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 flat-recycling. However, it would still generate large horizontal distributive effects and harm a significant 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; Carbon tax; Distributional effects; Demand system; Micro-simulation

*Acknowledgments: I want to thank Fanny Henriet and Katheline Schubert for their comments. I am also very grateful to Mahdi Ben Jelloul, Antoine Bozio, Stéphane Gauthier, participants at several seminars and conferences, and anonymous referees of this journal.

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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, public support for carbon pricing remains low, as showcased by the recent protests against the carbon tax rise in France. Initiated in 2014 at 7€/tCO_2, the French carbon tax was planned to gradually increase in order to reach 86.2€/tCO_2 in 2022, and even higher levels in a near future. In November 2018, in a context of high oil prices, the protests of the Yellow Vests against the tax led to the abandonment of the increases initially scheduled. Since, the tax has remained at its 2018 level, 44.6€/tCO_2. Similarly, the additional increases initially planned for the diesel tax have been abandoned. As of today, the future of the French carbon tax remains deeply uncertain. The negative impact of the tax on households' purchasing power was certainly what contributed the most to public discontent. In particular, Yellow Vests appeared concerned with the disproportionate burden that taxes on energies could impose on low income households, and more specifically on those most dependent on fossil fuels such as rural and peri-urban households.

The objective of this paper is to precisely characterize and quantify the distributive effects of French energy taxes. Based on TAXIPP, a micro-simulation model of taxation for French households (see Appendix B for a description of the model), I evaluate French fiscal policy on energies between 2016 and 2018, i.e. the last evolution before the emergence of the protests. The policy essentially involved an increase in the carbon price on all energies except electricity — which was already subject to the European Union Emissions Trading Scheme. While numerous studies have already assessed the *vertical* distributive effects of energy taxes — i.e. distributive effects between households along the income dimension — this paper contributes to the literature by investigating their *horizontal* distributive effects — i.e. between households with similar incomes. In particular, it shows that while low-income households may on average gain from an environmental tax after revenue-recycling, some of them could suffer large losses. This result echoes concerns raised by the Yellow Vests that carbon taxation may have a disproportionate impact on certain categories of households, such as rural and peri-urban households, but not necessarily all poor people. Understanding and quantifying these phenomena is key to a better design for these policies, and thus to improve both the fairness and support for ambitious environmental policies.

Several papers have investigated the distributive effects of energy taxes in France (e.g. Ruiz & Trannoy, 2008; Bureau, 2011; Berry, 2019). Yet, partly due to the lack of a comprehensive database, few works have jointly covered housing and transport, and existing studies all focus on vertical equity. To investigate these issues together, I created a novel dataset by matching the French transport survey (ENTD) and the consumer expenditures survey ("Budget de Famille", BdF). Using this new dataset, I micro-simulate fiscal policy on energies between 2016 and 2018. Given the relatively small scale of the tax, the use of micro-simulation is relevant as general equilibrium effects should play a limited role. As argued by Bourguignon & Spadaro (2006), these models are the best fit for a precise investigation of the distributive effects of policy changes, as they fully take into account households' heterogeneity. The model accounts for behavioral responses through heterogeneous price and income elasticities estimated using a *Quadratic almost ideal demand system* (QUAIDS, see Banks et al., 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.

Elasticities are then translated into changes in quantities and greenhouse gas emissions. For a given technology, the short-run 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, whereby energy taxes are regressive when effort rates are computed as a function of disposable income (e.g. Poterba, 1991; Metcalf, 1999; Grainger & Kolstad, 2010), but are almost not when total expenditures are instead used to measure standards of living (see Poterba, 1989; Metcalf, 1999; Flues & Thomas, 2015). Also, I find that the compensation mechanism proposed by the government and targeted towards low-income households does not solve regressivity. However, recycling the revenue left after this mechanism through homogeneous lump-sum transfers — a mechanism known as flat-recycling (e.g. West & Williams, 2004; Bento et al., 2009; Bureau, 2011; Williams et al., 2015) — would make the policy progressive.

From the above conclusions, it might seem straightforward to improve the acceptability of energy taxes. However, in the recent literature authors have emphasized the importance of the horizontal distributive effects of these taxes, which could be a major deterrent against their implementation (Rausch et al., 2011; Pizer & Sexton, 2019; Cronin et al., 2019; Sallee, 2019). 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 out due to the policy. Additionally, 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 are expected to be much larger in magnitude within income groups than across income groups, and could dampen the policy's acceptability.

Important progress has recently been made by general equilibrium models to incorporate more heterogeneity in households' characteristics (e.g. Rausch et al., 2011; Rausch & Schwarz, 2016). Yet, it is still unclear what the drivers are of the heterogeneous incidence of energy taxes (Pizer & Sexton, 2019). The literature has mostly focused on geographical criteria, looking at the differentiated impact across regions, and has emphasized the role of income composition. Thanks to micro-simulation, I adopt a more agnostic approach to characterize the determinants of the tax incidence at the household level. Among many drivers, I show that the energy used and to a lesser extent the urban density of the household residence account for a large 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 urban density has no effect, while indexing them on the type of energy used for heating only slightly softens horizontal equity issues.

This paper contributes to several strands of the literature. First, it uses statistical matching to build the most comprehensive existing database to study energy taxation in France. Using these data, it also offers an extensive evaluation of the most recent 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 presents the data, and section 3 the estimation of households' elasticities with respect to their energy consumption. Section 4 evaluates the expected environmental effects of the policy and distributive effects between income groups. Section 5 discusses distributive effects within income groups and highlights the determinants of the tax incidence in order to propose alternative revenue-recycling mechanisms. Section 6 concludes. Technical elements are reported in the appendix, and an online appendix adds supplementary material to describe the matching of household surveys.

2 Data

2.1 The French household 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 represents respectively 27% and 12% of total emissions. Yet, most studies on French data have ignored one of these sectors. Bureau (2011) studies the distributional impacts of a carbon tax followed by lump-sum transfers, but focuses on transport fuels only. Using "Budget de Famille" (BdF) survey data, Nichèle & Robin (1995) cover both issues but they do not estimate elasticities specifically for energies, nor do they precisely detail the distributive effects of the tax. Closer to the present work, Berry (2019) investigates a previous increase in the carbon price on energies using the "Phebus" database. However, the smaller sample size and the limited quantity of information in this survey do not enable further exploration of the determinants of horizontal distributive effects.

In this paper, I use the latest version of the "Budget de Famille" (BdF, 2011) consumer survey. Because of its very large set of variables describing households, and because it gathers accurate information on all their expenditures,[1] BdF is the best database to study indirect taxation, and in particular energy taxes. It is also the only database through which a demand system can be estimated for French households. Consumption of housing energies is 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 carried out all year long. For the computation of the demand system, households are matched with monthly price indices from Insee (the French national statistical institute). More details on the data and the imputation of price indices are given in the model estimation appendix (section C).

2.2 Data to simulate the policy

Although very convenient to estimate a demand system, BdF presents one limitation when studying horizontal distributive effects. As transport fuel consumption is reported over a short period of time, the heterogeneity in consumption between households is over-estimated. This excessive variability disappears when average expenditures for household groups are studied, but is problematic when the distribution *within these groups* is addressed. To overcome this problem, I therefore use statistical matching to match each household in BdF to a household from the last transport survey, "Enquête Nationale Transports et Déplacement", (ENTD)[2] where annual distances travelled are reported. This enables me to recover the dis-

[1]The survey covers the consumption of all goods following the international nomenclature COICOP.
[2]This survey was conducted in 2008 on 20,178 households.

tribution of expenditures without over-estimating its dispersion. A high-quality matching is possible because BdF and ENTD are both quite large, both come from the French statistical institute (Insee), both study the same population, and they share a large number of common variables with identical definitions. More details on the matching procedure can be found in the online appendix.[3] The final dataset contains 10,342 observations.[4] Because the last BdF was conducted in 2011, I use national accounts to homogeneously inflate households' energy expenditures and incomes in order to make the data representative of 2016, the date from which the policy changes are studied. Table III in the appendix gives descriptive statistics for several variables and ten household groups corresponding to income deciles.[5]

3 Estimating households' responses to prices

3.1 The Quadratic almost ideal demand system

In order not to over-estimate the tax burden and the extent of regressivity of indirect taxation policies, one needs to take into account behavioral responses, that is, the effect of taxes on consumption choices (see West & Williams, 2004). I therefore estimate price and income elasticities on energy goods. These estimates will then be used to compute the reduction in consumption following the policy.

Since all household expenditures are reported in the BdF survey, this dataset can be used

[3]Matching is performed using the non-parametric NND hotdeck method. The procedure applied closely follows standard guidelines as can be found in two recent Eurostat reports (2013 and 2017) and in a series of contributions by D'Orazio and coauthors (2006 and 2014).

[4]Households from overseas departments and territories (DOM-TOM) are excluded since indirect taxes are set differently.

[5]The income deciles used throughout the paper are constructed on the basis of disposable income per consumption unit. Consumption units follow the equivalence scale of the OECD, i.e. it is equal to 1 for the first adult in the household, plus 0.5 for each other person aged 14 years or older, and 0.3 for each person under 14 years old.

to evaluate elasticities through a demand system. The advantage over reduced-form equations is that demand systems build on an underlying model of household consumption behavior across all goods, which also serves to estimate a system of joint equations instead of separate regressions. I estimate the *Quadratic Almost Ideal Demand System* (QUAIDS) introduced by Banks et al. (1997). This model extends the *Almost Ideal Demand System* (AIDS) proposed by Deaton & Muelbauer (1980b) 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 on preferences which could create a specification bias in the estimation. The QUAIDS considers the consumption by individuals of k different categories of goods and the share in their total expenditures they each represent. The full model — and the procedure used for its estimation — is presented in appendix C, and leads to an estimation of 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 which include diesel and gasoline. The second group gathers housing energies, including electricity, natural gas and domestic fuel.[6] The third group is the remainder of non-durable products. Given that the survey is cross-sectional and expenditures are reported over a short period, the data do not enable the inclusion of durable products in a meaningful way. As

[6] Wood and coal are marginal in French household energy consumption.

a result, I cannot account for the effect of energy prices on the purchase of newer vehicles or cleaner heating technologies. The elasticities should therefore be understood as short-run responses to price variations.

3.2 Results

Table IV in appendix C reports income and uncompensated price elasticities for four specifications, with the 95% confidence intervals for these estimates. Specifications (1) and (2) use Stone-Lewbel (SL) price indices (see appendix) that can be used to obtain household-specific prices. Specifications (1) and (3) use an IV for total expenditures that would otherwise be endogenous in equation 1 (see appendix). The results appear similar in all four specifications, although the confidence intervals are larger without SL price indices.

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 energies and -1.0 for the remainder of non-durable goods. These results are in accordance with common estimates in the literature.[7] On French data, Combet et al. (2009) found transport and housing energy elasticities of respectively -0.5 and -0.11 on time series data. Using BdF 2006, Clerc & Marcus (2009) found a higher elasticity of -0.7 for transport fuels, but did not find any reliable results for housing energies. On panel data, Bureau (2011) finds a more conservative estimate of a short-term elasticity of -0.22 for transport fuels. From BdF 2001, Ruiz & Trannoy (2008) found uncompensated price elasticities of -0.55 and -0.38 for transport and housing expenditures, although they did not

[7] For a meta-analysis of common estimates in the literature, see Espey (1996) for transport and Espey & Espey (2004) for electricity.

focus on energy only. Finally, on BdF 2011 and through the computation of Engel curves, Berry (2019) found -0.19 for transport and -0.36 for housing energies. I believe the data and techniques employed in the present work offer accurate results. They bring new evidence that households react to energy prices in the short run, although the adjustment in consumption is somewhat limited for housing energies.

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 size of the urban unit (5 categories).[8] Uncompensated price elasticities for transport and housing energies are given for all these groups in Table V in appendix C. Overall, it appears that for both types of energies, elasticities are (in absolute value) decreasing with income, and lower for more urban households. On the income dimension, the results are consistent with the findings of Reaños & Wölfing (2018) on housing energies. With respect to city size, they are consistent with Labandeira et al. (2006) for transport but not for housing, for which these authors 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 higher privation in energy consumption. If some of them

[8] The urban units considered are all of similar sizes and correspond to rural towns, small cities, medium cities, large cities and the Parisian agglomeration.

are already at the edge of their basic energy needs, their decrease in consumption could have critical welfare implications that will not be captured by the monetary effects. This should be kept in mind, as restricting attention to monetary effects will lead to an understatement of the welfare impact on those who reacted more strongly to prices.

4 Environmental and distributive effects of energy taxes

This section and the following one are the core of this article. Taking 2016 as the reference year, I study the effects of the switch to the 2018 legislation. This includes a higher price on carbon for all energies (44.6€/tCO_2 against 22€ in 2016) except electricity, and an additional increase for diesel (0.026€ per liter) with the aim of progressively catching up with the higher rate currently imposed on gasoline.[9] I first consider the environmental effects and then turn to distributive issues.

4.1 The effects on greenhouse gas emissions

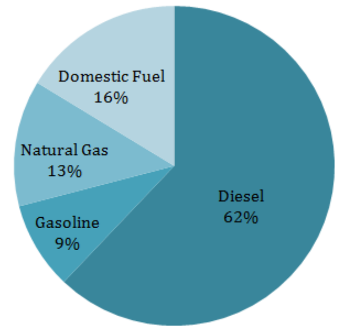
The primary objective of the policy is to reduce the negative environmental impacts of energy consumption. I therefore start by evaluating the extent to which it could contribute to reducing greenhouse gas (GhG) emissions. For each energy, I apply the elasticities obtained with the QUAIDS to determine how quantities are expected to change after the policy, and infer the short-run impact on emissions. Figure 1 summarizes the effect by energy.

The policy is expected to reduce GhG emissions by more than 3 million tons of CO_2 equivalent (CO_2e), that is, slightly less than 0.7% of French total annual emissions, and around

[9] To give an idea, the carbon tax should increase the price on domestic fuel from 0.706€ to 0.779€ per liter, 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€.

Figure 1: Annual reduction in GhG emissions by energy, in thousands of tons of CO_2e.

Energy	**CO_2e emissions**
Diesel	1,893
Gasoline	270
Natural Gas	389
Domestic fuel	497
Total transports	2,164
Total housing	886
Total energies	3,049



Example: following the policy and holding technology constant, annual GhG emissions from diesel are expected to decrease by 1,893 thousand tons of CO_2e. This corresponds to 62% of the reductions expected from all energies.

1.5% of emissions due to the transport and residential sectors.[10] By way of comparison, between 1990 and 2013 total French emissions decreased by about 0.5% per year but increased at this same rate for transport 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 incentives to improve homes' energy efficiency would be more cost-effective is uncertain. As housing energy prices are not very salient to consumers, their effect may simply be delayed and more effective in the long run.

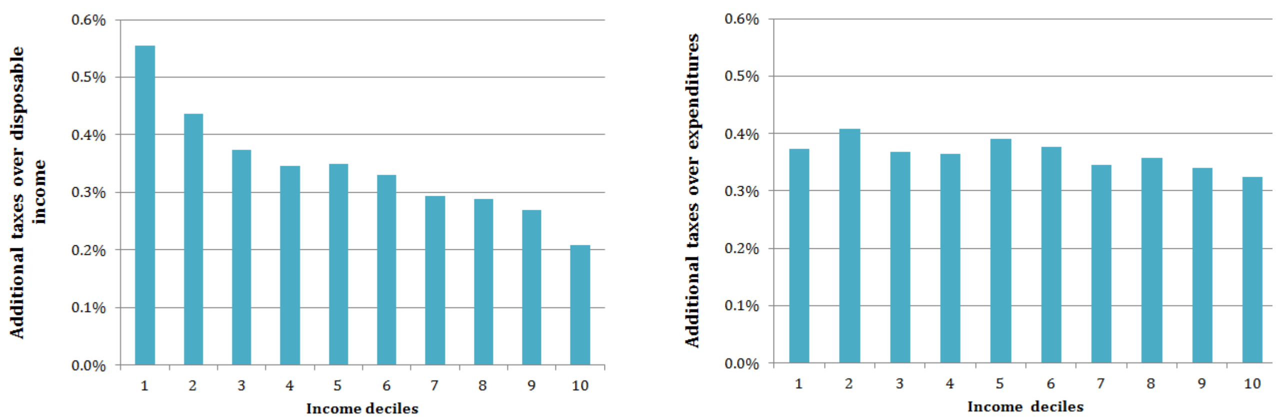
[10] 451 Mt equivalent CO_2 in 2016. Source: Citepa, SECTEN report.

4.2 Monetary effects between income groups

Besides the welfare costs due to reduced consumption, energy taxes will also affect welfare through monetary effects. In this respect, the most common fear — largely discussed in the literature — is that energy taxes are regressive (e.g. Poterba, 1991; Metcalf, 1999; Grainger & Kolstad, 2010). This regressivity could be detrimental to the acceptability of such schemes and a major deterrent for policies aimed at curbing polluting emissions. Thus, when designing fiscal policies, this needs to be taken into account by policymakers.

In the case of the French policy, with regard to effort rates on the new tax prior to revenue-recycling, we do indeed observe a decreasing pattern, as illustrated by Figure 2. However, this holds only when disposable income is considered 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 total expenditures are used as a measure of lifetime income. Which of these two measures is most relevant is subject to debate. The trade-off between these methods was originally discussed by Poterba (1989) and Metcalf (1999) who argued, following the permanent income hypothesis, that lifetime income is better reflected by the expenditures approach. A recent OECD paper (Flues & Thomas, 2015) discusses the trade-off for carbon taxes in 21 OECD countries. It also argues in favor of the expenditures approach since for students, the self-employed and retired people in particular, borrowings and savings create a large discrepancy between their income and their standards of living. Overall, one can consider these two approaches as complementary. While these figures point towards the regressivity of the carbon tax, the magnitude of the phenomenon appears smaller than is often assumed.

Figure 2: Average effort rate on the policy, by income decile.



EXAMPLE: for households belonging to the first 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 for 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 were replaced by energy vouchers (called "Chèque énergie") directed towards low-income households on the basis of their size and fiscal income. These vouchers can only be used to pay energy bills or for renovation works to improve the dwelling's energy efficiency. The distributive effects of this new compensation mechanism will critically depend on the evolution of the take-up rate, as yet unknown. However, assuming an identical take-up rate for both mechanisms, I find that energy vouchers simply compensate for the loss of social tariffs.

The energy vouchers are meant to be a compensation mechanism for low-income households. However, they currently represent a very low share of the tax revenue.[11] Given that the policy generates a large excess revenue, it leaves room for additional revenue-recycling

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

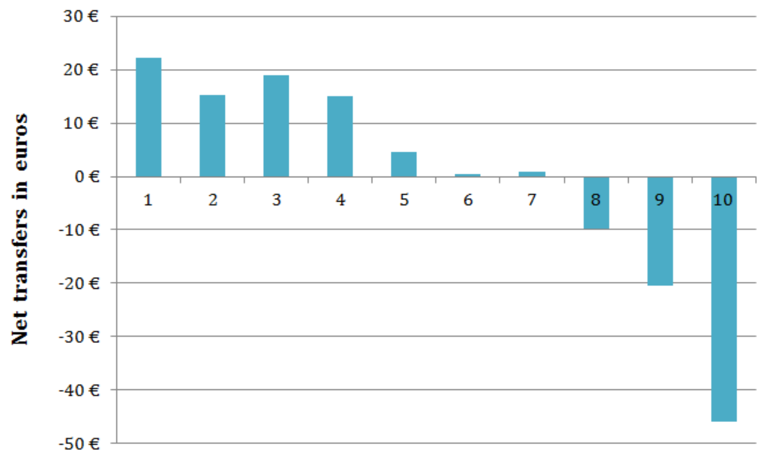
mechanisms. As many studies have shown, recycling the revenue of the tax through lump-sum transfers directed towards consumers can turn regressive taxes into progressive fiscal policies (e.g. West & Williams, 2004; Bento et al., 2009; Williams et al., 2015). In the rest of the article, I simulate a budget-neutral policy where the excess revenue — i.e. what remains after the official compensation scheme — is equally transferred to households as a proportion of their number of consumption units. In this situation — referred to as "flat-recycling" — we obtain a progressive policy as illustrated by Figure 3. 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 line 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 revenue. As shown by several studies (e.g. Dinan, 2012; Williams et al., 2015), if the government seeks a double dividend and uses this revenue to lower labor or capital taxes instead, the pattern could be different.

5 Horizontal distributive effects

5.1 Monetary effects within income groups

While there is an extensive literature on vertical equity issues related to environmental taxes, the literature looking at horizontal distributive effects — i.e. distributive effects between individuals with equivalent incomes — is still scarce, although growing. (Poterba, 1991) first highlighted the disparities in gasoline consumption among households with similar incomes. More recent contributions such as Rausch et al. (2011), Pizer & Sexton (2019), Sallee (2019),

Figure 3: Average net transfers per consumption unit after flat-recycling, by income decile.

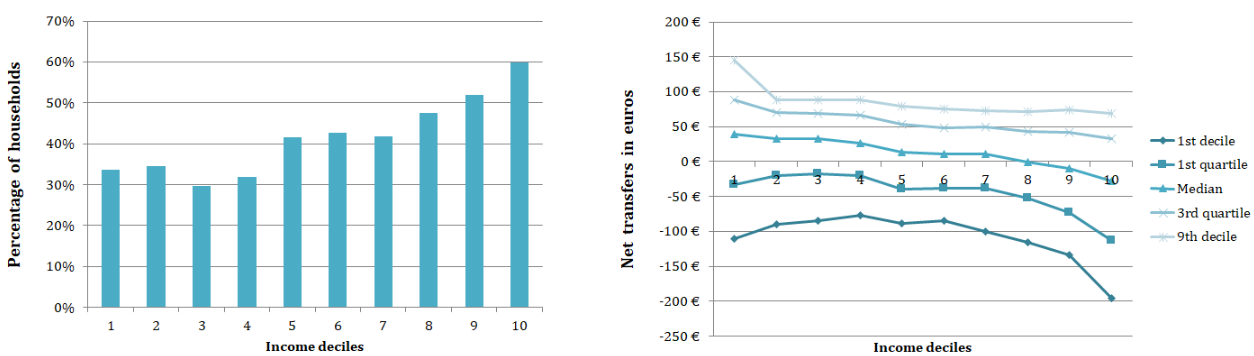


Example: on average, households belonging to the first income decile will receive an annual net transfer of 22€ after flat-recycling, against -46€ for those in the last income decile.

and Cronin et al. (2019) 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; Kaplow, 2000), one must still recognize that these effects are perceived as negative by society and could dampen the acceptability of environmental taxes. More formally, if we assume that the pre-existing distribution of resources is optimal given the available fiscal instruments, policymakers should seek to minimize distributive effects, including between households with similar incomes.

To investigate horizontal distributive effects, I first look at the share of households that are financially losing from the policy within income groups, after flat-recycling. Although the policy is progressive in this case, Figure 4 (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 the figure is still 40%. This is confirmed by the analysis of the within-income group distribution of net transfers. We can see in Figure 4 (right) that within the first income group, if 25% of households are expected to earn more than 87€ per consumption unit annually from the policy, 25% are also expected to lose more than 32€. The gap between the first and third quartiles 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 the bottom of the distribution in net transfers for all income groups, and in particular the 10th percentile, the decreasing trend is no longer clear and expected losses among the lowest income groups are as large as for any other group except the two last income deciles.

Figure 4: Share of households financially losing from the reform (left), and distribution of net transfers per consumption unit (right), by income decile.



Example: 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).

5.2 The determinants of within-income group distributive effects

From the preceding analysis, one may wonder whether it is possible to 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. (2019) stress the importance of the income composition but do not have information on other relevant household characteristics. Bento et al. (2009) and Rausch et al. (2011) 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 & Sexton (2019), 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 (c.u.) received by households after revenue-recycling on many characteristics. This approach is similar to the one recently employed by Sallee (2019) for the gasoline tax in the U.S. It is very agnostic as it enables me, 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 different specifications including (1-2) no elasticities, (3) homogeneous elasticities, and (4) the heterogeneous elasticities used above. A fifth specification (5) estimates the net transfers for a hypothetical reform where electricity would be subject to the same increase in the carbon tax as other energies. The results are reported in Table I below. Overall, they are all similar, although accounting for elasticities smooths distributive effects since households adjust their consumption downward when prices increase.

Table I: Regression of net transfers per consumption unit after revenue recycling on several household characteristics.

	(1)	(2)	(3)	(4)	(5)
R^2	0.051	0.382	0.371	0.373	0.363
N	10,342	10,342	10,342	10,342	10,342
Elasticities	no	no	yes	yes	yes
Heterogeneous	no	no	no	yes	yes
Electricity taxed	no	no	no	no	yes
Intercept	15.64	27.16**	22.09**	25.18***	25.50***
	(2.65)	*(8.41)*	*(7.42)*	*(7.51)*	*(6.85)*
Disposable income	-6.43e-04***	-2.42e-04***	-1.94e-04***	-2.97e-04***	-2.94e-04***
	(3.56e-05)	*(3.92e-05)*	*(3.47e-05)*	*(3.51e-05)*	*(3.20e-05)*
Disposable inc. sqr.	3.13e-10***	1.15e-10***	9.31e-11***	1.42e-10***	1.22e-10***
	(3.00e-11)	*(2.74e-11)*	*(2.42e-11)*	*(2.45e-11)*	*(2.23e-11)*
Domestic fuel		−76.42***	−71.20***	−69.92***	−55.99***
		(2.37)	*(2.09)*	*(2.11)*	*(1.93)*
Natural gas		−79.66***	−75.57***	−76.24***	−61.54***
		(1.83)	*(1.62)*	*(1.64)*	*(1.49)*
Transport fuels		−39.93***	30.08***	−30.50***	−28.16***
		(3.13)	*(2.76)*	*(2.79)*	*(2.55)*
Diesel		−60.38***	−44.24***	−45.00***	−39.37***
		(2.05)	*(1.81)*	*(1.83)*	*(1.67)*
Rural	−8.58**	−8.11**	−5.49*	−3.28	−4.96*
	(2.96)	*(2.69)*	*(2.38)*	*(2.40)*	*(2.19)*
Small cities	4.15	2.92	2.25	3.33	2.27
	(3.38)	*(2.80)*	*(2.47)*	*(2.50)*	*(2.28)*
Large cities	13.13***	2.45	2.04	-0.41	−0.70
	(2.99)	*(2.44)*	*(2.16)*	*(2.18)*	*(1.99)*
Paris	43.55***	9.07**	7.25**	2.58	2.48
	(3.48)	*(3.04)*	*(2.70)*	*(2.72)*	*(2.48)*
West/south		4.88**	4.95**	4.44**	4.27**
		(1.76)	*(1.56)*	*(1.58)*	*(1.44)*
Building before 1949		−6.31**	−6.59***	−6.66***	−3.92*
		(2.02)	*(1.79)*	*(1.81)*	*(1.65)*
Building 1949/74		−2.56	−3.04	−3.03	−0.36
		(2.04)	*(1.80)*	*(1.82)*	*(1.66)*
Individual housing		−8.89***	−8.78***	−9.47***	−11.75***
		(2.34)	*(2.07)*	*(2.09)*	*(1.90)*
Owner		−2.64	−1.61	−1.32	−1.79
		(2.15)	*(1.90)*	*(1.92)*	*(1.75)*
Living area *(m^2)*		−0.28***	−0.26***	−0.26***	−0.27***
		(0.02)	*(0.02)*	*(0.02)*	*(0.02)*
Nb. consumption units		58.29***	47.96***	50.80***	49.27***
		(2.04)	*(1.80)*	*(1.82)*	*(1.66)*
Nb. in labor force		−2.72	−1.39	−1.54	−0.73
		(1.40)	*(1.24)*	*(1.25)*	*(1.14)*
Student		44.85***	41.68***	41.58***	49.27***
		(6.66)	*(5.88)*	*(5.94)*	*(5.42)*
Age		0.93**	0.94***	0.91**	0.57*
		(0.31)	*(0.27)*	*(0.28)*	*(0.25)*
Age sqr.		−0.01*	−0.01**	−0.01**	0.00
		(0.00)	*(0.00)*	*(0.00)*	*(0.00)*
Vehicle age		0.68***	0.52***	0.55***	0.48***
		(0.14)	*(0.13)*	*(0.13)*	*(0.12)*
Share distance to work		0.35*	0.28	0.28	0.24
		(0.17)	*(0.15)*	*(0.15)*	*(0.14)*

* 0.05 ** 0.01 *** 0.001

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 low magnitude, so that for most of the income distribution the effect is close to being linear. With respect to households' residential location, we see from regression (1) that living in rural areas or smaller cities has a negative impact, while living in Paris largely increases expected transfers, with an expected gain of 52€ per c.u. relative to rural households. This is in accordance with Glaeser & Kahn (2010), who show the negative link between urban density and household CO_2 emissions from transports and housing in the U.S. Indeed, one may expect rural households to differ in many respects, such as distance to their workplace. However, as shown by the other specifications, once other characteristics are controlled for, the urban density variables appear to be far less significant, suggesting that this effect is actually largely driven by covariates not directly related to location. In particular, the type of energy used appears to be the major determinant as it is strongly significant both economically and statistically. Households using natural gas or domestic fuel are expected to lose more than 70€ per c.u. relative to other households. Interestingly, given the low 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 goes down to around 60€. The burden on these households is therefore not explained by the exclusion of electricity from the policy.[12] With respect to transport, accounting for elasticities, households using private vehicles lose on average an additional 30€ per c.u. from the policy, the effect being far stronger for diesel users who lose an additional 45€ per c.u. As the share of diesel and domestic fuel users is higher among rural

[12]Note that the effect on households using domestic fuel is softened by the switch from social tariffs — which did not apply to fuel — to energy vouchers, which are not conditional on the energy used.

and suburban households,[13] these results largely explain the higher magnitude of the urban density dummies in the first regression. Still, the high correlation between urban density and carbon tax incidence is in line with Yellow Vests' concerns regarding the high burden borne by rural and peri-urban households.

Looking at climatic regions, we also see that all else being equal, households living in the south or west of France are expected to gain slightly (+4€ in regression (4)). Yet, contrary to what might have been expected given the spatial heterogeneity of temperatures during winters, the impact is relatively small. The distributive effects of energy taxation between regions with different climates therefore seems limited and should not have significant political implications. Other interesting effects of note are the very large gains for students (more than 40€ on average), and the expected losses for people living in individual (-9€) and larger dwellings (-0.3 € per square meter). With respect to energy efficiency, one can note the negative and significant effect of living in an older building.[14]. Family composition also matters a lot: having a larger household has a strong positive effect (+51€ per c.u.) which might be explained by the sharing of many energy expenditures such as heating, in particular once we control for dwelling size. Interestingly, controlling for a number of characteristics, the number of household members in the labor force and the share of commutes in private vehicles to the workplace are not statistically significant. While working further from home has an obvious negative effect on transfers, this effect disappears when it is taken as a share of the total distance travelled: having on average more travel constraints does not create a higher exposure to energy taxes. Lastly, it can be noted that although many characteristics are identified as

[13] 76% of rural households in the sample have at least one diesel vehicle, against 36% of Parisians. For the use of domestic fuel, they are respectively 34% and 5%.

[14] The two dummies have been chosen to capture years with major changes in insulation standards.

significant drivers of the tax incidence, unobserved heterogeneity still plays a major role. In all specifications, the R-square is around 0.38, leaving a large part of unexplained variations. This result suggests that designing policies to solve horizontal distributive effects could be a difficult task.

5.3 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 D, but they basically correspond to 1) an additional transfer based on the urban density of the household's residence, 2) an additional transfer to households heating with domestic fuel or natural gas, and 3) both additional transfers. In each of these scenarios the official energy vouchers are lowered such that total transfers to low-income households (i.e. those eligible under 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 prominent in the public debate, and are supposed to be observable by the State, although this observation might be costly.[15] Table II shows for each scenario the net transfers per consumption unit for the households losing the most within the first three income deciles. Relative to the official revenue-recycling mechanism, we see that vouchers differentiated by residential area do not lead to significant improvements. Because the urban density of the residential location is a poor proxy for the tax incidence, it follows that targeted transfers based on this criterion do not improve horizontal equity. If

[15] One could also raise concerns over the constitutionality of locally differentiated transfers, given the principle of equality before taxation. The exact criteria on which these transfers could be based would be critical for their implementation to be feasible.

these vouchers enhance the situation of rural and suburban households, it is at the expense of other, highly exposed households. When targeted according to the heating mode, these vouchers outperform the official ones for the first income group but do not make big differences 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 II: Net transfers per consumption unit for the 25th percentile (left) and 10th percentile (right) of households losing the most within income deciles, for alternative recycling.

	1st **decile**	2nd **decile**	3rd **decile**
Official	-32.8€ / -110.4€	-19.5€ / -89.2€	-16.9€ / -84.3€
By area	-30.6€ / -109.6€	-18.8€ / -89.2€	-16.8€ / -83.9€
By energy	-22.0€ / -87.8€	-18.0€ / -77.9€	-16.0€ / -80.0€
By area and energy	-19.1€ / -96.4€	-15.8€ / -77.6€	-14.4€ / -79.4€

Example: when revenue-recycling is differentiated by residential area, 25% of households in the first income decile lose at least 30.6€ from the policy after flat-recycling, and 10% lose at least 109.6€.

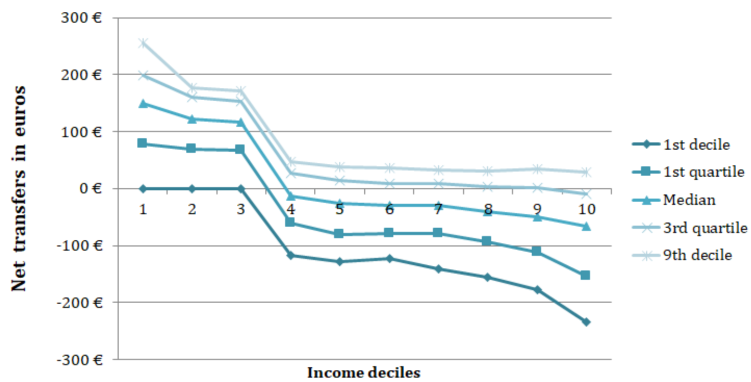
By indexing these vouchers on many other dimensions, one may hope to target more precisely the most vulnerable households and thus reduce the policy's distributive effects. However, because households' heterogeneity is largely unobservable by the State, this strategy offers little promise. As shown by the third alternative (by area and energy), combining targeted transfers does not necessarily improve the results. This result is consistent with the findings of Sallee (2019) for the U.S., who shows that the difficulty to precisely target households may prevent Kaldor-Hicks improving policies to be Pareto improving. Also, even though 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 that pollute more, this strategy would reduce the environmental benefits of the policy. This problem could be partly alleviated by phasing out these specific transfers over time — assuming people are only constrained in their heating technology in the medium run. Nonetheless, one should also consider that distributing vouchers specifically to households that use 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 that of the policy itself is not straightforward.

An alternative to the previous transfers could be to subsidize energy-efficiency improvements. The French government already finances subsidies for clean vehicles as well as tax credits for less carbon-intensive heating technologies and insulation improvements.[16] Such policies could potentially reduce both pollution and distributive issues in the medium run. Unfortunately, they can hardly be evaluated from cross-sectional data. Further work would be needed to assess their cost-effectiveness and actual distributive impact. Indeed, the take-up of these policies could be low among the poorest households, which are more credit constrained, resulting in a windfall for higher-income households and raising non-additionality concerns. Given the difficulty of precisely targeting households on criteria other than their income, another possibility in the short run would therefore be to offer more generous compensations to all low-income households. Figure 5 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 borne by medium-income households.

Overall, this evidence suggests that when accounting for horizontal heterogeneity, the

[16] The two mechanisms are respectively called "Prime à la conversion" and "Crédit d'Impôt pour la Transition Énergétique (CITE)".

Figure 5: Distribution of net transfers per consumption unit after additional transfers to low-income households, by income decile.



EXAMPLE: 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.

policy solutions to the distributional impacts of environmental taxes are far less clear-cut. If not everybody can financially gain from these policies, it is ultimately a matter of political choice to decide how to split the burden between different household groups.

6 Conclusions

Through the *ex ante* micro-simulation of the latest reform of energy taxes in France, 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 does not change this picture. However, returning the revenue left over 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 much greater in magnitude than the vertical ones. I investigated the determinants of the tax incidence and simulated alternative transfers targeted towards the policy's losers. While such mechanisms could soften distributive issues somewhat, their effect is likely to be limited and should be weighted against their costs.

The French government initially committed to an ambitious trajectory for the carbon price that was supposed to reach 86.2€ by 2022, and keep growing to even higher rates after that date. Following the recent protests by the Yellow Vests against the impact of these taxes on household purchasing power, the trajectory has been abandoned. Given the urgent need to take action against climate change and other environmental issues, it is necessary to find a way to increase the support for environmental policies by dealing with their distributive effects. As shown in this paper, recycling the entire revenue of the tax through lump-sum transfers would make the majority of poor households net winners, and potentially increase acceptability. Dealing with horizontal heterogeneity seems more difficult in the short run, however. In the long run, energy efficiency improvements seem necessary to reduce both emissions and distributive effects.

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Appendices

A Descriptive statistics

Table III: Descriptive statistics for matched data, average per income decile.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Annual Disp. income	16,371€	25,829€	31,039€	36,709€	40,509€	46,585€	53,498€	60,286€	71,199€	113,557€
Annual expenditures transport energies	700€	846€	894€	1,037€	1,215€	1,343€	1,400€	1,500€	1,588€	1,534€
Annual expenditures housing energies	1,272€	1,542€	1,572€	1,635€	1,720€	1,783€	1,875€	1,903€	2,046€	2,520€
Annual total expenditures	23,142€	24,430€	27,728€	30,571€	31,895€	36,104€	39,880€	42,699€	49,467€	62,426€
% rural	16.8%	22.3%	24.0%	23.6%	25.2%	23.1%	25.6%	22.9%	22.1%	17.4%
% small cities	14.0%	18.5%	19.6%	16.5%	18.3%	17.4%	16.5%	17.0%	17.1%	11.2%
% medium cities	19.6%	21.6%	19.6%	21.8%	19.4%	22.1%	17.0%	17.7%	16.8%	15.0%
% large cities	33.3%	24.7%	26.3%	24.6%	24.3%	24.1%	24.2%	24.8%	22.1%	23.4%
% Paris	16.3%	12.9%	10.6%	13.4%	12.8%	13.3%	16.7%	17.6%	21.9%	33.0%
% natural gas	37.9%	40.1%	40.3%	40.3%	40.9%	42.0%	40.1%	41.9%	42.7%	51.5%
% domestic fuel	11.0%	14.9%	17.1%	14.6%	17.8%	15.0%	12.7%	14.1%	14.8%	13.9%
% transport fuels users	58.7%	66.4%	70.3%	77.9%	82.6%	86.9%	89.8%	89.7%	89.9%	90.6%
% diesel users	36.6%	42.4%	45.5%	49.9%	54.1%	60.7%	65.8%	65.3%	61.5%	62.3%
% gasoline users	24.5%	29.1%	30.0%	37.6%	39.1%	38.8%	35.8%	39.9%	44.5%	48.1%
Weekly home-work distance (km)	13.8	24.9	25.6	47.3	48.6	60.2	60.5	63.2	81.4	66.8
Age vehicle (years)	6.8	7.6	7.9	8.1	8.4	8.2	7.7	7.3	7.3	6.3
% building before 1949	28.2%	29.8%	25.8%	26.4%	22.9%	23.0%	21.6%	22.1%	24.1%	25.4%
% individual housing	31.6%	47.2%	50.9%	52.1%	59.3%	60.6%	59.9%	61.9%	63.3%	57.8%
Living area (m^2)	71	79	81	83	88	91	94	99	105	118
# consumpt. units	1.46	1.54	1.51	1.55	1.52	1.56	1.59	1.56	1.55	1.51
# in labor force	0.69	0.77	0.78	0.92	0.97	1.11	1.21	1.24	1.24	1.23
Age representative	44.2	53.0	54.8	54.7	54.0	51.8	49.7	50.8	51.7	53.2

NOTE: Income deciles are constructed on the basis of disposable income per consumption unit.

B The microsimulation model TAXIPP

The microsimulation of the policy's impact on households is performed using the model TAXIPP. The model is managed by the Institut des Politiques Publiques (IPP) at the Paris School of Economics (PSE).[17] For the study of indirect taxation, the model uses consumer survey data as described in section 2 of this paper. For each household in the dataset and for each good it consumes the model computes — from the expenditures reported in the data — the amount paid for various taxes. These computations simply replicate the legislation. For instance, if one is interested to know what is the contribution of an household to taxes on energies, the model uses the following formula to decompose expenditures (E):

$$E = qQ = (1 + t)(p + a)Q \tag{2}$$

with Q the quantity of energy consumed, q the final price, p the price without taxes, t the VAT rate and a the excise (e.g. carbon) tax. From this we can compute the household spending in VAT ($E_{VAT} = t(p + a)Q$) and in excise tax (aQ). From the expenditures provided in consumers survey, one can easily recover quantities of energies consumed since $Q = E/q$. The only exception is for gas as it is subject to contracts with both a fixed and a marginal cost. For this energy, the formula thus becomes $Q = (E - F)/q$ with F the fixed cost of the contract. As various contracts are available to French consumers, the model takes the regulated prices proposed by the historical company "Engie" (ex "GDF-Suez") and computes from households' gas expenditures the quantity they would have consumed if they had subscribe to each of these contracts. Assuming households are rational and can approximately forecast their future consumption, the model matches each household to the

[17]For more information on the model, see https://www.ipp.eu/en/tools/taxipp-micro-simulation/.

contract that would provide the largest quantity (i.e. the optimal contract given its observed expenditures). Thus, households with the largest consumption are matched to the contract with the most expensive fee but the lower variable price, and vice-versa.

Beyond the computation of taxes currently paid by households, the model also allows to assess the impact of policies, such as the increase in the carbon tax studied in this paper. In order to simulate the impact of a change in the carbon tax (i.e. an increase in a), one simply needs to compute the impact of such a change on the final price and the effect on quantities consumed. In this paper, we assume the change in prices equals the increase in excise taxes. This is akin to suppose that the tax burden falls by 83% on consumers.[18] From this increase in prices, one can then apply the elasticities estimated in this paper to compute the new expenditures E' for each household. If we denote e the price elasticity of the good, by log-differentiation of $E = qQ$ we have:

$$\frac{dE}{E} = \frac{dq}{q} + \frac{dq}{q}\frac{dQ}{dq}\frac{q}{Q} = \frac{dq}{q}(1+e) \tag{3}$$

hence:

$$E' = E + dE = E\left(1 + (1+e)\frac{dq}{q}\right) \tag{4}$$

from which one can use the methodology previously described to compute the new contribution to taxes.

[18] If we denote i the tax incidence on consumers, dq the change in prices and da the change in the excise tax, then for marginal changes we have $dq = i \times da \times (1+t)$, so that we can approximate $dq = da$ assuming $i = 1/(1+t) \simeq 0.83$. On U.S. data Marion & Muehlegger (2011) find that gasoline taxes are in general fully-passed onto consumers. Carbonnier (2007) analyses shifts in the French VAT and finds that part of the burden is born by producers, in particular in highly concentrated sectors. Considering the little competitiveness of the French energy sector, it seems relevant to assume that the tax burden will be born not entirely although in the largest part by consumers.

C The Quadratic Almost Ideal Demand System

C.1 The model

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

$$\ln V(\mathbf{p}, m) = \left[\left\{ \frac{\ln m - \ln a(\mathbf{p})}{b(\mathbf{p})} \right\}^{-1} + \lambda(\mathbf{p}) \right]^{-1} \tag{5}$$

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

$$\ln a(\mathbf{p}) = \alpha_0 + \sum_{i=1}^{k} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \gamma_{ij} \ln p_i \ln p_k \tag{6}$$

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 & Muelbauer (1980b) who recommend taking 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 first two 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 with the consumption of good i. Then, using Roy's identity we can derive:

$$w_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \beta_i \ln \left\{ \frac{m}{a(\mathbf{p})} \right\} + \frac{\lambda_i}{b(\mathbf{p})} \left[\ln \left\{ \frac{m}{a(\mathbf{p})} \right\} \right]^2, \quad i = 1, ..., k \tag{7}$$

The aim of the QUAIDS is to estimate this equation for all goods i.

C.2 Elasticities

The estimates obtained for the parameters serve 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 logarithm of expenditures, we get:

$$\mu_i \equiv \frac{\partial w_i}{\partial \ln m} = \frac{\partial w_i}{\partial m} m = -w_i + w_i \frac{m}{q_i} \frac{\partial q_i}{\partial m} = \beta_i + \frac{2\lambda_i}{b(\mathbf{p})} \left[\ln \left\{ \frac{m}{a(\mathbf{p})} \right\} \right] \tag{8}$$

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

$$e_i = \frac{\partial q_i}{\partial m} \frac{m}{q_i} = 1 + \frac{\mu_i}{w_i} \tag{9}$$

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

$$\mu_{ii} \equiv \frac{\partial w_i}{\partial \ln p_i} = w_i(1 + e_{ii}^u) = \gamma_{ii} - \mu_i \left(\alpha_i + \sum_k \gamma_{ik} \ln p_k \right) - \frac{\lambda_i \beta_i}{b(\mathbf{p})} \left[\ln \left\{ \frac{m}{a(\mathbf{p})} \right\} \right]^2 \tag{10}$$

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

$$e_{ii}^u = \frac{\mu_{ii}}{w_i} - 1 \tag{11}$$

Estimation is performed using the Stata package *aidsills* introduced by Lecocq & Robin (2015). It uses iterated linear least-squares (ILLS) and provides elasticities at the mean of each variable, together with their standard errors.

C.3 Households' heterogeneity

The command *aidsills* serves to introduce heterogeneity in households' preferences through the inclusion of demographic variables. The procedure makes use of the translating approach of Pollak & Wales (1981). If $\mathbf{s^h}$ represents the set of demographic variables, the intercept in the share equation becomes household-specific and is written:

$$\alpha^{\mathbf{h}} = \mathbf{A}\mathbf{s^h}, \qquad \mathbf{A} = (\alpha'_{\mathbf{i}})$$

which then translates into households' specific elasticities. We can thus estimate heterogeneous responses for different groups of households by conditioning on some of their characteristics — such as income or city size — without having to estimate elasticities on sub-samples.

C.4 Specification and estimation

The main difficulty in estimating demand systems with survey data stems from the lack of variability in prices. For each household, and for each good it consumes, I match the prevailing monthly price index[19] of the French statistical institute (Insee) according to the period of the survey. Like Nichèle & Robin (1995), I take the last three surveys — 2001, 2006 and 2011 — for a total of 20 periods,[20] hence 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 out by households, from which we can deduce the exact 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 compute Stone-Lewbel price indices (see Lewbel, 1989) that use households' consumption mix to derive personalized prices. For a bundle i consumed by household h, the price index is written:

$$\ln(p_{ih}) = \sum_{l=1}^{N_i} \frac{w_{lh}}{w_{ih}} \ln(p_{lh}) \tag{12}$$

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 is used to construct price indices that rely on heterogeneity of consumer preferences *within each bundle*. This heterogeneity serves to introduce more variations in prices. It has been widely used in the literature that has computed demand systems, and to my knowledge is the only efficient strategy to construct price indices with high enough variability from cross-sectional data. In an assessment of this method, Hoderlein & Mihaleva (2008) have shown that it produces better empirical results than standard aggregate price indices.

[19] These price indices are national. The information regarding households' geographical location are not precise enough to match households with local price indices.

[20] There were 8 waves in 2001, 6 in 2006 and 2011. For each survey I exclude overseas departments and restrict the sample to households with positive consumption on all bundles, for a total of 18,090 households.

However, one should still be careful about the potential endogeneity introduced by this 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, since expenditures are used in the construction of prices, there is a risk of biasing 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 indices. 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 composition, age, heating mode, the urban density of their residential location and other characteristics that could explain the composition of households' bundles. I also use time fixed effects to account for seasonality in consumption. Finally, because expenditures are endogenous in demand systems, I use households' disposable income as an instrument (see Lecocq & Robin, 2015).

C.5 Results

Tables IV and V below report the elasticities estimated from the QUAIDS, respectively at the sample mean, and at the sample mean of given categories.

Table IV: 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	-0.49	-0.44	-0.47
	[-0.51;-0.42]	[-0.62;-0.36]	[-0.57;-0.31]	[-0.60;-0.35]
elas. unc. housing	-0.21	-0.21	-0.15	-0.18
	[-0.27;-0.16]	[-0.26;-0.15]	[-0.25;-0.04]	[-0.28;-0.08]
elas. unc. other	-1.03	-1.03	-0.97	-0.97
	[-1.04;-1.01]	[-1.04;-1.01]	[-1.02;-0.92]	[-1.01;-0.92]
elas. exp. transport	0.48	0.54	0.45	0.52
	[0.44;0.53]	[0.52;0.56]	[0.41;0.50]	[0.50;0.54]
elas. exp. housing	0.58	0.47	0.56	0.47
	[0.53;0.63]	[0.45;0.49]	[0.51;0.61]	[0.44;0.49]
elas. exp. other	1.07	1.07	1.07	1.07
	[1.06;1.07]	[1.07;1.07]	[1.07;1.07]	[1.07;1.07]
N	18,090	18,090	18,090	18,090
R^2 eq. transport	0.291	0.291	0.289	0.288
R^2 eq. housing	0.309	0.309	0.277	0.277
R^2 eq. other	0.368	0.368	0.349	0.349

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

Table V: Transport and housing energy price elasticities by group.

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

EXAMPLE: households belonging to the first income decile and living in a rural area have transport and housing energy price elasticities of respectively -0.54 and -0.43.

NOTE: Due to the imprecision of the estimation for small categories, the housing energy price elasticity is expected to be positive for ten groups. For the sake of consistency of the micro-simulation analysis I impose an *ex post* zero upper-bound. 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.

D Policies simulated

D.1 The official policy

In this paper I study the effects of switching to the 2018 legislation for energy taxes, compared to the reference situation of 2016. The policy studied therefore implies the following evolution: 1) An increase in the price of CO_2 that goes from 22€ to 44.6€ per ton. 2) An additional 0.026€ per liter increase in the diesel tax to gradually catch up with the gasoline tax. 3) Energy vouchers transferred towards low-income households, based on their fiscal income and their size. These vouchers 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 enlarged the "Crédit d'impôt pour la transition énergétique" (Cite) whose aim is to help people finance energy efficiency improvements in their dwelling, and a scrapping premium to improve the energy efficiency of the vehicle fleet. These last changes are not modelled in TAXIPP.

D.2 Targeted transfers design

The paper also evaluates the potential of targeted transfers to reduce the burden borne by some of the poorest households. From the output of regression (1) in Table I, I design a mechanism called transfers "by area" which gives rural households *already eligible for the official energy voucher* an additional 52€ per consumption unit. Following the regression results, the transfers amount to 39€ for small cities, 43€ for medium cities, 30€ for large ones and zero for Paris. From the output of the four other specifications, I also design a mechanism called "by energy" in which households heating with fuel or gas receive an additional 70€ voucher per consumption unit. In the third scenario "by area and energy", both additional transfers are included. For all these alternatives, the initial energy vouchers based on income and household size are decreased such that the total cost of the policy stays the same.