The vertical and horizontal distributive effects of energy taxes:

A micro-simulation 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 progressive after revenue-recycling, but generates large horizontal distributive effects. The determinants of the tax incidence are characterized precisely, and alternative revenue-recycling strategies are simulated on this basis. The paper argues that when households differ on multiple dimensions, fuel poverty can be used to identify the most vulnerable with respect to energy consumption. If public acceptance of energy taxes depends on Rawlsian considerations, it can substitute for the common focus on low-income households and be used as a better barometer of a policy's acceptability.

JEL classification: D12, H23, I32

Keywords: Energy taxes, Distributional effects, Fuel Poverty, Demand system, Micro-simulation

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1 Introduction

This paper starts from one problem and one puzzle. The problem is the low acceptability of environmental taxes. 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 converge on the result that these taxes are regressive but recycling their revenue through lump-sum transfers can turn them into progressive policies. Thus, if acceptability depends on Rawlsian considerations, one could think that these policies would satisfy society's criteria by favouring lower-income households. However, despite this consensus, the acceptability problem seems far from being solved. In particular, in many countries the concept of fuel poverty - that characterizes households who meet financial difficulties to satisfy their energy needs - has emerged and draw much attention in the public debate (see for instance Erard et al (2015) [18]). Hence the puzzle since, while associations politicians and other civic actors are very concerned with fuel poverty, it has yet been largely ignored by economists. One can then wonder whether economists have a better understanding of the issue or if they missed something. In this article, I will give credit to the second option, and argue that when considering both *vertical* and *horizontal* equity - i.e. between households with similar income - fuel poverty indicators enable to identify the households most exposed to energy taxes. When households differ not only with respect to their income, one can therefore re-define the Rawlsian objective as mitigating the losses of these households, and not only ensuring the policy's progressivity. This argument should, I believe, solve the previously mentioned puzzle. And making use of this tool for policy design, we can hope to make progress with respect to the acceptability problem as well.

The objective of the paper is to assess the relative importance of horizontal and vertical distributive effects of energy taxes, and their implications for the acceptability of these policies. It 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] - coupled with a revenue-recycling that includes energy cheques targeted towards low-income households. 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 carbon tax returned through lump-sum transfers, and energy consumption patterns in France are very similar to most other OECD countries.

Several papers have investigated the distributive effects of energy taxes in France (e.g. Ruiz and Trannoy (2008) [46], Bureau (2011) [7], Berry (2017) [2]). Yet, partly because of a lack of a comprehensive database, there has been little works covering jointly housing and transports. Existing studies all tend

[1]TAXIPP is the micro-simulation model of the Institut des Politiques Publiques (IPP).

[2]European Union Emissions Trading Scheme

to focus on vertical equity, and none of them includes an assessment of the effects on both transports and housing fuel poverty. To investigate 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) [6], 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 households, and for households living in rural area and smaller cities. 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 expenditures, quantities, and CO_2 emissions. I assess the expected reduction in aggregate CO_2 emissions from households savings in energies, and compare for several households' groups the burden created by the tax in terms of reduced consumption. I then focus on monetary effects. Through the computation of effort rates, I analyse how the burden of the tax is spread across income groups, before and after revenue recycling. The results confirm the general findings of the literature that energy taxes alone are regressive when computing effort rates as a function of disposable income (e.g. Poterba (1991) [43], Metcalf (1999) [34], Grainger and Kolstad (2010) [23]), but not when taking total expenditures instead to measure standards of living (see Poterba (1989) [42], Metcalf (1999) [34], Hassett et al (2013) [24], Flues and Thomas (2015) [21]). Also, I find that the revenue-recycling mechanism proposed by the government and partly targeted towards low-income households should turn this regressive carbon tax into a progressive environmental policy (see West and Williams (2004) [50], Bureau (2011) [7], Williams et al (2015) [52]).

From the previous conclusions, it could seem straightforward to improve the acceptability of energy taxes. However, a recent literature has started to emphasize that horizontal distributive effects of energy taxes could be important in magnitude and a major deterrent for their implementation. Pizer and Sexton (2017) [40] found that for Mexico, the U.K. and the U.S. energy expenditures are more heterogeneous within income groups than across them. Rausch et al (2011) [44] use a general equilibrium model with heterogeneous agents and show that in the U.S. horizontal distributive effects from a carbon tax are expected to be more important than vertical effects, in particular for low-income households. Cronin et al (2017) [13] stress that revenue-recycling could even worsen horizontal equity issues. In this paper, I analyse the distribution of gains and losses within income groups. In particular, I show that 25% of households in the bottom income decile are expected to lose more from the policy 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.

In face of the multi-dimensional households' heterogeneity and its important implications for distributive issues, one may find difficult to assess the overall welfare impact of a policy with respect to equity. I argue that despite the little interest they have received by economists so far, fuel poverty indicators are useful tools for policy evaluation. When households are heterogeneous on multiple dimensions, these indicators enable to better target the most vulnerable with respect to energy consumption than just focusing on the first income deciles. I define an indicator based on the work of Hills (2012) [25] and the French observatory for fuel poverty (ONPE, 2014) [38], and show that it aggregates all the dimensions of heterogeneity between households relative to energy consumption. Based on this indicator, I show that the revenue-recycling enables the policy to almost neutralise the increase in the number of fuel poor households, but close to half of those already in fuel poverty are expected to lose from the policy. These losses are also expected to be important in magnitude, and over a third of fuel poor households are expected to lose more from the fiscal reform than the median household in the top income decile. This result raises the concern that, despite being progressive, the policy could still face a low acceptability.

Important progress have been recently made by general equilibrium models to incorporate more heterogeneity in households characteristics (e.g. Rausch et al (2011) [44], Rausch and Schwarz (2016) [45]). Yet, it is still unclear what are the drivers of the heterogeneous incidence of energy taxes (Pizer and Sexton (2017) [40]). The literature on US data has mostly focused on geographical criteria looking at the differentiated impact across States, and general equilibrium models have 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, while indexing transfers on the geographic location has almost no effect, when based on the type of energy used for heating they significantly soften horizontal equity issues for the poorest households, as well as the impact on fuel poor households. Finally, considering their costs in terms of environmental incentives and implementation, I discuss the potential of these cheques to improve public acceptance, against other revenue-recycling mechanisms such as financial incentives to improve energy efficiency.

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. Third, it gives new insights into the way economists should consider fuel poverty. Although imperfect, this indicator proves to be useful as it aggregates the complex multi-dimensional heterogeneity of households, gives a measure of the welfare costs of the policy on the most vulnerable, and as such can be taken as a barometer of its acceptability.

The paper is organised as follows. Section 2 discusses the choice of the main database and presents the imputation procedure from other data sources. Section 3 sketches households' consumption patterns, their contributions to indirect taxes, as well as their greenhouse gases emissions. Section 4 estimates the QUAIDS and computes elasticities. Section 5 evaluates the expected environmental and distributive effects of the fiscal policy on energies, both across and within income groups. Section 6 presents the fuel poverty indicator and argues that it can be used to assess the welfare impact of energy taxes on the most vulnerable. It then evaluates the policy using this indicator. Finally, it highlights the determinants of horizontal distributive issues and proposes alternative revenue-recycling mechanisms based on these results. Finally, section 7 concludes. Technical elements are reported in appendix.

2 Data

2.1 Which survey to use?

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) [7] 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) [37] covered both issues but they did not estimated elasticities specifically for energies, nor did they precisely detailed the distributive effects of the tax. With respect to fuel poverty, there has been numerous works on French data, most of them focusing only on housing energies (see ONPE 2014 [38]). A notable exception is Mayer et al (2014) [33] who aggregate data for both housing and transports, but their study is restricted to the city of Strasbourg. In addition, these studies are mostly descriptive and do not evaluate the effects of fiscal policies. Closer to this work, Berry (2017) [2] investigates a previous increase in the carbon price on energies. She uses the Phebus database and analyses vertical distributive effects and fuel poverty with respect to housing. 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 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 realised 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 realised 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.

2.2 Statistical matching and imputation

Yet, one could still point towards two weaknesses of the survey BdF. First, with respect to housing, there is no variable describing the objective quality of thermal isolation nor the subjective perception of cold

[3] BdF 2011 inflated for 2016

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

in the accommodation. These variables are potentially relevant to study energy consumption and fuel poverty, and are available only in the housing survey "Enquête Logement" (EL). Secondly, transport fuel consumption is reported on a very short period in BdF and may miss-represent actual consumption behaviour. Indeed, as shown on figure 12 in appendix, too many households report a null consumption over that period, or conversely an over-consumption once the data are annualised. On this respect, one could want to take advantage of information available in the transports survey "Enquête Nationale Transports et Déplacements" (ENTD) where annual distances travelled are reported.

To overcome these limits of BdF I apply statistical matching techniques to impute variables from EL and ENTD. 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 analysis of the distributive effects of energy taxation in France. Matching these surveys enables first to enrich the already large database by adding variables relevant to study housing energy consumption and fuel poverty, and second to correct the distribution of transport fuels consumption. Comprehensive methodological guidelines for matching procedures can be found in a recent Eurostat report [29] and in a series of contributions by D'Orazio and coauthors [17] and [16] on which this work builds. The procedure used in this paper as well as some of the outputs are given in appendix (see section A.3 and figures 11 and 12).

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

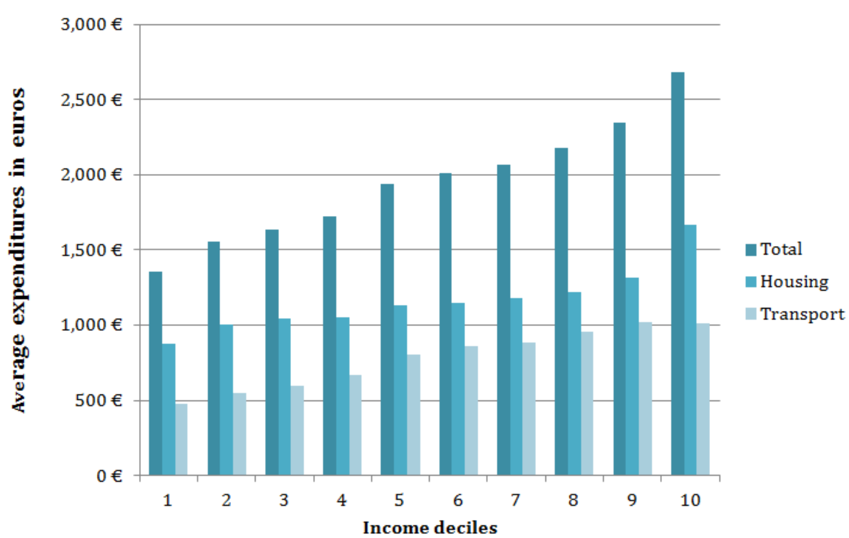
3 Households and energy consumption: a descriptive approach

Before turning to the policy evaluation, one might first want to use the previously constructed database to get an overview of French households' energy consumption patterns. In the following, I compare different groups with respect to their energy expenditures, contribution to energy taxes and CO_2 emissions. All results presented are representative of the reference year, 2016. As we will see, the patterns are similar to what we generally observe in other OECD countries.

3.1 Who consumes energy?

Figure 1 plots households' annual expenditures per consumption unit (c.u.) in energy goods by decile of standards of living in 2016. For the construction of these groups, standards of living are computed as the households' disposable income per consumption unit. For simplicity we consider them as income deciles in the discussion. 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.

Figure 1: Households' annual expenditures in energy per c.u. in 2016, by income decile



Lecture: In 2016, households belonging to the first income decile spent on average 1,353€ in energies per consumption unit, including 873€ for housing energies and 480€ for transport fuels.

If we now consider the share of disposable income spent in energy consumption, we get a completely different picture: it is decreasing with income. The same result is found when looking at the effort rate on energy taxes, i.e. the share of their budget spent by households in energy taxes. Due to the high degree of complexity of taxes on gas and electricity[6] I focus here on transport fuel taxes. As pictured in figure 2, using disposable income as denominator the transport fuel tax is overall regressive, although not strictly: low-income households spend a larger share of their income in contribution to this tax than wealthier households. Interestingly, when taking total expenditures as denominator instead, the pattern is completely changed: it takes the form of an inverted U-shape and the income deciles who contribute the most are the fifth and sixth (figure 2). Thus, the choice of the denominator leads to very different policy implications. Which of these two figures is the most relevant is not obvious. The trade-off between these two methods has originally been discussed by Poterba (1989) [42] and Metcalf (1999) [34] who argued, following the permanent income hypothesis, that lifetime income is better reflected by the expenditures approach. A recent OECD paper (2015) [21] 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, self-employed and retired people, borrowings and savings create a large discrepancy between their income and their standards of living. Nevertheless, because in BdF expenditures are reported on a short period of time, it may be a noisy representation of the actual standards of living. When considering large enough households groups, the noise should average out and the results be unbiased. In these situations it will be interesting to compare the two approaches and highlight their respective implications. However when considering households individually - e.g. when sorting them into deciles or when identifying those subject to fuel poverty as in section 6 - the disposable income will be preferred to measure standards of living.

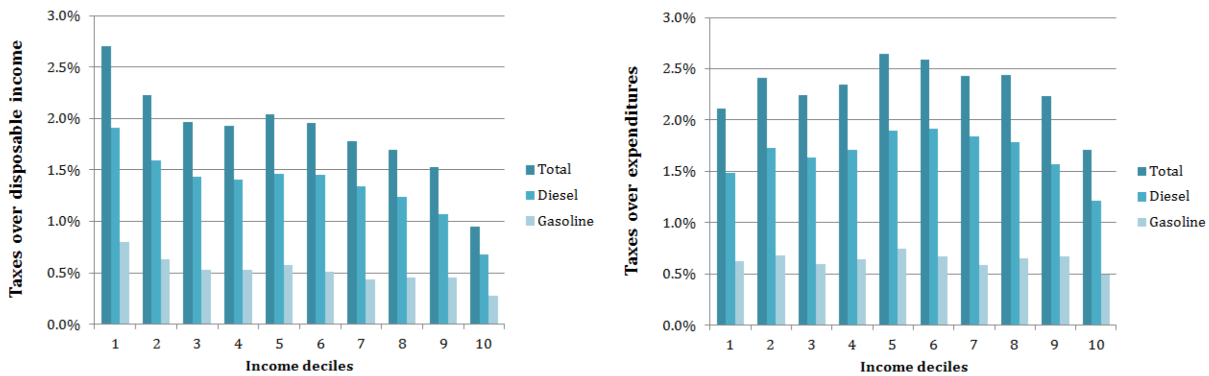
Considering households' geographical location[7] (see figure 13 in appendix) it also appears that those living in rural areas and smaller cities spend on average more in energy, both for transports and housing. The average expenditures for rural households amount to 2,424€ a year per consumption unit 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 analysing the incidence of tax policies. If we now distinguish by age groups[8], 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 observation is that this decline comes entirely from transport fuels while housing energy expenditures continue to increase. This pattern could be explained through other dimensions highly correlated with age, such as income

[6] These energies are priced through two-part tariffs, and subject to numerous taxes, some of them varying according to geographical criteria. It is therefore difficult to reconstruct current individual contributions. This however will not prevent to compute the additional contributions following the new carbon tax that only depend on quantities consumed.

[7] The classification proposed here is based on the size of the urban unit.

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

Figure 2: Households' effort rate on the fuel tax using disposable income (left) and total expenditures (right), by income decile



LECTURE: In 2016, households belonging to the first income decile were paying 2.7% of their disposable income in fuel taxes, but as a share of their annual expenditures it represented only 2.1%.

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. If they keep the same accommodation, and in addition are more present at home, they may in fact increase their energy consumption.

3.2 Who pollutes?

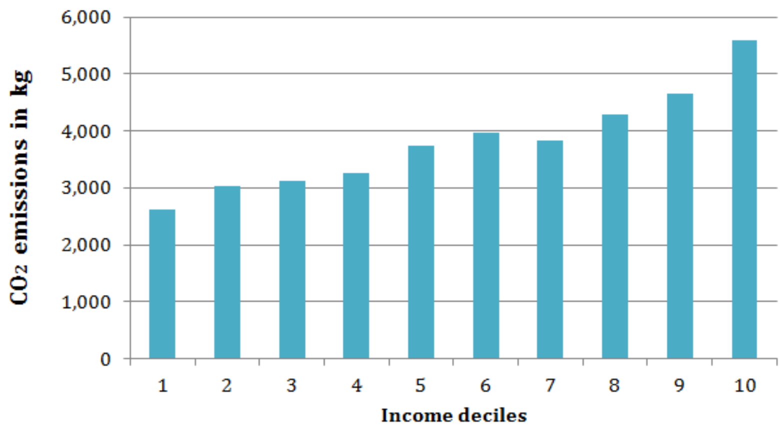
Another concern of importance is the level of CO_2 emissions and how it varies for different household groups. Emissions are calculated from the quantities of each energy consumed by households[9]. For electricity and gas, these quantities are obtained by matching households to energy contracts. The details of the procedure are given in section A.2 in appendix.

Comparing annual emissions by income deciles (see figure 3) we see a strictly increasing pattern meaning that households with higher income emit more CO_2 on average. In particular, households in the last income decile generate on average twice as much emissions as those in the first. This pattern is almost entirely due to the higher consumption of energies of high-income households, and to a lower extent to the fact that these households consume on average more carbon-intensive energies. Figures 14 in appendix depict emissions by geographical area, age group and heating mode. They show that on average rural households emit more than urban, that emissions increase with age up to the sixties and then decrease, but more strikingly that households heating with domestic fuel pollute almost three times

[9]To this end, I use parameters of average carbon emissions per quantity of resource used from the French environmental agency (Ademe).

more than those heating with electricity. As a consequence, richer and rural households, as well as those using fuel and to a lesser extent gas for heating will be more likely to bear a high cost of a carbon tax, although as a share of their income this picture might change.

Figure 3: Households' annual CO_2 emissions from energy consumption per c.u., by income decile



LECTURE: In 2016, households belonging to the first income decile were emitting on average 2,614kg of CO_2 per consumption unit from their energy consumption.

4 Estimating households' responses to prices

4.1 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 analysing 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) [50]). 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) [14] 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 generalised to account for heterogeneity in preferences through the inclusion of demographic variables as described in Poi (2012) [41]. I estimate the model on three categories of goods (i.e. $k = 3$). The first is transport fuels that includes diesel and gasoline[10]. 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 Insee according to the period of the survey. As Nichèle and Robin (1995) [37], I take the last three

[10] For the decomposition between the two goods, see appendix A.1

surveys - 2000, 2005 and 2011 - for a total of 20 periods[11] 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) [30]). 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

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

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) [26] 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. I therefore 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.

In order to check the robustness of the results, I also estimate alternative specifications where I do not use personalised 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. 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) [28]. Elasticities are given at the sample mean, but conditional elasticities can be calculated

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

for specific households groups. I therefore allow for heterogeneity in responses by computing elasticities for households in each income decile within each of the five geographic categories (city size), hence a total of 50 different groups.

4.2 Results

Table 1 reports income and uncompensated price elasticities for four specifications, with the 95% confidance 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[12]. On French data, Combet et al (2009) [10] found transport and housing energies elasticities of respectively -0.5 and -0.11 on time series data. Using BdF 2005 Clerc and Marcus (2009) [9] 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) [7] finds a more conservative estimate for transport fuels of -0.22. From BdF 2001, Ruiz and Trannoy (2008) [46] found uncompensated 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) [2] 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.

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 5 in appendix. Overall, it appears that for both types of energies elasticities are (in absolute value) decreasing with income. For transport fuels, elasticities are similar across groups except for Paris where they are expected to be significantly lower. For housing, households living in larger cities are also expected to have weaker reactions to prices. For Paris, this elasticity is even expected to be positive for the 8 richest income groups. This 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

[12] For a meta-analysis of common estimates in the literature, see Espey (1996) [20] for transports and Espey-Espey (2004) [19] for electricity.

Table 1: 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;-0.34]
elas. unc. housing	-0.21	-0.21	-0.14	-0.17
	[-0.27;-0.16]	[-0.26;-0.15]	[-0.24;-0.04]	[-0.27;-0.07]
elas. unc. other	-1.03	-1.03	-0.97	-0.97
	[-1.04;-1.01]	[-1.04;-1.01]	[-1.01;-0.92]	[-1.01;-0.92]
elas. exp. transport	0.48	0.54	0.46	0.52
	[0.44;0.53]	[0.52;0.56]	[0.41;0.50]	[0.51;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;0.48]
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]

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

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 losses incurred by these richer households and therefore the heterogeneity in gains and losses.

Several implications can be deduced from these results. First, if low-income households react more strongly to prices - which is consistent with a higher constraint over their budget - they will soften the monetary impact of the policy through a higher adjustment in consumption. Second, these elasticities also indicate that the welfare cost of the policy for low-income households could also come from a higher privation in energy consumption. If some of these households 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. Thus, to perform a comprehensive evaluation of the welfare impacts of the policy, one should not restrict his attention to monetary effects only. The response to prices in terms of quantities will also have important welfare effects.

5 Environmental and distributive effects of energy taxes

This section together with the following are the core of this article. Using heterogeneous elasticities computed as described in the previous section, I evaluate the environmental and distributive effects of the French reform of energy taxes for 2018. Taking 2016 as the reference year - i.e. all variables are inflated to represent consumption and incomes at that period and the reference legislation is the one of 2016 - 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[13]. I first consider the environmental effects as well as the changes in quantities consumed, and then turn to monetary effects.

5.1 The effects on quantities and emissions

The primary objective of the policy is to reduce the negative environmental impact of energy consumption. I therefore start by evaluating the extent to which it could contribute to reduce 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 effect on emissions. Table 2 summarises the effects by energy. The method for computations is developed in appendix.

The policy is expected to reduce GhG emissions by more than 3 millions of tons of equivalent CO_2, that is slightly more than 0.6% of French annual emissions, and around 1.5% of emissions due to transports and residential sectors[14]. By comparison, between 1990 and 2013 emissions have decreased by about 11% in total but have increased for transports and residential sectors by respectively 12% and 11%, hence an average rate of $+0.5\%$ a year. Abstracting from efficiency gains due to higher incentives to invest in low-consumption technologies, the expected environmental impact of the policy is therefore rather small but still significant. 71% of the effects are expected to come from transports, the rest being due to reduction in housing energies consumption. Interestingly, diesel is by far the energy contributing the most, with expected reductions seven times superior than gasoline. This is due to a combination of factors among which the larger share of diesel in the French vehicle fleet, the higher tax imposed on diesel by the policy, and the higher elasticity of its consumers who on average, relative to consumers of gasoline, are larger and younger households, more numerous in rural areas, and drive longer distances. The direct implication

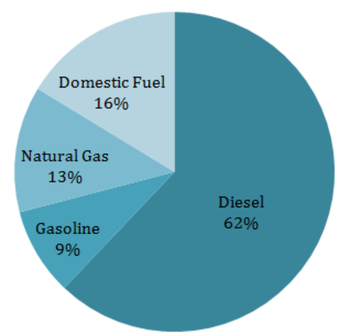
[13] To give an idea, the carbon tax should increase the price on domestic fuel from 0.706€ to 0.779€ per litre, excluding the indirect effect on VAT. For diesel, together with the additional adjustment tax, the price is expected to increase from 1.11€ to 1.19€. Note that excluding indirect effects on VAT is akin to suppose a partial shift of taxes to prices of around 80%, which seems a very realistic assumption.

[14] 497.8 Mt equivalent CO_2 in 2013, developpement-durable.gouv

is that, with respect to consumption, these consumers will face a higher welfare cost due to the policy. Indeed, as shown in figure 4 diesel consumers are expected to adjust their consumption around twice more than gasolines'. Interestingly, the split between diesel and gasoline being approximately constant across income groups, the heterogeneity of the impact will be due to factors largely unrelated to income. Looking at housing energies, we also observe that the reduction in emissions due to domestic fuel is more important than natural gas, while only 14.6% of households consume this energy in the sample against 41% for natural gas. This very important contribution is partly explained by the high carbon content of domestic fuel, but is also due to the higher elasticity displayed on average by households consuming this energy.

Table 2: Annual reduction in CO_2 emissions by energy, in thousands of tons

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



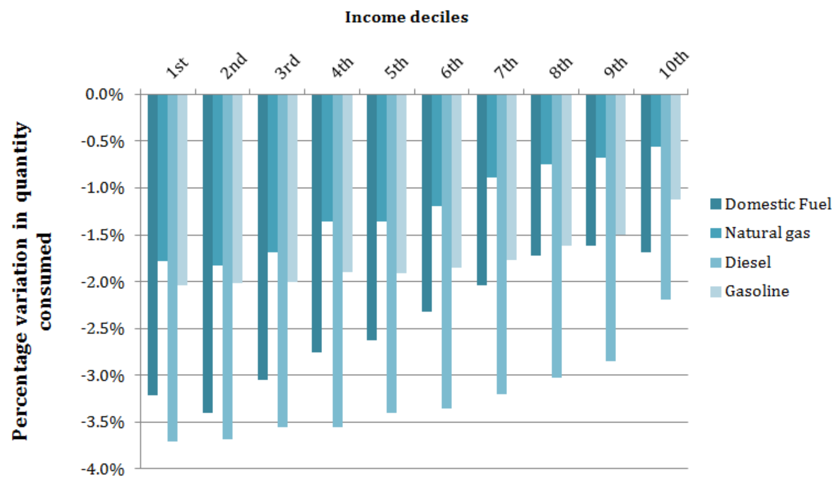
Lecture: Following the policy and holding technology constant, CO_2 emissions from diesel are expected to decrease by 1,893 thousands of tons in 2018 compared to 2016. It corresponds to 62% of the reductions expected for all energies.

From these observations follow important welfare implications. The reduction in energy consumption represents a welfare cost for households. The heterogeneity in this matter implies therefore that the burden will not be equally shared. As shown on figure 4 this welfare cost will be larger for lower-income households, but the within-decile heterogeneity suggests that income will only be one of the dimensions determining the distribution of the welfare effects of the policy.

5.2 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) [43], Metcalf (1999) [34], Grainger and Kolstad (2010) [23]). 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

Figure 4: Average reduction in energy quantities consumed among consumers, by income deciles



Lecture: Households consuming domestic fuel and belonging to the 2nd income decile are expected to reduce their consumption by 3.4% following the policy.

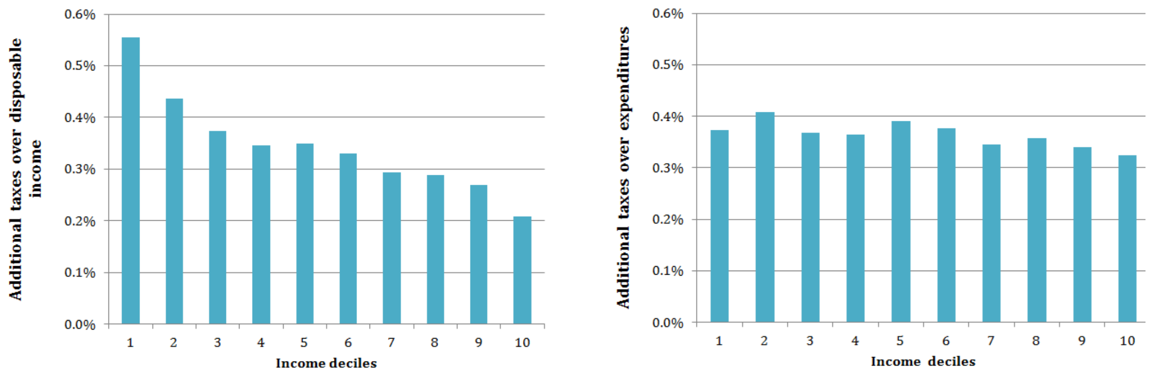
policies, this needs to be taken into account by policy makers.

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 5. However, this holds only when considering disposable income as the denominator. When using total expenditures instead, 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, but these figures still show that energy taxes might be less regressive than what is often assumed.

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) [50], Bureau (2011) [7], Williams et al (2015) [52]). For this reason, the French government has decided to redistribute part of the revenue through energy cheques directed towards low-income households on the basis of their size and fiscal income. These cheques can then be used to pay energy bills or to replace old installations such as oil-fired boilers. They replace social tariffs on energies that used to allow for a discount on energy bills for low-income consumers. The exact scale and conditions for eligibility are given in appendix (see table 8). Since these cheques should only represent less than one tenth of the total revenue of the policy[15], I had to make an assumption about the way the rest of the money will be

[15] From the model I find an annual revenue for the 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 effort rate on the policy, by income decile



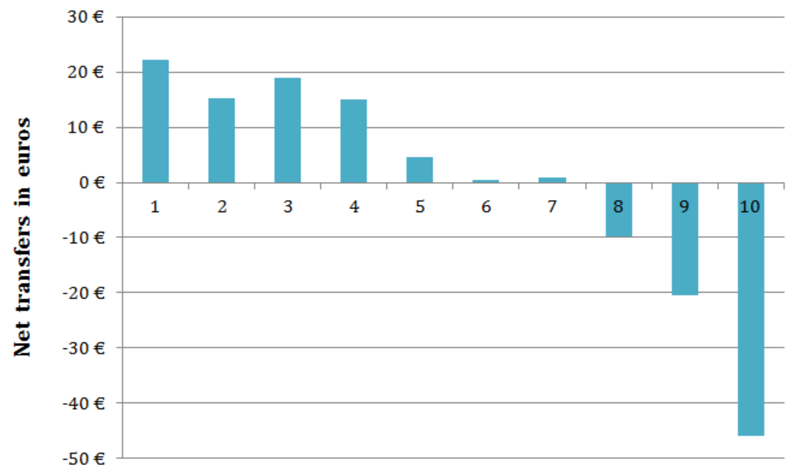
Lecture: For households belonging to the 1st income decile, the increase in energy taxes following the policy will represent 0.55% of their disposable income, against 0.21% for those in the last income decile. As a share of their total expenditures, it represents respectively around 0.37% and 0.32%.

spent in order to simulate a budget-neutral reform. Assuming it will be equally spread across individuals - which would be the case if the government was financing an equally valued public good - we obtain a progressive policy, although not strictly, as illustrated by figure 6. 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 we can use the revenue to compensate low-income households. Beyond this general finding and looking specifically at the French policy, one should still keep in mind that this result holds under the assumption of an equal split of the revenue that remains after energy cheques. As shown in several studies (e.g. Dinan (2012) [15], Williams et al. (2015) [52]), if the government seeks for a double dividend and uses this revenue to lower labour or capital taxes instead, the pattern could be different.

5.3 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 individuals with equivalent income - is still scarce, although growing. In its 1991 paper Poterba [43] first highlighted the disparities in gasoline consumption among households with similar income. More recent contributions such as Rausch et al. (2011) [44], Pizer and sexton (2017) [40] and Cronin et al (2017) [13] 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) [36], Kaplow (2000) [27]), one must still recognise that these effects are perceived as negative by society and could dampen the

Figure 6: Average net transfers per c.u. after revenue recycling, by income decile



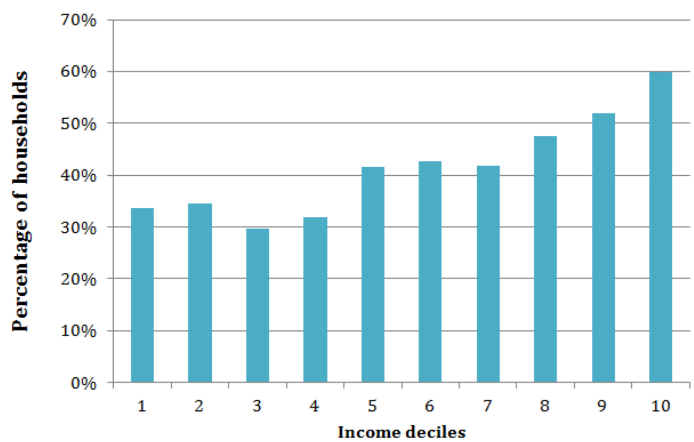
Lecture: On average, households belonging to the first income decile will receive an annual net transfer of 22€ after revenue-recycling, against -46€ for those in the last income decile.

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 minimise any distributive effects, including between households with similar incomes.

To investigate horizontal distributive effects, one might first look at the share of households financially losing from the policy within income groups. Figure 7 shows that even within the three first income deciles, there are around a third of households expected to receive negative net transfers from the policy. 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 8 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.

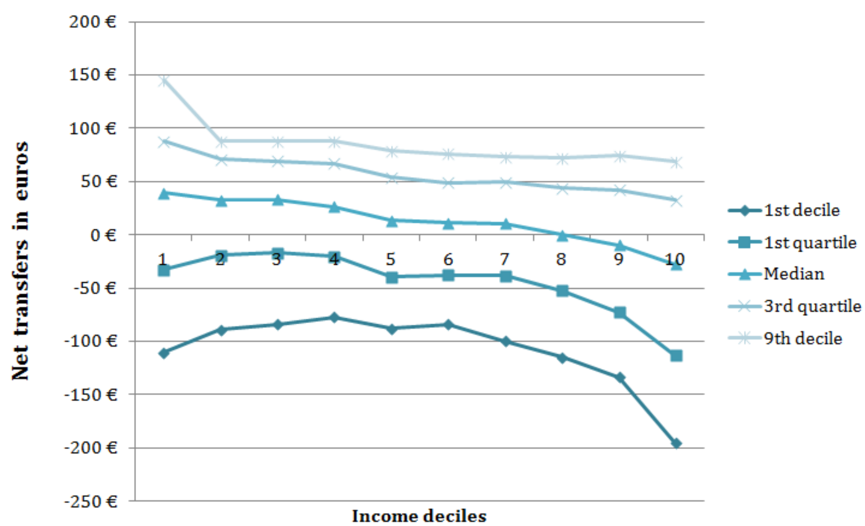
To sum up, these figures clearly show that horizontal heterogeneity is in magnitude much more important than vertical heterogeneity. Given that the relative importance of the two effects on welfare is rather uncertain, policy makers face a difficult challenge. If on the one hand vertical equity is enhanced through

Figure 7: Share of households financially losing from the reform, by income decile



LECTURE: After revenue recycling, 34% of households belonging to the first income decile are expected to receive negative net transfers from the policy.

Figure 8: Distribution of households' net transfers per c.u., by income decile



LECTURE: After revenue recycling, 25% of households in the first income decile are expected to lose more than 32€ in net transfers per consumption unit due to the policy.

a progressive policy, and on the other hand the policy creates additional horizontal distributive effects, they may find difficult to conclude about the global impact on welfare. To evaluate the acceptability of a policy, they may therefore look for new tools to assess the incidence on the most vulnerable households.

6 Multidimensional distributive effects and fuel poverty

6.1 A simple indicator for welfare evaluation: fuel poverty

Interestingly, the preceding remarks can be related to a puzzle in environmental policies. While fuel poverty has become a very popular concept in the public sphere, economists have tended to let it aside. The lack of theoretical grounds and the necessarily arbitrary thresholds used in these indicators have made them reluctant to use this concept. Also, by focusing on vertical equity they usually tend to see fuel poverty as only a sub-problem of poverty. The discussion that follows will show that nonetheless, fuel poverty indicators are useful tools for aggregating the complex multi-dimensional households' heterogeneity and measure the welfare implications of environmental taxes with respect to equity.

Building on the work of the French observatory for fuel poverty (ONPE, 2014) [38] I define an household as being fuel poor in housing if it satisfies at least one of three criteria. The first is the standard effort rate on energy (ERE) and considers an household fuel poor if it spends more than 10% of its budget in housing energy, and belongs to one of the three first income deciles. The second is the Low Income High Consumption (LIHC) indicator inspired by the work of Hills (2012) [25] who considers an household to be fuel poor if it spends more in energies than the median consumer, and is below the poverty line defined as 60% of the median income. These two measures must identify households who reduce their budget on potentially necessary goods in order to satisfy their energy needs. The third and last criterion identifies households as fuel poor if they belong to one of the three first income deciles and declare to have felt cold (FC indicator thereafter) in their accommodation during winter for financial reasons[16]. Contrary to the two first measures, this third indicator should capture people who cannot satisfy their energy needs because their budget is already tight. Similarly, I define households to be fuel poor with respect to transports if they satisfy the first two previous criteria, where energy expenditures are those related to transports instead of housing. As privation with respect to transport fuels consumption is harder to define (see Berry et al (2016) [3]), I let aside this dimension and focus on the financial burden only.

The fuel poverty indicator I consider results therefore from both arbitrary choices and subjective information. In addition, the first two criteria would ideally suppose to compute theoretical demands in energy for households, that is their energy consumption necessary to satisfy their basic needs. Instead, the data used in this study report actual energy consumption that may exceed these needs. Nonetheless, I will argue that this indicator is relevant to study the welfare implications relative to the distributive

[16] In EL households are asked the reasons why they felt cold. I consider as financial reasons when they felt cold either because energy was too expensive, their heating installation is inefficient, their thermal isolation is of too poor quality, or they were cut from heating energy because they did not pay their bills.

effects of environmental taxes. Indeed, the indicator is useful as it recognises the multi-dimensional nature of the problem. As we have seen, the distributive effects of environmental taxes are not just a matter of income. Other dimensions on which households may be constrained - e.g. distance from work, thermal isolation, type of energy used for heating - are also key to understand these distributive effects. The LIHC and ERE enable to synthesize the interplay between all these dimensions through their impact on energy consumption. And although reported expenditures may not correspond to theoretical basic needs, considering households in the three first income deciles we can assume that such high levels of expenditures will crowd out other basic needs, implying a high welfare cost. The second advantage of this concept is to take into account privation behaviours. The extent to which privation could be aggravated by the tax is indeed captured by the FC criterion. This point is of particular interest when households display heterogeneous responses to taxes. Relative to measures of the loss in consumer surplus (see for instance Parry (2015) [39]), it has the advantage of focusing on the most vulnerable households without making unrealistic assumptions on the form of the demand function. Energy being a basic need for low consumption levels, there may be threshold effects in terms of welfare when households cut their consumption below a certain level. This can hardly be accounted for when looking at consumers surplus with one unique and linear demand curve. Finally, the fuel poverty indicator recognises that variations in budget and quantities consumed have higher welfare implications for low than for high income households. If acceptability depends on Rawlsian criteria, i.e. on the outcome of the most vulnerable households, then the fuel poverty indicator is an interesting tool for policy evaluation, and a good barometer for the acceptability of a policy.

6.2 Fuel poverty and public acceptability

From BdF data inflated for 2016, I estimate that around 3.7 millions French households were fuel poor with respect to housing, and almost 1.6 millions with respect to transports where I do not account for privation. The union of both sectors gives almost 4.4 millions households fuel poor on at least one of these dimensions - i.e. 15.5% of the population - and the intersection 0.9 millions. Thus, we see that although fuel poverty has different determinants for housing and transports, the two are not completely orthogonal since 57% of transports fuel poor are also housing fuel poor. Decomposing the indicator in its several components and comparing households by group (see figures 15 to 17 in appendix), we essentially see that households that are older, heating with domestic fuel or living in rural areas are by far less prone to be fuel poor because of the cold but are also much more likely to be fuel poor on the basis of the effort rate. Conversely, young households as well as people living in large cities (Paris excluded) are more subject to the cold. With respect to transports, young households are the most exposed to fuel poverty, but surprisingly the same cannot be said of rural households who on average are not more likely to be fuel poor than households living in large cities. Finally, on both transports and housing lower income households are the most likely to be fuel poor even within the three first income deciles.

Turning to the policy, I look at the expected transfers received by fuel poor households. Figure 9 decomposes the distribution of net transfers in several quantiles. It shows that while a short majority of fuel poor households are expected to win financially from the policy, the effect is heterogeneous and some of them are expected to face an important financial burden. In particular, aggregating these transfers fuel poor households are expected to lose on average, and 35% of them are expected to lose more than the median household in the top income decile. The ones that were already in the worst situation with respect to energy consumption are therefore expected to bear large costs from the policy. If society's acceptance of a carbon tax depends on its effects on the most vulnerable, the current mechanism clearly fails to meet this Rawlsian objective.

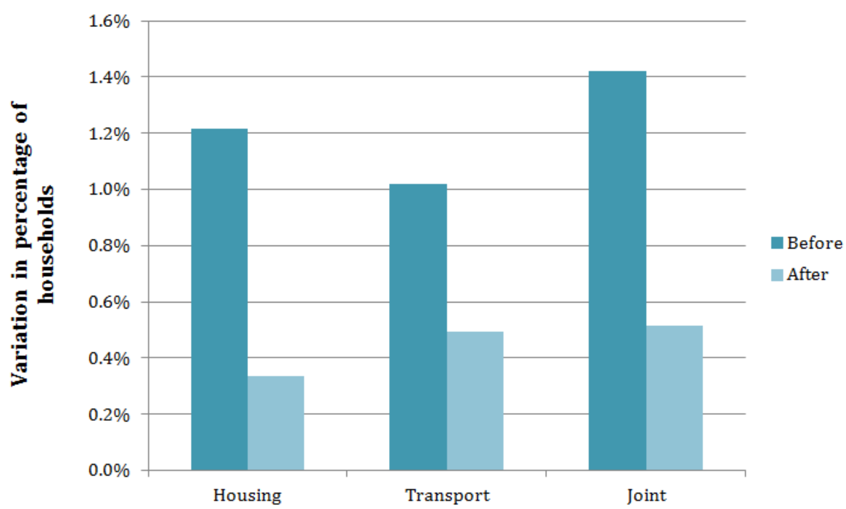
With respect to the number of fuel poor, I estimate the variation by computing the indicators with the new expenditures. Thus, ignoring the effects on the FC and focusing on the LIHC and ERE, I find that prior to revenue recycling the number of fuel poor households is expected to increase by 1.2% in housing, 1.0% in transports and 1.4% for the joint fuel poverty. After revenue recycling however, this number substantially decreases. Since energy cheques are intended to pay housing energy bills, the main result is that housing fuel poverty is reduced and only increases by slightly more than 0.3% relative to the reference situation. Since the remaining of the revenue is assumed to be a neutral lump-sum transfer, fuel poverty with respect to transports will also be affected but less significantly. After revenue-recycling the increase in the number of transports fuel poor households slightly falls to 0.5%. In the same way, the number of households being either transport or housing fuel poor is expected to increase by only 0.5%. In the end, the effect of the policy on the number of fuel poors is of very small magnitude and can be assumed not significant.

In order to do a comprehensive assessment of the policy, one must also look at its expected effect on the FC indicator. Indeed, as suggested by figure 18 in appendix, the increase in fuel poverty following the policy is largely softened by the fact that households react to prices by decreasing their consumption. Focusing on monetary indicators without taking into account privation behaviours therefore leads to underestimate the impact on fuel poverty. To assess this second effect, I estimate a logit model to predict FC households as a function of their energy consumption in kilowatt per hour and their income (see table 6 in appendix). I then aggregate individual likelihoods to get an estimation of the expected number of households subject to the FC indicator, and replicate the exercise using quantities and income after the policy. However, I cannot find any significant effect of quantities consumed on the FC indicator. This is due to the high endogeneity of the quantities since higher likelihood of feeling of cold usually comes together with higher energy consumption. By controlling for numerous characteristics I can partly reduce

Figure 9: Net transfers received by fuel poor households after revenue-recycling, by quantiles

Lecture: After revenue-recycling, 10% of fuel poor households are expected to lose more than 135€ in public transfers, and 10% are expected to gain more than 100€.

Figure 10: Change in the number of fuel poor households after the policy, before and after revenue-recycling



Lecture: After revenue recycling, the number of fuel poor households is expected to rise by 0.49% with respect to transportation fuels.

this bias, but it is still insufficient to get reliable results. Yet, this exercise remains useful as it enables to identify through the control variables the households most likely to be subject to the FC indicator. In particular, we see that everything else equal, going from a low to a high quality of isolation for walls would decrease the likelihood of being subject to FC by almost 27 percentage points. Similarly, having a majority of double glazing would decrease the likelihood by 7.1 percentage points. This result tends to suggest that increasing incentives to invest in energy efficiency could be an efficient policy to reduce fuel poverty.

With respect to other characteristics we also see that, everything else equal, owners are by far less likely to be cold (-5.2 percentage points) while living in individual accommodation increases this probability (+2.7 percentage points). Households size as well as the number of members in the labour force have no significant effect, but surprisingly being a student decreases very significantly the likelihood of being subject to FC (-14.4 percentage points). On the geographical dimension, it appears that living in a medium or large size city is expected to increase the likelihood of being subject to FC relative to rural areas and smaller cities, and to a lesser extent Paris. Considering climate, living in more temperate regions (west and south of France) is expected to decreases the likelihood (-2.6 percentage points). Finally with respect to the energy used, the choice of domestic fuel has no significant impact relative to electricity, but using natural gas would increase the likelihood by 5.1 percentage points.

6.3 The determinants of within-income group distributive effects

From the preceding analysis, it appears that the multidimensional heterogeneity of households matters for the welfare associated to energy consumption. One can then wonder whether we can identify specific determinants of the tax incidence that could be accounted for in the policy design to improve acceptability. Cronin et al (2017) [13] stress the importance of the income composition but do not have information on other relevant households characteristics. Rausch et al (2011) [44] point toward 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) [40], 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 (see table 7 in appendix). 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 four different specifications including (1) the heterogeneous elasticities used above, (2) homogeneous elasticities computed using the SL price index and (3) without the SL price index, and (4) a fourth case without elasticities. Overall, the results are similar although the fourth 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 will imply 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 again 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. On the geographical dimension, we see that living 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, the impact is rather small. The distributive effect 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 can observe a clear link between age and energy consumption (see figure 13 in appendix), 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, unobservable 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. In particular, it is unclear whether using targeted lump-sum transfers to compensate households depending on characteristics other than income can solve this issue.

6.4 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 standard cheques are lowered such that total transfers stay the same. I restrict my attention to these dimensions because they are among the most important determinant 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 3 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 significantly the spread and even slightly increase it for the second and third deciles. 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. When targeted according to the heating mode however, these cheques outperform the official ones, in particular for the first income group. If not solved, horizontal distributive effects are softened by this mechanism. Considering fuel poor households, we also see that targeted transfers based on energy mode reduce the spread of the transfers they are expected to receive (see table 4). If they also seem to contribute to increase more the number of fuel poor households (see table 9 in appendix), this last result is not significant as too few households are making the transition in or out of fuel poverty.

Table 3: 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 first income decile is expected to be 120.4€ per consumption unit.

Thus, if policy makers' objective is to reduce the distributive effects of the policy, transfers targeted on heating mode appear to be a more efficient strategy than standard income-based transfers. This result follows from the fact that income is only one of the numerous dimensions determining the distributive effects of energy taxes. By focusing on this dimension only, fiscal policies put aside important distributive effects that can dampen the policy's acceptability. However, these benefits should be weighted against

Table 4: Net transfers per c.u. received by fuel poor households, by quantiles, for alternative revenue-recycling scenarios

	0.1	**0.25**	**0.5**	**0.75**	**0.9**
Official	-135.3€	-64.1€	9.4€	63.6€	100.5€
+ **Rural**	-136.0€	-63.4€	10.1€	65.1€	100.4€
+ **By energy**	-125.7€	-54.5€	10.7€	59.3€	87.9€
+ **Rural** + **By energy**	-125.7€	-53.6€	12.0€	59.1€	87.9€

Lecture: If revenue recycling is partly targeted towards rural households, we may expect that 25% of fuel poor households will lose more than 63.4€ in net transfers.

the costs of these mechanisms. In particular, as these transfers would introduce incentives not to switch technologies for households polluting more, it would reduce the potential 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.

Given the importance of horizontal distributive effects of energy taxes, standard income-based transfers alone seem insufficient to solve the acceptability problem. One must therefore think of policies that could reduce horizontal transfers without distorting incentives to reduce pollution. To this aim, the solution proposed by the French government to extend energy efficiency credits to the replacement of old boilers, and to enlarge the scrapping premium to renew the vehicle fleet, could be efficient. This policy would again target households with high carbon emissions, but by helping them to reduce their pollution instead of financially compensating the associated costs. As such, we can expect this policy to reduce both polluting emissions and horizontal distributive effects. Also, as we have seen, thermal isolation is the main determinant of the feeling of cold in the accommodation. Improving isolation quality could therefore generate large welfare benefits. Unfortunately, given the difficulty to estimate the effects of such policy on the transition in heating technologies 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.

7 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. However, returning the revenue through lump-sum transfers targeted towards poor households make the policy progressive. I then stressed the existence of horizontal equity issues that are in magnitude much more important than vertical ones. To synthesize these multiple effects, I argued that one can use a fuel poverty indicator. When households differ on multiple-dimensions, it enables to better identify the most vulnerable with respect to energy consumption than considering all low-income households. Based on this indicator, I have shown that a significant share of these households are expected to bear a large burden from the policy even after revenue-recycling. This raises the concern that although progressive, this policy could face a low acceptability.

Thanks to the micro-simulation approach, I have then characterized the main determinants of the tax incidence. Among the many drivers identified, the energy used for heating as well as the geographic location are the most important variables to determine horizontal distributive effects. Using these criteria to construct targeted transfers, we have seen first that when indexed on the geographic criterion these transfers had almost no effect on horizontal equity. However, when indexed on the heating energy instead they are expected to significantly soften horizontal distributive effects. This holds both considering all low-income households, and more specifically fuel poor households. However, these benefits should be weighted against the costs of this strategy. Not only this mechanism could generate bad environmental incentives, but people may care more about the horizontal equity of the policy itself than of the policy output. A maybe more appealing strategy could thus be the one proposed by the French government: by giving financial incentives to improve energy efficiency, one can expect to lower both emissions and distributive effects. Together with income-based transfers towards the poorest households, this policy could potentially be more efficient to improve public acceptance. However, the cost-effectiveness of this mechanism to tackle both polluting emissions and distributive effects needs to be assessed.

Although this study focused on a specific French 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 are not dramatically different in France compared to other OECD countries. It would nonetheless be interesting to replicate this study to other countries. In particular, if for European Union countries electricity is taxed on the EU-ETS market, the inclusion of electricity for other countries could lead to new interesting results.

Appendices

A Methodological comments

A.1 Computing the current effort rate on the fuel tax

In order to determine households' contributions to transport fuel taxes that differ for diesel and gasoline, I have used information on the vehicles owned by each household to separate fuel expenditures into these two different goods. Data from aggregate consumption are then used to determine how much a household with x diesel and y gasoline cars spends on average on each of these products. Although imprecise at the household level, when looking at groups this method should not bias the results. The underlying assumption is that across groups, households with the same types of vehicles split their fuel consumption between diesel and gasoline in the same way.

For each type of fuel, I identify the part that is paid in fuel tax. I use the technique detailed in Ruiz and Trannoy (2008) [46] to determine from excise duties and prices the implicit rate of taxation. The final price of transport fuels is such that:

$$q = (1 + t)(p + a) \tag{2}$$

where t is the value added tax (VAT), a the excise duty, q the price including taxes and p the price without taxes. If we define τ as the implicit tax rate of the fuel tax, we have:

$$q = (1 + t)(1 + \tau)p$$

so that

$$\tau = \frac{a}{p} \tag{3}$$

Then because from (2) we have

$$p = \frac{q}{1 + t} - a$$

combined with (3) we obtain:

$$\tau = \frac{a(1 + t)}{q - a(1 + t)} \tag{4}$$

Once the implicit tax rate obtained for each fuel, it is straightforward to infer households contributions to the fuel tax based on their expenditures. Since expenditures are determined by:

$$E = qQ = (1 + t)(1 + \tau)pQ \tag{5}$$

where E is expenditures and Q the quantity consumed, we have

$$E_{wvat} = (1 + \tau)pQ$$

the expenditures without VAT, and

$$C = \tau p Q = E_{wvat} \frac{\tau}{1+\tau} \tag{6}$$

the contribution to the fuel tax that is identified.

A.2 Energy contracts

There exist several contracts for electricity and gas that take the form of two-part tariffs, but information on each household's contracts are not available in BdF. In order to compute quantities for these products, one therefore needs to make few assumptions and impute contracts to households.

The imputation of natural gas contracts was done as follows. First, I have reduced the set of contracts to the regulated prices proposed by the historical company *Gaz de France* (GDF). Although other contracts are available, this subset must reflect rather accurately the order of magnitude of gas prices. Second, using this subset I have computed from households' gas expenditures the quantity they would have consumed if they had subscribed to each of these contracts. Assuming households are rational and can approximately forecast their future consumption, I have matched each household to the contract that would have given him the largest quantity to consume. Thus, households with the largest consumption are matched to the contract with the most expensive fee but the lower variable price, and vice-versa. For electricity, more expensive fix fees are not associated with cheaper marginal prices but with larger power capacities. Matching contracts based on optimal choice would therefore lead to match all households with the cheapest contract. Instead, based on information about the share of households having each type of electricity meter, I ranked households according to their electricity expenditures and matched consumers to electricity meters assuming those who consume the most have a larger electricity meter. As for gas, I also restricted the set of contracts to what is called "blue tariffs", that are also regulated tariffs of the historical company *Electricité de France* (EDF).

It should be noted that this procedure is essential to compute households consumption in quantities as well as their CO_2 emissions. However, marginal prices being close from a contract to another, the results regarding the effects of the policy will not be very sensitive to the choice of the contract.

A.3 Statistical Matching

To make sure households are comparable, I first check the degree of similarity between variables' distribution across surveys. This is done using both visual comparisons such as histograms and numerical measures, in particular the Hellinger distance. This distance is used to reduce the comparison between two distributions to a unique scalar in $[0;1]$. It gives a simple criterion common to all variables. In the case of two discrete distributions it is defined as:

$$d(X,Y) = \frac{1}{\sqrt{2}}\left[\sum_i \left(\sqrt{Pr(X=i)} - \sqrt{Pr(Y=i)}\right)^2\right]^{1/2}$$

A rule of thumb is to consider two distributions as similar if their distance is lower than 5% (see Leulescu & Agafitei (2013) [29]). Keeping only variables exhibiting a very high degree of similarity between samples, I then select common variables for matching according to several criteria. First, using data-mining techniques I determine the sub-sample of variables that taken together give the best predictive power in a regression for the variables I want to impute. I then determine the best specification based on specific *ex post* tests for the matching quality. Figure 11 shows the share of households who declare suffering from cold for a reason related to their budget. It shows that considering different households' groups, the matching correctly reproduces the share of households exhibiting this feature. One can replicate this exercise by considering other groups than those presented. All the results confirm that marginal and conditional distributions are correctly replicated in the matched data-set, both for the housing and transports surveys.

The last criterion to judge the matching quality is the credibility of the *Conditional Independence Assumption* (CIA) on which the matching strategy relies. If one starts with a dataset containing a set of variables Y and X that he wants to match with another dataset containing Z and X, using X as explanatory variables, the CIA implies that all common variations of Y and Z are explained by X. The CIA is a necessary condition to the validity of the matching. Unfortunately, in the absence of exogenous information on the joint distribution of X, Y and Z, there is no empirical test to check whether it is satisfied. One can simply consider its plausibility and the potential risks if it does not hold. Controlling for a large number of households characteristics such as geographical location, household's size, heating mode and many other demographics, we may hope that the assumption is close to be satisfied. In any case, when considering groups of individuals, since conditional distributions are correctly replicated, the results will be robust.

A.4 The Quadratic Almost Ideal Demand System

A.4.1 The QUAIDS model

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

$$\ln V(\mathbf{p}, m) = \left[\left\{\frac{\ln m - \ln a(\mathbf{p})}{b(\mathbf{p})}\right\}^{-1} + \lambda(\mathbf{p})\right]^{-1} \quad (7)$$

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

$$\ln a(\mathbf{p}) = \alpha_0 + \sum_{i=1}^{k} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^{k} \sum_{j=1}^{k} \gamma_{ij} \ln p_i \ln p_k \tag{8}$$

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) [14] 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 that $\sum_i w_i \equiv 1$), 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

$$w_i = \alpha_i + \sum_{j=1}^{k} \gamma_{ij} \ln p_j + \beta_i \ln \left\{ \frac{m}{a(\mathbf{p})} \right\} + \frac{\lambda_i}{b(\mathbf{p})} \left[\ln \left\{ \frac{m}{a(\mathbf{p})} \right\} \right]^2, \quad i = 1, ..., k \tag{9}$$

The aim of the QUAIDS is to estimate this equation for any good i. The estimates obtained for the parameters enable to compute the income and price elasticities with respect to each bundle of goods.

A.4.2 Elasticities

If we differentiate the share equations with respect to the log of expenditures, we get:

$$\mu_i \equiv \frac{\partial w_i}{\partial \ln m} = \beta_i + \frac{2\lambda_i}{b(\mathbf{p})} \left[\ln \left\{ \frac{m}{a(\mathbf{p})} \right\} \right] \tag{10}$$

We also know that

$$\frac{\partial w_i}{\partial \ln m} = \frac{\partial w_i}{\partial m} \frac{\partial m}{\partial \ln m} = \frac{\partial w_i}{\partial m} m \tag{11}$$

If we recall that $w_i = p_i q_i / m$ we find

$$\frac{\partial w_i}{\partial m} = -\frac{p_i q_i}{m^2} + \frac{p_i}{m}\frac{\partial q_i}{\partial m} = -\frac{w_i}{m} + \frac{w_i}{q_i}\frac{\partial q_i}{\partial m} \tag{12}$$

Together with (10) it gives

$$\mu_i \equiv \frac{\partial w_i}{\partial \text{ln} m} = -w_i + w_i \frac{m}{q_i}\frac{\partial q_i}{\partial m} \tag{13}$$

If we rearrange we obtain

$$e_i = \frac{\partial q_i}{\partial m}\frac{m}{q_i} = 1 + \frac{\mu_i}{w_i} \tag{14}$$

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

$$\mu_{ii} \equiv \frac{\partial w_i}{\partial \text{ln} p_i} = \gamma_{ii} - \mu_i \left(\alpha_i + \sum_k \gamma_{ik} \text{ln} p_k \right) - \frac{\lambda_i \beta_i}{b(\mathbf{p})} \left[\text{ln} \left\{ \frac{m}{a(\mathbf{p})} \right\} \right]^2 \tag{15}$$

since

$$\frac{\partial \text{ln} a(\mathbf{p})}{\partial \text{ln} p_i} = \alpha_i + \sum_k \gamma_{ik} \text{ln} p_k \tag{16}$$

and

$$\frac{\partial b(\mathbf{p})}{\partial \text{ln} p_i} = \beta_i b(\mathbf{p}) \tag{17}$$

If we recognize that

$$\frac{\partial w_i}{\partial \text{ln} p_i} = \frac{\partial w_i}{\partial p_i} p_i \tag{18}$$

and recalling that $w_i = p_i q_i / m$ we find

$$\frac{\partial w_i}{\partial p_i} = \frac{q_i}{m} + \frac{p_i}{m}\frac{\partial q_i}{\partial p_i} = \frac{q_i}{m}(1 + e_{ii}^u) \tag{19}$$

and making use of previous results we obtain

$$e_{ii}^u = \frac{\mu_{ii}}{w_i} - 1 \tag{20}$$

Differentiating w_i with respect to $\text{ln} p_j$ instead, we obtain a similar result except that now we have

$$\frac{\partial w_i}{\partial p_j} = \frac{\partial q_i}{\partial p_j}\frac{pi}{m} \tag{21}$$

which after some calculations implies $e^u_{ij} = \frac{\mu_{ij}}{w_i} - \delta_{ij}$ where δ_{ij} is the Kronecker delta whose value is 1 if $i = j$ and 0 otherwise. The budget and uncompensated price elasticities are then respectively $e_i = \frac{\mu_i}{w_i} + 1$ and $e^u_{ij} = \frac{\mu_{ij}}{w_i} - \delta_{ij}$.

A.4.3 Estimation

Estimation is performed using the Stata package *aidsills* introduced by Lecocq and Robin (2015) [28]. 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) [41]) because the latter does not provide standard errors, and does not enable to instrument expenditures.

A.5 Measuring the impact of policies

The policy simulated in the paper introduces an additional excise duty on the consumption of energy goods. It therefore increases their price by a certain amount. If we denote E the level of expenditures before the policy, and dE the variation in expenditures due to the policy, we have the level of adjusted expenditures $E' = E + dE$ with, by log-differentiation of $E = PQ$ where P is the price and Q the quantity,

$$\frac{dE}{E} = \frac{dP}{P} + \frac{dQ}{Q} \tag{22}$$

hence

$$\frac{dE}{E} = \frac{dP}{P} + \frac{dP}{P}\frac{dQ}{dP}\frac{P}{Q} = \frac{dP}{P}(1+e) \tag{23}$$

where e is the price elasticity of the good. It follows that

$$E' = E + dE = E\left(1 + (1+e)\frac{dP}{P}\right) \tag{24}$$

To compute adjusted expenditures, I use the heterogeneous elasticities computed from the QUAIDS, and for dP I take the additional amount of excise duties imposed by the policy. This is akin to suppose that the tax burden falls almost entirely on consumers. It is only *almost* since it does not include the increase in the VAT tax base. For diesel and gasoline, on US data, Marion and Muehlegger (2011) [32] found that taxes are in general fully-passed onto consumers. Carbonnier (2007) [8] 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.

Given that households will receive transfers after the policy, one could argue that these will affect their expenditures. This would in turn change the revenue of the tax, hence the transfers and so on. In the paper I focus on the first order effect of the policy and do not look for the fix point of the problem. Indeed, the transfers are of little magnitude relative to households resources (0.55% of households' total expenditures on average), and expenditures elasticities being around 0.5 for energy goods, the impact of revenue recycling on energy consumption is not significant.

A.6 The official policy

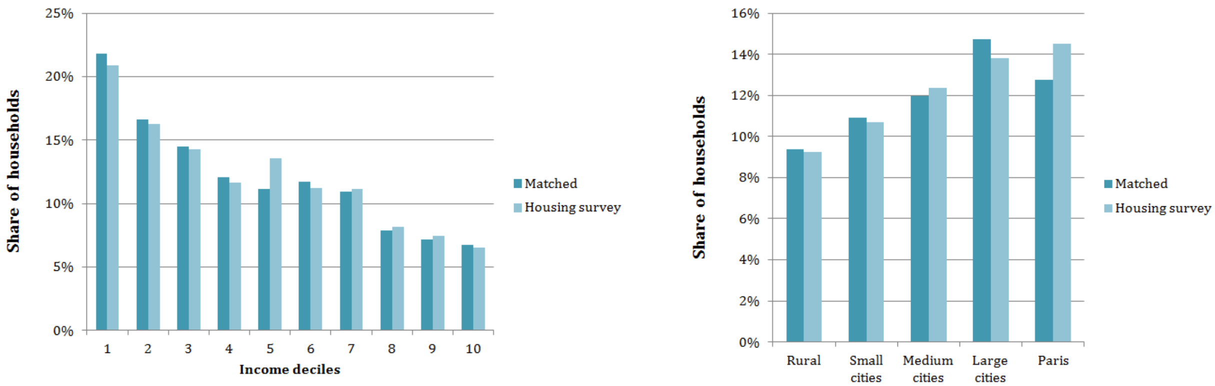
In this paper I study the effects of turning to the 2018 legislation for energy taxes, compared to the reference situation of 2016. The policy studied implies therefore the following evolutions: 1) An increase in the price of CO_2 that goes from 22€ to 44.6€ per ton. 2) An additional 0.026€ per litre increase in the diesel tax to eventually catch-up with the gasoline tax. 3) Energy cheques transfered towards low-income households, based on their fiscal income and their size. The exact scale is given by table 8. These cheques must 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 sur 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.

A.7 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 transfers based on income and households' size are decreased such that the total cost of the policy stays the same.

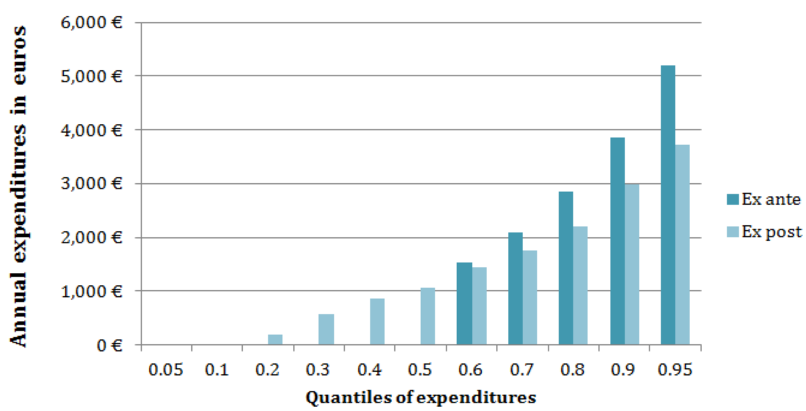
B Figures

Figure 11: Share of households who declare suffering from cold in the housing survey *vs.* in the matched dataset, by income decile (left) and area (right).



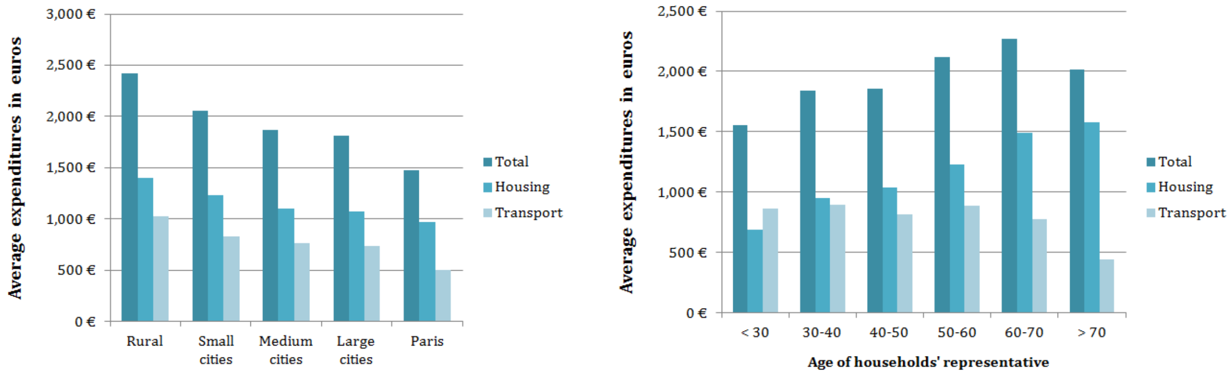
Lecture: In the housing survey, 20.9% of households in the first income decile were declaring feeling cold in their home. They are 21.8% in the matched dataset.

Figure 12: Households' annual expenditures in transport fuels by quantile, before *vs.* after matching



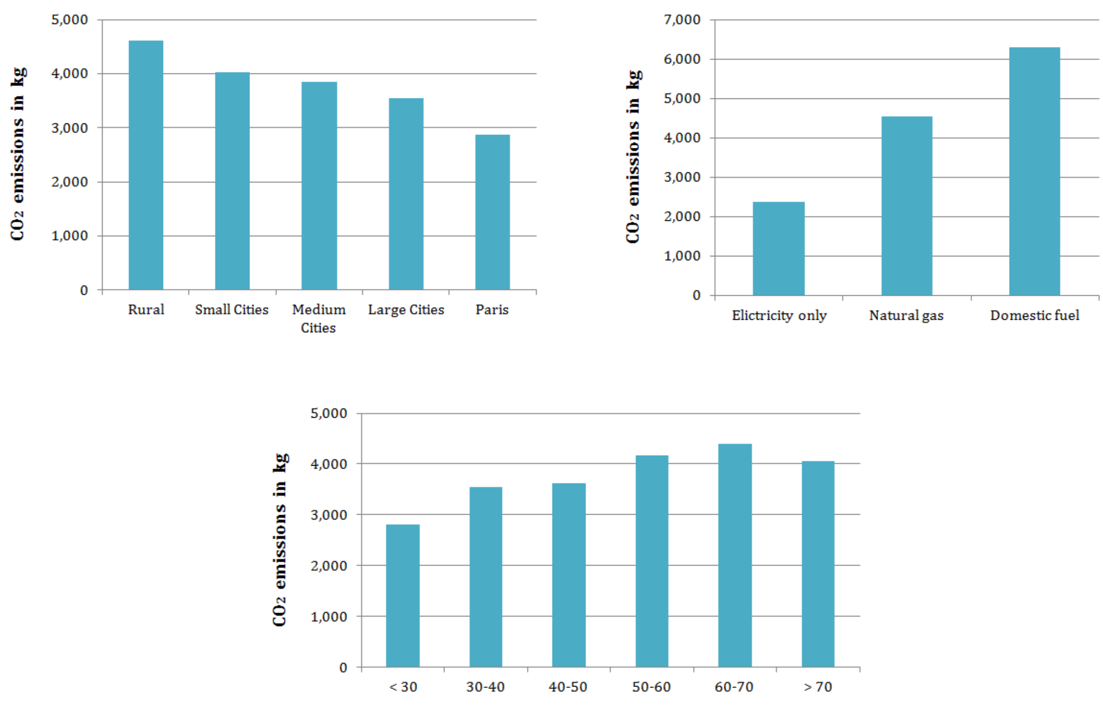
Lecture: After imputation of annual distances from the transports survey, 60% of households in the dataset spend less than 1,450€ in transports fuel annually. Before imputation, 60% were spending less than 1,523€.

Figure 13: Households' annual expenditures in energies per c.u., by geographical area (left) and age group (right)



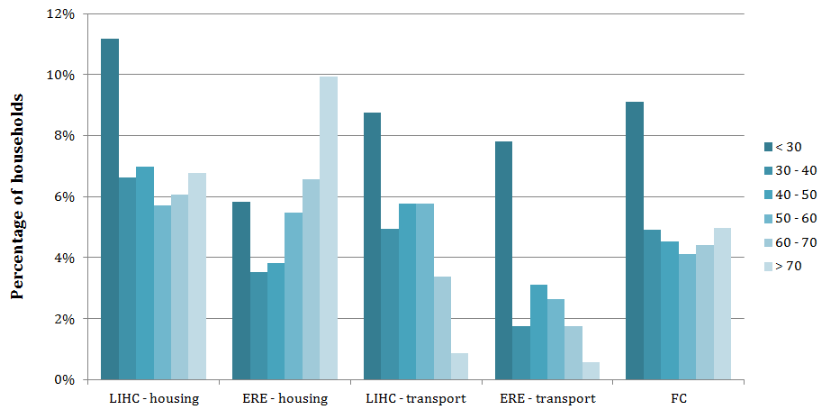
LECTURE: In 2016, households living in the Parisian agglomeration were on average spending 1,471€ in energies, including 972€ in housing energies and 499€ in transport fuels.

Figure 14: Households' annual CO_2 emissions from energy consumption per c.u., by geographical area (left), heating mode (right) and age (bottom)



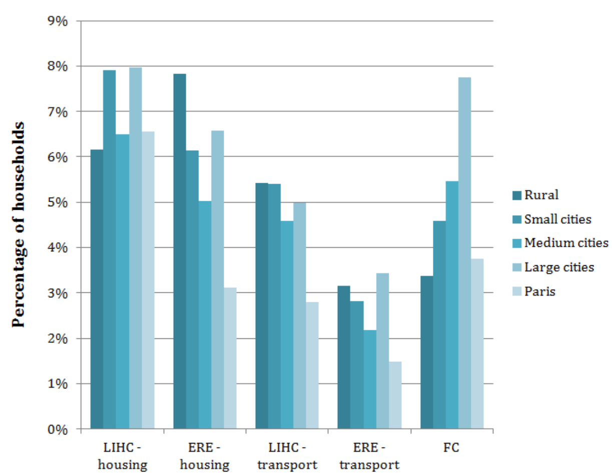
LECTURE: In 2016, rural households were emitting on average 4,611kg of CO_2 per consumption unit from their energy consumption.

Figure 15: Share of fuel poor households by age group and by sub-indicator



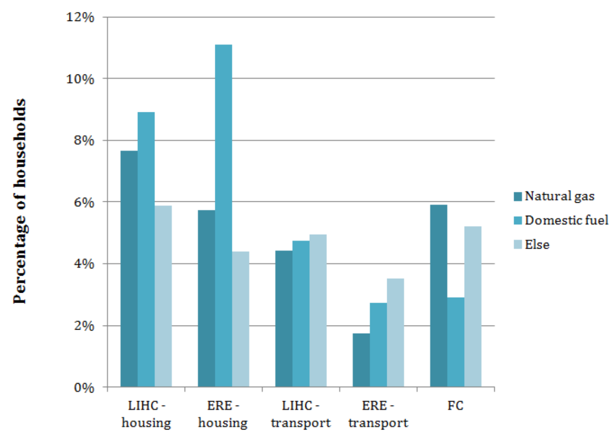
Lecture: Almost 6% of households whose representative is less than 30 years old spend more than 10% of their income in housing energies.

Figure 16: Share of fuel poor households by geographical area and by sub-indicator



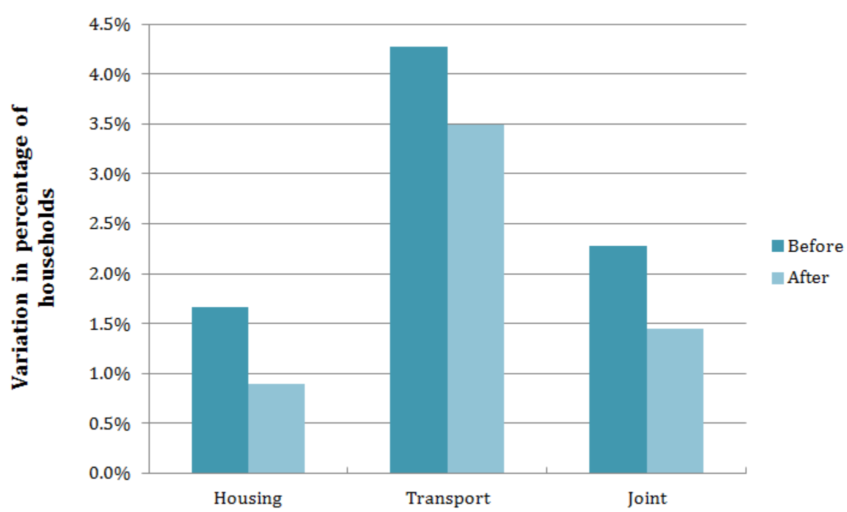
Lecture: Almost 8% of households living in large cities declare to feel cold in their home for financial reasons, and belong to the three first income deciles.

Figure 17: Share of fuel poor households by heating mode and by sub-indicator



Lecture: Almost 8% of households using natural gas are both below the poverty line and above the median consumption in housing energies.

Figure 18: Change in the number of fuel poor households after policy without reactions to prices, before and after revenue-recycling



Lecture: After revenue recycling, the number of fuel poor households is expected to rise by 3.49% with respect to transport fuels if we assume households do not change their consumption in reaction to the tax.

C Tables

Table 5: 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 2^{nd} income decile and living in a rural area have transports and housing energy price elasticities of respectively -0.54 and -0.43.

Table 6: Marginal effect of explanatory variables on FC indicator

	(1)	(2)
N	8,441	8,441
Disposable income	-1.383e-05***	-2.339e-06***
	(2.20e-07)	(6.77e-07)
Quantity natural gas	9.221e-07**	-1.281e-07
	(3.32e-07)	(3.91e-07)
Quantity domestic fuel	-2.372e-05***	7.14e-06
	(4.25e-05)	(1.12e-05)
Double glazing		−0.0710***
		(0.009)
Bad walls isolation		0.1245***
		(0.009)
Good walls isolation		−0.1446***
		(0.009)
Building before		−0.0289**
		(0.010)
Building 1949/74		−0.0494***
		(0.010)
Individual housing		0.0272*
		(0.012)
Owner		−0.0516***
		(0.013)
Living area		−0.0002
		(-0.0002)
Housing benefits		0.0337***
		(0.010)
Nb. consumption units		0.0110
		(0.010)
Nb. in labor force		0.0098
		(0.006)
Rural		−0.0394*
		(0.016)
Small cities		−0.0316*
		(0.016)
Large cities		0.0244*
		(0.010)
Paris		−0.0093
		(0.013)
West/south		−0.0256**
		(0.009)
Domestic fuel		0.0060
		(0.033)
Natural gas		0.0509***
		(0.011)
Student		−0.1443***
		(0.026)
Age		−0.0030***
		(0.001)
Age sqr.		$2.352e-05$**
		(8.72e-06)
Monoparental		0.0087
		(0.011)

* 0.05 ** 0.01 *** 0.001

Lecture: Everything else equal, living in a rural area decreases the likelihood of being identified as fuel poor through the FC indicator by 3.94 percentage points.

Table 7: Regression of net transfers per consumption unit after revenue recycling on several households' characteristics

	(1)	(2)	(3)	(4)
R^2	0.308	0.308	0.309	0.291
N	10,342	10,342	10,342	10,342
Elasticities	yes	yes	yes	no
SL price index	yes	yes	no	no
Heterogeneous	yes	no	no	no
Intercept	−6.452	−9.420	−9.565	−12.67
	(8.145)	(8.049)	(8.177)	(9.302)
Disposable income	-4.174 e-04***	-3.136 e-04***	-3.211e-04***	-3.927e-04***
	(3.714e-05)	(3.671e-05)	(3.729e-05)	(4.242e-05)
Disposable inc. sqr.	2.004e-10***	1.507e-10***	1.544e-10***	1.878e-10***
	(2.58e-11)	(2.55e-11)	(2.59e-11)	(2.95e-11)
Domestic fuel	−70.56***	−71.82***	−73.81***	−77.38***
	(2.220)	(2.194)	(2.228)	(2.535)
Natural gas	−76.33***	−75.65***	−76.79***	−79.85***
	(1.719)	(1.699)	(1.726)	(1.964)
Rural	−7.055**	−9.218***	−9.365***	−13.11***
	(2.518)	(2.488)	(2.527)	(2.875)
Small cities	2.238	1.155	1.207	1.512
	(2.624)	(2.593)	(2.634)	(2.997)
Large cities	2.509	4.932*	5.038*	6.255*
	(2.288)	(2.261)	(2.297)	(2.613)
Paris	15.86***	20.37***	20.70***	26.65***
	(2.835)	(2.802)	(2.847)	(3.238)
West/south	3.531*	4.046*	4.112*	3.749*
	(1.655)	(1.635)	(1.661)	(1.890)
Double glazing	11.11***	11.17***	11.41***	11.82***
	(2.090)	(2.066)	(2.099)	(2.388)
Bad walls isolation	2.519	2.292	2.362	3.196
	(2.707)	(2.676)	(2.718)	(3.092)
Good walls isolation	2.739	2.742	2.797	2.757
	(1.747)	(1.726)	(1.753)	(1.995)
Building before 1949	−1.263	−1.269	−1.284	0.8527
	(1.886)	(1.864)	(1.894)	(2.154)
Building 1949/74	−1.386	−1.406	−1.443	−0.3370
	(1.913)	(1.891)	(1.921)	(2.185)
Individual housing	−16.18***	−15.37***	−15.66***	−17.54***
	(2.190)	(2.165)	(2.199)	(2.501)
Owner	−6.228**	−6.377**	−6.569**	−8.770***
	(2.080)	(2.056)	(2.088)	(2.376)
Living area (m^2)	−0.2984***	−0.2950***	−0.3009***	−0.3254***
	(0.021)	(0.021)	(0.022)	(0.025)
Housing benefits	5.941*	6.208*	6.380**	9.491***
	(2.466)	(2.437)	(2.476)	(2.817)
Nb. consumption units	43.89***	41.12***	41.92***	48.69***
	(1.968)	(1.944)	(1.975)	(2.247)
Monoparental	−0.3961	−1.012	−0.9708	0.4766
	(2.934)	(2.899)	(2.945)	(3.351)
Nb. in labor force	−0.8042	−0.6518	−0.6809	−1.608
	(1.332)	(1.316)	(1.337)	(1.521)
Student	53.46***	53.23***	53.59***	60.54***
	(6.256)	(6.183)	(6.281)	(7.145)
Age	0.3584	0.4032	0.4138	0.2064
	(0.291)	(0.288)	(0.293)	(0.333)
Age sqr.	0.0024	0.0020	0.020	0.0062*
	(0.003)	(0.003)	(0.003)	(0.003)
Vehicle age	−0.4494***	−0.4626***	−0.4716***	−0.6299***
	(0.114)	(0.113)	(0.115)	(0.131)
Share distance to work	0.3130	0.3120	0.3176*	0.4047*
	(0.161)	(0.159)	(0.162)	(0.184)

* 0.05 ** 0.01 *** 0.001

Table 8: Official energy cheques for revenue-recycling depending on fiscal revenue per consumption unit

Fiscal revenue / c.u.	<**5600€**	<**6700€**	<**7700€**
1 c.u.	144€	96€	48€
< **2 c.u.**	190€	126€	63€
2 or more c.u.	227€	152€	76€

Reference: Article R124-3 du Code de l'énergie

Table 9: Variation in the number of fuel poor households after alternative revenue-recycling scenarios

	Housing	**Transport**	**Joint**
Official	+0.33%	+0.49%	+0.51%
Rural	+0.38%	+0.49%	+0.55%
By energy	+0.88%	+0.49%	+0.88%
Rural + By energy	+1.14%	+0.49%	+1.04%

Lecture: If revenue-recycling is partly targeted to rural households, the number of fuel poor is expected to increase by 0.38% with respect to housing.

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