Distributional impacts of an emission tax on greenhouse gas emissions from European agriculture

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Abstract

We study the distributional impacts of a tax on greenhouse gas (GHG) emissions from European farms, as well as the implications of various redistribution schemes of the collected tax. The progressivity/regressivity of an emission tax depends on the farm distribution of (i) initial (i.e. pre-tax) emissions, and (ii) abatement costs. We use a supply-side micro-economic model of the European agricultural sector to assess methane and nitrous oxide emissions and the associated marginal abatement costs for 1,802 farm types representative of about 3.7 millions real farms. The findings indicate that a standard emission tax (without redistribution) would tend to increase gross margin inequalities–as measured by the Gini index–within the sector. They also show that a flat, budget-neutral redistribution scheme could substantially reduce existing gross margin inequalities in the sector.

Keywords: Climate policy, Emission tax, Income inequality, Recycling-revenue, Lump-sum transfer

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1. Introduction

The agricultural sector is a major contributor to greenhouse gas (GHG) emissions. Shukla et al. (2019) indicates that the contribution of agriculture, forestry and other land use (AFOLU) amounts to about 22% of global anthropogenic emissions of GHG. This is mainly due to methane (CH_4, emitted by cattle breeding) and nitrous oxide (N_2O, coming from fertilizers) (Pellerin et al., 2017). The agricultural sector may also play a key role in the reductions in emissions necessary to meet climate objectives. Mitigation in this sector can come from changes at both the intensive and the extensive margins, as well as through the adoption of more environmental-friendly farming practices and technologies.

Despite the weight of this sector in total GHG emissions and its mitigation potential, agriculture is today still exempted from the scope of climate policy. Market-based instruments like an emission tax, based on the polluter pays principle could deliver cost-effectivity in order to internalize the damage caused by CO_2 emissions (Goulder and Parry, 2008).

One of the reason for the lack of such policies may be their distributional effects. An emission tax can be regressive and increase income inequality. First, this assumption could be explained by the expenditure of carbon intensive goods that weighs more on poor households. Second, this also could be due to the heterogeneity of abatement costs. Households and firms do not mitigate their carbon emissions with the same facility. For instance, it will not be as easy as a rich household for a poor household to buy a new and less-polluting car. Agriculture is precisely a sector where abatement costs widely differ from a farm to another. De Cara et al. (2005) highlighted a spatial heterogeneity of abatement costs in the European agricultural system. For a certain amount of carbon tax, some regions could mitigate their emissions ten times than other regions. Isbasoiu (2019) showed that an emission price of 38€/tCO_2eq may be enough for the agricultural sector to reduce its emissions by 10% on average. However, there is a big variability between regions concerning marginal abatement costs. Mediterranean regions show higher-than-average marginal abatement costs whereas regions in Western and Central Europe tend to show lower-than-average marginal abatement costs.

In this paper, we study to what extent it is possible, through recycling-revenue tools, to build a progressive climate policy for producers. This work is an empirical contribution. Using datas from the Farm Accountancy Data Network (FADN) and an economic supply side model (AROPAj), we study the impact of a two-part instrument climate policy – an emission tax and a refund of the tax revenue – (Sterner and Höglund Isaksson, 2005) on income inequality for farmers. We assess the distributional effects on farmers' income of a Pigovian tax and of three schemes of refunding the tax revenue; a refund equal to the initial average tax revenue, a refund equal to the average tax revenue and a refund with respect to the weight of the farm in initial emissions.

This issue has been mainly studied for the fossil sector. Micro-level studies are especially relevant to explore this topic (Dissou and Siddiqui, 2014; Fremstad and Paul, 2019). They generally find that a carbon tax is regressive (Stiglitz, 2019; Mathur and Morris, 2014; Bureau, 2011; Grainger and Kolstad, 2010; Metcalf, 2009). Some authors emphasizes that revenue-recycling tools could lead to a progressive carbon policy (Douenne, 2018; Goulder et al., 2019). Klenert and Mattauch (2016) demonstrate in a theoretical article that a carbon tax reform is progressive if revenues are recycled as uniform lump-sum transfers. If revenues are recycled by lump-sum transfers calculated in proportion to the household's productivities or recycled via income tax cuts, the carbon tax remains regressive. Callan et al. (2009) showed for Irish households that between 65% and 80% of the carbon tax revenue must be recycled to compensate the regressive effects of the tax. More recently, Berry (2019) compared several designs of cash transfer in order to make the carbon tax progressive. She showed, using French data, that for a flat cash transfer, 59% of revenue recycled could be enough to offset carbon tax regressivity. This could even fall to 18% if the cash transfer is targeted at low-income households.

Distributive impacts of emission tax has been little studied for agriculture. Our contribution is to assess the distributional effects of an emission tax to the European agriculture.

The paper is organised as follows. Section 2 presents the agroeconomic model (AROPAj) and FADN data we used in order to assess the distributional effects of an emission tax. Section 3 shows the results achieved for four types of emission tax : a Pigovian tax, a subsidy with respect to the abatement, a revenue recycled equals to the average emission transfered to all farms, a revenue recycled in proportion of the initial emissions of the farm transfered to all farms. Section 4 concludes.

2. Model

2.1. The agro-economic model

The model used in this study in order to estimate the distributional effects of an emission tax is a supply-side model of the EU agricultural sector, AROPAj (Jayet et al., 2016). This model is made of a set of several and independent linear-programming models (MILP). Each model describes the economic behavior of a representative farmer denoted by k. Farms are grouped into "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. Then "farm types" are weighted by their representative production size (f_k). Each farm type is assumed to choose the supply level and the input demand (x_k) that maximize its total gross margin (π_k). A farm is considered to be price-taker. This model can be written as follows, for its general form (De Cara et al., 2005):

$$\begin{cases} \max_{x_k} \pi_k(x_k, t) = g_k \cdot x_k(t) - t \cdot (e_k(0) - a_k(t) - \tilde{e}_k(t)) \\ \text{s.t. } \alpha_k \cdot x_k \leq z_k \\ x_k \geq 0 \end{cases} \tag{1}$$

– x_k is the n-vector of producing activities for farm type k

– g_k is the n-vector of gross margins

– t is the tax applied to GHG emissions (from 0 to 200€/tCO_2eq)

– $e_k(0)$ is the n-vector of GHG initial emissions for farm type k

– $a_k(t)$ is the n-vector of abatement for farm type k and at a level of tax t

– $\tilde{e}_k(t)$ is the n-vector of refund for farm type k and at a level of tax t

– α_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

– $e_k(t)$, the n-vector of GHG emissions for farm type k and at a level of tax t.

Abatement are defined by the following equation:

$$e_k(t) = e_k(0) - a_k(t) \tag{2}$$

x_k includes the area and output for each crop, the quantity of purchased animal feeding, milk and meat production, and animal numbers in each animal category. g_k includes all gross margins corresponding to each producing activities : revenue plus subsidies, minus variable costs. α_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 is bounded by the European land area. There are also constraints on the crop rotations. We assumed that the animal number may vary into a +-15% of the initial animal number in each category of animals, as is the real nature of livestock-related capital. Animal feeding are also Constrained. Jarrige (1988) delivers physiological laws of livestock. Another set of constraints concerns the CAP measures. 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).

2.2. FADN data

The Farm Accounting Data Network (FADN) is the main source of data. The 2009 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).

2.3. Gini index

A farmer's annual income may be negative and approximately 5% of farmer's incomes we have in the database are negative. Therefore we chose to assess the distributive effects of emission tax with a Gini index, adapted to negative income (Raffinetti et al., 2014). A Gini index, based on the Lorenz curve, is a good way to quantify the distribution of income.

2.4. At the sector level

Total emissions are given by:

$$E(t) = \sum_k f_k \cdot e_k(t) = E(0) - A(t) \tag{3}$$

Total abatement is given by:

$$A(t) = \sum_k f_k \cdot a_k(t) \tag{4}$$

The total (net) revenue raised by the emission tax amounts to:

$$T(t, \tilde{e}_k) = t \cdot \left(E(t) - \sum_k f_k \cdot \tilde{e}_k(t) \right) \tag{5}$$

2.4.1. Total Welfare

Let us assume that a farm k produces a social damage d_k due to its emissions e_k. Without the implementation of an emission tax, the total welfare can be written as follows:

$$W = \Pi - D(E) \tag{6}$$

$$W = \sum_k f_k \cdot g_k \cdot x_k - \sum_k f_k \cdot d_k(e_k) \tag{7}$$

$$\frac{\partial W}{\partial x_k} = 0 \iff \sum_k f_k \cdot g_k = \sum_k f_k \cdot \frac{\partial d_k}{\partial e_k} \cdot \frac{\partial e_k}{\partial x_k} \tag{8}$$

With a tax, the profit may be written as follows:

$$\Pi = \sum_k f_k \cdot g_k \cdot x_k - \sum_k f_k \cdot t \cdot (e_k - \tilde{e}_k) \tag{9}$$

$$\frac{\partial \Pi}{\partial x_k} = 0 \iff \sum_k f_k \cdot g_k = \sum_k f_k \cdot t \cdot \frac{\partial e_k}{\partial x_k} \tag{10}$$

Combining (8) and (10):

$$\sum_k f_k \cdot \frac{\partial d_k}{\partial e_k} \cdot \frac{\partial e_k}{\partial x_k} = \sum_k f_k \cdot t \cdot \frac{\partial e_k}{\partial x_k} \iff t = \frac{\sum_k \frac{\partial d_k}{\partial e_k}}{\sum_k 1} \tag{11}$$

In order to maximise the social welfare, if the redistributive part of the policy ($\tilde{e}_k$) does not depend on the producing activities (x_k) the tax t should be equal to the mean marginal damage of pollution.

2.4.2. Net revenue raised by the government

In the case of a Pigovian tax (without transfer), $\tilde{e}_k(t) = 0$, the government does not redistribute the tax revenue raised, so that:

$$T(t) = t \cdot E(t) \geq 0 \tag{12}$$

In the case where $\tilde{e}_k = \bar{e} = \frac{\sum_k f_k \cdot e_k(t)}{\sum_i f_i}$, the government entirely redistributes the tax revenue raised:

$$T(t) = t \cdot \left(E(t) - \sum_k f_k \cdot \frac{\sum_i f_i \cdot e_i(t)}{\sum_i f_i} \right) = t \cdot \left(E(t) - \frac{\sum_k f_k}{\sum_i f_i} \cdot E(t) \right) = 0 \tag{13}$$

This case corresponds to a situation where each agent k who emits (post-tax) less than per-firm average emissions receives $t \cdot (\bar{e} - e_k(t))$, and each agent who emits more than per-firm average emissions pays $t \cdot (e_k(t) - \bar{e})$.

In the case where $\tilde{e}_k = e_k(0) \cdot \frac{\sum_k f_k \cdot e_k(t)}{\sum_i f_i \cdot e_i(0)}$, the policy is budget-neutral since the total tax receipt amounts to:

$$T(t) = t \cdot \left(E(t) - \sum_j f_j \cdot e_j(0) \cdot \frac{\sum_k f_k \cdot e_k(t)}{\sum_i f_i \cdot e_i(0)} \right) = t \cdot \left(E(t) - E(0) \cdot \frac{E(t)}{E(0)} \right) = 0 \tag{14}$$

This case corresponds to a situation where the total tax revenue raised by the tax is refunded to each agent in proportion to his initial emission.

In the case where $\tilde{e}_k = \bar{e}_0 = \frac{\sum_k f_k \cdot e_k(0)}{\sum_i f_i}$, the government redistributes more than the tax revenue raised:

$$T(t) = t \cdot \left(E(t) - \sum_k f_k \cdot \frac{\sum_i f_i \cdot e_i(0)}{\sum_i f_i} \right) = t \cdot \left(E(t) - \frac{\sum_k f_k}{\sum_i f_i} \cdot E(0) \right) \leq 0 \tag{15}$$

This case corresponds to a situation where each agent k who emits (post-tax) less than initial per-firm average emissions receives $t \cdot (\bar{e}_0 - e_k(t))$, and each agent who emits more than initial per-firm average emissions pays $t \cdot (e_k(t) - \bar{e}_0)$.

The total abatement depends on the level of the tax t. The refund does not have any effect on the level of mitigation. In the case of a sigle Pigovian tax on GHG emissions ($\tilde{e}_k(t) = 0$), the more the farm pollutes, the more it is taxed. This case can be expected to be regressive if abatement costs are higher for lowest incomes, as it has been demonstrated for the fossil sector (Douenne, 2018; Callan et al., 2009). In the case where the refund is equal to the average tax revenue ($\tilde{e}_k(t) = \bar{e}$) and the case where the refund is equal to the initial average tax revenue ($\tilde{e}_k(t) = \bar{e}_0$), all farms are compensated with the same amount. If GHG emissions are income dependant, both cases can be expected to have an effect on gross margins' distrbution. If higher incomes pollute more than lower ones, they are charged with a bigger fee. As the refund is the same for all farms, these both policy schemes could be progressive. It is worth noting that, as total net emissions are decreasing with t, the case where $\tilde{e}_k(t) = \bar{e}_0$ is costly for the government. In the situation where the tax revenue is refunded in proportion to the initial emissions of the farm ($\tilde{e}_k = e_k(0) \cdot \frac{E(t)}{E(0)}$), the more a farm is pollutant, the more it is taxed but the more it receives money from the refund. So we can expect that this policy does not have a significant effect on gross margins' distribution.

3. Results

Table 1 is a description of total GHG emissions and total gross margin per decile, for European agriculture. We can see emissions increase with the gross margin. The first decile is an exception

Decile	Total GHG emissions E(0) [10^6tCO$_2$eq]	Total gross margin Π(0) [10^6€]
1	11.30	-667.52
2	4.64	1033.17
3	6.38	1580.39
4	9.08	2391.26
5	11.45	3713.01
6	17.35	5761.10
7	25.44	9235.12
8	45.17	15194.06
9	83.88	26724.01
10	192.14	74791.55

Table 1: Initial GHG emissions and gross margins for the European Union, 2009

as it emits almost the same amount of GHG emissions than the fifth decile while its gross margin is negative. The tenth and highest decile is a strong contributor to GHG emissions but also an important share in total gross margin. It emits 47.2% of total GHG emissions whereas it represents 53.5% of the total gross margin.

Figure 1 depicts the Gini index according to the tax (from 0 to 200€/tCO$_2$eq) for the single Pigovian tax on GHG emissions and the three types of refund we computed. The Pigovian tax ($\tilde{e}_k(t) = 0$) tends to increase income inequality with the level of the tax, as it has been often demonstrated for the fossil sector (Stiglitz, 2019; Berry, 2019; Mathur and Morris, 2014). A refund in proportion to the initial emissions of the farm ($\tilde{e}_k(t) = e_k(0)\frac{E(t)}{E(0)}$) seems to compensate the regressive effect of the tax. As we could expect it, an emission tax with a refund in proportion to the initial emissions is neutral concerning gross margins' distribution, it maintains the Gini index close to its initial level. This policy scheme is also neutral for the government (money raised by the tax is entirely redistributed). Another emission tax schemes that is neutral for the public decision-maker is the tax joined with a single transfer to all farms equals to the average emission ($\tilde{e}_k(t) = \bar{e}$). In this scheme, if a farm emits less than the average emission, it receives money, whereas a farm that emits more than the average emission is taxed. This policy tends to reduce gross margins inequality among farmers. Not only the refund compensates the regressive effect of the emission tax but it also reduces gross margins inequality with respect to its initial level. The refund equal to the initial average tax revenue ($\tilde{e}_k(t) = \bar{e}_0$) is the most progressive but it is costly for the government. In this

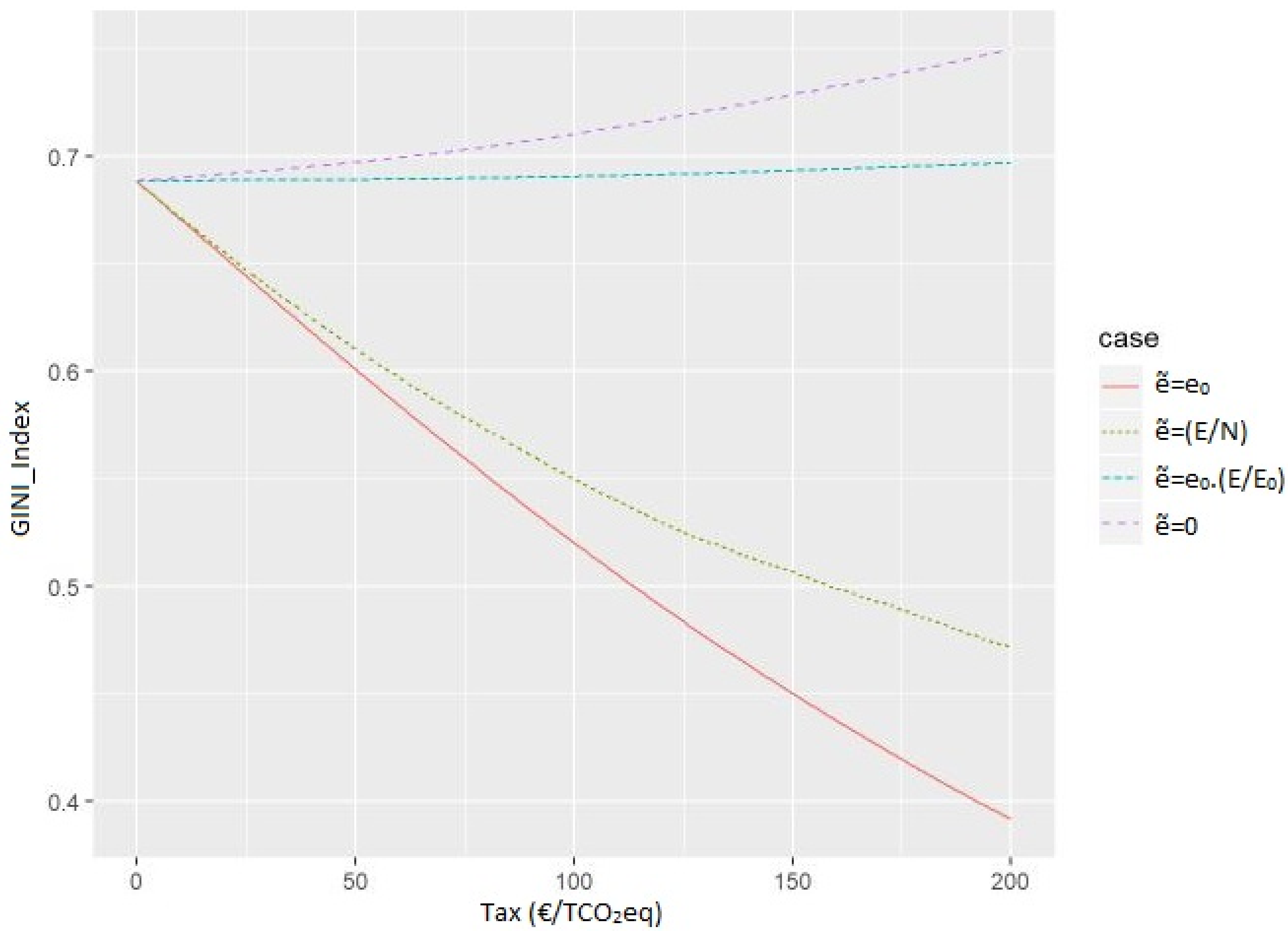

Figure 1: Gini index in function of an emission tax for the European Union, 2009

case, if a farm emits less than the average emission, it receives money, whereas a farm that emits more than the average emission is taxed.

An emission price of 30€/tCO_2eq, which is close to the carbon price on the European ETS market for the year 2019, corresponds to a mitigation of 7,5% of GHG emissions for the agricultural sector (De Cara et al., 2018). A Pigovian tax of 30€/tCO_2eq may slightly increase gross margins inequality. The Gini index varies from 0.685 to 0.695. However, a refund of the tax revenue equal to the average emission ($\tilde{e}_k(t) = \bar{e}$) could seriously decrease the Gini index (from 0.685 to 0.64). A refund equal to the initial average tax revenue ($\tilde{e}_k(t) = \bar{e}_0$) may even more decrease gross margins inequality (from 0.685 to 0.635).

Figure 2 shows the net amount of tax collected per farm in each decile with three emission prices (30, 50 and 100€/tCO_2eq) for a single Pigovian tax on GHG emission and for three tax

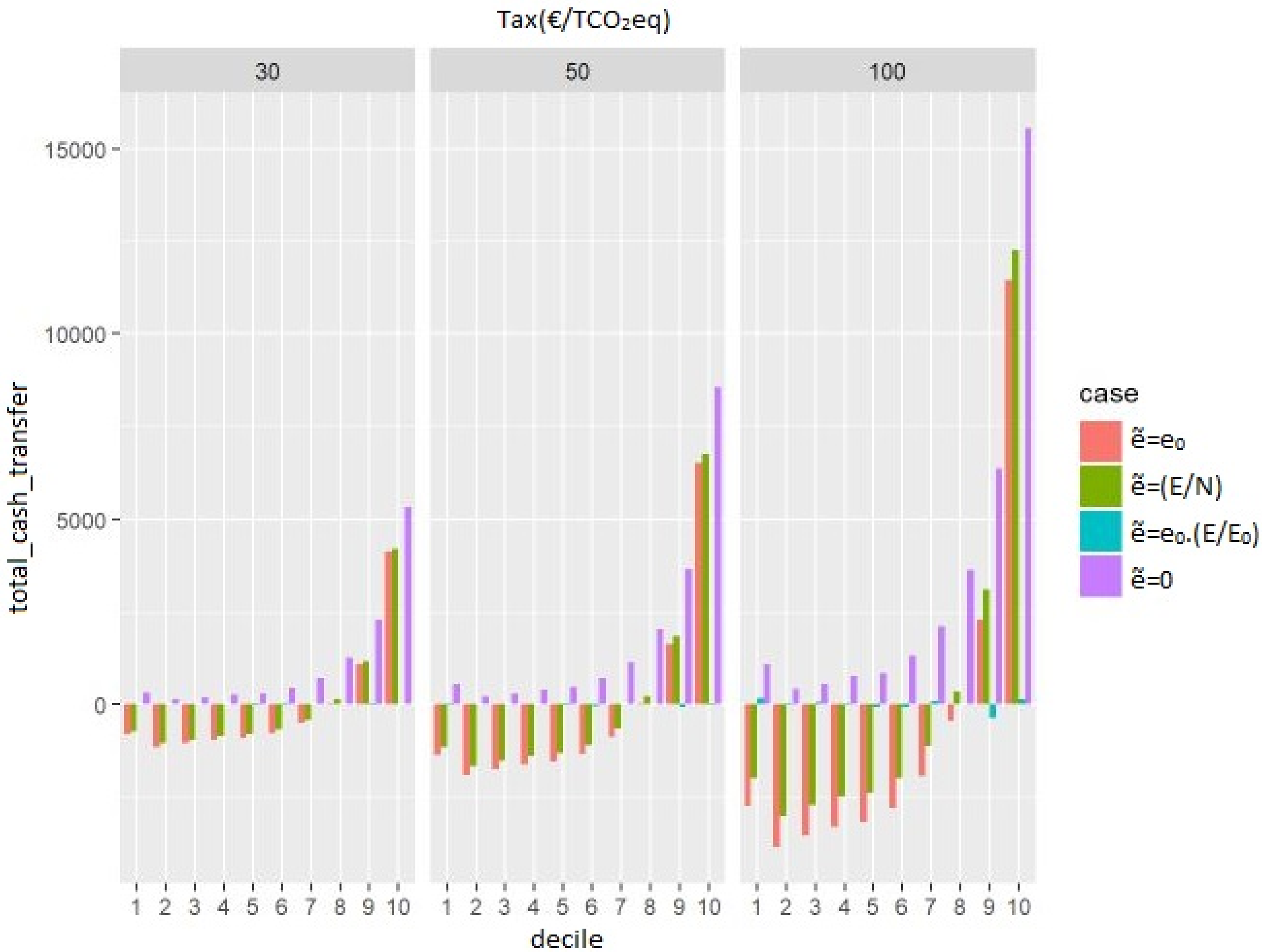

Figure 2: Total net amount of tax collected per farm in each decile with three emission prices (30, 50 and 100€/tCO_2eq) for the European Union, 2009

redistribution policies. An emission price of 30, 50 and 100€/tCO_2eq may respectively lead to a mitigation of 7.5%, 11% and 20% of the total GHG emissions from European agriculture (De Cara et al., 2018). In the case of the Pigovian tax ($\tilde{e}_k(t) = 0$), we can see that the highest deciles are more taxed than the lowest ones. Despite this finding, figure 1 shows that farmers' gross margin inequality increases when the revenue from the tax is not redistributed. The regressivity of the Pigovian tax may come from abatement costs, that are proportionally more important for lower gross margins than for upper ones. This phenomenon also occurs in the fossil sector (Stiglitz, 2019). In the case of a refund equal to the initial average tax revenue ($\tilde{e}_k(t) = \bar{e}_0$), The first eight deciles benefit from the policy, nevertheless it may be costly for highest gross margins. Even at an emission price of 100€/tCO_2eq, the average farm from one of the two highest deciles still emits more than the initial average emission. In the case of a transfer equal to the average tax revenue ($\tilde{e}_k(t) = \bar{e}$), the seven first deciles receive money. This scheme is costly for farms in the three highest deciles, that emit more than the average level of GHG emission. When the redistribution is in proportion with the weight of the farm in initial GHG emissions ($\tilde{e}_k(t) = e_k(0) \cdot \frac{E(t)}{E(0)}$), no decile benefits or loses from the emission tax scheme. In the light of the figure 1, we can say that this policy does not change the distribution of farmers' gross margin.

It is noteworthy that the revenue from the Pigovian tax is higher for the first decile than for the second or the third one. This could be explained by the fact that a significant part of the lowest income has a pollutant type of farming.

4. Conclusion & Discussion

In this paper, we assess and quantify the distributional effects of an emission tax on European farmers' income. Using an agricultural supply side model (AROPAj), based on FADN data, our study relates to three schemes of refunding tax revenue; a refund equal to the average tax revenue, a refund equal to the initial average tax revenue and a refund proportional to initial GHG emissions of the farm. We applied a Gini index adapted in order to better take into account negative gross margins.

In line with the literature, we find that a single Pigovian tax on GHG emission is regressive. Nevertheless, we show that it is possible to compensate the regressivity of the Pigovian tax, refunding the emission tax revenue. For instance, a refund in proportion to the initial emissions of the farm may offset the regressivity of the emission tax. Refunding the same amount to all farms, equal to the average tax revenue, could even lead to a strong decrease in farmers' gross margin inequality.

A very short-term objective is to complete this work with an analysis of the distributive effects in terms of both type of farming and geographical disparities. For example, This could lead to a better understanding of the important weight of GHG emissions for the first decile.

Berry, A. (2019). The distributional effects of a carbon tax and its impact on fuel poverty: A microsimulation study in the french context. *Energy Policy*, 124:81–94.

Bureau, B. (2011). Distributional effects of a carbon tax on car fuels in france. *Energy Economics*, 33(1):121–130.

Callan, T., Lyons, S., Scott, S., Tol, R. S. J., and Verde, S. (2009). The distributional implications of a carbon tax in ireland. *Energy Policy*, 37(2):407–412.

De Cara, S., Henry, L., and Jayet, P.-A. (2018). Optimal coverage of an emission tax in the presence of monitoring, reporting, and verification costs. *Journal of Environmental Economics and Management*, 89:71–93.

De Cara, S., Houzé, M., and Jayet, P.-A. (2005). Methane and nitrous oxide emissions from agriculture in the eu: A spatial assessment of sources and abatement costs. *Environmental and Resource Economics*, 32(4):551–583.

Dissou, Y. and Siddiqui, M. S. (2014). Can carbon taxes be progressive ? *Energy Economics*, 42:88–100.

Douenne, T. (2018). The vertical and horizontal distributive effects of energy taxes: A case study of a french policy. FAERE Working papers.

Fremstad, A. and Paul, M. (2019). The impact of a carbon tax on inequality. *Ecological Economics*, 163:88–97.

Goulder, L. H., Hafstead, M. A., Kim, G., and Long, X. (2019). Impacts of a carbon tax across us household income groups: What are the equity-efficiency trade-offs ? *Journal of Public Economics*, 175:44 – 64.

Goulder, L. H. and Parry, I. W. H. (2008). Instrument choice in environmental policy. *Review of Environmental Economics and Policy*, 2(2):152–174.

Grainger, C. A. and Kolstad, C. D. (2010). Who pays a price on carbon ? *Environmental and Resource Economics*, 46(3):359–376.

Isbasoiu, A. (2019). *Analyse multicritère des politiques publiques environnementales dans l'Union Européenne*. phdthesis, AgroParisTech.

Jarrige, R. (1988). *Alimentation des Bovins, Ovins et Caprins*. INRA Editions, Paris (France).

Jayet, P.-A., Petsakos, A., Chakir, R., Lungarska, A., De Cara, S., Petel, E., Humblot, P., Godard, C., Leclère, D., Cantelaube, P., Bourgeois, C., Bamière, L., Ben Fradj, N., Aghajanzadeh-Darzi, P., Dumollard, G., Ancuta, I., and Adrian, J. (2016). The european agro-economic aropaj model. Technical report, INRA, UMR Economie Publique, Thiverval-Grignon.

Klenert, D. and Mattauch, L. (2016). How to make a carbon tax reform progressive : The role of subsistence consumption. *Economics Letters*, 138:100–103.

Mathur, A. and Morris, A. C. (2014). Distributional effects of a carbon tax in broader u.s. fiscal reform. *Energy Policy*, 66:326–334.

Metcalf, G. E. (2009). Designing a carbon tax to reduce u.s. greenhouse gas emissions. *Review of Environmental Economics and Policy*, 3(1):63–83.

Pellerin, S., Bamière, L., Angers, D., Béline, F., Benoit, M., Butault, J.-P., Chenu, C., Colnenne-David, C., De Cara, S., Delame, N., Doreau, M., Dupraz, P., Faverdin, P., Garcia-Launay, F., Hassouna, M., Hénault, C., Jeuffroy, M.-H., Klumpp, K., Metay, A., Moran, D., Recous, S., Samson, E., Savini, I., Pardon, L., and Chemineau, P. (2017). Identifying cost-competitive greenhouse gas mitigation potential of french agriculture. *Environmental Science and Policy*, 77:130–139.

Raffinetti, E., Siletti, E., and Vernizzi, A. (2014). On the gini coefficient normalization when attributes with negative values are considered. *Statistical Methods & Applications*, 24(3):507–521.

Shukla, P., Skea, J., Calvo Buendia, E., Masson-Delmotte, V., Pörtner, H.-O., Roberts, D. C., Zhai, P., Slade, R., Connors, S., van Diemen, R., Ferrat, M., Haughey, E., Luz, S., Neogi, S., Pathak, M., Petzold, J., Portugal Pereira, J., Vyas, P., Huntley, E., Kissick, K., Belkacemi, M., and Malley, J. e. (2019). Climate change and land: an ipcc special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Technical report, IPCC.

Sterner, T. and Höglund Isaksson, L. (2005). Refunded emission payments theory, distribution of costs, and swedish experience of nox abatement. *Ecological Economics*, 57:93–106.

Stiglitz, J. E. (2019). Adressing climate change through price and non-price interventions. *European Economic Review*, 119:594–612.