Taxing energy in France: distributive and environmental effects under a Quadratic Almost Ideal Demand System

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This paper makes use of econometrics techniques.

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Abstract:

This paper proposes to evaluate two potential reforms of energy taxes for France as well as the effects of the 2015 and 2016 increases in the rate of the "Contribution-Climat-Energie". We provide an estimation of the environmental impact of each of these scenarios, as well as their distributive effects. The model allows for households' specific responses in quantities to price shifts through elasticities, that we estimate using a Quadratic Almost Ideal Demand System. We then discuss the social acceptability of these scenarios and propose several options for revenue-recycling. In particular, we try to identify on which criteria we should design the policy in order to account both for environmental and distributive concerns. Our results point toward the high expected environmental efficiency of a reform that would aim at catching up the taxation of diesel toward the rates of gasoline, relative to the small financial burden it raises. The examination of the distributive effects shows that all scenarios of reform are rather regressive prior to revenue-recycling, but using lump-sum transfers to redistribute the new fiscal revenue we can construct progressive policies.

Contents

1 Introduction

On September 2013, the French Minister of environment Philippe Martin confirmed the introduction of a carbon tax on energies in France for 2014. Called "Contribution-Climat-Energie" (CCE), the aim of this tax was to induce a reduction in consumption of the most polluting energies, and a switch toward other resources with less carbon content. In 2013 energy consumption represented 72 % of the total emissions of greenhouse gas (GHG) in France, 40 % of which being due to transport fuels[1]. However, the pulic acceptance of an ambitious green tax is threatened by several issues. First, because they raise the cost of energy consumption, households may fear to loose purchasing power. Second, since we may expect low-income households to pay a larger share of their income in these taxes, it raises equity concerns. While carbon pricing is getting increasingly popular among policy makers to deal with climate change, this additional tax burden biased toward the poor could be a problem for its implementation. Therefore, when designing environmental reforms, the choice of the revenue recycling policy is critical to induce public acceptance.

This paper proposes to study both the environmental and the distributive impacts of various scenarios of environmental policies through the implementation of taxes on energies. Thanks to the model TAXIPP[2] of the Institut des Politiques Publiques (IPP), it takes a micro-simulation approach in order to characterize households' heterogeneity with respect to these issues. Running the model on the French households' expenditure survey "Budget des Familles" (BdF)[3], we characterize the consumption patterns of households depending on various characteristics. In particular, we find that richer households, as well as households living in the periphery of cities, spend on average more on energy. With respect to age, we find a non-monotonic relationship with increasing consumption up to a certain age after which it tends to decrease. In terms of shares of their income, it appears that poorer households spend more in energy than richer.

[1]in Global Warming Potential (GWP). Source: Citepa, rapport SECTEN (avril 2015)

[2]TAXIPP is a flexible model working on several types of databases, and has proven to be very successful in modeling the French tax and transfers system. The module "Indirect Taxation" written in Python language has been developed more recently in an attempt to describe households contributions to indirect taxes, and simulate reforms of value added taxes as well as energy taxes.

[3]All along the paper we will focus on the survey 2011. For the estimation of the demand model we also use data from 2000 and 2005

They also spend more in taxes, i.e. these taxes are regressive. However, using total expenditures instead of income as suggested by Poterba (1989) [27], the regressive pattern is less clear and we rather find an inverted U-shape. We also describe how households' carbon emissions from energy vary with their income. This relation has been explored very recently by Levinson and O'Brien (2015) [22] who draw "Environmental Engel Curves" (EEC). Replicating their method on French data and focusing on energy consumption, we identify a similar pattern for these curves, i.e. they are increasing and concave.

In order to evaluate tax reforms on energies, we compute elasticities for the corresponding goods to assess the behavioral responses to changes in prices. To this end, we estimate a demand model of the type *Quadratic Almost Ideal Demand System* (QAIDS) developed by Banks, Blundell and Lewbel (1997) [3]. We estimate the model on three categories of goods: energy, which itself is decomposed between transport and housing fuels, and the rest of non-durable goods. We find average price elasticities around -0.7 for transport fuels, -0.1 for housing energy and -1.0 for the rest of non-durable goods. These results are all consistent with the literature on French data. Plugging these results into our micro-simulation model, we then estimate various reforms of energy taxes that account for households' behavioral responses. We present an evaluation of four scenarios. Based on data for 2014, we simulate the effects of the increase in the rate of the CCE in 2015 and 2016 compare to 2014. We also propose a reform where the taxation of diesel catches up the level of gasoline, and a carbon price of 50€ on all energies, i.e. a carbon tax with more ambitious rates than the current CCE and that also includes electricity.

We evaluate the impact of these reforms along several dimensions. For environmental purposes, we study the effect of each scenario on households' energy consumption and carbon emissions. We show evidences of the strong expected environmental effect of taxing transport fuels given the small burden it raises in terms of revenue. We also emphasize the unequal sharing of efforts in reduction of emissions between energies, with electricity contributing by far less compare to domestic and transport fuels, and to a lesser extent compare to gas. Turning to distributive concerns, we look at the variation in contribution to taxes due to the reform, and the share of households income it represents. The use of micro data enables to distinguish the effects by households' groups such as income deciles or the area of residence. Our model shows the regressive nature of these scenarios of reform before revenue-recycling, although using total expenditures instead of income the pattern is closer to an inverted U-shape. This is more striking for the fuel tax on diesel that even becomes progressive for the first seven income deciles. We then discuss the potential solutions to overcome the regressivity. Restricting to budget neutral reforms, we propose two ways to redistribute the tax revenue. First, by reducing the value-added tax rates, either on the full rate, or on the reduced rates that are usually targeted to poor households. Second, by giving to households standard lump-sum transfers called green cheques. We observe that revenue-recycling through reduction in VAT does not solve equity issues. This is consistent with the results obtained by Ruiz and Trannoy (2008) [29] that VAT cuts in France cannot be used to achieve distributive objectives. However, for all reforms green cheques enable to find a progressive pattern of taxation. This is consistent with West and Williams (2004) [31] and Bureau (2011) [8] who both find that regressive energy taxes can be turned into progressive tax policies using such transfers. Finally, we turn to distributive concerns with respect to households' characteristics other than income. We identify the sources of heterogeneity between households' energy expenditures and discuss the potential solutions to soften the welfare costs for some households without diminishing incentives to reduce carbon emissions.

This paper contributes to at least three strands of the literature. First, we believe it is the first time that the quantities of energy consumed by individual households are computed for French data. Determining energy consumption in quantities is a crucial step toward the evaluation of the environmental impact of any tax reform. By adopting specific strategies that we will detail, we overcome the problems caused by the complex structure of energy contracts and obtain both quantities consumed and CO_2 emitted by individual households. Thanks to this result, we construct the first Environmental Engel Curves for French data on energy consumption.

Second, few papers have estimated elasticities for energy goods at the micro level on French households' expenditure survey data. In their seminal paper Ruiz and Trannoy [29] estimate a QAIDS on the data BdF. They worked with eight categories of goods and obtained consistent results, but they do not provide elasticities specifically for energy goods. Closer to our work, Clerc and Marcus [12] compare macro elasticities from national account data to micro elasticities from BdF 2005 using a QAIDS. At the micro level, they obtain an elasticity of -0.7 similar to ours for transport fuels, but they do not find any consistent result for housing energy. The main difficulty faced when estimating demand models on French household expenditure survey data is the lack of variation in prices. Building on the earlier work of Lewbel (1989) [23] we adopt a new strategy that enables to increase the variation in prices and therefore to find more consistent results for energy goods.

Third, this paper contributes to the discussion on potential energy tax reforms in France. Thanks to our micro-simulation approach, we precisely characterize both macro and micro impacts of various scenarios. In particular, we assess the environmental impact through the expected variations in CO_2 emissions, and the distributive impact before and after redistribution of the tax revenue. With this respect, we bring further arguments in the discussion about the optimal tools for redistribution and emphasize the nice properties of green cheques over cuts in VAT rates. We also contribute to the discussion on how to tackle households' heterogeneity with respect to other characteristics than income. This leads to several policy advice.

The paper is organized as follows. Section 2 reviews the current legislation of energy taxes, explains the structure of energy prices, and describes the data. Section 3 sketches households' consumption patterns and their contributions to indirect taxes given various characteristics. It then studies their carbon emissions and presents the Environmental Engel Curves. Section 4 estimates the QAIDS and compute elasticities. Section 5 evaluates the diverse reforms both on their macro and micro impacts. Section 6 discusses the solutions to redistribute tax revenue. Finally, section 7 concludes. Technical elements are reported in appendix.

2 Energy prices and taxes, and the data "Budget des Familles"

2.1 Transport fuels

The domestic tax on energetic products (in French, Taxe intérieure sur la consummation de produits énergétiques, TICPE thereafter)[4] is an excise duty perceived on the consumption of most energy products, in particular transport and domestic fuels. It is a fix amount applied to the quantities consumed. It comes in addition to the pre-tax price of fuels, and only after its application is added the full-rate value-added tax (VAT). If we denote α the excise duty, t the value-added tax rate, p_{ttc} and p_{ht} respectively the including and excluding taxes prices, we get:

$$p_{ttc} = (1 + t)(p_{ht} + \alpha)$$

The tax is paid directly by the consumer to the distributor that will then pay it to the State[5]. At its origin in 1928, the tax on oil products was not implemented as a corrective tax, but was first thought as a mean to compensate for the decline of the salt tax and a less harmful way than direct taxation to raise public revenue[6]. As a result, the TICPE does not depend on the level of externalities created by each energy and therefore cannot be considered as a true environmental tax. The most obvious example of this discrepancy between the TICPE and an environmental tax is the persistent difference between diesel and gasoline taxation. While it is today acknowledged that diesel is socially more harmful than gasoline, for historical reasons diesel still benefits from lower excise duties[7].

[4]The TICPE replaced in 2011 the domestic tax on oil products (Taxe inétrieure sur les produits pétroliers, TIPP thereafter) to take into account the evolution of the tax base with the inclusion of biofuels.

[5]The list of products subject to the TICPE is common to all European Union countries that also fix the lower bounds of the tax. In France, the exact values of the excise duties are determined each year in the Finance Acts, and referenced at the article 265 of the Community Customs Code. In 2016 the level of the tax was fixed to 64.12 € for gasoline, 48.81 € for diesel and 9.63 € for domestic fuel. Since 2007 the regions can also apply modulations to the national tariffs for transport fuels, with a maximum surcharge of 2.50 € per hectolitre both for diesel and gasoline.

[6]Indeed, today the TICPE still represents the fourth revenue of the State. In 2013, it amounted to 23.7 billions of euros, i.e. more than 1.1 % of GDP. Source: *Les Comptes des Transports en* 2014

[7]For a discussion of these historical reasons, see Pasteau, Perez and Teulière, "Le diesel: enjeux économiques, politiques publiques, comparaison internationale" - Environmental Rersearch and Teaching Institute (ERTI)

2.2 Domestic energy

Domestic energies include electricity, natural gas, domestic (liquid) fuel and solid fuels. The data "Budget des Familles" give households' expenditures for all these goods[8].

While the taxation of domestic fuel follows the same legislation than transport fuels, taxation of electricity and gas are more complex. This complexity comes partly from the dual pricing of these energies. They are both subject to a two part tariff: a fixed fee, and a payment proportional to the quantity consumed. Since several contracts are proposed, the dual pricing of these energies has been an important deterrent for economists to study housing energy consumption. Indeed, households' expenditure surveys give only the amount spent by households on each of these goods. Because we do not know to which contract they did subscribe, it is not possible to directly compute the quantity of energy they consumed.

In order to realize a complete evaluation of environmental reforms, we need to find a convincing strategy to compute these quantities. They are a necessary step to study the variations in CO_2 emissions that will determine the environmental impact of the potential reforms. In this paper we have adopted two different strategies for gas and electricity, that enable to match each household with a specific contract. The exact methodology is explained in appendix. Based on these contracts we can infer both the prices the household faced, and the quantities he consumed. We are aware that this method is imperfect. Nevertheless, no other strategy have yet been proposed. We believe our assumptions reasonable and the method enables to find aggregated quantities close to what is actually observed. This finding argues in favor of our technique.

Another challenge that have made economists reluctant to study electricity and gas taxation is the complexity of the legislation, and the difficulty to translate it in systematic computations. Indeed, electricity is subject to four taxes. First, the transmission tariff contribution (CTA), an *ad valorem* tax on the fix fee of the contract[9]. Second, an excise duty, the tax contribution to the public service charges for electricity (CSPE), whose aim is to finance the energetic transition

[8]Because we cannot disentangle coal from wood and other expenditures in solid fuels, we will not consider it in our evaluation. Note however that the expenditures reported represent very small amounts compare to other energies

[9]In 2016, it was fixed at 27.04 % of the fix part of the transmission tariff applied by the manager of the electricity distribution network

toward renewable energies[10]. Third, the tax on electricity consumption (TFCE), decided by municipal and departmental General Councils, that also takes the form of a tax on the quantity consumed[11]. Finally, the value-added tax (VAT) that applies after the addition of the previous taxes, at the reduced rate on the fix price of the contract and at the full rate on the variable price. For gas, taxes represent a small part of the final price (less than 20 %), but they are numerous and complex. As for electricity, the CTA and VAT apply in the same conditions. In addition, we apply the domestic tax on natural gas consumption (TICGN)[12].

Thus, computing households' contribution to these taxes requires to overcome several difficulties. First, it is important to know the quantities consumed to apply excise duties. Second, it requires specific information about the transmission tariff to compute the CTA. Finally, for electricity we must know the local legislation to which households are subject to. Given that the last two information are not available, we could not compute the contributions to these taxes. Nonetheless, because our strategies enable to find quantities, it is still possible to study the variation in contributions following the increase in excise duties. Even if we will not be able to observe the current effort of households on electricity and gas taxes, we will still be able to evaluate who contributes the most to the reforms under study.

2.3 The data "Budget des familles"

In order to study empirically households' consumption behavior we use data from the consumer survey "Budget des Familles" (BdF) of the French statistical institute (Insee). These surveys are realized every five years on a sample of more than 10,000 households[13]. Besides a large set of households' characteristics, they gather accurate information on their expenditures on a period of two weeks[14], by type of good, according to the international nomenclature "Classification of Individual Consumption by Purpose" (COICOP). Regular expenditures are noted in a notebook, and more specific expenditures - durable goods, housing rent, etc. - are transcribed

[10] In January 2016 it amounted to 22.5 € per MWh

[11] It is simply bounded to 9.6 € per MWh

[12] Since January 2016, this tax incorporates the tax contribution to the public service charges for gas (CSPG) and the contribution to the social tariff of solidarity gas (CTSSG) that aimed respectively at financing the incorporation of bio gas in the natural gas network, and helping the poorest households to access to natural gas.

[13] We exclude from the sample overseas department and territories (DOM-TOM) since indirect taxes are set differently

[14] Only one week for 2011

in a questionnaire. Three visits are made by an interviewer to make sure that the procedure has been correctly followed.

To avoid any seasonality effect, several waves of surveys are realized all along the year. However, the resulting data could still be problematic: as often with survey data, there is an issue of reporting bias that results in significant differences between the consumption reported by households and their actual consumption behavior. The discrepancy between the two can be show by comparing the weighted aggregate consumption of our sample with aggregate data from national accounts. If in theory the two should be equal, in practice the first is always lower. This is particularly striking when looking at tobacco and alcoholic beverages, but to a lesser extend this is also true for other types of goods. To correct for this reporting bias, we use a method in the spirit of Altimir (1987) [2] and inflate households energy expenditures, i.e. we multiply spending by ratios calculated from national accounts, such that for these products the aggregation of our data can reflect the true value of total expenditures[15]. This method must still be improved. In particular, there is a need to realize a certain number of adjustments for scope differences, the type of households surveyed, or the expenditures not paid by households (for instance health expenditures covered by social security). Solving these issues for the survey BdF is currently under study. For the moment we believe the method enables to produce better results for energy but its generalization to all goods is still problematic. For this reason, we inflate for energies and income only, and let other consumption unchanged.

In addition to these information, we use data from the French housing survey ("Enquête logement", Insee) to compute the imputed rent. We then define households' disposable income as their total revenue, minus their direct contribution, plus the imputed rent for owners.

[15]At the aggregate level we must reach the good quantities. At the individual level, we find the good quantities under the assumption that reporting bias are identical across households.

3 Households and energy consumption

The micro-simulation model TAXIPP "Indirect Taxation" aims at modeling the French legislation regarding indirect taxes. Using the data BdF 2011 inflated for 2014, it is then possible to compute a large number of variables to describe consumption patterns and households' contributions to different taxes, as well as their respective contributions to carbon emissions. In the following we compare different groups of households depending on their standard of living, age and where they live. The detail of these categories is given in appendix.

3.1 Who consumes energy?

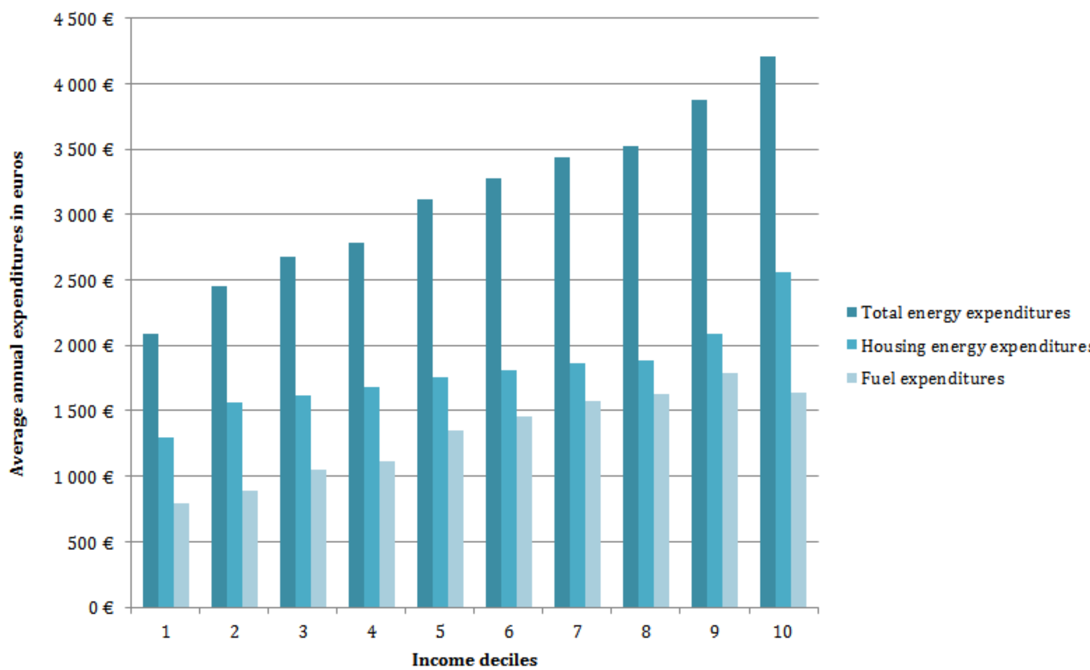
Figure 1 plots the annual consumption of households in energy goods by deciles of standard of living in 2014. For simplicity we often consider them as income deciles. It depicts a strictly increasing pattern of energy expenditures across groups, with the last group spending on average twice as much as the first[16]. Focusing on transport fuels, it also appears that the richest households located in the tenth decile consume less of these products than those in the ninth, but also consume by far more housing energy. Thus, on total energy consumption any income group consumes strictly more than the groups that are poorer. 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. The lower transport fuel consumption for the last decile could be attributed to the location of these households that live more in large cities where they do not need to use their private vehicles.

On figure 17 it also appears that households living in the periphery spend on average more in energy, both for transports and housing[17]. These households may differ in many socio-demographic characteristics, but even thinking about the effect of not being in a city *per se*, we can easily imagine why rural households would spend more on energy: for instance, they are likely to have on average larger accommodations, or to be more in need of driving private vehicles. These features may have an important impact on their consumption of energies, and will be critical when analyzing the repercussions of tax reforms. In particular, the question will arise to know whether these households are constrained on these consumption or not (i.e.

[16] 4205 € against 2090 €

[17] On all energies they spend on average 4013 € per year, against 3536 for those living in small and medium cities and 2657 for households living in large cities

Figure 1: Annual households' expenditures in energy in 2014, by income decile



whether they can reduce them at low welfare costs) and whether we should compensate them more.

Finally, if we distinguish by age groups, it appears that the relationship is non-monotonic. The expenditures affected to energy are increasing both for transport and housing up to their fifties, 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, transport fuel consumption drops sharply when people enter in their sixties. Several explanations can be thought of. First, as we saw energy consumption is positively correlated with income. If this is because income itself has a positive effect on energy consumption, then we can attribute this inverse U-shape to the same pattern followed by households' income. Another potential explanation is that energy consumption is linked to the number of members in an household. As age increases, households start to have children, and these children grow and might contribute to higher energy consumption. When their parents arrive at their sixties however, most children have left home and the number of households members decreases. If households can easily reduce their travels in private vehicles when their children leave home or when they get retired, they may find it harder to adjust their housing energy consumption. If they keep an accommodation of the same size, and if in addition because retired they are more present at home, they may in fact increase their consumption of energy, in particular for heating.

Other groups could have been chosen to describe households' heterogeneity with respect to energy consumption. The choice of these in particular reflects both policy concerns (with respect to income and living area) and the complexity to disentangle the many possible sources of heterogeneity (living area and age).

3.2 Who pays energy taxes?

Before thinking about potential reforms of the taxation of energy and their distributive impact, we might be interested by the current distribution of contributions to these taxes. To this end, we first need to deduce from the reported expenditures and the legislation the actual contribution of each household. As we saw in section 2.2, the nature of the tax system on gas and electricity does not enable to deduce households' contributions for these energies. However for fuels some calculations make it possible. The derivation of the formula are in the appendix.

Beyond the contribution in level, a statistic of higher interest is the effort rate, that is the share of total income that these contributions represent for various groups of households. With this respect, several methodologies can be used and they each deserve some attention. When normalizing individual consumption, we can either divide them by households' disposable income, or by their total expenditures. The two methods have different theoretical justifications and, as we will see, lead to quite different results. The trade-off between these two methods has originally been discussed by Poterba (1989) [27] and Metcalf (1999) [25] who argued that lifetime income were better reflected by the expenditure approach. A more recent OECD paper (2015) [15] discusses the trade-off for carbon taxes in European Union countries. They also argue rather in favor 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 standard of living. Moreover, as consumption taxes, it makes more sense to judge energy taxes with respect to total consumption. Nevertheless, because in BdF expenditures are noted on a short term basis, it may be a noisy representation of the actual standard of living. For this reason, in the following we will present the results using the two approaches and discuss the alternative implications.

As pictured in figure 2, using disposable income as denominator the TICPE is a regressive tax: low income households spend a larger share of their income in contribution to this tax than wealthier households[18]. The pattern found in our data is not strictly regressive since the fourth decile pays in proportion less than the fifth and sixth, but overall the shape of contribution as a share of disposable income is decreasing. 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 between the fifth and the ninth (figure 3). Thus, the choice of the denominator leads to very different political implications.

Figure 2: Households' effort rate on TICPE by income decile - disposable income

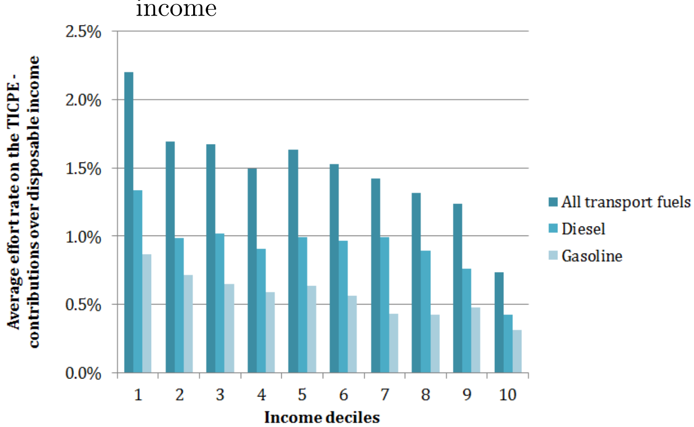
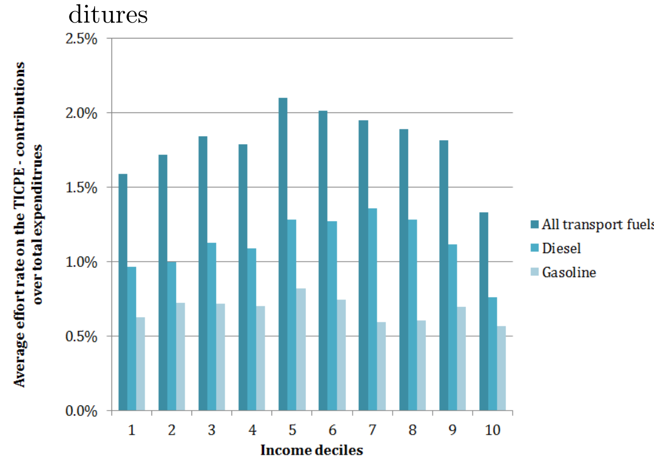


Figure 3: Households' effort rate on TICPE by income decile - total expenditures



3.3 Who pollutes: Environmental Engel Curves

Another variable of interest is the level of carbon emissions of households and how it varies along several dimensions. Using average carbon emissions per quantity of resource used from the french environmental agency (Ademe), we compute from the quantities of energies consumed the associated CO_2 emissions.

[18] 2.2% for the 1st income decile against 0.7% for the last.

In a recent paper, Levinson and O'Brien [22] introduced the concept of Environmental Engel Curves (EEC) to describe how households emissions vary with their income. We follow closely their methodology and use both non-parametric and parametric methods to describe this relation. The exact methodology is detailed in the appendix. Briefly, the parametric EEC consists in an OLS regression of carbon emissions on several explanatory variables. These variables are then set at their mean value, and making the revenue vary we can plot the behavior of carbon emissions. Figures 4 and 5 represent respectively the non-parametric and parametric approaches. They both suggest an increasing and concave relationship between income and emissions from energy. The parameter associated to the quadratic term of revenue in the regression is negative and significantly different from zero. This result is consistent with the findings of Levinson and O'Brien for American data, although we focused on energy only. Furthermore, although significantly concave, it appears that households with lowest yearly income (firsts dots of the non-parametric plot, around 3,000 kg) emit around three times less than those with highest income (last dots around 10,000 kg). The environmental impact of richer households is therefore significantly more important.

Figure 4: Non-parametric environmental engel curve based on CO_2 emissions from energy

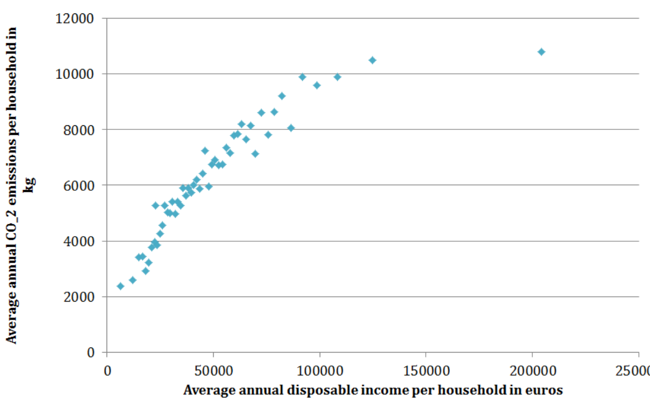
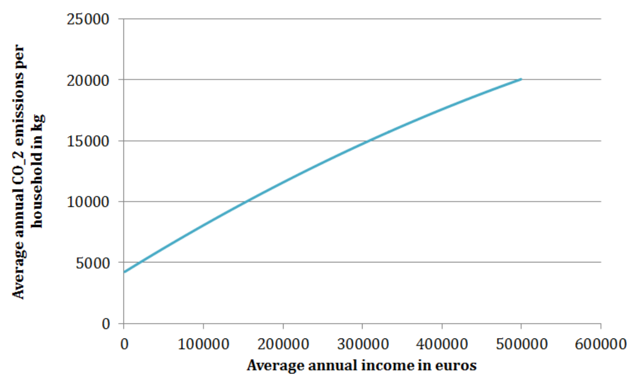


Figure 5: Parametric environmental engel curve based on CO_2 emissions from energy



Looking at the other variables in the regression, we see that many of them are significant. In particular, everything else supposed held constant, households living in large cities emit by far less carbon than others (-1426 kg per year compare to the reference group). Other variables such as age or occupation seem to matter for carbon emissions, but most strikingly the type of energy used for heating display an important role. Using domestic fuel would on average increase annual carbon emissions by 8265 kg, and using natural gas would increase it by 4344 kg compare to electricity only. As a consequence, richer and rural households, as well as those using fuel and gas for heating will likely pay on average more the cost of a carbon tax, although as a share of their disposable income this picture might change.

4 The Quadratic Almost Ideal Demand System

4.1 Model and specification choice

Modeling reforms of indirect taxation can be done in two manners. It is possible to model accounting effects only, i.e. holding everything else constant analyzing the effects of a change in the legislation. However, in order to give a more accurate estimation of the effects of a reform, one can also take into account behavioral responses to taxes. To this end, we estimate price and income elasticities with respect to different categories of goods on which we will apply the reforms. These elasticities will then be integrated to the model and allow to describe the variations in consumption following the change in tax rates.

A popular way to evaluate elasticities today is to use demand systems. Several demand systems derived from consumer theory have been proposed since the early work of Richard Stone (1954), but one that has drawn particular attention is the *Almost Ideal Demand System* (AIDS) proposed by Deaton and Muellbauer (1980b) [13]. This demand system considers the consumption that individuals make on I different categories of goods and the share of their total expenditure m they each represent. It outperforms the previous models such as the *Rotterdam model* (Barten 1964; Theil 1965) or the *Translog model* (Christensen, Jorgensen, Lau 1975) because it gathers many of their respective properties: among others, it gives a first order approximation to any demand system, and it respects the axioms of choice. The model is nonetheless constrained by a strong assumption, that is the linearity of Engel curves. In an extension to this model, Banks Blundell and Lewbel (1997) [3] proposed a more general model, the *Quadratic Almost Ideal Demand System* (QAIDS) that generalizes the previous allowing for non-linear Engel curves. The model is presented in the appendix.

We estimate the *QAIDS* on three categories of goods. The first is composed of transport fuels only, that are grouped in one unique post of consumption in the nomenclature COICOP. The second group gathers all housing energies reported in BdF: electricity, gas, domestic fuel and solid fuels. The third group is the rest of non-durable goods consumed. Expenditures being reported on very short periods of time, we cannot hope to estimate elasticities for durable goods since they are mostly the result of savings and do not reflect actual purchasing power.

The main difficulty in estimating demand systems with French consumer survey data comes from the lack of variability in prices. For each household, and for each good he consumes we match the prevailing monthly price index of the Insee according to the period of the survey. Since surveys are organized in 8 waves for BdF 2000, and 6 for BdF 2005 and 2011, for each good we have a maximum of 20 different prices if we merge the three years together. Hence the difficulty to estimate significant elasticities. To overcome this issue, we use the method proposed by Lewbel (1989) [23] to construct weighted price indexes. 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 prices. 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 group. This heterogeneity enables to introduce more variation in prices. As shown by Hoderlein and Mihaleva (2008) [18] the method of Lewbel produces better empirical results than standard aggregate price indexes. Because the bundle of transport fuels is composed of one unique good, we use the technique mentioned in section 3.2 and described in the appendix to distinguish diesel from gasoline and introduce additional price variations based on the respective prices of these two goods. The category housing energy having a limited number of goods, we used a similar approach to improve price variation. Each household being matched to a specific gas contract, we create additional price variation for this good[19].

We use data from the 2000, 2005 and 2011 surveys. We add fixed effects in the estimation to control for time changing characteristics. We also use demographic variables to control for a large number of households' characteristics that might be endogenous. Demographics enable to introduce heterogeneity in households' preferences. In the main specification of our model,

[19]For electricity this method could not be applied since contracts differ on the fix fee, but not on the variable price.

we use the age of the household's representative, the number of children, of active members, as well as the area of residence. Because there might be reporting errors in the surveys, we cut the outliers that we define as households with more than 25% of their expenditures either in transport or housing energies. Our final sample contains 30,256 observations.

The original QAIDS model does not correct for potential selection bias. For this reason, some authors - in particular Ruiz and Trannoy [29] - have made the choice to estimate linear approximations to the QAIDS that allow for a Heckit procedure[20]. In our case selection could be an issue as many households[21] did not reported any consumption of transport fuels in the survey. We can attribute this to two reasons. First, it might be that these households do not own a car and therefore never consume transport fuels. The null consumption therefore arises as a corner solution in the optimization of their utility derived from consumption. This explanation is likely to explain the largest part of these zero consumption. Second, it is also possible that some households do consume transport fuels, but did not during the period of the survey. This is more likely for 2011 since consumption was reported only over a week. However, one should be careful before correcting for selection in a QAIDS. Since this procedure can only be implemented in linear approximations to the QAIDS, the authors have to move far from the spirit of the original model. In particular, in the linear approximation the quadratic term $(\frac{\lambda_i}{b(\mathbf{p})})$ is independent of the price level. In their seminal paper, Banks et al. [3] stress the importance for this parameter to depend on the price level[22]. In addition, this approximation comes at the cost of loosing cross-price elasticities (the terms γ_{ij} are not estimated). For these reasons, we chose not to correct for selection in our specification.

Two commands are available on Stata to estimate the model. "quaids" introduced by Poi (2012) [26] uses non-linear seemingly unrelated regressions (NLSUR) and provides households' specific elasticities calculated at the value of their own parameters. We use these estimates later in the model to introduce heterogeneity in behavioral responses. In the following we report global elasticities with the NLSUR estimation as weighted averages of households specific

[20] They estimate a two stage model. They ignore cross-price effects and use the Stone price index. The model becomes linear in its parameters

[21] 39.7% of the final sample

[22] "When $\lambda(\mathbf{p})$ is independent of prices, the indirect utility function reduces to a form observationally equivalent to the PIGLOG class, which includes the AI model and the translog model" (Banks et al. 1997, page 532)

elasticities[23]. The command "aidsills" proposed by Lecocq and Robin (2015) [21] uses iterated linear least-squares (ILLS) and provides elasticities at the mean of each variables. Thus it ignores heterogeneity (no individual specific response), but it has the advantage to give standard errors for these elasticities[24].

4.2 Results

We estimate the model with alternatively the ILLS and the NLSUR methods. Using the estimates we can then compute elasticities. Both methods yield similar results summarized in tables 1 and 2.

We find budget elasticities[25] between 0.6 and 0.7 for transport fuels, 0.55 and 0.8 for housing energy and between 1 and 1.1 for the rest of non durable products. Uncompensated price elasticities are around -0.7 for transport fuels, -0.1 to -0.15 for housing energy and -1.0 for the rest of non durable goods. These results are in accordance with intuition and confirm previous estimates on French data. Using BdF 2005 Clerc and Marcus [12] found an elasticity of -0.7 for fuels at the micro level, but did not found any reliable result for housing energy. On macro data however, they obtained results similar to ours for this category[26]. We believe the use of the three surveys 2000, 2005 and 2011 as well as the strategies adopted to increase price variations enabled to outperform their estimation. However, we must still be cautious with these results. Indeed, while the estimates for transport fuels and non durable goods are stable, the elasticity for housing energy is quite sensitive to the specification choice. In particular, absent the dummy variable to control whether people consume only electricity or not, the estimate becomes slightly positive.

Conditioning on certain variables, we can also compare elasticities across groups of individuals. Tables 5 to 8 sketch the estimates for those below and above the median expenditure level, for rural households as well as for those consuming only electricity among housing energies.

[23] This is the method used by Jansky (2013) [19] who takes the weights as households' share of the total expenditure in the relevant bundle. Since households with large consumption of a good will - *ceteris paribus* - have more impact on the variation in quantities, this procedures give them a higher weight and is therefore more representative of the effects at the macroeconomic level.

[24] For the estimation procedure, see appendix

[25] These are with respect to the budget and not income

[26] -0.06 and -0.17 on the short and long run respectively

Table 1: Elasticities using ILLS estimation - at means

	Budget elasticity	**Uncompensated price elasticity**	**Compensated price elasticity**
Transport fuels	0.630*** (0.011)	-0.701*** (0.046)	-0.658*** (0.046)
Housing energy	0.551*** (0.013)	-0.129*** (0.027)	-0.100*** (0.027)
Other non-durable goods	1.056*** (0.001)	-1.022*** (0.016)	-0.094*** (0.016)

NOTE: *** indicates a p-statistic below 0.001.

Table 2: Elasticities using NLSUR estimation - weighted average

	Budget elasticity	**Uncompensated price elasticity**	**Compensated price elasticity**
Transport fuels	0.663	-0.674	-0.674
Housing energy	0.819	-0.114	0.263
Other non-durable goods	1.034	-0.958	-0.018

Overall, it appears that richer and urban households have a slightly lower budget elasticity for energy, as well as a slightly lower (in absolute value) price-elasticity for transport fuels. More striking is the difference between groups on the price-elasticity of housing energy. Our results indicate that while poorer and rural households react significantly to changes in the price of energy (with elasticities of respectively -0.250 and -0.309), richer households show almost no reaction (-0.014, not significant at the 90% level). Another striking result is the positive price elasticity for housing energy consumption among those who consume electricity only (0.249). We can hardly justify such result. A plausible explanation is that these peoples have only one unique good in the bundle "housing energy" so that there is barely any price variation leading to a poor estimation. Our guess is that the actual elasticity, although maybe negative, should be of small magnitude.

One could be tempted to deduce from these elasticities what are the groups of people most constrained on energy consumption. We should however be careful with this type of exercise. If poor and rural households seem to react more strongly to price incentives on housing energy, it might be at a higher welfare cost. We can hardly interpret the low elasticity of richer households as them being constrained on their energy consumption. A more convincing interpretation might be that energy being a lower share of their total income, they are able to sustain price increases without affecting their consumption behavior. On the other hand, for poor households or people living outside cities, energy represents a more important share of their budget. These people may therefore be relatively constrained in their budget (and not in their consumption) and have to reduce their consumption even though it might imply using less energy than they need for comfort (for instance reducing heat during winter). Although it is difficult to reach clear conclusions on these issues, we need to keep these results in mind when designing tax reforms.

Overall our various strategies enabled to provide results consistent with both economic intuition and the literature, but as shown with the example of electricity-only households, the estimation is still problematic for some groups of people. Yet, for now we do not see any perspective to overcome this last issue given current data available. In the following we will estimate various reforms of energy taxes using the elasticities obtained. The results will therefore rely on these findings. Caution will be required when interpreting the results.

5 What are the impacts of energy taxes?

The main objective of this paper is to evaluate several potential reforms as well as the existing "Contribution-Climat-Energie" (CCE) on several dimensions that matter for public policies. The impacts of these reforms are of two kinds: macro and micro. The macro impacts we will focus on are the variations in total quantities consumed, in CO_2 emissions, and in tax revenue. The micro impacts are more directly linked to households, and computed using micro-simulation techniques. The main concern will be the distributive effects of the reforms. Using data from BdF 2011 inflated for 2014, we will study the impact of the increases of the CCE in January 2015 and 2016. While the carbon price was fixed at 7 € in 2014, it increased by 7.5 € in 2015 and 2016 to drive the price up to 22 €[27]. We will also conduct an evaluation of two other potential reforms: the catch up of the taxation of diesel toward the level of gasoline, and a carbon tax on energies that also include electricity, and with a more ambitious rate than the CCE of 50 €[28].

5.1 At the aggregate level

The primary objective of the reforms we evaluate is to reduce the negative environmental impact of energy consumption. The first criterion to judge these reforms is therefore to evaluate the extent to which they could contribute to reduce emissions of greenhouse gas. To measure this, we first need to determine the variations in the quantity of energy consumed. Starting from the quantities calculated from the survey data, we can apply the elasticities obtained with the $QAIDS$ to determine the variation after the reform, and deduce the effect on carbon emissions. These elasticities are also used to compute the variation in tax revenue. Table 3 summarizes the macro effects of each tax reform. The method for computations are given in the appendix.

A first striking result is the high performance of the fuel tax even tough the tax base is restricted to diesel only. It achieves a reduction of 4.562 Mt of carbon which represents around 1% of the total GHG emissions in France[29], and almost three times more than what should have made the increase of the CCE from the tariffs of 2014 to those of 2015[30]. This is the

[27] Prices are per ton of CO_2.

[28] We look at the impact of an increase in the price of energies subject to the reform, taking into account price elasticities for these goods, and holding all other variables constant

[29] 497.8 Mt equivalent CO_2 in 2013, developpement-durable.gouv

[30] By comparison, the efforts made since 1990 have enabled to reduce these emissions by 10% which represents about 0.46% a year.

Table 3: Macro impacts of reforms

	Energy	**CCE 2014-2015**	**CCE 2014-2016**	**Carbon tax**	**Fuel tax**
Quantities	Diesel	-215.0	-423.4	-1149.3	-1715.0
	Gasoline	-71.5	-141.2	-387.6	0
	Electricity	0	0	211.4	0
	Gas	-861.4	-1669.4	-4288.6	0
	Domestic fioul	-121.0	-235.7	-616.7	0
CO_2 **emissions**	Transport fuels	-744.7	-1468.1	-3995.2	-4561.9
	Electricity	0	0	19.0	0
	Gas	-206.7	-400.7	-1029.3	0
	Domestic fioul	-375.0	-730.7	-1911.7	0
	Total housing	-581.7	-1131.4	-2921.9	0
	Total	-1326.4	-2599.5	-6917.1	-4561.9
Tax revenue	Total	931.7	1848.6	5865.9	2334.2

NOTE: Quantities are expressed in millions of liters for fuel, in GWh for electricity and gas. Emissions are expressed in thousands of tons of CO_2. Tax revenue are expressed in millions of euros. They do not include gains in VAT.

case because it represents a large share of households energy consumption, it has a high carbon content, and households display a higher price-elasticity than for other energies. Considering the many other externalities of diesel[31] it seems very efficient for environmental objectives to reduce the gap between the taxation of gasoline and diesel. In addition, it is worth to notice the relatively low revenue raised by this tax given its efficiency it terms of emissions. This smaller burden could be an argument in its favor, although an analysis at the microeconomic level is needed to say more.

A second result - that could have been expected from our results on group specific elasticities

[31] Noise, congestion and infrastructure costs of private vehicles, air quality through micro particles, the list is quite long.

for housing energies - is the positive estimated impact of the carbon tax on the quantities of electricity consumed. The consequence is that the carbon tax is expected to actually increase carbon emissions from electricity consumption. This result is difficult to believe. Nonetheless, it appears that the effect is very small in magnitude so the overall efficiency of the tax is barely affected.

A third observation is that while domestic fuel is consumed by only a small share of households, it contributes to a large share of reduction in emissions[32]. This is true to a lesser extent for natural gas. The underlying reasons are similar to those observed for diesel. The consumption of these products is more elastic than electricity (although less than transport fuels) and they have a higher carbon content. As a consequence, we can expect that households consuming these goods will support a large part of the tax burden, while those consuming electricity only should be less affected. This burden will be both in terms of budget - high cost of the tax - and consumption - important reduction of energy use - so the welfare loss could be substantial for them.

Overall these results point toward the high environmental efficiency of the fuel tax - a catch-up of the taxation of diesel toward the gasoline - and the unequal sharing of the effort between energies. These results should be taken as short term impacts. Indeed, the elasticities estimated with the QAIDS are short term reactions. Furthermore, the assumption underlying these results is that for each household, technology is held constant. In the long run, we could expect the reforms to have an impact on the car purchasing decisions of households, or on the choice of heating energy. In a recent paper, Busse et al. (2013) [9] have shown evidences that when the price of gasoline increases, people forecast correctly the future expected costs and turn to vehicles with smaller fuel consumption. This additional effect on technology could therefore increase greatly the potential of these reforms[33].

[32] In our data set, 16.5% of households consume domestic fuels. For the carbon tax, it represents 65.4% of the reduction in carbon emissions coming from domestic energeies, and 27.6 % of the total.

[33] These effects on technology are however difficult to quantify *ex ante*. As shown by D'Haultfoeuille et al. (2011) [14] the costs of the ecological bonus/malus introduced in France in 2008 could not be measured *ex ante* because of the complexity of agents' reaction and a potential dead-weight effect

5.2 At the households' level

Besides the environmental efficiency of the reforms, we are interested in their distributive impact. In section 3 we showed the contributions to energy taxes for various categories of households. We now turn to a predictive analysis of the expected distributive impact of the reforms. In particular, we will be interested by the differences in the contributions of rich and poor, as well as urban and rural households.

Figure 20 depicts the cost in euros born on average by households in each income decile. It appears clearly that, for any scenario, richer households pay more of the tax. It is only for the fuel tax that the last decile pays less than the seventh, eighth and ninth. It also appears that although the environmental impact of the fuel tax is much more important, for households in the first deciles it does not cost much more on average than the increase in CCE at the price of 2016. For the five first deciles, the difference is less than 20 € per year. It is only starting from the sixth decile that the difference becomes more substantial.

Comparing in terms of effort rates, the picture is completely reversed. Taking the income based approach (figure 6), the pattern of the CCE and the carbon tax are strictly regressive. For the carbon tax, the first decile ends up paying close to 1% of its disposable income in this new tax, more than three times more than what it represents for the last decile. Also, we observe that the increase in the rates of the CCE costed for 2015 and 2016 respectively 0.13% and 0.25% of their disposable income to the bottom decile[34]. Interestingly, the pattern is quite different with respect to the fuel tax. In percentage of its income, the first income decile is still by far the largest contributor. However the relation is non-monotonic. From the second to the eighth decile, the average contribution is rather stable around 0.2% of the disposable income. Then it decreases sharply with the richest households down to less than 0.1% for the top decile.

Taking an expenditure-based approach (figure 7), the conclusions in terms of regressivity are softened. The contributions for the CCE and the carbon tax describe overall an inverted U-shape with the fifth decile paying the largest part of its expenditures in energy taxes. From the first to the last decile, effort rates on the reforms are not so dispersed between income groups, between 0.66% and 0.91% for the carbon tax, 0.21% and 0.29% for the CCE 2016, and 0.105% and 0.145% for the CCE 2015. Strikingly, up to the seventh decile the fuel tax appears to be progressive. These observations are consistent with Poterba (1991) [28] who finds that gasoline taxes are not

[34] This is taking into account the change in tax rates only

regressive anymore when taking an expenditure-based approach, but rather describe an inverted U-shape pattern. These results hide nonetheless some important disparities among each income group. As shown in figure 21, households living in large cities would bear lower costs than other households for the fuel tax, and this difference is more pronounced with the fuel tax than for the other scenarios of reform.

Figure 6: Cost of the reform divided by disposable income, by income decile

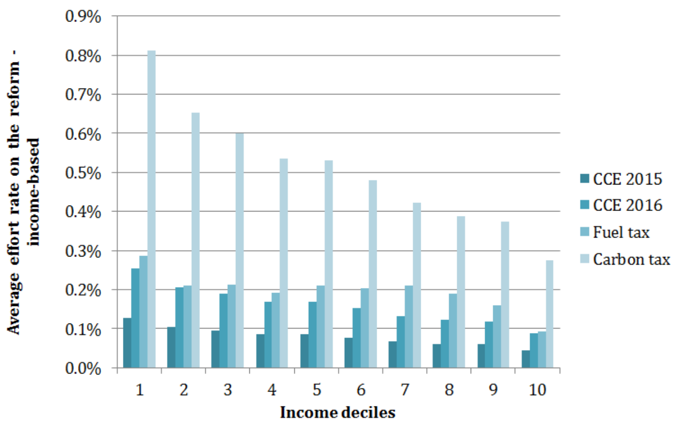
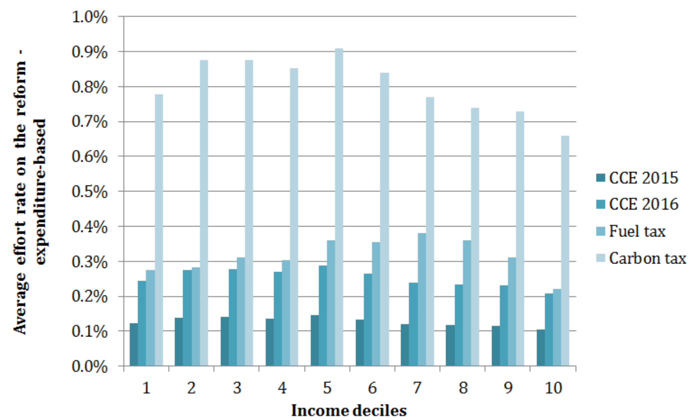


Figure 7: Cost of the reform divided by total expenditures, by income decile



Overall, we have shown that taxes on housing energy are regressive with respect to the income based approach, and that the relation was similar to an inverted U-shape with the expenditures approach. For our fuel tax, regressivity was less clear, and taking the expenditure approach we even found a clear progressive pattern among the seven firth deciles. As discussed in the literature (Poterba (1989), Metcalf (1999)), for energy taxes the expenditure based approach is certainly more relevant since total expenditures may better describe lifetime income. And as we judge the progressivity of direct taxes based on income, energy taxes being consumption taxes, it makes more sense to judge them with respect to total consumption. These results should however be taken with some cautious. First, as we discussed earlier, data are imperfect. Second, this analysis is restricted to the impact of the change in tax rates. Except for households' behavioral response[35], all other variables are held constant. Several papers have tried to identify

[35]Note that comparing tax regressivity with and without behavioral response, West and Williams (2004) [31] find that allowing for consumer responses softens the regressivity.

the regressivity of the carbon tax in British Columbia using Computable General Equilibrium models. While most empirical studies in partial equilibrium find that this tax is regressive, Beck et al. [4] show evidences that in general equilibrium the pattern is in fact progressive. In another article, Beck Rivers and Yonezawa [5] discuss the extent to which rural households are more affected than others. They find that these households benefit less from the tax than others, but in terms of welfare they still gain from the tax. These results point toward the limits of the partial equilibrium approach and enables to see in which direction our results could potentially be biased.

6 How to redistribute tax revenue?

The important costs that environmental taxes impose on low income households has been the major deterrent for their implementation. Hence, when designing tax reforms it is crucial to think about solutions to improve their social acceptability. To this end, we may want to redirect revenue recycling toward specific targets, such as poor, young, rural or larger households. In the following we will discuss two ways to redistribute the tax revenue. The first will be to reduce the rates of the VAT, either on the full rate only, or both on the full and reduced rates. The second alternative, closer to a textbook approach of externalities, is to redistribute the revenue through lump-sum transfers indexed on the number of consumption units in the household. We will see how these strategies perform in terms of distributive concerns, first with respect to income, and then for other households characteristics that matter for their energy purchasing decisions.

6.1 The income dimension

Since energy taxes are consumption taxes, it is tempting to redistribute their revenue through reduction in other indirect taxes. The additional revenue raised could be used to reduce the value-added-tax which is heavily supported by households, especially by the poor (figure 22). For each reform we evaluated, we propose two scenarios of revenue recycling through cuts in VAT rates. The first implements a cut in the full-rate. The second implements a smaller cut on the full-rate, but also decreases the rates for the reduced and hyper reduced rates[36]. This second scenario is supposed more targeted toward poorer households since they consume more extensively the goods subject to reduced VAT rates. For each reform, the rates are adjusted so that the total reform with revenue recycling is budget neutral. Table 9 gives the necessary reductions for each scenario.

Figures 8 and 9 plot the fiscal gains by income decile for any possible scenario. It says for each income decile whether on average people financially benefited from the reform or not. The results are quite puzzling. It indicates a clear regressive pattern for all reforms after both revenue recycling strategies. Reducing the full-VAT rate only, we see that for all scenarios the first six deciles all loose on average. With respect to the carbon tax, the first deciles are even penalized with the revenue-recycling through reduced VAT rates. Most strikingly, the last decile largely

[36] The full, reduced and hyper-reduced rate of VAT were fixed at respectively 20%, 5.5% and 2.1% in 2014

Figure 8: Fiscal gains of households following the reforms, after full-rate VAT cut

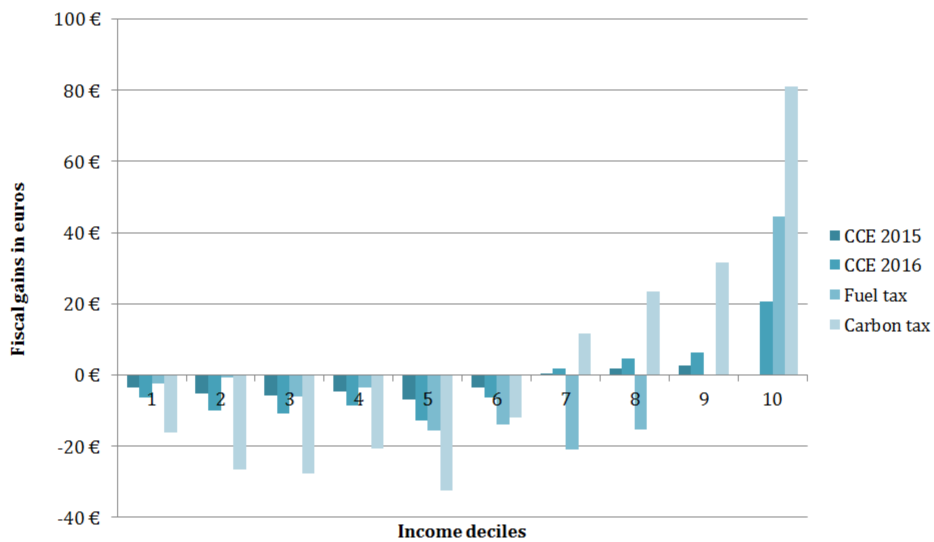
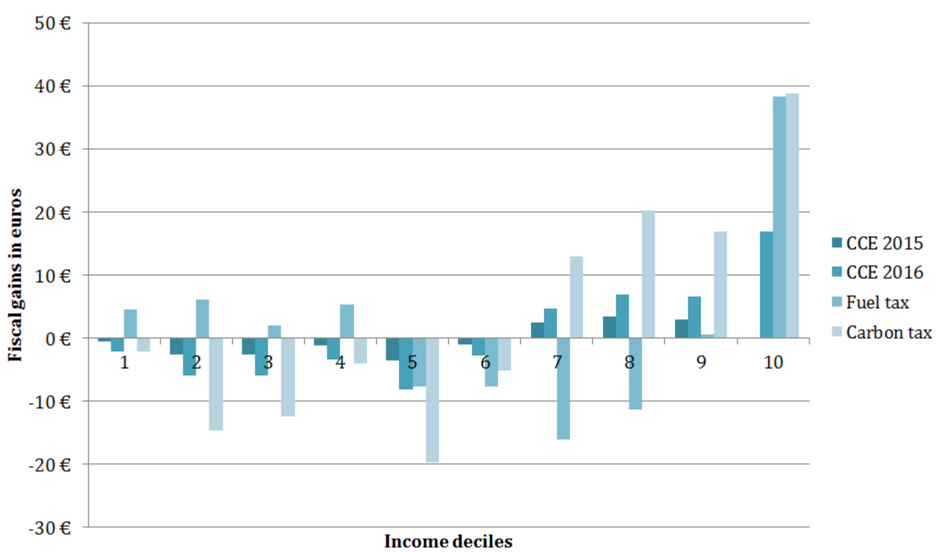


Figure 9: Fiscal gains of households following the reforms, after reduced and full-rate VAT cut



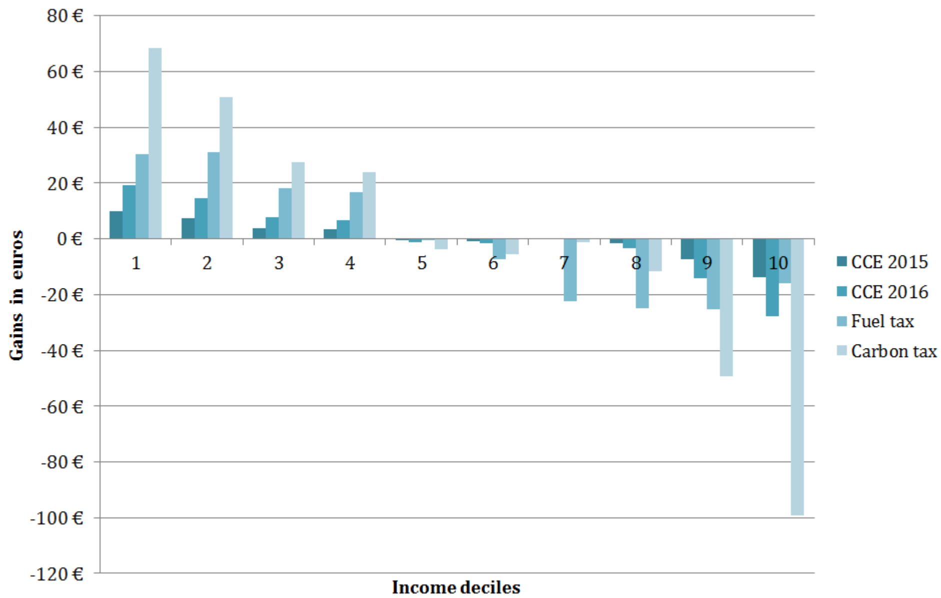
wins from any of these scenarios. Overall, it is difficult to see how revenue-recycling through cuts in VAT rates could make energy taxes progressive. This finding coincides with those of Ruiz and Trannoy [29] who found that given the intra income-groups heterogeneity in consumption it is difficult to achieve distributive objectives with indirect taxes.

An alternative way to redistribute the revenue of energy taxes is to use lump-sum transfers that we call "green cheques". Examples of studies that have investigated this approach in the case of fuel taxes are West and Williams (2004) [31] and Bureau (2011) [8] respectively on US and French data. They both found that this scheme could turn regressive fuel taxes into progressive fiscal policies. We propose a scenario where for all reforms, the total revenue is redistributed to households as a function of the number of consumption units. Other solution could be to redistribute according to the number of adults, or working people in the household. However, our calculations show that these methods are biased toward richer households.

Green cheques have two important advantages. The first is their simplicity, which is arguably an important quality that could help for their implementation. Each year, households would receive directly a cheque that reflects the revenue that, together with the other citizens, they have contributed to raise. On this cheque could also figure a note on the environmental benefits of the reform. We believe a direct payment and some fiscal pedagogy could greatly contribute to the social acceptability of the reforms we proposed. A great problem with taxation is that for many people, it seems that the money raised simply disappears from their pocket. The second advantage of green cheque is their neutrality, i.e. they are close to textbook lump-sum transfers. In standard microeconomic theory it is argued that lump-sum transfers should be used to tackle distributive issues in order to not distort any incentive. If green cheques are only a function of the number of consumption units we can assume that people will not be induced to manipulate any variable in order to benefit more from the reform. This is arguably a very nice property of this revenue-recycling strategy. In the next subsection we will see how this neutrality can be problematic if households are heterogeneous and constrained on many different characteristics, but for now we turn to the analysis of the distributive impact with respect to income.

Contrary to scenarios involving revenue-recycling through cuts in VAT rates, the distributive pattern described in figure 10 is very progressive with respect to income. For all reforms proposed, the first income deciles on average win from the reform which is paid by the last deciles. For the carbon tax that involve large costs paid mainly by poor households before

Figure 10: Fiscal gains of households following the reforms, after green cheques



revenue-recycling, it appears that only the last two income deciles would contribute by more than 12€ a year. The first bracket would gain on average 68€ annually, up to the fourth decile the gains are above 20€, and for the next three brackets the losses are between 1€ and 6€ per year. For the CCE 2015 and 2016, the results are comparable except that they imply lower amounts. The underlying logic of this strictly progressive pattern is that poorer households, although they contribute more to the reform as a fraction of their revenue, contribute less in absolute value. Therefore, when giving them back what people contribute on average, they end up with positive fiscal gains. As a consequence, the almost 100€ paid by the top income bracket reflects nothing but the large carbon emissions of this group. With respect to the fuel tax, the pattern is not strictly progressive. The first five income groups on average win from the reform, but the seventh to ninth income brackets pay on average more than the last group. This is due to the low level of fuel consumption in the last group that therefore does not finance the reform anymore. Also, people in the first income decile gain relatively less compare to other reforms.

Overall, we see that with respect to distributive concerns, it makes more sense to redistribute revenue through green cheques than VAT rates cuts. This result is consistent with the literature both for indirect tax cuts and lump-sum transfers. Whereas lowering VAT rates leads to absurd results where richer households both contribute more to carbon emissions and financially benefit from the taxes, green cheques penalize richer households for polluting more. Hence in addition to the nice properties of these cheques, it also enables to create a truly progressive pattern for each of the reforms.

6.2 Caracterizing consumers' heterogeneity

When thinking about distributive effects, the most obvious dimension to look at is income. This might be because heterogeneity with respect to this variable is very important, matters a lot for agents, or because this is a variable that they can hardly choose. Indeed, if people were free to choose this variable, most of them would choose to earn more. Then, if income is seen as imposed to households so that they cannot modify this variable[37], we cannot implement a reform that would punish low income households for having low incomes. The question then arises whether there are other such characteristics that households can hardly choose and that would also make them potential victims of our policies, and whether we should target specifically these households in the revenue-recycling.

As a first step we look at households' heterogeneity of contributions within income deciles. Figures 11 and 12 depict respectively the share of loosers in each decile and the average loss among loosers after green cheques. On the one hand, while 20 to 24% of households loose from the reforms in the first income decile, they are more than 50% to loose in the last for all scenarios except for the fuel tax (40%). On the other hand, loosers of the first group are expected to bear an average cost of almost 150€ for the fuel tax, and above 200€ for the 50€ carbon tax. This last number is above the expected loss of the sixth following groups, and represents 0.72% of their average annual disposable income. If it is quite clear that richer households are in proportion more numerous to loose from the reforms, overall richer loosers do not loose more on average. This is a strong evidence of the concerns that could raise these reforms if within income groups heterogeneity was not taken into account.

In order to identify the variables that matter for energy consumption, we estimate reduced-

[37] One could argue the choice of income is made through trade-off in education, effort or in the choice of sector of activity. Nonetheless, we might expect that for a lot of people income is seen as a highly constrained variable. Not only it relies on decisions taken in the past that can hardly be affected afterward, but also on sociological features and luck.

Figure 11: Percentage of loosers after green cheques within income deciles

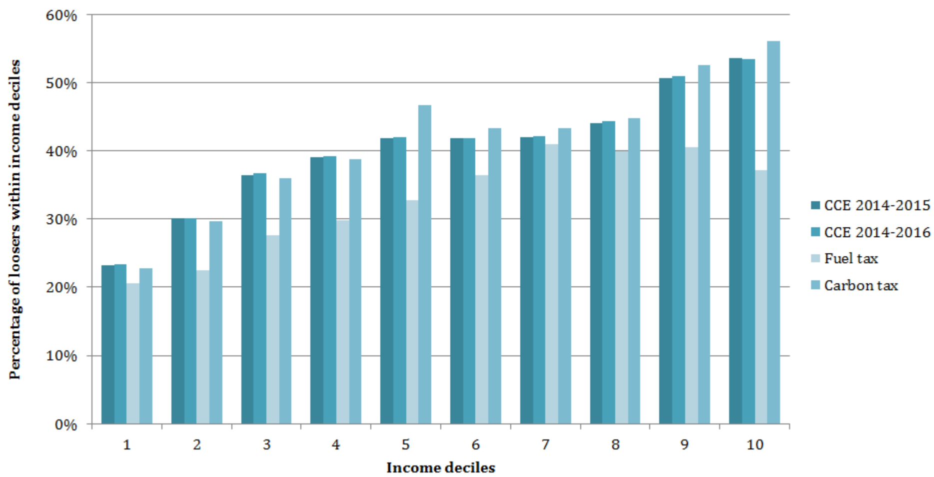
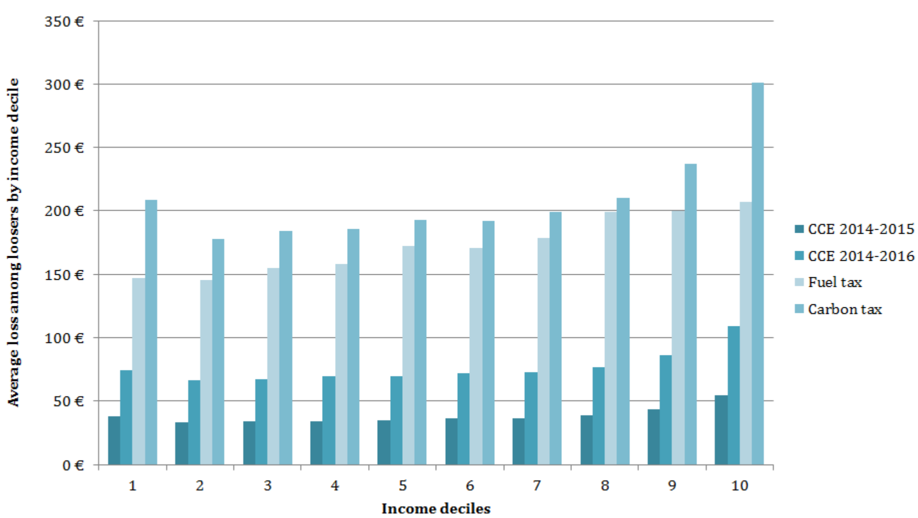


Figure 12: Average loss of loosers after green cheques within income deciles



form parameters for the effect of different observable characteristics reported in BdF on energy expenditures. More precisely, we run two regressions of the form:

$$Exp_i = \alpha_0 + \alpha_1 \mathbf{X}^D + \epsilon$$

where Exp_i denotes the households' expenditures for products i where i is either transport fuels or housing energy, and $\mathbf{X}^D$ denotes multiple covariates affecting energy demand. The full specification and the results are reported in the appendix.

Almost all variables appear to have statistically significant effects at the 95% confidence level. At no surprise we see that both for transport and housing energies, expenditures are increasing and concave with respect to disposable income. Increasing and concave is also the relationship between transport fuels and age, whereas for housing energy there is no evidence of concavity (quadratic term not statistically or economically significant). For area of residence, we use two dummy variables that indicate whether households live in large cities or in the periphery of a city compare to the default case where they live in small or medium cities. The effect of each dummy is economically significant for both types of energies. Households living in the periphery would tend to consume, everything else held constant, 59€ more for transport fuels annually, and 70€ for housing energy. On the other hand households living in large cities are expected to spend on average respectively 451€ and 267€ less for these two energies. Summing these four results, households living in the periphery are expected to spend on average 847€ more than households living in large cities for equivalent characteristics with respect to the other variables. Interestingly, the estimates for work occupation show a positive effect on transport fuels consumption (+215€), and a negative effect on housing energy consumption (-28€). We might deduce from this result that households that work consume more fuel because they need to take their vehicle to work, and conversely since they spend an important part of their day at work they consume less energy in their own accommodation. Finally, we identify a very important impact of consuming domestic fuel (+1795€) and to a lesser extend natural gas (+748€) compare to households that consume electricity only among domestic energies.

From the preceding results we can expect a very large heterogeneity in contributions among each income bracket. The key question is then to determine whether or not this heterogeneity should be taken into account in the revenue-recycling policy. The green cheques proposed above are indexed on the number of consumption units in the household. If we assume households will not manipulate their fertility decisions as a result of the policy[38] we can correct for this heterogeneity without affecting incentives to pollute. With respect to job occupation, energy taxes could penalize workers so that if we do not compensate this group, we depreciate incentives to work. This result would even be stronger with the fuel tax. There is then a trade-off between incentives to work and incentives not to pollute. We can think of several solutions to overcome this problem. Potentially efficient policies could involve subsidizing firms for encouraging car-sharing or developing common transports to go to work. The advantage of such policy is that it would reinforce the environmental benefits of the reform playing on the extensive margin of drivers: some people would drop their car to share the ride with others. However, it could potentially be costly, and since not all firms would engage in these contracts, not all workers would benefit from it. Another solution that might be less costly, is to redistribute to workers directly or through reduction in labor taxes. If one recognizes that the incentive to work will mainly be affected at the extensive margin, i.e. on the decision to take a job or not, it follows that the individuals concerned will be those at the bottom of the wage distribution. Therefore we can target the policy to low wage earners and not to the full population of workers, which dramatically reduces the cost of the policy.

The heterogeneity with respect to age is a bit complex to understand. Indeed, this heterogeneity could come from preferences that evolve with age, but also from other more constrained parameters. For instance, it could be that retired people are more in need to stay at home so that they must spend more on housing energies. They might also have health issues that require more heating. Hence, from a policy point of view it is not so clear whether or not we should compensate people differently as a function of age.

One of the key question that is likely to be important in the debate around the policies is the case of urban versus rural households. For these households there is an important trade-off that is to know whether we should compensate rural households to soften the distributive effect they are bearing, or on the contrary leave great incentives for these households to move closer to their work, closer to cities or simply in more recent accommodations. The underlying question is therefore whether living in the periphery is a free choice or if it is largely constrained. Since we think with the other variables being held constant, income or occupation status cannot be taken

[38] Having an additional child rises consumption units by 0.3 which is equivalent to a green cheque of 41€ for the carbon tax. Holding everything else equal, this is unlikely to affect fertility decisions.

as constraints on the decision of living area. One can then consider that living in the periphery, holding other observed characteristics constant, reflects mainly households' unobserved heterogeneous preferences. When trading-off an accommodation in a city against in the periphery, these households may feel better off with the second option. Their preferences can also have lead them toward sectors of activities that have increased the attractiveness of the periphery compare to cities. Nonetheless, even if one considers that the heterogeneity with respect to living area is determined by preferences, it does not mean that households are not constrained on them. We cannot expect households to easily switch to a different sector of activity, neither to move from their current accommodation because some legislative parameters have been changed. Furthermore, even assuming that people could move, this would probably be at a high welfare cost. The challenge is then to find a way to not punish households that have decided to live in the periphery in the past, while at the same time giving more appeal to recent accommodations in area closer to cities. A possible strategy would then be to index green cheques on the area of residence[39] for people who have moved in before the reform. This mechanism could be complicated to implement but would have the advantage to make the policy socially more acceptable, and not too costly in the long run. Indeed, depending on the rapidity of the turn-over, the population that would benefit from these additional subsidies would decrease. If we consider that energy taxes are intended to be long term reforms, in the long run this cost would shrink.

Our results also pointed toward the large heterogeneity in contributions between households who use electricity only, those who use natural gas and households using domestic fuel. The problem is a bit akin to the one of rural households. We can hardly punish people for their past investments, but we still would like to induce them to change their technology. An option similar to the one proposed for rural households could therefore be implemented. However, since the required investments to change heating technology is by far less important than the decision to move from an accommodation, we might want to give more incentives to households currently using gas or fuel to turn to electricity. A potential solution would be to subsidize people who change their heating technology toward cleaner resources. Since households are constrained by unobserved characteristics with respect to their ability or their willingness to change their technology, we could propose a set of contracts in the spirit of the mechanism

[39] We could for instance label the cities where some are said to be more constrained than others

design literature. Households unobserved willingness to switch technology could therefore be revealed by these mechanisms[40]. One could then determine the structure and parameters of these contracts in order to solve the trade-off between a maximum number of households turning to cleaner resources, and a lower rent extraction from these households. Note however that the concept of rent-extraction would somewhat differ from the standard informational-rent of the mechanism design literature. Since these contracts do not imply a participation constraint, some households may accept the offer and still incur a welfare loss compare to the situation prior the policy.

The link between the willingness to change technology and the welfare loss from the reform is not clearly defined. Handling distributive issues in addition to the rent-efficiency trade-off is likely to be complex. Modeling the previous contracts goes well beyond the scope of this paper. Neither do we intend to model the other potential solutions for rural households or workers. These intuitions should rather be seen as potential ways to extend our analysis on the social acceptability of potential energy tax reforms.

[40]One then would have to determine what type of contracts to build. Most likely, it could be discrete choices of turning to electricity against a fix subsidy, but these choices may also imply the installation of solar panels or other ways to create energy through cleaner technologies.

7 Conclusions

The model we propose provides precise results on how to design energy tax reforms. Some policies advice follow from our analysis. A first conclusion we can draw is the environmental gains that could be made by correcting for the incoherence of the existing fuel tax (TICPE). Although the tax base is reduced compare to other energy taxes, it achieves very important reductions in carbon emissions. A second conclusion is that some mechanisms could greatly improve public acceptance with respect to tax policies. In particular, green cheques appear to solve distributive issues with respect to income. On other dimensions - living area, occupation, or past investment decisions - distributive effects are more difficult to handle. Our findings tend to indicate that the heterogeneity with respect to these dimensions could be more important for transport fuels. Thus, the catch-up of diesel taxes toward the rate applied for gasoline should rather be progressive. With a strong signal sent to households on the future costs of diesel, we would give time for them to adjust their technology and soften the distributive impacts on these people.

We recognize this model has some limits. However we believe it is flexible enough to be extended in many ways. In particular, future work could imply measuring the effects of a more general carbon tax that would not be restricted to energies only. Matching any good in BdF with a certain carbon content in an input/output model as done recently by Grainger and Kolstad (2010) [17], we could generalize our study. This would also enable to compute Environmental Engel Curves on all goods consumed by households. Another potential extension would be to merge the module "indirect taxation" to the rest of TAXIPP in order to interact indirect and direct taxes. We could then think about more complex redistribution schemes for revenue-recycling and investigate simultaneously distributive concerns and potential double-dividend effects as in Chiroleu-Assouline and Fodha (2014) [11]. The insights of the Public Finance literature could also be used to find a way to tackle households' heterogeneity within income groups. As shown recently by Gauthier and Henriet (2016) [16], with optimal non-linear direct taxation it is still possible to use linear indirect commodity taxes to create a finer redistribution within income classes and relax incentive constraints on labor supply. From this framework we could thus examine in the presence of corrective taxes how taxes on other commodities could soften within income groups distributive effects.

Appendices

A Derivation of results

A.1 Implicit tax rate of the TICPE

In order to determine households' contributions to transport fuels taxes, we first have to distinguish the share of their transport fuel expenditures they spend for diesel and gasoline. Indeed, since the excise duties applied to each of these fuels are different, we need to separate them into two categories. Using information on the number of gasoline and diesel vehicles owned by each household, we have separated the fuel expenditures into these two different goods. Data from aggregate consumption were used to determine how much a household with one diesel and one gasoline car spends on average on each of these products. From these information we could input to each household a given consumption for both diesel and gasoline. Then, using data on the share of gasoline consumption spent on the various fuels (leaded, unleaded 95 or 98, or unleaded fuel with ethanol) we split it in each of these categories. Although imprecise at the household level, when looking at groups this method should not bias the results. The underlying assumption is that across groups (where groups are based on income, area of residence or age) households with the same types of vehicles split their fuel consumption between diesel and gasoline in the same way. As any assumption it is subject to criticisms, but we do not see any convincing argument why it should not hold. Therefore, in the absence of a better method, we rely on this strategy.

For each type of fuel, we identify the part that is paid in TICPE. Because it is an excise duty, the task is not as straightforward as it would be with an *ad valorem* tax. We use the technique detailed in Ruiz and Trannoy (2008) [29] to determine from excise duties and prices the implicit rate of taxation. Let's start from the simple case where we apply the legislation to determine the price of fuel including taxes:

$$p_{ttc} = (1+t)(p_{ht} + a) \tag{1}$$

where t is the VAT full rate, a the excise duty, p_{ttc} the price including taxes and p_{ht} the price without taxes. If we define τ to be the implicit tax rate of the TICPE, we have:

$$p_{ttc} = (1+t)(1+\tau)p_{ht}$$

so that

$$\tau = \frac{a}{p_{ht}} \tag{2}$$

Then because from 1 we have

$$p_{ht} = \frac{p_{ttc}}{1+t} - a$$

combined with 2 we obtain:

$$\tau = \frac{a(1+t)}{p_{ttc} - a(1+t)} \tag{3}$$

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

$$E = p_{ttc}Q = (1+t)(1+\tau)p_{ht}Q \tag{4}$$

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

$$E_{htva} = (1+\tau)p_{ht}Q$$

the expenditures without VAT, and

$$C = \tau p_{ht}Q = E_{htva}\frac{\tau}{1+\tau} \tag{5}$$

the contribution to the TICPE that is identified.

A.2 Energy contracts

In order to find the quantities of gas consumed by households from their expenditures and from the set of potential contracts, we have made several assumptions. First, we have reduced the set of contracts to the regulated prices proposed by the historical company *Gaz de France* (GDF). Although other, maybe more competitive contracts are available, this subset must reflect rather accurately the order of magnitude of gas prices. Second, using this subset of potential contracts, we have computed from households' gas expenditures the quantity they would have consumed if they had suscribe to each of these contracts. Assuming households are rational and can approximately forecast their future consumption, we 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.

Unfortunately, this strategy was not implementable for electricity. As we did for gas, we restrained the set of contracts to what is called "blue tariffs", that are also regulated tariffs of the historical company *Electricité de France* (EDF) [41]. However, these contracts depend on the power of the electricity meter of the household. For households with important electricity consumption, high power is needed. Therefore, to bigger electricity meters are associated more expensive contracts. Matching contracts based on optimal choice would therefore lead to match all households with the same cheapest contract. Instead, we used an alternative strategy. Based on information about the share of households having each type of electricity meter, we ranked households according to their electricity expenditures and matched consumers to electricity meters assuming those who consumed the most were the most likely to have a larger electricity meter.

Using these two strategies we have been able to associate a fix and a variable tariff for electricity and gas for all households. Substracting the fix fee from expenditures and dividing the rest by the variable price, we could finally obtain the quantity consumed by these households.

A.3 Households groups

All along the paper we compare households by groups. These groups include income deciles, area of residence and age. The choice of representing continuous variables (age and income) in discrete groups over continuous representations such as Kernel methods is due to the easier interpretation of the results. For public policy purposes, it is important to clearly identify what groups of people will display what consumption or emissions, or other variables. I believe such thresholds make the interpretation more straightforward than continuous analysis. Also, aggregating at the level of deciles we still have groups of around 1,000 households which insure a rather large sample within each group.

To construct income deciles, we rank households according to their standard of living. Standard of living is taken to be the disposable income divided by the number of consumption units in the household. From this ranking, we create ten groups that are our "income deciles". The average households' annual disposable income and total expenditures are reported in table 4. Age groups are constructed from the age reported by the reference member of the household.

[41] There exist other regulated tariffs for electrivity, with variable price depending on the day or hour of use. Since we have not these information, we could not use these contracts to infer the price households faced.

From this variable "age_pr", we construct six groups including : less than 30 years old, between 30 and 40, 40 and 50, 50 and 60, 60 and 70 and more than 70 years old. The groups for area of residence are constructed from the variable "cataeu" reported in BdF 2011. This variable takes nine values: 1) cities belonging to a large pole (10,000 jobs or more), 2) cities belonging to the periphery of a large pole, 3) cities with multiple poles of great urban areas, 4) cities belonging to a medium pole (5,000 to 10,000 jobs), 5) cities belonging to the periphery of a medium pole, 6) cities belonging to a small pole (1,500 to 5,000 jobs), 7) cities belonging to the periphery of a small pole, 8) other cities with multiple poles, 9) and cities isolated from the poles. To facilitate interpretation and because some of these categories do not contain many observations, we gather them in three groups: large cities, that includes only 1), medium and small cities, 3) 4) and 6), and the periphery that includes all the rest. This nomenclature is imperfect, but it should still give an idea of the degree of isolement of households vis-à-vis their workplace or other important locations.

A.4 Environmental Engel Curves

We follow closely the strategy adopted by Levinson and O'Brien [22]. To place as few restrictions as possible on its shape, we first derive a non-parametric EEC. Although Kernel regression could also have been used, we replicated the method of the authors and ranked the households according to their disposable income, and we separated them in fifty groups of 2% of the population. We then calculated the average carbon emissions from energy for each group and plotted it as a function of the average income of the group.

For the parametric estimation, we ran an OLS regression of the form:

$$E_i = \beta_1 Y_i + \beta_2 Y_i^2 + X_i \gamma + \epsilon_i \quad (6)$$

where E_i is the emission level of individual i, Y_i his income and X_i a set of socio-demographic characteristics. It includes disposable income and its square (our variables of interest), the number of consumption units, dummy variables for periphery or large cities compare to medium and small cities, age and its square, a dummy for household being a single person, whether the reference person and his spouse (if he has one) works, if the household uses domestic fuel, gas or electricity only, and time fixed effects. Taking all variables at their mean except for the two firsts, we then plot carbon emissions as a function of income.

A.5 The Quadratic Almost Ideal Demand System

A.5.1 The QAIDS model

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

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

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. In their seminal paper, Deaton and Muellbauer recommend to take the value of the minimal standard of livings, i.e. the minimum value of $\ln(m)$ in our sample[42]. 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, and we obtain $w_i = (p_i q_i)/m$ the share of the total expenditure associated to the consumption of good i. Then, using Roy's identity we can derive

[42] The minimum value of the log of the disposable income is 5.86 in our sample, but taking values between 5 and 10 as it is common in the literature does not affect much our results.

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

The aim of the QAIDS model is then to estimate this equation for any good i in our model. The estimates obtained for the parameters of the model enable to compute the income and price elasticities with respect to each category of goods.

A.5.2 Elasticities

If we differentiate the share equation 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 11 it gives

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

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 equation with respect to the price of the same good, we get

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

since

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

and

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

If we recognize that

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

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

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

and making use of previous results we obtain

$$e^u_{ii} = \frac{\mu_{ii}}{w_i} - 1 \tag{20}$$

Differentiating w_i with respect to $\ln p_j$ 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 $e^u_{ij} = \frac{\mu_{ij}}{w_i} - \delta_{ij}$. Using the Slutsky equation we also find the compensated price elasticity, $e^c_{ij} = e^u_{ij} + e_i w_j$.

A.5.3 Estimation

We estimate equation 9 assuming there is an additive error term u_{hi} where h denotes the household and i the bundle of good. Because the error terms are not supposed to be independent, this is a system of non-linear seemingly unrelated regressions. Fitting these regressions separately could therefore introduce a bias in the estimation. Moreover, cross restrictions on the values of the parameters require fitting the equations jointly. The estimation of the parameters works with numerical methods. In particular, it uses iterative feasible generalized nonlinear least squares (IFGNLS). Because the three shares sum to 1 for all individuals, we only estimate two of those equations. Which one is dropped is irrelevant for the result. The command "quaids" introduced by Poi (2012) [26] implements automatically the procedure. For each household it then uses the parameters estimated to compute elasticities. However, it does not give standard errors for these elasticities.

The alternative method we use, the command "aidsills" was introduced recently by Lecocq and Robin (2015) [21]. Its aim was to give a method of estimation less demanding in terms of computations, and that would enable to control for endogenous prices. Starting from the observation that equation 9 is conditionally linear in price aggregators, it uses Blundell and Robin's (1999) [7] iterated linear-least squares estimators. The Stone price index and the unit-vector are the initial price aggregators for $a()$ and $b()$ respectively. Then it performs multiple iterations using seemingly unrelated regressions (SUR). If convergence occurs, then the estimators of all parameters are consistent and asymptotically normal. Using these parameters, the post-estimation command then computes the elasticities at the mean of the sample. The drawback is that it does not give household specific elasticities. However, it computes asymptotic standard errors for the macro-elasticities.

A.6 Measuring the impact of reforms

The module "indirect taxation" of TAXIPP reproduces the French legislation with respect to indirect taxes and uses the data BdF to compute numerous variables of interest, such as the quantity of good consumed by households, the amount of tax they pay or their level of emissions. In addition, it can also model potential reforms of these taxes and compute the adjusted values of these variables after the reform. The different scenarios we propose have all similar effects: by introducing an additional excise duty on the consumption of energy goods, it increases their price by a certain amount. If we denote E the level of expenditure before the reform, and dE the variation in expenditures due to the reform, 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

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

From this formula, we can easily interpret the effect of the elasticity on adjusted expenditures. If consumers are not elastic, i.e. if the quantities they consumed are not affected by the price, then $e = 0$ and the new expenditures reflect fully the price increase: $E' = E\left(1 + \frac{dP}{P}\right)$. On the other hand, if they are very elastic such that $e = -1$ then we obtain $E' = E$ meaning that households adjust perfectly their consumption such that there is no variation in their expenditures.

To compute the adjusted expenditures from our data, we set values for e and dP. For e, we use the households' specific elasticities computed from the QAIDS. For dP we use the additional amount of excise duty imposed by the reform. 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. In their seminal paper Besley and Rosen (1999) [6] find that tax incidence on consumers can be above unity. However, for France Carbonnier (2007) [10] finds more conservative estimates and conclude that the share of the burden shifted to consumers depends on the competitiveness of the sector. Since the energy sector is not perfectly competitive in France, it seems relevant to assume that the tax burden will be born not entirely although in the largest part by consumers.

Adjusted quantities can then be deduced from adjusted expenditures dividing by the new price $P' = P + dP'$. From adjusted quantities we can similarly find adjusted emissions. The adjusted contributions (hence the new tax revenue) can finally be found by applying to new expenditures the new legislation.

A.7 Regressing energy consumption on observable characteristics

We run an OLS regression specified as follow:

$$\begin{aligned} Exp_{htjk} = \alpha_0 + \alpha_1 rev\_disp\_loyerimput + \alpha_2 rev\_disp\_loyerimput\_2 + \\ \alpha_3 age\_group\_pr + \alpha_4 age\_group\_pr\_2 + \alpha_5 ocde10 + \alpha_6 alone + \\ \alpha_7 occupe\_both + \tau_t + \mu_j + \eta_k + \epsilon_h \end{aligned} \tag{25}$$

where Exp_{htjk} is the expenditure in energy for household h that is surveyed at time t, living in area j using technology k. Area of living are defined as either large cities, small and medium cities, or periphery. Technologies dummy variables include whether the household consume domestic fuel, natural gas or none of them. $rev\_disp\_loyerimput$ represents the households' disposable income as defined earlier and $rev\_disp\_loyerimput\_2$ its square. age_group_pr is the age group as defined earlier and again $age\_group\_pr\_2$ its square. $ocde10$ is the number of consumption units, $alone$ is a dummy equal to 1 if the person of reference is single and *occupe_both* is a dummy equal to 1 if all adults in the household work. The dependent variable is taken to be expenditures in transport fuels (labeled "*poste_coicop*_722") in a first regression, and expenditures in housing energies (labeled "*depenses_energies_logement*") in a second.

There is no underlying demand model, so estimates are reduced-forms parameters. We assume OLS is consistent and that we can interpret these parameters as effects *ceteris paribus*. In reality, there must be some endogeneity that is not accounted for in this specification, but we believe the results still yields a good idea of the heterogeneity of households consumption linked to all these observed characteristics.

B Figures

Figure 13: Level of transport fuels excise duties (TICPE)

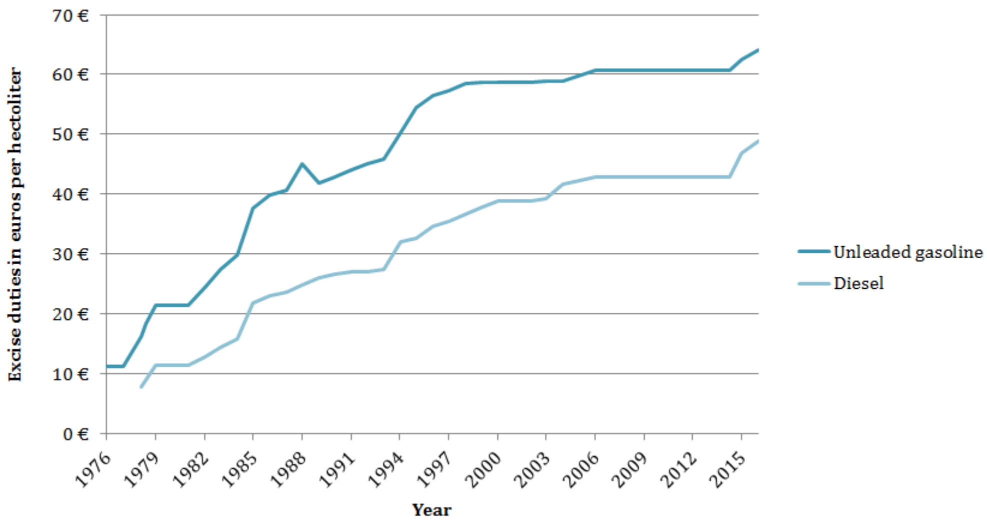


Figure 14: Fuel price with and without taxes from 1990 to 2015

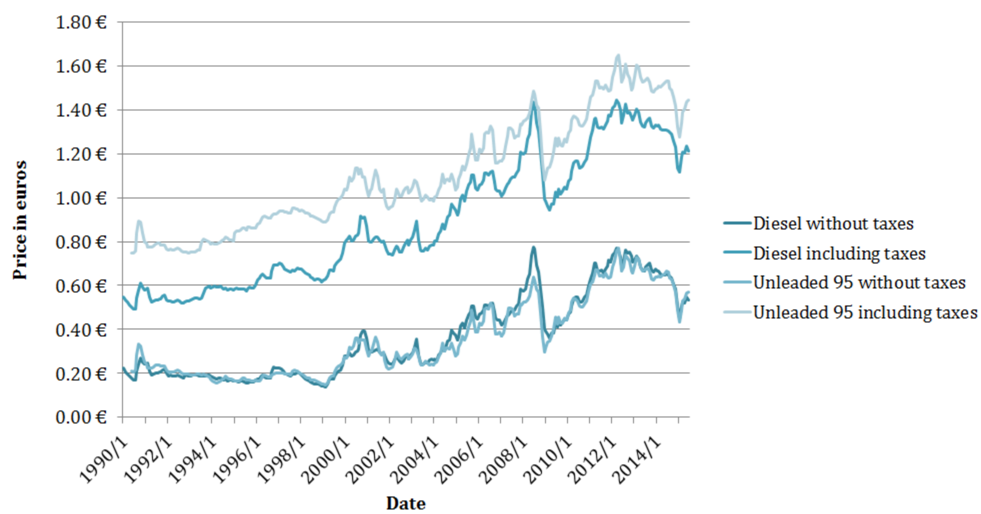
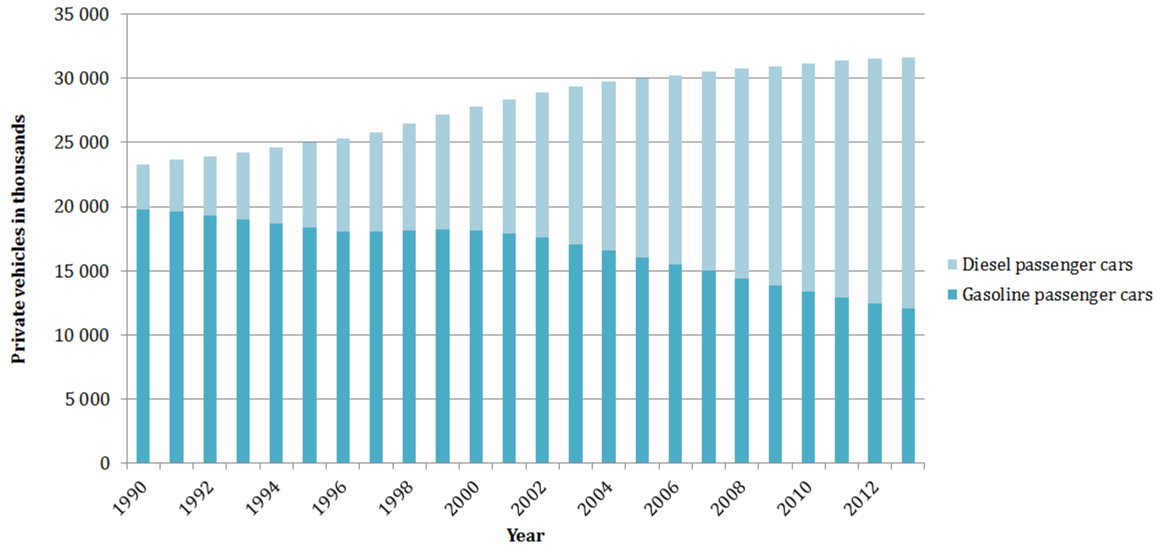


Figure 15: Size of the vehicle fleet in metropolitan France, in thousands of vehicles



Lecture: In 1990, a bit less than 20 millions gasoline private vehicles were registered in metropolitan France. In 1996, a bit more than 30 millions private vehicles were registered in metropolitan France.

Source: *Compte des Transports* 2014.

Figure 16: Annual households' expenditures in energy in 2014, by age group

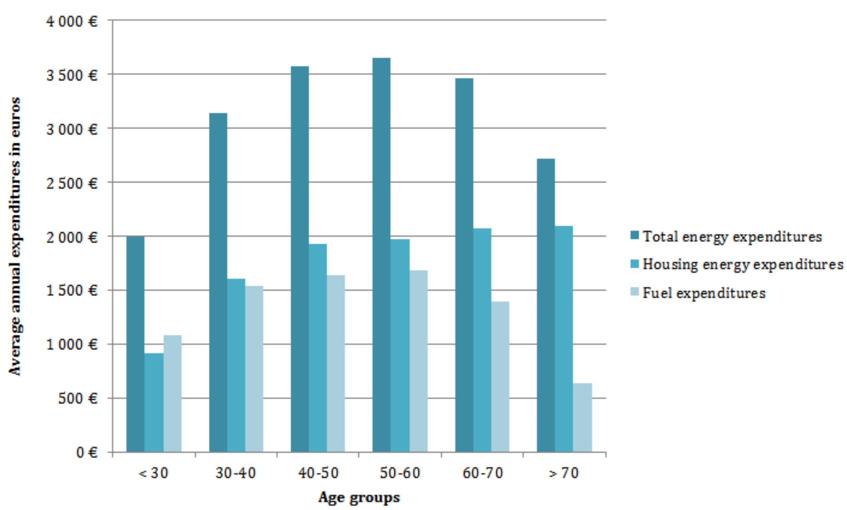


Figure 17: Annual households' expenditures in energy in 2014, by area of residence

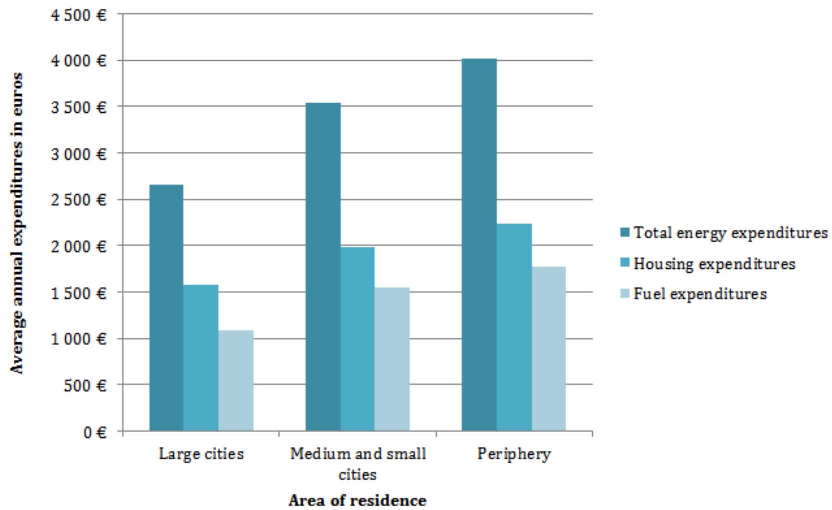


Figure 18: Share of households' disposable income spent on energy consumption in 2014, by income decile

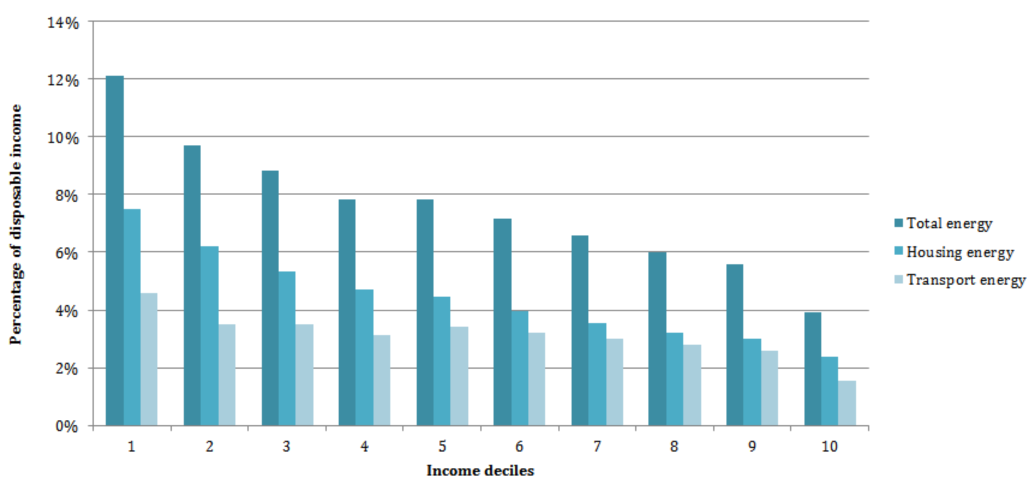


Figure 19: Regression for parametric Environmental Engel Curve

```
                            OLS Regression Results
==============================================================================
Dep. Variable:     emissions_CO2_energies   R-squared:                       0.396
Model:                                OLS   Adj. R-squared:                  0.395
Method:                     Least Squares   F-statistic:                     423.7
Date:                    Wed, 11 May 2016   Prob (F-statistic):               0.00
Time:                            16:33:50   Log-Likelihood:            -1.0265e+05
No. Observations:                   10342   AIC:                         2.053e+05
Df Residuals:                       10325   BIC:                         2.055e+05
Df Model:                              16
Covariance Type:                nonrobust
=========================================================================================
                            coef    std err          t      P>|t|      [95.0% Conf. Int.]
-----------------------------------------------------------------------------------------
Intercept              -233.6354    394.010     -0.593      0.553     -1005.971   538.700
rev_disp_loyerimput       0.0403      0.002     21.252      0.000         0.037     0.044
rev_disp_loyerimput_2 -1.715e-08   1.28e-09    -13.406      0.000     -1.97e-08 -1.46e-08
ocde10                  873.8949    130.811      6.681      0.000       617.481  1130.309
strate_1              -1425.8345    168.329     -8.471      0.000     -1755.793 -1095.876
strate_3                172.7004    175.745      0.983      0.326      -171.794   517.195
age_group_pr            538.9584    160.907      3.350      0.001       223.550   854.366
age_group_pr_2          -50.8012     22.409     -2.267      0.023       -94.728    -6.875
alone                  -946.6144    138.989     -6.811      0.000     -1219.059  -674.169
occupe_both             479.9245    131.126      3.660      0.000       222.892   736.957
gaz                    4344.2562    113.296     38.344      0.000      4122.175  4566.337
fioul                  8265.1751    139.773     59.133      0.000      7991.192  8539.158
vag_23                 -333.9294    170.339     -1.960      0.050      -667.827    -0.032
vag_24                 -241.7874    170.379     -1.419      0.156      -575.762    92.187
vag_25                  287.8001    170.060      1.692      0.091       -45.551   621.151
vag_26                  737.6758    170.283      4.332      0.000       403.888  1071.464
vag_27                  359.0425    177.184      2.026      0.043        11.727   706.358
==============================================================================
Omnibus:                     2818.471   Durbin-Watson:                   2.018
Prob(Omnibus):                  0.000   Jarque-Bera (JB):            11942.505
Skew:                           1.283   Prob(JB):                         0.00
Kurtosis:                       7.597   Cond. No.                     4.88e+11
==============================================================================

Warnings:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 4.88e+11. This might indicate that there are
strong multicollinearity or other numerical problems.
```

Figure 20: Cost of the reform for households by income decile

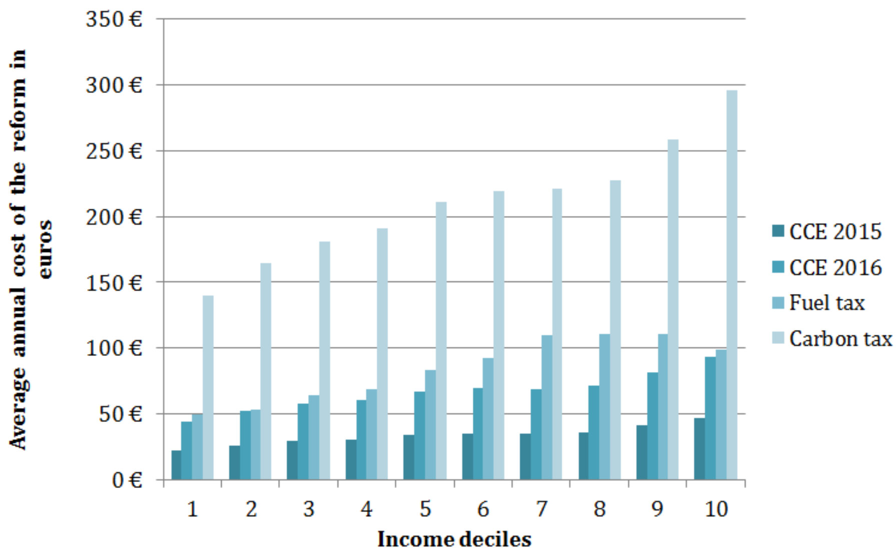


Figure 21: Cost of the reform divided by total expenditures, by area of residence

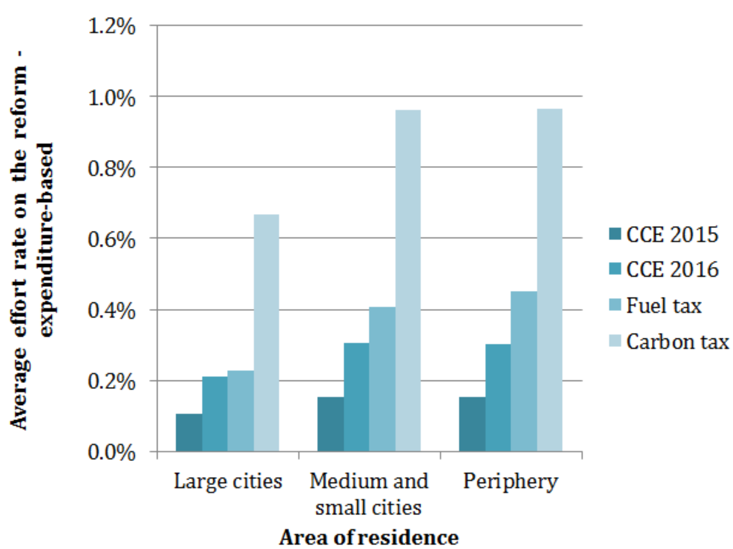


Figure 22: Households' effort rate on indirect taxes by income decile

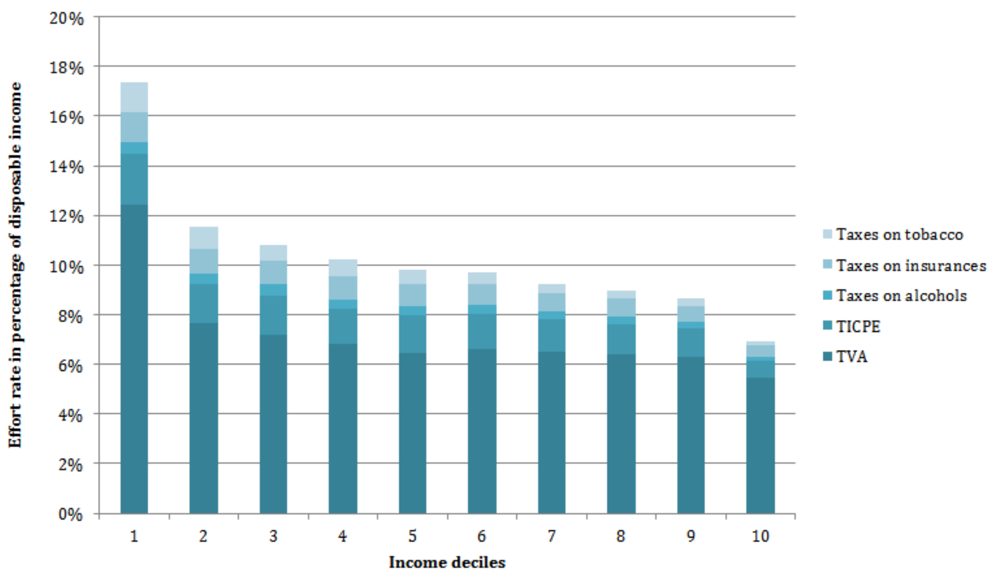


Figure 23: Regression for housing energy expenditures

```
                            OLS Regression Results
==================================================================================
Dep. Variable:     depenses_energies_logement   R-squared:                   0.385
Model:                                    OLS   Adj. R-squared:              0.384
Method:                         Least Squares   F-statistic:                 403.7
Date:                        Tue, 10 May 2016   Prob (F-statistic):           0.00
Time:                                10:18:50   Log-Likelihood:            -87967.
No. Observations:                       10342   AIC:                     1.760e+05
Df Residuals:                           10325   BIC:                     1.761e+05
Df Model:                                  16
Covariance Type:                    nonrobust
=========================================================================================
                            coef    std err          t      P>|t|     [95.0% Conf. Int.]
-----------------------------------------------------------------------------------------
Intercept               -14.9919     95.289     -0.157      0.875      -201.776   171.792
rev_disp_loyerimput       0.0129      0.000     28.120      0.000         0.012     0.014
rev_disp_loyerimput_2 -4.484e-09   3.09e-10    -14.491      0.000     -5.09e-09 -3.88e-09
ocde10                  255.9772     31.636      8.091      0.000       193.965   317.989
strate_1               -267.8685     40.709     -6.580      0.000      -347.667  -188.070
strate_3                 70.1868     42.503      1.651      0.099       -13.127   153.500
age_group_pr            121.2765     38.914      3.117      0.002        44.997   197.556
age_group_pr_2            4.1946      5.420      0.774      0.439        -6.429    14.818
alone                   -95.4367     33.614     -2.839      0.005      -161.326   -29.548
occupe_both             -28.6873     31.712     -0.905      0.366       -90.849    33.474
gaz                     747.7679     27.400     27.291      0.000       694.059   801.477
fioul                  1795.1793     33.803     53.107      0.000      1728.918  1861.440
vag_23                   -2.7050     41.195     -0.066      0.948       -83.456    78.046
vag_24                   -7.1697     41.205     -0.174      0.862       -87.939    73.600
vag_25                   70.2898     41.128      1.709      0.087       -10.329   150.908
vag_26                  145.2338     41.182      3.527      0.000        64.509   225.958
vag_27                   85.9461     42.851      2.006      0.045         1.950   169.942
==============================================================================
Omnibus:                     5918.367   Durbin-Watson:                   2.009
Prob(Omnibus):                  0.000   Jarque-Bera (JB):           132680.050
Skew:                           2.301   Prob(JB):                         0.00
Kurtosis:                      19.933   Cond. No.                     4.88e+11
==============================================================================

Warnings:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 4.88e+11. This might indicate that there are
strong multicollinearity or other numerical problems.
```

Figure 24: Regression for transport fuels expenditures

```
                            OLS Regression Results
==============================================================================
Dep. Variable:      poste_coicop_722   R-squared:                       0.132
Model:                           OLS   Adj. R-squared:                  0.131
Method:                Least Squares   F-statistic:                     98.33
Date:               Tue, 10 May 2016   Prob (F-statistic):         1.44e-302
Time:                       10:18:49   Log-Likelihood:                -92531.
No. Observations:              10342   AIC:                         1.851e+05
Df Residuals:                  10325   BIC:                         1.852e+05
Df Model:                         16
Covariance Type:           nonrobust
=========================================================================================
                            coef    std err          t      P>|t|      [95.0% Conf. Int.]
-----------------------------------------------------------------------------------------
Intercept               372.0154    148.154      2.511      0.012        81.605   662.426
rev_disp_loyerimput       0.0077      0.001     10.772      0.000         0.006     0.009
rev_disp_loyerimput_2  -3.62e-09   4.81e-10     -7.525      0.000     -4.56e-09 -2.68e-09
ocde10                  239.7858     49.187      4.875      0.000       143.370   336.201
strate_1               -451.9455     63.294     -7.140      0.000      -576.015  -327.876
strate_3                 58.5313     66.083      0.886      0.376       -71.004   188.067
age_group_pr            477.3402     60.503      7.889      0.000       358.742   595.939
age_group_pr_2          -73.5646      8.426     -8.730      0.000       -90.082   -57.048
alone                  -467.8966     52.262     -8.953      0.000      -570.340  -365.453
occupe_both             215.9824     49.305      4.381      0.000       119.334   312.631
gaz                     -46.6212     42.601     -1.094      0.274      -130.127    36.885
fioul                   290.2246     52.557      5.522      0.000       187.203   393.246
vag_23                  -66.7743     64.050     -1.043      0.297      -192.325    58.776
vag_24                  -57.3524     64.065     -0.895      0.371      -182.932    68.227
vag_25                   91.4820     63.945      1.431      0.153       -33.863   216.827
vag_26                  233.8689     64.029      3.653      0.000       108.359   359.378
vag_27                  105.3576     66.624      1.581      0.114       -25.238   235.953
==============================================================================
Omnibus:                     3035.295   Durbin-Watson:                   2.022
Prob(Omnibus):                  0.000   Jarque-Bera (JB):            10521.872
Skew:                           1.463   Prob(JB):                         0.00
Kurtosis:                       6.982   Cond. No.                     4.88e+11
==============================================================================

Warnings:
[1] Standard Errors assume that the covariance matrix of the errors is correctly specified.
[2] The condition number is large, 4.88e+11. This might indicate that there are
strong multicollinearity or other numerical problems.
```

C Tables

Table 4: Households average annual disposable income and expenditures, by income decile

Income deciles	Disposable income	Total expenditures	Ratio expenditures / income
1	17,272€	18,029€	1.04
2	25,309€	18,813€	0.74
3	30,254€	20,688€	0.68
4	35,662€	22,448€	0.63
5	39,701€	23,189€	0.58
6	45,653€	26,088€	0.57
7	52,238€	28,741€	0.55
8	58,771€	30,787€	0.52
9	69,358€	35,569€	0.51
10	107,495€	44,896€	0.42

Table 5: Elasticities for below median expenditure level households, using ILLS estimation

	Budget elasticity	**Uncompensated price elasticity**	**Compensated price elasticity**
Transport fuels	0.675*** (0.014)	-0.726*** (0.043)	-0.676*** (0.043)
Housing energy	0.593*** (0.015)	-0.250*** (0.023)	-0.213*** (0.023)
Other non-durable goods	1.057*** (0.002)	-1.022*** (0.016)	-0.109*** (0.016)

Note: *** indicates a p-statistic below 0.001.

Table 6: Elasticities for above median expenditure level households, using ILLS estimation

	Budget elasticity	**Uncompensated price elasticity**	**Compensated price elasticity**
Transport fuels	0.588*** (0.014)	-0.678*** (0.050)	-0.641*** (0.050)
Housing energy	0.513*** (0.018)	-0.014 (0.031)	0.010 (0.031)
Other non-durable goods	1.055*** (0.001)	-1.021*** (0.015)	-0.083*** (0.016)

Note: *** indicates a p-statistic below 0.001.

Table 7: Elasticities for rural households, using ILLS estimation

	Budget elasticity	**Uncompensated price elasticity**	**Compensated price elasticity**
Transport fuels	0.604***	-0.681***	-0.642***
	(0.013)	(0.050)	(0.050)
Housing energy	0.643***	-0.309***	-0.266***
	(0.011)	(0.021)	(0.021)
Other non-durable goods	1.057***	-1.021***	-0.103***
	(0.001)	(0.016)	(0.016)

NOTE: *** indicates a p-statistic below 0.001.

Table 8: Elasticities for households consuming electricity only, using ILLS estimation

	Budget elasticity	**Uncompensated price elasticity**	**Compensated price elasticity**
Transport fuels	0.601***	-0.680***	-0.642***
	(0.012)	(0.050)	(0.050)
Housing energy	0.352***	0.249***	0.262***
	(0.019)	(0.041)	(0.041)
Other non-durable goods	1.055***	-1.022***	-0.073***
	(0.001)	(0.015)	(0.015)

NOTE: *** indicates a p-statistic below 0.001.

Table 9: Revenue-recycling - green cheques and VAT cuts by reform

Reforms	**Instrument**	**CCE 2014-2015**	**CCE 2014-2016**	**Carbon tax**	**Fuel tax**
Full rate VAT cut	Reduction in full rate	0.4%	0.8%	2.6%	1%
Reduced and full rate VAT cuts	Reduction in full rate	0.2%	0.5%	1%	0.5%
	Reduction in reduced rate	0.4%	0.6%	3%	1%
	Reduction in hyper reduced rate	0.4%	0.6%	1%	1%
Green cheques	Amount per consumption unit	21.87€	43.39€	137.67€	54.78€

Note: For VAT cuts, the numbers express percentage points decreases compare to the rates of 2014. For green cheques, the amount denote the value of the cheque per consumption unit in an household. All parameters are set such that any reform is budget neutral.

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