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The vertical and horizontal distributive effects of energy taxes: *A case study of a French policy*

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Abstract:

This paper proposes a micro-simulation assessment of the distributional impacts of the French carbon tax. It shows that the policy is regressive, but could be made progressive by redistributing the revenue through a flat-recycling. However, it would still generate large horizontal distributive effects and harm an important share of low-income households. The determinants of the tax incidence are characterized precisely, and alternative targeted transfers are simulated on this basis. The paper shows that given the importance of unobserved heterogeneity in the determinants of energy consumption, horizontal distributive effects are much more difficult to tackle than vertical ones.

JEL classification: D12, H23, I32

Keywords: Energy taxes; Distributional effects; Demand system; Micro-simulation

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1 Introduction

It is paradoxical that while environmental taxes are considered by economists as one of the most efficient instruments to deal with environmental problems, it is still underdeveloped if not absent from the policy mix of most countries. Among the many reasons that might explain this paradox, distributional concerns certainly play an important role. A large literature has addressed this issue through the analysis of the *vertical* distributive effects of these policies - i.e. distributive effects between households along the income dimension. Most of the studies agree that these taxes are regressive but a neutral redistribution of their revenue can turn them into progressive policies. However, despite this consensus, the acceptability problem seems far from being solved. In this paper, I will argue that to understand the distributional concerns associated with environmental taxes, we should consider not only their vertical, but also *horizontal* distributive effects - i.e. between households with similar incomes. In particular, while low-income households may on average gain from an environmental tax after revenue-recycling, some of them could experience important losses. Understanding and quantifying these phenomena is key to better design these policies, and thus reduce their distributive costs and facilitate the implementation of ambitious environmental policies.

The paper is based on the model TAXIPP[1], a micro-simulation model of indirect taxation for French households. It evaluates the French fiscal policy on energies announced for 2018. The policy is essentially an increase in the carbon price on all energies except electricity already subject to the EU-ETS[2]. Although the analysis will focus on this specific policy, I believe the qualitative results are more general. The policy studied is close to a standard

[1]TAXIPP is the micro-simulation model of the Institut des Politiques Publiques (IPP).
[2]European Union Emissions Trading Scheme

carbon tax, and energy consumption patterns in France are very similar to most other OECD countries. In addition, the results appear to be robust when applying a similar tax increase to electricity.

Several papers have investigated the distributive effects of energy taxes in France (e.g. Ruiz and Trannoy (2008) [34], Bureau (2011) [5], Berry (2017) [3]). Yet, partly because of a lack of a comprehensive database, there has been little works covering jointly housing and transports, and existing studies all focus on vertical equity. To investigate together these issues, I used statistical matching techniques and matched together households from the French housing and transports surveys with households in the last consumer expenditures survey "Budget de Famille". Using this new comprehensive database, I micro-simulate the fiscal reform on energies announced for 2018. Given the relatively small scale of the tax, the use of micro-simulation is relevant as general equilibrium effects should play a very limited role. As argued by Bourguignon and Spadaro (2006) [4], these models are best fitted to look precisely at distributive effects of policy changes as they fully take into account households' heterogeneity. The model accounts for behavioural responses through heterogeneous price and income elasticities estimated using a *Quadratic almost ideal demand system* (QUAIDS, see Banks, Blundell and Lewbel [1] (1997)). I find that the median household reacts significantly to transport fuel prices with an uncompensated price elasticity around -0.45, and to a lesser extent to housing energy prices with an elasticity of -0.2. I also find that reactions are expected to be stronger for lower income and less urban households. This heterogeneity in responses is important as these households will therefore adapt more their consumption to soften the monetary impact of the policy.

Elasticities are then translated into changes in quantities and greenhouse gas emissions.

For a given technology, the response to prices appears to have a limited impact on aggregate emissions. With respect to monetary effects, I compute effort rates and analyze how the tax burden is spread across income groups, before and after revenue recycling. The results confirm the findings of the literature that energy taxes are regressive when computing effort rates as a function of disposable income (e.g. Poterba (1991) [30], Metcalf (1999) [24], Grainger and Kolstad (2010) [16]), but almost not when taking total expenditures instead to measure standards of living (see Poterba (1989) [29], Metcalf (1999) [24], Hassett et al (2013) [17], Flues and Thomas (2015) [15]). Also, I find that the compensation mechanism proposed by the government and targeted towards low-income households will not solve regressivity. However, recycling the revenue left after this mechanism through homogeneous lump-sum transfers - a mechanism known as flat-recycling (see West and Williams (2004) [36], Bento et al (2009) [2], Bureau (2011) [5], Williams et al (2015) [37]) - would make a progressive policy.

From the previous conclusions, it could seem straightforward to improve the acceptability of energy taxes. However, a recent literature has started to emphasize that their horizontal distributive effects could be important in magnitude and a major deterrent for their implementation (Rausch et al (2011) [31], Pizer and Sexton (2017) [27], Cronin et al (2017) [8]). In this paper, I analyze the distribution of gains and losses within income groups. In particular, I show that after flat-recycling, over a third of low-income households are expected to lose from the policy. Also, 25% of households in the bottom income decile are expected to lose more than the median household in the top income decile. This result confirms that distributive effects within income groups are expected to be much larger in magnitude than across income groups and could dampen the policy's acceptability.

Important progress have been recently made by general equilibrium models to incorporate more heterogeneity in households characteristics (e.g. Rausch et al (2011) [31], Rausch and Schwarz (2016) [32]). Yet, it is still unclear what are the drivers of the heterogeneous incidence of energy taxes (Pizer and Sexton (2017) [27]). The literature has mostly focused on geographical criteria looking at the differentiated impact across regions, and emphasized the role of income composition. Thanks to micro-simulation, I adopt a more agnostic approach to characterize the determinants of the heterogeneous tax incidence at the household level. Among many drivers, I show that the energy used for heating and to a lesser extent the geographical location account for an important share of horizontal distributive effects. I illustrate this point by testing alternative scenarios for revenue-recycling using targeted transfers based on these characteristics. I find that indexing transfers on the geographic location has no effect, while indexing them on the type of energy used for heating enables to only slightly soften horizontal equity issues. Finally, comparing these limited benefits against the costs in terms of environmental incentives and implementation, I discuss the potential of these transfers to improve public acceptance, against other revenue-recycling mechanisms.

This paper contributes to several strands of the literature. First, through the use of statistical matching techniques, it builds the most comprehensive existing database to study energy taxation for France. Using these data, it also offers an extensive evaluation of the forthcoming environmental fiscal policy. Second, this paper adds new evidence on the incidence of energy taxes with respect to both vertical and horizontal heterogeneity. In particular, it sheds new light on the importance of the latter and its implications for the acceptability of environmental taxes. It also goes further than previous studies by using micro-simulation to identify the determinants of this heterogeneity at a more precise level. Given the urgent need to implement ambitious environmental policies and in particular carbon pricing, it is crucial to better understand the concerns associated with these instruments. Only then will we be able to bring effective solutions to improve their acceptability.

The paper is organized as follows. Section 2 discusses the choice of the main database, presents the imputation procedure from other data sources, and briefly sketches households' consumption patterns. Section 3 presents the QUAIDS and the elasticities estimated. Section 4 evaluates the expected environmental and distributive effects of the policy, both across and within income groups. Section 5 highlights the determinants of the tax incidence and proposes alternative revenue-recycling mechanisms based on these results. Section 6 concludes. Technical elements are reported in appendix.

2 Data

2.1 Housing, transports and consumer surveys

A comprehensive study of the incidence of energy taxes on households must include both housing and transport energies. In France, energy consumption from the transport and residential sectors represent respectively 27% and 12% of total emissions, and in 2016 they accounted for 2.8% and 5.0% of the total expenditures of the median household[3]. Yet, most studies on French data have let aside one of these issues. Bureau (2011) [5] studies the distributional impacts of a carbon tax followed by lump-sum transfers, but focuses on transport fuels only. Using the data "Budget de Famille" (BdF) Nichèle and Robin (1995) [26] covered both issues but they did not estimated elasticities specifically for energies, nor

[3]BdF 2011 inflated for 2016

did they precisely detailed the distributive effects of the tax. Closer to this work, Berry (2017) [3] investigates a previous increase in the carbon price on energies using the Phebus database. However the smaller sample size and the limited number of information in this survey does not enable to explore further the determinants of horizontal distributive effects. Also, since households' expenditures are given for energy only, elasticities are estimated from the survey BdF and then matched for each income decile to households in Phebus.

In this paper, I instead directly make use of the last version of the consumer survey "Budget de Famille" (BdF, 2011). Because of its very large set of variables describing households, and because it gathers accurate information on all their expenditures, I believe BdF is the best database to study indirect taxation, and in particular energy taxes. The survey is realized every five years on a sample of more than 10,000 households[4]. Consumption of housing energies are taken from households' bills, and for most other goods they answer questionnaires to report their expenditures. To avoid seasonality effects, several waves of surveys are realized all along the year. I also correct for potential reporting bias by inflating households energy expenditures and incomes to reconcile micro data with aggregates from national accounts. This also enables to make the data representative of 2016, the date from which the policy changes are studied.

Yet, one limitation of the survey BdF is that transport fuel consumption is reported on a very short period of time. Therefore, actual consumption behaviour may be miss-represented with too many households reporting a null consumption over that period, or conversely an over-consumption once the data are annualized. To overcome this problem

[4] I excluded from the sample overseas department and territories (DOM-TOM) since indirect taxes are set differently.

and not over-estimate the heterogeneity in transport fuel consumption, I therefore apply statistical matching techniques and match households in BdF with those in the transport survey "Enquête Nationale Transports et Déplacements" (ENTD) where annual distances travelled are reported. In addition, I also match statistically households in BdF with those in the housing survey "Enquête Logement" (EL), in order to collect additional information on accommodation's characteristics. A matching of high quality is possible because these surveys are all quite large[5], come from the same statistical institute, study the same population, and share a large number of common variables with identical definitions. I believe the construction of this database necessary to perform the most comprehensive and robust analysis of the distributive effects of energy taxation in France. Comprehensive methodological guidelines for matching procedures can be found in two recent Eurostat reports [22] and [35] and in a series of contributions by D'Orazio and coauthors [12] and [11] on which this work builds.

2.2 Households and energy consumption: a descriptive approach

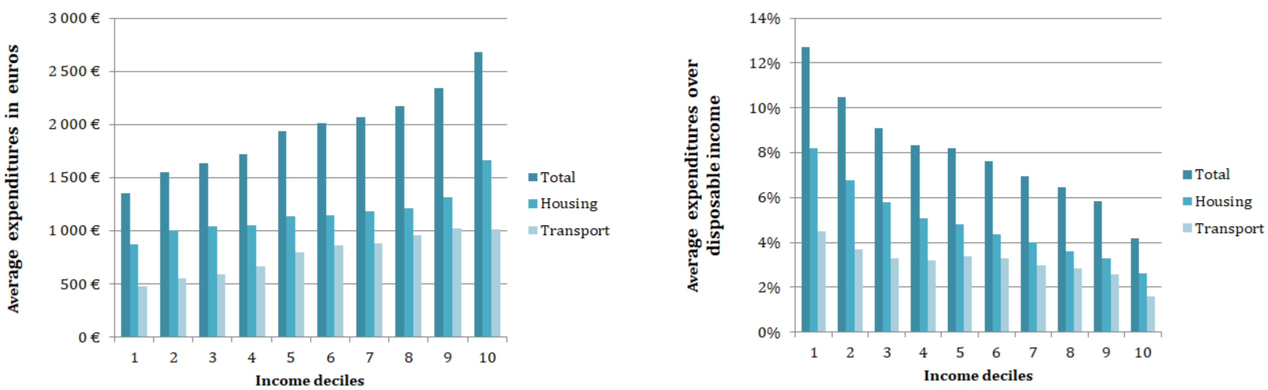
Figure 1 (left) plots households' annual expenditures in energy per consumption unit (c.u.) by income decile[6] in 2016. The figure depicts a strictly increasing pattern of energy expenditures across groups, with the last group spending on average twice as much as the first. This pattern is rather intuitive since we can expect richer households to have on average larger accommodations, more energy consuming devices and in particular vehicles with higher fuel consumption. However, considering energy expenditures as a share of households disposable income (right), we find that this share is decreasing with income. As a consequence, as a

[5]For metropolitan France, the number of households surveyed for BdF, EL and ENTD are respectively 10,342, 27,137 and 20,178

[6]Groups are constructed on the basis of disposable income per consumption unit

share of their income we may anticipate that lower income households will be more affected by energy taxes although they consume less energy in total and emit less CO_2.

Figure 1: Households' annual expenditures in energy per c.u. (left) and as a share of their disposable income (right) in 2016, by income decile



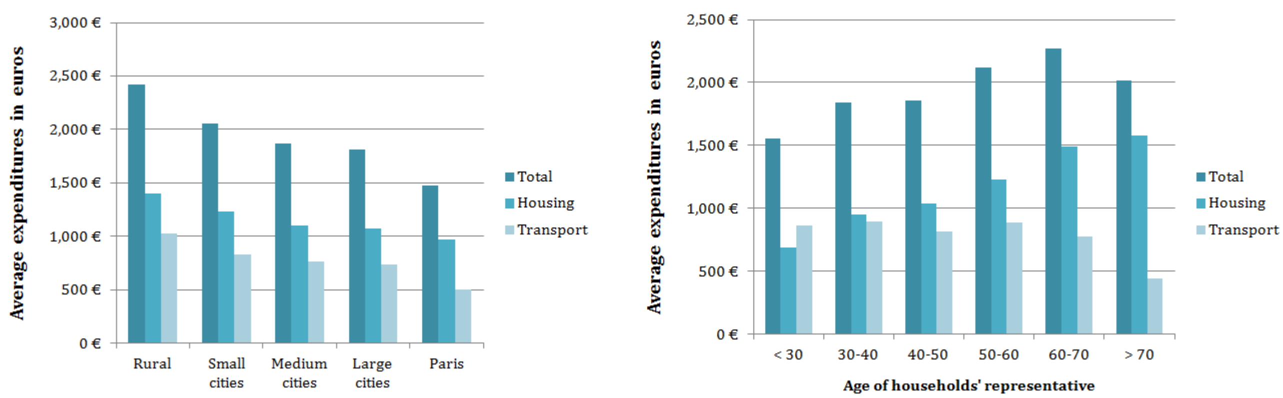
LECTURE: In 2016, households belonging to the first income decile spent on average 1,353€ in energies per c.u., including 873€ for housing energies and 480€ for transport fuels. It represented respectively 13%, 8% and 5% of their disposable income.

Besides the heterogeneity on the income dimension, households living in rural areas and smaller cities also spend on average more in energies, both for transports and housing. As shown by figure 2 (left), the average expenditures for rural households amount to 2,424€ a year per consumption unit against 1,812€ in large cities and 1,471€ for those living in the agglomeration of Paris. These households may differ in many respects including income, but other factors such as larger accommodations and higher driving constraints could also play a major role. These features will therefore be critical when analyzing the incidence of tax policies. If we distinguish by age groups[7] (right), it appears that the relationship is non-monotonic. Expenditures affected to energy are increasing both for transports and housing up to the sixties, and then the overall energy consumption starts to decline. A striking

[7]Age is taken as the one of the household's representative at the moment of the survey.

observation is that this decline comes entirely from transport fuels while housing energy expenditures continue to increase. This pattern is consistent with the findings of Labanderia and co-authors (2006) [20] and could be explained through other dimensions highly correlated with age, such as income or households' composition. If households can easily adjust their travels when their children leave home or when they get retired, they may find it harder to reduce their housing energy consumption.

Figure 2: Households' annual expenditures in energies per c.u., by geographical area (left) and age group (right)



Lecture: In 2016, households living in the Parisian agglomeration spent on average 1,471€ in energies, including 972€ in housing energies and 499€ in transport fuels.

Although very preliminary, these remarks are important for several reasons. First, these descriptive statistics show that the energy consumption patterns in France are standard relative to other OECD countries. Second, the decreasing share that energy consumption represents over households income indicates that a carbon tax on energies might be regressive. Third, it already appears that income is only one of the numerous dimensions on which households differ. This last point will be critical when considering the distributive effects of the policy.

3 Estimating households' responses to prices

3.1 The Quadratic almost ideal demand system

Modelling reforms of indirect taxation can be done in two manners. The simplest possible way is to model accounting effects only, i.e. holding everything else constant analyzing the effects of a change in the legislation. A more realistic approach however is to take into account behavioural responses, that is the effect of taxes on consumption choices. Neglecting households responses is likely to lead to over-estimate the tax burden and the extent of regressivity (see West and Williams (2004) [36]). In order to obtain a better estimation of the incidence of energy taxes, I therefore estimate price and income elasticities on energy goods, that I then integrate to the micro-simulation model.

Since all households expenditures are reported in the database, I evaluate elasticities through a demand system. The advantage over reduced form equations is that demand systems build on an underlying model of households consumption behaviour over all goods, which also enables to estimate a system of joint equations instead of separate regressions. I estimate the *Quadratic Almost Ideal Demand System* (QUAIDS) introduced by Banks Blundell and Lewbel (1997) [1]. This model extends the *Almost Ideal Demand System* (AIDS) proposed by Deaton and Muellbauer (1980b) [9] by allowing for non-linear Engel curves. It is preferred to other demand systems because it gathers many of their respective properties without making strong assumptions over preferences that could create a specification bias in the estimation. The QUAIDS considers the consumption that individuals make on k different categories of goods and the share of their total expenditures they each represent. The full model is presented in appendix, and leads to estimate the following equations:

$$w_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \beta_i \ln \left\{ \frac{m}{a(\mathbf{p})} \right\} + \frac{\lambda_i}{b(\mathbf{p})} \left[\ln \left\{ \frac{m}{a(\mathbf{p})} \right\} \right]^2, \quad i = 1, ..., k \tag{1}$$

where i and j represent bundles of goods and w_i the share of bundle i in total expenditures m, p_i its price index, and $a(\mathbf{p})$ and $b(\mathbf{p})$ two distinct price aggregators. These equations can be generalized to account for heterogeneity in preferences through the inclusion of demographic variables. I estimate the model on three categories of goods (i.e. $k = 3$). The first is transport fuels that includes diesel and gasoline. The second group gathers all housing energies. The third group is the rest of non-durable products.

The main difficulty to estimate demand systems with survey data comes from the lack of variability in prices. For each household, and for each good he consumes, I match the prevailing monthly price index of the French statistical institute (Insee) according to the period of the survey. As Nichèle and Robin (1995) [26], I take the last three surveys - 2000, 2005 and 2011 - for a total of 20 periods[8] hence a maximum of 20 different prices for each good. For transport fuels, more variations can be introduced by making use of the quantities reported in the notebook filled by households, from which we can deduce the price they faced. For housing energies and many other non-durable goods, this strategy cannot be used. To overcome the low variability in prices, I use Stone-Lewbel price indexes (see Lewbel (1989) [23]). Under the assumption that households *within-bundle* utility functions - i.e. the sub-utility that represents preferences between various products within a bundle of goods - are Cobb-Douglas, one can construct a price index as a geometric average of products price indexes. For a bundle i consumed by household h, we get:

[8] There were 8 waves in 2000, 6 in 2005 and 2011

$$\ln(p_{ih}) = \sum_{l=1}^{N_i} \frac{w_{lh}}{w_{ih}} \ln(p_{lh}) \tag{2}$$

where w_{lh} is the consumption share of good l belonging to the bundle i for household h, w_{ih} the consumption share of bundle i in total consumption for this household, and p_{lh}, p_{ih} their respective price index. Without any additional assumption on the form of the *between bundles* utility function, this method enables to construct price indexes that rely on heterogeneity of consumers preferences within each bundle. This heterogeneity enables to introduce more variation in prices. It has been widely used in the literature computing demand systems, and to my knowledge is the only efficient strategy to construct price indexes with high enough variability from cross-sectional data. In an assessment of this method, Hoderlein and Mihaleva (2008) [18] have shown that it produces better empirical results than standard aggregate price indexes. However, one should still be careful about the potential endogeneity introduced by Lewbel's procedure. When *within-bundle* utility functions are Cobb-Douglas, the weights used in the price index correspond to households' exogenous preference parameters. But if this assumption is not met, expenditures being used in the construction of prices, there is a risk to bias identification. In order to check the robustness of the results, I therefore estimate an alternative specification where I do not use personalized Stone-Lewbel price indexes. Instead, I group households in preference categories based on their size and location (city size and region of France) and compute an average price index for each category. While the variability in prices is reduced, the threat of endogeneity in the price index is also significantly lowered.

To further reduce any chance of endogeneity, I add controls to account for diversity in households' preferences such as their age, heating mode, geographical location and other characteristics that could explain households' bundles composition. I also use time fixed effects to account for seasonality in consumption. Finally, because expenditures are endogenous in demand systems, I use households' total income as an instrument. The model is estimated using the procedure introduced by Lecocq and Robin (2015) [21]. Elasticities are given at the sample mean, as well as for specific households groups.

3.2 Results

Table I reports income and uncompensated price elasticities for four specifications, with the 95% confidence interval for these estimates. Specifications (1) and (2) use the SL price indexes, and (1) and (3) the IV for total expenditures. The results appear similar in all four specifications, although the confidence intervals are larger without the SL price indexes.

I find budget elasticities around 0.5 for both transport and housing energies and close to 1 for other non durable products. Uncompensated price elasticities are around -0.45 for transport fuels, -0.2 for housing energy and -1.0 for the rest of non durable goods. These results are in accordance with common estimates in the literature[9]. On French data, Combet et al (2009) [7] found transport and housing energies elasticities of respectively -0.5 and -0.11 on time series data. Using BdF 2005 Clerc and Marcus (2009) [6] found a higher elasticity of -0.7 for transport fuels, but did not found any reliable result for housing energies. On panel data, Bureau (2011) [5] finds a more conservative estimate of a short-term elasticity of -0.22 for transport fuels. From BdF 2001, Ruiz and Trannoy (2008) [34] found uncompensated

[9] For a meta-analysis of common estimates in the literature, see Espey (1996) [14] for transports and Espey-Espey (2004) [13] for electricity.

price elasticities of -0.55 and -0.38 for transport and housing expenditures, although they did not focus on energy only. Finally, on BdF 2011 and through the computation of Engel curves, Berry (2017) [3] found -0.19 for transports and -0.36 for housing energies. I believe the techniques employed in this work, and the use of the last three surveys for more price variations in the sample enable to offer accurate results. This brings new evidences that households react to energy prices in the short run, although the adjustment in consumption is somewhat limited for housing energies.

Table I: Elasticities from the QUAIDS

	(1)	(2)	(3)	(4)
SL price index	yes	yes	no	no
Instrument expenditures	yes	no	yes	no
elas. unc. transport	-0.47 [-0.51;-0.42]	-0.49 [-0.62;-0.36]	-0.44 [-0.57;-0.31]	-0.47 [-0.60;-0.34]
elas. unc. housing	-0.21 [-0.27;-0.16]	-0.21 [-0.26;-0.15]	-0.14 [-0.24;-0.04]	-0.17 [-0.27;-0.07]
elas. unc. other	-1.03 [-1.04;-1.01]	-1.03 [-1.04;-1.01]	-0.97 [-1.01;-0.92]	-0.97 [-1.01;-0.92]
elas. exp. transport	0.48 [0.44;0.53]	0.54 [0.52;0.56]	0.46 [0.41;0.50]	0.52 [0.51;0.54]
elas. exp. housing	0.58 [0.53;0.63]	0.47 [0.45;0.49]	0.56 [0.51;0.61]	0.47 [0.44;0.48]
elas. exp. other	1.07 [1.06;1.07]	1.07 [1.07;1.07]	1.07 [1.07;1.07]	1.07 [1.07;1.07]

Note: the 95% confidence intervals are given in brackets. Elasticities are calculated at the sample mean of each variable.

To allow for heterogeneity in households responses to taxes, I also compute elasticities conditional on certain characteristics. In particular, I define fifty categories based on income

(10 income deciles) and city size (5 levels). Uncompensated price elasticities for transport and housing energies are given for all these groups in table II. Overall, it appears that for both types of energies, elasticities are (in absolute value) decreasing with income, and lower for more urban households[10]. On the income dimension, the results are consistent with the findings of Tavor Reanos and Wölfing (2018) [33] on housing energies. With respect to city size, they are consistent with Labandeira and co-authors (2006) [20] for transports but not for housing for which they found more elastic demand for urban households. The intuition behind the present results is that, for lower income and less urban households, energy represents a higher budget share, hence a stronger response to price increases in order to soften their budget constraint.

From the previous result follows an important implication: by reacting more strongly to prices, low-income and less urban households will soften the monetary impact of the policy through a higher adjustment in consumption. As a result, the welfare cost of the policy for these households will also come from a higher privation in energy consumption. If some of them are already at the edge of their basic energy needs, their decrease in consumption could have critical welfare implications that will not appear in the monetary effects. This should be kept in mind as restricting attention to monetary effects will lead to understate the impact on those who reacted more strongly to prices.

[10]For Paris, the price elasticity for housing energies is even expected to be positive for the 8 richest income groups. This last result is likely due to the imprecision of the estimation for small categories. For the consistency of the micro-simulation analysis I therefore impose an *ex post* zero upper-bound for uncompensated price elasticities. This constraint does not introduce large effects in the results. If anything, it will give more conservative results by lowering the heterogeneity in gains and losses.

Table II: Transports and housing energy price elasticities by group

	Rural	**Small cities**	**Medium cities**	**Large cities**	**Paris**
1^{st} **decile**	(-0.54/-0.43)	(-0.55/-0.39)	(-0.58/-0.37)	(-0.55/-0.21)	(-0.49/-0.01)
2^{nd} **decile**	(-0.54/-0.43)	(-0.54/-0.37)	(-0.56/-0.34)	(-0.54/-0.21)	(-0.45/-0.01)
3^{rd} **decile**	(-0.52/-0.39)	(-0.53/-0.35)	(-0.56/-0.32)	(-0.51/-0.16)	(-0.47/0.07)
4^{th} **decile**	(-0.52/-0.37)	(-0.51/-0.34)	(-0.53/-0.29)	(-0.50/-0.13)	(-0.44/0.04)
5^{th} **decile**	(-0.51/-0.35)	(-0.50/-0.33)	(-0.54/-0.28)	(-0.47/-0.10)	(-0.42/0.06)
6^{th} **decile**	(-0.49/-0.32)	(-0.50/-0.29)	(-0.51/-0.26)	(-0.47/-0.08)	(-0.36/0.14)
7^{th} **decile**	(-0.48/-0.29)	(-0.46/-0.25)	(-0.48/-0.23)	(-0.44/-0.04)	(-0.41/0.14)
8^{th} **decile**	(-0.45/-0.27)	(-0.44/-0.22)	(-0.46/-0.23)	(-0.42/-0.02)	(-0.34/0.22)
9^{th} **decile**	(-0.45/-0.26)	(-0.42/-0.20)	(-0.44/-0.19)	(-0.36/0.05)	(-0.29/0.32)
10^{th} **decile**	(-0.38/-0.28)	(-0.37/-0.20)	(-0.37/-0.19)	(-0.30/0.08)	(-0.17/0.38)

LECTURE: Households belonging to the 1^{st} income decile and living in a rural area have transports and housing energy price elasticities of respectively -0.54 and -0.43.

4 Environmental and distributive effects of energy taxes

This section and the following are the core of this article. Taking 2016 as the reference year, I study the effects of turning to the 2018 legislation. This includes a higher price on carbon for all energies (44.6€ per ton of CO_2 against 22€ in 2016) except electricity, and an additional increase for diesel (2.6€ per hectolitre) with the aim to progressively catch up with the higher rate currently imposed on gasoline[11]. I first consider the environmental effects and then turn to distributive issues.

4.1 The effects on greenhouse gas emissions

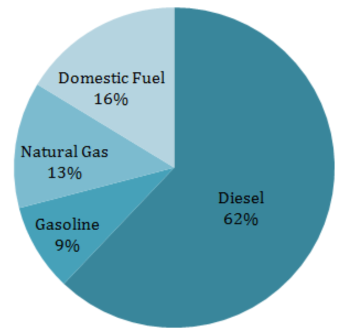
The primary objective of the policy is to reduce the negative environmental impacts of energy consumption. I therefore start by evaluating the extent to which it could contribute to reduce

[11] To give an idea, the carbon tax should increase the price on domestic fuel from 0.706€ to 0.779€ per litre, excluding the indirect effect on VAT. For diesel, together with the additional adjustment tax, the price is expected to increase from 1.11€ to 1.19€.

greenhouse gas (GhG) emissions. For each energy, I apply the elasticities obtained with the QUAIDS to determine how quantities are expected to change after the policy, and infer the impact on emissions. Figure 3 summarizes the effect by energy.

Figure 3: Annual reduction in GhG emissions by energy, in thousands of tons of CO_2e

Energy	CO_2**e emissions**
Diesel	1,893
Gasoline	270
Natural Gas	389
Domestic fuel	497
Total transports	2,164
Total housing	886
Total energies	3,049



LECTURE: Following the policy and holding technology constant, annual GhG emissions from diesel are expected to decrease by 1,893 thousands of tons of CO_2e. It corresponds to 62% of the reductions expected from all energies.

The policy is expected to reduce GhG emissions by more than 3 millions of tons of CO_2 equivalent (CO_2e), that is slightly less than 0.7% of French annual emissions, and around 1.5% of emissions due to transport and residential sectors[12]. By comparison, between 1990 and 2013 total French emissions have decreased by about 0.5% per year but have increased at this same rate for transports and housing. Abstracting from efficiency gains due to higher incentives to invest in low-consumption technologies, the expected environmental impact of the policy is therefore rather limited. Interestingly, despite the larger budget share of housing energies compared to transport fuels, only 29% of the emissions saved are expected to come from this sector. This result reflects not only their lower average carbon content, but also their lower price elasticity. It raises the concern that the price-signal could be insufficient to significantly reduce emissions in this sector. Whether other mechanisms such as fiscal

[12] 451 Mt equivalent CO_2 in 2016. Source: Citepa, SECTEN report

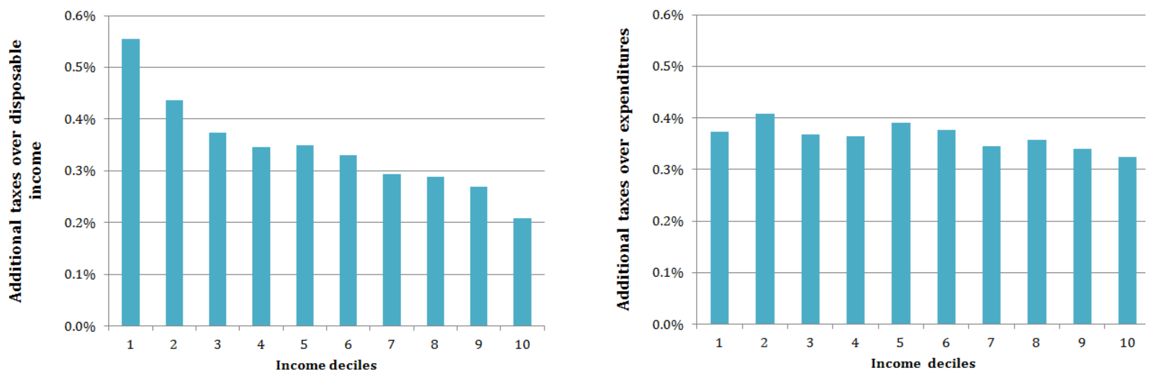
incentives to improve homes' energy efficiency would be more cost-effective is uncertain. Housing energy prices being little salient to consumers, their effect may simply be delayed and more effective in the long run.

4.2 Monetary effects between income groups

Besides the welfare costs due to a reduced consumption, energy taxes will also affect welfare through distributive monetary effects. On this respect, the most common fear - largely discussed in the literature - is that energy taxes might be regressive (e.g. Poterba (1991) [30], Metcalf (1999) [24], Grainger and Kolstad (2010) [16]). This regressivity could be detrimental for the acceptability of such schemes and be a major deterrent for policies that would aim at curbing polluting emissions. Thus, when designing fiscal policies, this needs to be taken into account by policy makers.

In the case of the French policy, considering effort rates on the new tax prior to revenue-recycling, we can indeed observe a decreasing pattern as illustrated by figure 4. However, this holds only when considering disposable income as the denominator (left). When using total expenditures instead (right), the pattern is rather flat. These results confirm the general finding that energy taxes are regressive with respect to income, but almost not when using total expenditures as a measure of lifetime income. Which of these two measures is most relevant is subject to debate. The trade-off between these methods has originally been discussed by Poterba (1989) [29] and Metcalf (1999) [24] who argued, following the permanent income hypothesis, that lifetime income is better reflected by the expenditures approach. A recent OECD paper (2015) [15] discusses the trade-off for carbon taxes in 21 OECD countries. It also argues in favour of the expenditures approach since in particular for students, selfemployed and retired people, borrowings and savings create a large discrepancy between their income and their standards of living. Overall, one can consider these two approach as complementary. If these figures point towards the regressivity of the carbon tax, the magnitude of the phenomenon appears less important than what is often assumed.

Figure 4: Average effort rate on the policy, by income decile



LECTURE: For households belonging to the $1^{s}t$ income decile, the increase in energy taxes following the policy will represent 0.55% of their disposable income, against 0.21% for those in the last income decile. As a share of their total expenditures, it represents respectively around 0.37% and 0.32%.

To compensate the regressivity of energy taxes, the French government used to grant social tariffs on energies to allow for a discount on energy bills for low-income consumers. In 2018, these tariffs have been replaced by energy cheques directed towards low-income households on the basis of their size and fiscal income. These cheques can exclusively be used to pay energy bills or renovation works to improve the accommodation's energy efficiency. The distributive effects of this new compensation mechanism will critically depend on the evolution of the take-up rate, yet unknown. However, assuming an identical take-up rate for both mechanisms I find that energy cheques simply compensate for the loss of social tariffs.

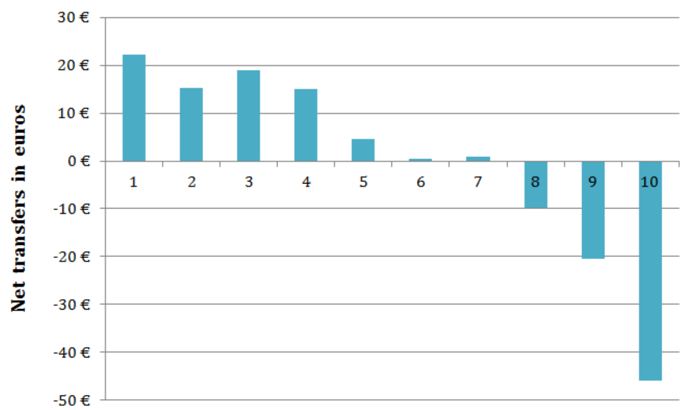
The energy cheques are meant to be a compensation mechanism for low income households. However, they currently represent a very low share of the tax revenue[13]. Given that the policy generates a large excess revenue, it leaves room for additional revenue-recycling mechanisms. As many studies have shown, recycling the revenue of the tax through lump-sum transfers directed towards consumers can turn regressive taxes into progressive fiscal policies (e.g. West and Williams (2004) [36], Bento et al (2009) [2], Bureau (2011) [5], Williams et al (2015) [37]). In the following of the article, I simulate a budget-neutral policy where the excess revenue - i.e. what remains after the official compensation scheme - is equally transferred across households in proportion of their number of consumption units. In this situation - referred to as "flat-recycling" - we obtain a progressive policy as illustrated by figure 5. The net transfers following the policy are then positive for the first five income deciles, around zero for the sixth and seventh, and negative for the last three. This is in accordance with previous studies and confirms that regressivity is not an issue as long as the revenue can be returned to households. Beyond this general finding and looking specifically at the French policy, one should keep in mind that this result holds under the assumption of an equal split of the policy revenue. As shown by several studies (e.g. Dinan (2012) [10], Williams et al. (2015) [37]), if the government seeks for a double dividend and uses this revenue to lower labour or capital taxes instead, the pattern could be different.

4.3 Monetary effects within income groups

While there exists an extensive literature on vertical equity issues related to environmental taxes, the literature looking at horizontal distributive effects - i.e. distributive effects between

[13] From the model I find an annual revenue for the increase in tax of 4,101 millions of euros. Energy cheques should cost 354 millions of euros for the same period, that is 8.6% of the total.

Figure 5: Average net transfers per c.u. after flat-recycling, by income decile

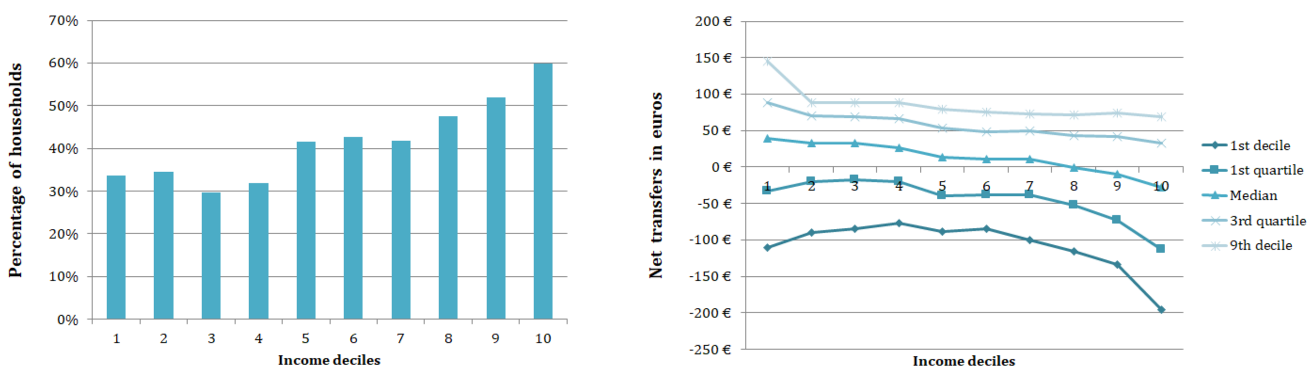


LECTURE: On average, households belonging to the 1^st income decile will receive an annual net transfer of 22€ after flat-recycling, against -46€ for those in the last income decile.

individuals with equivalent income - is still scarce, although growing. In its 1991 paper Poterba [30] first highlighted the disparities in gasoline consumption among households with similar income. More recent contributions such as Rausch et al. (2011) [31], Pizer and sexton (2017) [27] and Cronin et al (2017) [8] have shown that horizontal distributive effects could in fact be of higher magnitude than vertical ones. Although there is a debate about the normative implications of horizontal equity (see Musgrave (1990) [25], Kaplow (2000) [19]), one must still recognize that these effects are perceived as negative by society and could dampen the acceptability of environmental taxes. Also, if we assume that the pre-existing distribution of resources is optimal given available fiscal instruments, policy makers should seek to minimize any distributive effects, including between households with similar incomes.

To investigate horizontal distributive effects, I first look at the share of households financially losing from the policy within income groups, after flat-recycling. Although the policy is progressive in this case, figure 6 (left) shows that within the three first income deciles we can expect around a third of households to receive negative net transfers. This proportion tends to increase with income, but not sharply. Almost half of the households in the ninth decile are expected to receive positive net transfers, and for the top decile they are still 40%. This is confirmed by the analysis of the within income group distribution of net transfers. We can see on figure 6 (right) that within the first income group, if 25% of households are expected to earn annually more than 87€ per consumption unit from the policy, they are also 25% expected to lose more than 32€. The gap between the first and third quartile of net transfers within this income group is therefore much higher than the gap in average net transfers between the first and last income deciles. In the first income decile, 25% of households lose more than the median household in the top income group. Finally, considering for all income groups the bottom of the distribution in net transfers, and in particular the 10^{th} percentile, the decreasing trend is not clear anymore and expected losses among the lowest income groups are as important as for any other group except the two last income deciles.

Figure 6: Share of households financially losing from the reform (left), and distribution of net transfers per c.u. (right), by income decile



LECTURE: After flat-recycling, 34% of households belonging to the first income decile are expected to receive negative net transfers from the policy (left), including 25% losing more than 32€ per consumption unit (right).

To sum up, these figures clearly show that horizontal heterogeneity is in magnitude more important than the vertical one. This finding may explain the surge of the debate around fuel poverty in European countries. Once we recognize households differ in numerous dimensions other than income, we may indeed look for a new way to characterize those most exposed to energy taxes. I believe the concept as currently defined and measured is little relevant since it gathers very different aspects of vulnerability that require different policy treatments. But the importance it has taken in the public debate clearly indicates that more research is needed to understand the heterogeneity of households with respect to energy consumption beyond the sole focus on income. It is only by recognizing the multi-dimensionality of the issue that we will be able to find proper solutions to the lack of acceptability of environmental taxes.

5 Multidimensional distributive effects

5.1 The determinants of within-income groups distributive effects

From the preceding analysis, one can wonder whether we can identify specific determinants that would explain the heterogeneity of the tax incidence, and that could then be accounted for in the policy design. Cronin et al (2017) [8] stress the importance of the income composition but do not have information on other relevant households characteristics. Bento et al (2009) [2] and Rausch et al (2011) [31] both point towards the heterogeneous impacts of a carbon tax across regions, as well as differences across racial and ethnic groups. However, they do not explain the determinants of these differences. As pointed out by Pizer and Sexton (2017) [27], other important drivers including housing and commute characteristics could play a major role, and are not considered in these papers.

In order to identify the determinants of the horizontal heterogeneity of the tax incidence, I regress the net transfers per consumption unit received by households after revenue-recycling on many characteristics. This approach is very agnostic as it enables, without any *a priori*, to identify the role played by all these dimensions holding the others constant. Because one can expect these results to depend critically on elasticities, I estimate three different specifications including (1) the heterogeneous elasticities used above, (2) homogeneous elasticities, and (3) and no elasticities. A fourth specification (4) estimates the net transfers for an hypothetical reform where electricity would be subject to the same increase in the carbon tax as other energies. The results are reported in table III below. Overall, they are all similar although the third specification exacerbates the distributive effects since households are expected not to adjust their consumption when prices increase.

Holding everything else constant, we see that on average a higher income implies lower net transfers. The relationship is slightly convex but the quadratic term is of little magnitude, so that for most of the income distribution the effect on net transfers is close to be linear. The impact of heating with domestic fuel and natural gas relative to electricity are negative, and strongly significant both economically and statistically. Households using these energies are expected to lose more than 70€ per consumption unit relative to other households. Interestingly, given the law carbon content of electricity in France, the result is robust to the inclusion of this energy in the policy: in that situation the effect only go down to around 60€. The burden on these households is therefore not explained by the exclusion of electricity from the policy. It should also be noted that the effect on households using domestic fuel is softened by the switch from social tariffs - that did not applied to fuel - to energy cheques that are not conditional on the energy used. On the geographical dimension, we see that living

Table III: Regression of net transfers per consumption unit after revenue recycling on several households' characteristics

	(1)	(2)	(3)	(4)
R^2	0.308	0.308	0.291	0.301
N	10,342	10,342	10,342	10,342
Elasticities	yes	yes	no	yes
Heterogeneous	yes	no	no	yes
Electricity taxed	no	no	no	yes
Intercept	−6.452	−9.420	−12.67	−3.014
	(8.145)	(8.049)	(9.302)	(7.408)
Disposable income	-4.174 e-04***	-3.136 e-04***	-3.927e-04***	-4.051e-04***
	(3.714e-05)	(3.671e-05)	(4.242e-05)	(3.38e-05)
Disposable inc. sqr.	2.004e-10***	1.507e-10***	1.878e-10***	1.755e-10***
	(2.58e-11)	(2.55e-11)	(2.95e-11)	(2.35e-11)
Domestic fuel	−70.56***	−71.82***	−77.38***	−56.58***
	(2.220)	(2.194)	(2.535)	(2.019)
Natural gas	−76.33***	−75.65***	−79.85***	−61.59***
	(1.719)	(1.699)	(1.964)	(1.564)
Rural	−7.055**	−9.218***	−13.11***	−8.279***
	(2.518)	(2.488)	(2.875)	(2.290)
Small cities	2.238	1.155	1.512	1.290
	(2.624)	(2.593)	(2.997)	(2.386)
Large cities	2.509	4.932*	6.255*	1.873
	(2.288)	(2.261)	(2.613)	(2.081)
Paris	15.86***	20.37***	26.65***	14.28***
	(2.835)	(2.802)	(3.238)	(2.579)
West/south	3.531*	4.046*	3.749*	3.443*
	(1.655)	(1.635)	(1.890)	(1.505)
Double glazing	11.11***	11.17***	11.82***	9.799***
	(2.090)	(2.066)	(2.388)	(1.901)
Bad walls isolation	2.519	2.292	3.196	3.231
	(2.707)	(2.676)	(3.092)	(2.462)
Good walls isolation	2.739	2.742	2.757	2.927
	(1.747)	(1.726)	(1.995)	(1.588)
Building before 1949	−1.263	−1.269	0.8527	0.8983
	(1.886)	(1.864)	(2.154)	(1.716)
Building 1949/74	−1.386	−1.406	−0.3370	1.106
	(1.913)	(1.891)	(2.185)	(1.740)
Individual housing	−16.18***	−15.37***	−17.54***	−17.79***
	(2.190)	(2.165)	(2.501)	(1.992)
Owner	−6.228**	−6.377**	−8.770***	−6.327***
	(2.080)	(2.056)	(2.376)	(1.892)
Living area (m^2)	−0.2984***	−0.2950***	−0.3254***	−0.3051***
	(0.021)	(0.021)	(0.025)	(0.020)
Housing benefits	5.941*	6.208*	9.491***	4.904*
	(2.466)	(2.437)	(2.817)	(2.243)
Nb. consumption units	43.89***	41.12***	48.69***	43.31***
	(1.968)	(1.944)	(2.247)	(1.789)
Mono-parental	−0.3961	−1.012	0.4766	−1.839
	(2.934)	(2.899)	(3.351)	(2.668)
Nb. in labor force	−0.8042	−0.6518	−1.608	−0.1475
	(1.332)	(1.316)	(1.521)	(1.211)
Student	53.46***	53.23***	60.54***	55.72***
	(6.256)	(6.183)	(7.145)	(5.690)
Age	0.3584	0.4032	0.2064	0.0880
	(0.291)	(0.288)	(0.333)	(0.265)
Age sqr.	0.0024	0.0020	0.0062*	0.0037
	(0.003)	(0.003)	(0.003)	(0.002)
Vehicle age	−0.4494***	−0.4626***	−0.6299***	−0.4321***
	(0.114)	(0.113)	(0.131)	(0.104)
Share distance to work	0.3130	0.3120	0.4047*	0.2718
	(0.161)	(0.159)	(0.184)	(0.147)

* 0.05   ** 0.01   *** 0.001

in rural areas or smaller cities has a negative impact, while living in Paris largely increases expected transfers (+15€ relative to medium size cities in specification (1)). Looking at climatic regions, we also see that everything else equal, households living in the south or west of France are expected to slightly gain (+3.5€). Yet, contrary to what might have been expected given the spatial heterogeneity of temperatures especially during winters, the impact is rather small. The distributive effects of energy taxation between regions with different climates seems therefore limited and should not bear large political implications. Other interesting effects to notice are the very large gains of students (+53€ on average), and the expected losses for owners (-6€), and people living in individual (-16€) and larger accommodations (-0.30 € per square meter). With respect to energy efficiency, one can notice the negative and strongly significant effect of vehicle age. In housing, having a majority of double glazing is expected to increase transfers significantly (+11€) but for walls isolation I do not find any significant impact. The same can be said of the building's age, where the dummies, although chosen to capture years with important changes in isolation norms, have no significant effect on expected transfers. With respect to family composition, having a larger household has a strong positive effect (+44€ per consumption unit) which might be explained by the sharing of many energy expenditures such as heating, in particular once we control for the accommodation's size. Although we observed in section 2 a clear link between age and energy consumption, once we control for other households demographics the relationship is not statistically significant. Interestingly the number of households' members in the labour force has no significant effect, but the share of travels in private vehicles to the workplace has an expected positive impact, although not always significant at the 0.05 level. If working further from his home has an obvious negative effect on transfers, as a share of the total distance travelled this effect is reversed: having on average more constrained travels does not create a higher exposure to energy taxes. Lastly, one can notice that although many characteristics are identified as significant drivers of the tax incidence, unobserved heterogeneity still plays a major role. In all specifications, the R-square is around 0.3, leaving a large part of unexplained variations. This result suggests that designing policies to solve horizontal distributive effects could be a difficult task.

5.2 Alternative revenue-recycling strategies

To test this last hypothesis, I evaluate three alternative revenue-recycling mechanisms. The details of these schemes are given in appendix, but they basically correspond to 1) an additional transfer to rural household, 2) an additional transfer to households heating with domestic fuel or natural gas, 3) both additional transfers. In each of these scenarios the official energy cheques are lowered such that total transfers to low-income households (i.e. those eligible to the official compensation scheme) stay the same. The excess revenue and the flat-transfers that follow are therefore unchanged. I restrict my attention to these dimensions because they are among the most important determinants identified in the data, are very present in the public debate, and are supposed to be observable by the State, although this observation might be costly. Table IV shows for each scenario the interquartile range in net transfers for the first three income deciles. Relative to the official revenue-recycling mechanism, we see that cheques targeted to rural households do not enable to reduce the spread. The result is robust to higher values of targeted transfers. Because the geographic location is a poor proxy for the tax incidence, it follows that targeted transfers based on this criterion do not improve horizontal equity. If these cheques enhance the situation of rural households, it is at the expense of other very exposed ones. When targeted according to the heating mode, these cheques outperform the official ones for the first income group but do not make any difference for the second and third. We thus see that these mechanisms have the potential to slightly soften horizontal distributive issues, but their effect remains limited.

Table IV: Interquartile range in net transfers per consumption units

	1^{st} **decile**	2^{nd} **decile**	3^{rd} **decile**
Official	120.7€	90.3€	85.9€
Rural	120.4€	90.6€	86.2€
By energy	104.7€	88.0€	85.0€
Rural + By energy	104.6€	88.4€	85.2€

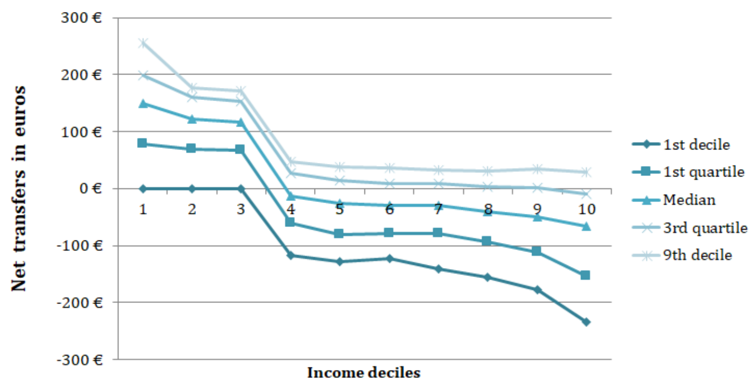
LECTURE: When revenue-recycling is partly targeted to rural households, the interquartile range in net transfers among households in the 1^st income decile is expected to be 120.4€ per consumption unit.

By indexing these cheques on many other dimensions, one could hope to target more precisely the most vulnerable households and thus reduce the policy's distributive effects. However, because households' heterogeneity is largely unobservable by the State, this strategy offers little promises. As shown by the third alternative - Rural + By energy - combining targeted transfers does not necessarily improve the results. Also, even if it has the potential to somewhat reduce distributive effects, the benefits of this mechanism should be weighted against its costs. As these transfers would introduce incentives not to switch technologies for households polluting more, it would reduce the environmental benefits of the policy. This problem could be partly solved by phasing-out these specific transfers through time - assuming people are constraint on their heating technology only in the medium run. Nonetheless, one needs to also consider that distributing cheques specifically to households using more carbon intensive energies could be perceived as unfair. As mentioned earlier, the normative aspects of horizontal equity are ambiguous. Whether people are more concerned about the equity of the policy outcome or of the policy itself is not straightforward.

An alternative solution to the previous transfers could be to subsidize energy-efficiency improvements. Such policy could again target low-income households with high carbon emissions. This would help them reduce their emissions and energy budget, and as such we could expect in the medium/long run improvements with respect to both pollution and distributive issues. Unfortunately, given the difficulty to estimate the effects of such policy on the energy transition with survey data, I could not evaluate this mechanism. Further work would be needed to assess the cost-effectiveness of such policy and the actual distributive impact on households, both in the short and long run. In particular, because the renovation of accommodations could take time, it is very likely that in the short-run many low-income households would still lose. Given the difficulty to precisely target households on other criteria than their income, another possibility in the short-run would therefore be to offer more generous compensations to all low-income households. Figure 7 depicts a mechanism defined such that no more than 10% of households lose in the first three income deciles. As we can see, such transfers would imply a larger distortion between income groups with in particular substantial losses born by medium-income households.

Overall, these evidences suggest than when accounting for horizontal heterogeneity, the policy solutions to the distributional impacts of environmental taxes are by far less obvious. If not everybody can financially win from these policies, it is at the end a matter of political choice to decide how to split the burden between different income groups.

Figure 7: Distribution of net transfers per c.u. after additional transfers to low-income households, by income decile



Lecture: When additional transfers are targeted towards low-income households to ensure no more than 10% of losers, 25% of households in the fourth income decile are expected to lose more than 60€ in net transfers per consumption unit due to the policy.

6 Conclusions

Through the *ex ante* micro-simulation of a French policy of energy taxes, I have shown that these taxes were regressive with respect to disposable income, and almost flat with respect to total expenditures. The small scale compensation mechanism proposed by the French government should not change this picture. However, returning the revenue left through homogeneous lump-sum transfers would make the policy progressive. Yet, even in this situation the policy's acceptability could be dampened by horizontal distributive effects that are in magnitude much larger than vertical ones. I investigated the determinants of the tax incidence and simulated alternative transfers targeted towards the losers from the policy. If such mechanisms could somewhat lower distributive issues, their effect would be limited and should be weighted against their costs. In the long run, energy efficiency improvements seem necessary to reduce both emissions and distributive effects.

A good understanding of the distributive issues associated with environmental taxes is essential. The French government has announced an ambitious trajectory for the carbon price that should reach 86.2€ by 2022 and then keep growing to even higher rates. This ambition is with no doubt good news given the urgent need to take actions against climate change and other environmental issues. However, the present paper raises two threats that should attract our attention. One is the equity cost that the policy could generate if sufficient efforts are not undertaken to protect the most fragile households. The second is the risk that these distributive issues generate an important social pressure and lead the government to step back from its ambitious environmental targets.

Although this study focused on a specific policy, I believe the results are more general. The policy considered is close to a textbook corrective environmental tax with lump-sum rebates, and energy consumption patterns in France are very comparable to other OECD countries. Also, if the French carbon tax does not apply to electricity, we saw that the results are robust to its inclusion. It would nonetheless be interesting to replicate this study to other countries, in particular where electricity is more carbon intensive and could generate further distributional concerns.

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Appendices

A The Quadratic Almost Ideal Demand System

The QUAIDS starts from a quite general specification on the form of the indirect utility function:

$$\ln V(\mathbf{p}, m) = \left[\left\{ \frac{\ln m - \ln a(\mathbf{p})}{b(\mathbf{p})} \right\}^{-1} + \lambda(\mathbf{p}) \right]^{-1} \tag{3}$$

where $\ln a(\mathbf{p})$ is the transcendental logarithm function that can be written

$$\ln a(\mathbf{p}) = \alpha_0 + \sum_{i=1}^{k} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \gamma_{ij} \ln p_i \ln p_k \tag{4}$$

with p_i the price of the bundle of goods i. $b(\mathbf{p})$ is a Cobb-Douglas price aggregator that takes the form

$$b(\mathbf{p}) = \prod_{i=1}^{k} p_i^{\beta_i}$$

and

$$\lambda(\mathbf{p}) = \sum_{i=1}^{k} \lambda_i \ln p_i, \qquad \text{where} \quad \sum_{i=1}^{k} \lambda_i = 0$$

All the parameters of the model can be estimated except for α_0 in the translog price index. This parameter must therefore be set arbitrarily. I follow Deaton and Muellbauer (1980b) [9] who recommend to take the value of the minimal standards of living in the sample. Finally, economic theory requires a certain number of constraints to hold on the value of the parameters: the following restrictions are implied for the two-firsts by adding-up (to make sure $\sum_i w_i \equiv 1$), the third by homogeneity, and the last by Slutsky symmetry:

$$\sum_{i=1}^{k} \alpha_i = 1, \quad \sum_{i=1}^{k} \beta_i = 0, \quad \sum_{j=1}^{k} \gamma_{ij} = 0, \quad \text{and} \quad \gamma_{ij} = \gamma_{ji}$$

Now, if we take q_i the quantity of good i consumed, $p_i q_i$ is the expenditure for good i, then $w_i = (p_i q_i)/m$ is the share of the total expenditure associated to the consumption of good i. Then, using Roy's identity we can derive:

$$w_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \beta_i \ln \left\{ \frac{m}{a(\mathbf{p})} \right\} + \frac{\lambda_i}{b(\mathbf{p})} \left[\ln \left\{ \frac{m}{a(\mathbf{p})} \right\} \right]^2, \quad i = 1, ..., k \tag{5}$$

The aim of the QUAIDS is to estimate this equation for all goods i. The estimates obtained for the parameters enable to compute the income and price elasticities with respect to each bundle of goods. Indeed, if we differentiate the share equations with respect to the log of expenditures, we get:

$$\mu_i \equiv \frac{\partial w_i}{\partial \ln m} = \frac{\partial w_i}{\partial m} m = -w_i + w_i \frac{m}{q_i} \frac{\partial q_i}{\partial m} = \beta_i + \frac{2\lambda_i}{b(\mathbf{p})} \left[\ln \left\{ \frac{m}{a(\mathbf{p})} \right\} \right] \tag{6}$$

from which we can identify the budget elasticity of good i:

$$e_i = \frac{\partial q_i}{\partial m} \frac{m}{q_i} = 1 + \frac{\mu_i}{w_i} \tag{7}$$

Similarly, if we differentiate the share equations with respect to the price of the same good, we get:

$$\mu_{ii} \equiv \frac{\partial w_i}{\partial \text{ln}p_i} = w_i(1+e^u_{ii}) = \gamma_{ii} - \mu_i \left(\alpha_i + \sum_k \gamma_{ik}\text{ln}p_k\right) - \frac{\lambda_i \beta_i}{b(\mathbf{p})}\left[\text{ln}\left\{\frac{m}{a(\mathbf{p})}\right\}\right]^2 \tag{8}$$

since $\partial\text{ln}a(\mathbf{p})/\partial\text{ln}p_i = \alpha_i + \sum_k \gamma_{ik}\text{ln}p_k$ and $\partial b(\mathbf{p})/\partial\text{ln}p_i = \beta_i b(\mathbf{p})$. Thus the uncompensated price elasticity of good i is:

$$e^u_{ii} = \frac{\mu_{ii}}{w_i} - 1 \tag{9}$$

Estimation is performed using the Stata package *aidsills* introduced by Lecocq and Robin (2015) [21]. It uses iterated linear least-squares (ILLS) and provides elasticities at the mean of each variables, together with their standard errors. This method was chosen over the command *quaids* (see Poi (2012) [28]) because the latter does not provide standard errors, and does not enable to instrument expenditures.

B The official policy

In this paper I study the effects of turning to the 2018 legislation for energy taxes, compared to the reference situation of 2016. The policy studied implies therefore the following evolutions: 1) An increase in the price of CO_2 that goes from 22€ to 44.6€ per ton. 2) An additional 0.026€ per litre increase in the diesel tax to eventually catch-up with the gasoline tax. 3) Energy cheques transferred towards low-income households, based on their fiscal income and their size. These cheques replace the previous social tariffs on electricity and gas. All the previously mentioned changes are taken into account in the model. In addition, the policy will enlarge the "Crédit d'impôt pour la transition énergétique" (Cite) whose aim is to help people finance energy efficiency improvements in their accommodation, and a scrapping premium to improve the energy efficiency of the vehicle fleet. These last changes are not modelled in TAXIPP.

C Alternative scenarios for revenue-recycling

In the paper, I present the results for three alternative revenue-recycling policies. From regressions, I obtain that everything else equal, being a rural household is expected to increase on average households' net contributions to the tax by 10€ per consumption unit relative to non-rural households, while heating with domestic fuel and natural gas would increase it by slightly more than 70€ compared to households using other energies. I therefore design a first scenario called "Rural" where rural households *already eligible to the official cheques* receive an additional 10€ cheque per consumption unit. A second scenario called "By energy" where eligible households heating with fuel or gas receive an additional 70€ cheque per consumption unit. A third scenario in which both additional transfers are included. For all these alternatives, the initial energy cheques based on income and households' size are decreased such that the total cost of the policy stays the same.