pollutants whose emission function depends on soil and crop, like NO₃. In other words, the higher the level of tax, the higher the impact of a subsidy on land use. Moreover, the increase in area of miscanthus also decreases the increase in the area of grassland due to the N-tax.

In order to focus on the effects of various policies on the crops, we group the crops into three categories, according to their level of NO₃ natural losses: low for natural losses below 20 k.N/ha, medium for natural losses between 20 and 40 k.N/ha, and high for natural losses greater than 40 k.N/ha. We see that the medium polluting crops are unaffected by the tax alone while the most polluting crops (for example, soft wheat) are strongly impacted. The most polluting crop areas for NO₃ are reduced. Taxes on input use intensity have a double effect on agricultural production. First, taxes reduce cropland yields (because less inputs are used: intensive margin effect) and decrease the area devoted to some crops (extensive margin effect). The subsidizing of miscanthus only reduces the proportion of area devoted to other cropland production, without reducing the yields of those croplands. However, except for the most polluting crop, the reallocation induced by a N-tax (alone) and a subsidy (alone) is relatively low (about 2 or 3

Let $f(x, y)$ denote the miscanthus area due to tax (x) and subsidy (y). $f(x, y) \geq f(x, 0) + f(0, y)$
On the contrary, the mixed policy strongly modifies the allocation of crops, except for the least polluting crop. Especially, adding a subsidy decreases the medium and the most polluting crop areas. With a tax alone, the lands with lower marginal yields for soft wheat become unprofitable and are then converted into fallow or grassland. However, the higher the tax, the higher the marginal profits of plots the last abandoned. Therefore, miscanthus can show up on these last abandoned plots. For other crops, plots with lower marginal profits remain higher than plot dedicated to miscanthus. When adding the subsidy, miscanthus profitability increases, and it can become more profitable than both soft wheat and medium polluting crops. This is a conversion of crops with high and medium natural losses of NO$_3$, explaining the great abatement gain in the case of this pollutant. Obviously, both N$_2$O and NH$_3$ abatement also increases because some crops for which fertilizers are applied are converted into an environmentally-friendly crop. However, the mixed policy is only cost-effective for NO$_3$. The cost-effectiveness of a mixed policy arises from the trade-off between the gain in agricultural income due to a lower tax and the loss of agricultural income due to the conversion of crops to a less profitable crop (miscanthus) induced by the subsidy income. As the natural losses ($\beta$) are important for NO$_3$, and a subsidy decreases the medium polluting crop areas (this is not case with a tax alone), we can decrease the N-tax to have a positive trade-off while keeping the same abatement target. In the case of N$_2$O and NH$_3$, as natural losses ($\beta$) and emission factor ($\alpha$) are very low for the medium polluting crops, the abatement gain due to the conversion of these crop to miscanthus is low and a higher reallocation in favor of miscanthus is needed to compensate the additional emissions due to a lower tax.

The emission structure and the reallocation area induced by the tax and subsidy and the extensive margin effect explain why the mixed policy is cost-effective in the case the NO$_3$ and not for the gases. Therefore, the regulatory body is faced with a trade off between N0$_3$ and gas pollution control.

4.1 Basin heterogeneities

Abatement cost heterogeneity reflects the various crop production allocation between the basins as well as the differences in emission functions (cf ??) between the basins due to the diversity of soils and climatic conditions. First, we can see on figures [1] and [3] that the area devoted to the crops are mainly in the regions allowing a greater possibility of miscanthus reallocation. Indeed, miscanthus can reach respectively xx and xx % of the UAA. Second, when the cropland covers the greater part of UAA, the gain in production induced by a decrease in a tax is more important than for a basin where the UAA is slightly covered by croplands. For a given NO$_3$ abatement target, rather than implement a tax alone, it is less costly, and thus more cost-effective, to convert the crop with the lowest marginal profit to miscanthus and decrease the tax leading to higher yields for other crops. This is the case in the Seine basin. However, we can note some differences for the Artois basin. Indeed, if the mixed policy is cost-effective, the possible NO$_3$ abatement is lower. Two reasons can be advanced. Firstly, the tax does not decrease the area devoted to crops. The most polluting crops are substituted by
the medium polluting crop and not by grassland, fallow and miscanthus which reduces the expected abatement. Secondly, the low polluting crops cover a great proportion of cropland, reducing the possible abatement.

The Rhin river basin is similar to the Artois and Seine basins. It is a region with a majority of cropland leading to great gains (in production and profit) if the tax is reduced. However, in this region, the grassland area (and consequently livestock) increases instead of miscanthus, except when levels of the subsidy are high. The reallocation advantage is thus less advantageous than in the Seine and Artois basin. The situation in the Rhone basin is different. Less land is dedicated to crops (in percent of UAA) and the gain linked to a decrease in tax is less important. Moreover, the tax induces a slight crop reallocation in favor of the most polluting crop and only a high level of subsidy combined with a high level of tax significantly decrease the crop area and lead to a significant emergence of miscanthus. For these two basins, the mixed policy is cost-effective for NO$_3$. However, the substitution between livestock and cropland in the Rhin basin and the slight coverage of cropland (in % of UAA) limit the effect (about 0.5% of gain with a mixed policy).

In the Adour-Garonne river basin, to the contrary of the other basins, the crops having natural losses higher than 40 k.N/ha represent less than 4% of UAA. Moreover, these crop areas increase with a tax. Adding a subsidy does not bring the added extent of this area back under the initial size of it. In addition, we can note that cereals crops are less cultivated in this region, limiting the land reallocation effect. We find the same results for the Loire-Bretagne basin in the case of low tax levels.

5 Conclusion

We have assessed the improvement in nitrogen pollutant regulation under the combination of an N-input tax and a subsidy for a perennial crop. We show that the policy mix is cost-effective in terms of water pollution (NO$_3$) and can lead to some levels of abatement which are difficult to reach (in terms of costs and "possibility") if the policy is only based on an N-tax.

A specific policy by basin is needed because of heterogeneity of crop emission and the diversity of crop allocation between the basins. Moreover, water pollution being local, the abatement targets are not necessarily equal between basins. This strengthens the need for specific land-use policy (for example, a subsidy for perennial crops) by basin.

References


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6 Appendix

6.1 France Emission functions

<table>
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<tr>
<th>Crops</th>
<th>$a_{N_2}$</th>
<th>$b_{N_2}$</th>
<th>$a_{NH_3}$</th>
<th>$b_{NH_3}$</th>
<th>$a_{NO_3}$</th>
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Table 1: Interpolated as linear function: $E_i = b + a \cdot \text{Nitrogen}$; b,nitrogen in kg/ha/year

Figure 11: Seine basin land-use share

Figure 12: Seine basin crop share

Figure 13: Artois basin land-use share

Figure 14: Artois basin crop share
Figure 15: Rhin-Meuse basin land-use share

Figure 16: Rhin-Meuse basin crop share

Figure 17: Rhône-Méditerranée basin land-use share

Figure 18: Rhône-Méditerranée basin crop share

Figure 19: Adour-Garonne basin land-use share

Figure 20: Adour-Garonne basin crop share
Figure 21: Loire-Bretagne basin land-use share

Figure 22: Loire-Bretagne basin crop share
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