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A Fuel Tax Decomposition When Local Pollution Matters*

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Abstract

We study the optimal design of consumption taxes when both global and local externalities matter. Local externalities make the social impact of the consumption of externality-generating commodities varying across consumers. A typical example involves the greater damage caused by pollution from urban fuel consumers. We provide a condition for the validity of the targeting principle according to which externality concerns should only fall on the taxes on externality-generating commodities. When this condition is satisfied, one can decompose the tax on an externality-generating commodity into equity/efficiency and Pigovian contributions. The Pigovian contribution should exceed the average social damage if the fuel consumption of the greatest polluters is more responsive to fuel price. In an empirical illustration we find that the fuel tax in France is mostly explained by Pigovian considerations.

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1 Introduction

In many countries taxation is used to curb carbon dioxide emissions from fuel combustion which contribute to global warming. In the UK, for instance, the vehicle tax on diesel and other engines with low carbon dioxide emissions has been reduced in 2001. However public awareness has recently come that diesel combustion also generates large quantities of air pollutants that, unlike carbon dioxide, do not have a global but instead a local impact, as they tend to remain where they are emitted. In view of the high local pollution from diesel in urban areas, the UK now prepares to turn back its preferential tax treatment by introducing a so-called toxin tax. The shift of course reflects the evolution of our knowledge about energy sources. But it also illustrates that several possibly conflicting external effects may originate from one single good. Our paper identifies theoretical circumstances where one can decompose the tax on an externality-generating commodity into the various considerations that shape this tax. In an empirical illustration on France it quantifies each of these considerations for the fuel tax.

Although environmental concerns are certainly relevant for fuel taxation, other local externalities, e.g., traffic-related, as well as traditional efficiency and equity arguments also matter. So far the existing literature often has treated these considerations separately.[1] Our paper deals with all these considerations simultaneously when households differ according to their consumption tastes and the detrimental impact implied by their fuel consumption. This second dimension has remained about unexplored since the seminal analysis of Diamond (1973) and Green and Sheshinski (1976). It is however crucial to account for local externality: the social damage from the combustion of a given quantity of fuel is greater in densely populated urban areas. A first-best tax system would therefore involve personalized Pigovian fuel taxes varying across consumers, with higher fuel taxes on urban fuel consumers.

It may nevertheless be difficult to implement tax systems that violate horizontal equity criteria. Think of political economy considerations, legal rules that limit the possibility of non-uniform treatment of taxpayers, uncontrolled reselling operations from untaxed fuel consumers in rural areas, or the mere feasibility to track drivers as practical obstacles. In a second-best world where the fuel tax is required to be uniform over the whole tax jurisdiction, the government should typically exploit complementarity and substitution between fuel and other goods to set taxes that deter specifically fuel consumption in urban areas. Indeed this is a common justification for subsidies on public transportation.

Playing with several taxes to remedy for externalities is socially useful as far as changes in the taxes applied on goods other than fuel do not replicate the impact of a change in the

[1]Efficient fuel taxes are quantified by West and Williams (2007), Bento, Goulder, Jacobsen, and Haefen (2009), Molloy and Shan (2013), Davis (2014), Li, Linn and Muehlegger (2014), or Borck and Brueckner (2016). Fuel taxes are often found regressive which justifies a downward adjustment from efficient taxes; see, e.g., Poterba (1991), West (2004), Bento, Goulder, Jacobsen, and Haefen (2009) or Li and Peng (2016). There is clear evidence of health costs of pollution from motor vehicles, especially for children (Currie et al., 2014). See also Hou et al. (2010), Fu and Gu (2014), and Ebenstein et al. (2017).

fuel tax itself. This happens if changes in the taxes on other goods enable the government to target more specifically the fuel consumption of the greatest polluters than a change in the fuel tax alone. Otherwise, a 'sensitivity-neutral' condition is satisfied. This condition makes environmental concerns passed on the fuel tax only, thus generalizing the scope of the targeting principle in Sandmo (1975), Bovenberg and van der Ploeg (1994) and Kopczuk (2003) to the local externality case.

We show that, when the sensitivity-neutral condition holds, one can write the second-best optimal fuel tax as a sum of three components: (1) an efficiency/equity contribution summarized by a version of the many-person Ramsey rule derived by Diamond and Mirrlees (1971), (2) a Pigovian part designed to deal with the average social damage, and (3) a sufficient statistics that aggregates agents' heterogeneity in the external effects of their fuel consumption. This last component reflects the possibility to discourage fuel consumption from the greatest polluters: the total Pigovian contribution to the fuel tax should be set above the average social damage if the fuel consumption from the greatest polluters is more sensitive to an increase in the fuel price.

Using consumption microdata from France we find that the sensitivity-neutral condition is satisfied, assuming that observed current taxes coincide with the second-best optimal taxes. This allows us to provide an order of magnitude for each of the three components (1) to (3) focusing on the sole fuel tax. In the 131 percent fuel tax, one can attribute 115 percentage points to the Pigovian consideration (2). The 16 remaining points are explained by the many-person Ramsey consideration (1), an amount close to the standard rate of VAT of 19.6%. On its own, heterogeneity captured by the statistics (3) appears negligible: in France only the average social damage from fuel is reflected in the fuel tax. The reason for this surprizing property relies on the inability to discourage specifically fuel consumption in urban areas because urban display a lower but also more elastic fuel consumption than rural households. This combination finally yields an adjustment of the overall fuel consumption to a change in the fuel tax that is very similar in the two areas.

Recent theoretical studies by Eckerstorfer and Wendner (2013) and Wendner (2014) derive optimal tax rules in the presence of non-atmospheric externalities that extend Diamond (1973). They exhibit a special polar case where our sensitivity-neutral condition in fact is at work and makes the targeting principle valid. Our quantification exercise builds on the two benchmark analysis by Parry and Small (2005) and Griffith, O'Connell and Smith (2017). Unlike Parry and Small (2005) our setup allows for heterogeneity across households and relies on the assumption of an optimal fuel tax for France rather than a calibration methodology. Griffith, O'Connell and Smith (2017) examine a case where non-linearities in the externality from alcohol consumption imply heterogeneous external effects across consumers, which yields some form of local externality. In their analysis every good is assumed to be taxed at a uniform rate according to the quantity of ethanol it contains. As a result goods generating no externality, i.e., those containing no ethanol, are necessarily tax-free. In contrast we allow for differential taxation of clean goods which enables us to discuss the empirical scope for the targeting principle.

The paper is organized as follows. Section 2 describes the general setup and Section

3 characterizes the first-best policy. Section 4 gives optimal second-best commodity taxes and identifies circumstances where the targeting principle holds true. Section 5 is devoted to the empirical illustration on the fuel tax in France.

2 Theoretical setup

The economy consists of a continuum of consumers, one representative competitive firm and the government. Consumers are divided into a discrete number H of groups or types indexed by h. There are n^h consumers of type h in a total unit size population. The preferences of every type h consumer are represented by the utility function

$$u^h(\mathbf{x}, y, \ell) - \varphi^h(\mathbf{e}),$$

where $\mathbf{x} \in \mathbb{R}^I_+$ is a bundle of $I \geq 1$ clean consumption goods (that do not imply externalities), $y \in \mathbb{R}_+$ is the consumption of an externality generating good and $\ell \in \mathbb{R}_+$ is labor. The function u^h takes values in $\mathbb{R}$ and satisfies standard monotonicity and convexity properties.

Good y is a dirty good implying an externality entering the utility function through the H-dimensional vector $\mathbf{e}$ whose h-th component is $e^h = n^h y^h$, where y^h is the quantity of the dirty good consumed by one type h agent. The function φ^h is increasing in each component of $\mathbf{e}$ which makes the consumption of the dirty good detrimental to every agent. In the main strand of the literature the function φ^h is usually chosen symmetric in its arguments; often it depends on the aggregate consumption of the dirty good only (see, e.g., Sandmo, 1975; Cremer et al., 1998; Cremer et al., 2003; Sandmo, 2011). Such a representation is well suited to capture global 'atmospheric' externalities such as global warming. Indeed it may be that aggregate greenhouse gas emissions from automobile-based fuel consumption differ in rural and urban areas but the origin of the emission in fact is irrelevant for assessing the global warming external impact on welfare. When φ^h is symmetric in its argument, the role played by the index h in φ^h is to allow for heterogeneity in how much agents suffer from global externalities. This could for instance accommodate for global warming causing a greater damage in rural areas constrained to adapt to new agricultural models.

The main theoretical innovation of our paper is to deal with a more general formulation that allows the function φ^h to be asymmetric in its arguments. This implies that the identities of dirty good consumers matter to assess both how much a given type h of agents is suffering from the externality and the overall extent of the social damage this type is causing. We especially have in mind situations where local externalities make a given type h consumer exposed to the externality caused by other type h consumers while being not concerned at all by the externality caused by agents with types $h' \neq h$. The consumption of automobile services in urban areas certainly affects urban households to a greater extent than fuel combustion from rural areas, whereas the pollution from fuel combustion in rural areas is likely to have only a limited social damage in both urban and rural areas. This kind of situations can be captured by a function φ^h with a partial derivative for a urban type h with respect to the aggregate fuel consumption of urban households that is greater than its derivative in the aggregate fuel consumption of rural households; in the same way, the partial derivative of φ^h for a rural type h with respect to the aggregate fuel consumption from urban households could be set to about 0. The asymmetry in the function φ^h thus appears to be crucial to account for local externalities.

Our setup also deals with taste heterogeneity through the function u^h that governs consumption patterns, which permits a rich variety of consumption behaviors. For instance, referring again to rural and urban types of agents, heterogeneity in (u^h) allows urban households to consume less fuel and more public transport services than rural households. The geographical distribution of the population represented by (n^h) then gives rise to a profile $\mathbf{e}$ where pollution typically differs in rural and urban areas. In view of the heterogeneity in φ^h it is possible that rural households do not really care about the high pollution in densely populated urban areas but suffer from global warming to a greater extent than the rest of the population.

The only restriction in individual preferences comes from the assumed separability. The separable formulation implies that the externality influences neither consumption nor labor. This precludes a possible feedback where fuel consumption not only generates but also is partially determined by pollution. In practice policies that release public information about pollution to encourage the adoption of cleaner modes of transport and heating methods heavily rely on such a kind of feedback. However the few available empirical evidence suggests that this feedback could be very low in magnitude (Williams, 2003).

On the production side we consider a standard linear technology such that every unit of clean (resp., dirty) good j (resp., y) requires using a_j (resp., a_y) units of labor. Hence producer prices will be fixed in a competitive equilibrium. In the Ramsey tradition the government has to finance a given public deficit $R > 0$. The available tools are linear consumption (excise) taxes and income taxes and transfers. With fixed producer prices, choosing consumption taxes amounts to choose consumer prices. The presence of local externalities makes personalized consumer prices necessary to decentralize a first-best allocation. In the sequel we derive an optimal tax rule in a second-best world where taxes are required to be type-independent. This rule will be the basis for the empirical illustration on French data.

3 First-best benchmark

3.1 First-best optimum

Let β^h be the (given) social weight applying on every consumer of type h. The first-best optimum is a profile $(\mathbf{x}^h, y^h, \ell^h)$ and a vector of external effects $\mathbf{e}$ maximizing the social objective

$$\sum_h n^h \beta^h \left[u^h(\mathbf{x}^h, y^h, \ell^h) - \varphi^h(\mathbf{e}) \right]$$

subject to the feasibility constraint

$$\sum_h n^h \ell^h \geq \sum_j a_j \sum_h n^h x_j^h + a_y \sum_h n^h y^h + R$$

and subject to the form of the externality-generating process

$$e^h = n^h y^h \text{ for all } h.$$

The first-order conditions associated with labor and clean good j yield the familiar equalities between the marginal rates of substitution and the marginal rates of transformation,

$$-\frac{\partial u^h}{\partial x_j} = a_j \frac{\partial u^h}{\partial \ell} \text{ for all } j \text{ and } h. \tag{1}$$

The first-order conditions associated with labor and the dirty good are similar, up to the adjustment required to account for the external effects,

$$-\frac{\partial u^h}{\partial y} = \left(a_y + \sum_k n^k \frac{\beta^k}{\rho} \frac{\partial \varphi^k}{\partial e^h} \right) \frac{\partial u^h}{\partial \ell}, \tag{2}$$

where ρ is the (positive) Lagrange multiplier associated with the feasibility constraint. The adjustment from the marginal rate of transformation a_y that appears in (2),

$$\sum_k n^k \frac{\beta^k}{\rho} \frac{\partial \varphi^k}{\partial e^h},$$

equals the social damage caused by a marginal increase in the aggregate consumption of the dirty good by type h. In the presence of local externalities captured by the asymmetry properties of the individual damage function φ^h, different types of consumers typically cause different social damages.

3.2 Personalized Pigovian taxes

The government can achieve the first-best optimum in a decentralized setup by appealing to a set of consumer prices (q_j) for clean goods and personalized consumer prices (q_y^h) for the dirty good, provided that it can also use lump-sum personalized income taxes and transfers (T^h). In equilibrium the assumption of a linear technology implies $p_j = a_j$ for every clean good j and $p_y = a_y$ for the dirty good. Given consumer prices, income transfers, and the profile $\mathbf{e}$ of externalities, a type h consumer chooses consumption and labor that maximize

$$u^h(\mathbf{x}, y, \ell)$$

subject to

$$\sum_j q_j x_j + q_y^h y \leq \ell + T^h. \tag{3}$$

Let $\mathbf{q}^h = ((q_j), q_y^h)$ be the vector of consumption prices. The demand for consumption goods $(\xi_j^h(\mathbf{q}^h, T^h))$ and $\xi_y^h(\mathbf{q}^h, T^h)$ and the labor supply $\ell^h(\mathbf{q}^h, T^h)$ solutions to this program are such that the budget constraint (3) is satisfied at equality and

$$-\frac{\partial u^h}{\partial x_j} = q_j \frac{\partial u^h}{\partial \ell} \tag{4}$$

for every clean good j, and

$$-\frac{\partial u^h}{\partial y} = q_y^h \frac{\partial u^h}{\partial \ell}. \tag{5}$$

The corresponding indirect utility is $v^h(\mathbf{q}^h, T^h)$.

From (1) and (4), the decentralization of the first-best optimum requires $q_j = p_j = a_j$ for every clean good j. As is usual, commodity taxes on clean goods are useless to decentralize the first-best optimum. From (2) and (5) the consumer prices of the dirty good must be set so that

$$q_y^h = a_y + \sum_k n^k \frac{\beta^k}{\rho} \frac{\partial \varphi^k}{\partial e^h} \text{ for all } h.$$

Since $p_y = a_y$ the first-best Pigovian taxes on the dirty good equal

$$t_y^h = q_y^h - p_y = \sum_k n^k \frac{\beta^k}{\rho} \frac{\partial \varphi^k}{\partial e^h} \tag{6}$$

for every type h. The tax that should be paid by a consumer increases with the social damage that this type is causing. In the plausible case where emissions from fuel consumption cause a greater social damage in densely populated urban areas, the government should apply higher Pigovian taxes on fuel consumed by urban households.

4 Second-best taxation

In practice it may be difficult to implement personalized taxes on fuel. Indeed legal fiscal rules often have to satisfy some principle of equality before taxation that severely restricts the possible use of non-anonymous consumption taxes. In France regional governments can adjust the TICPE (Taxe Intérieure sur la Consommation de Produits Energétiques) part of the fuel tax chosen by the central government, which stands around 60 cents per liter, by an amount that is limited to $\pm\, 0.73$ cents per liter. Actually most regions choose not to implement any local modulation of the national tax, thus making the fuel tax about uniform over the whole territory. Even in the absence of such legal restrictions it seems unlikely that the central government is able to control where fuel consumption actually takes place. It would be possible to control where fuel is bought but this does not necessarily coincide with the geographical origin of local pollutants emissions: think of a driver purchasing gasoline in a rural area to travel to the neighboring city. For these reasons we now adopt the second-best viewpoint that the government can only rely on anonymous fiscal tools: neither personalized lump-sum income taxes nor personalized Pigovian taxes can be used.

4.1 Optimal discouragement

Let $(\mathbf{q}, T)$ be the vector of consumption prices and income transfers faced by every type of consumers. The tax authority chooses $(\mathbf{q}, T)$ maximizing

$$\sum_h n^h \beta^h \left[v^h(\mathbf{q}, T) - \varphi^h(\mathbf{e})\right]$$

subject to

$$\sum_j (q_j - p_j) \sum_h n^h \xi_j^h(\mathbf{q}, T) + (q_y - p_y) \sum_h n^h \xi_y^h(\mathbf{q}, T) \geq R + T,$$

with $\mathbf{e} = (e^h)$ and

$$e^h = n^h \xi_y^h(\mathbf{q}, T) \text{ for all } h.$$

The first-order condition associated with the optimal income transfer T is

$$\sum_h n^h b^h = 1, \tag{7}$$

where

$$b^h = \frac{\beta^h}{\lambda} \frac{\partial v^h}{\partial T} + \sum_k t_k \frac{\partial \xi_k^h}{\partial T} - t_y^h \frac{\partial \xi_y^h}{\partial T} \tag{8}$$

equals the change in social welfare implied by a small increase in an income transfer that would be designed specifically for a type h consumer. In line with Saez and Stancheva (2016) we shall use b^h as the actual social valuation of a type h consumer. The formula (8) shows that this valuation reflects three different considerations. First it integrates intrinsic considerations driven by the weights (β^h) that appear in the social welfare function: as expected, a high intrinsic valuation β^h of type h translates into a high social valuation b^h. Second, the social valuation of a type h rises when a (fictitious) targeted income transfer toward this type would yield a higher taxes (on both clean and dirty goods). This happens if the type h demand for normal goods displays a significant income effect. The third consideration relies on the last term in (8), which depends on the Pigovian tax t_y^h. This accounts for the fact that an income transfer toward type h would also affect the externality caused by these consumers: everything else equal, a type h consumer causing a high social damage (measured by a high Pigovian tax t_y^h) has a low social valuation.

Let ξ_i stand for the aggregate consumption of good i (clean or dirty), a function of $(\mathbf{q}, T)$. Using (7) and (8), the first-order condition in q_i can be written

$$\sum_k \sum_h n^h t_k \frac{\partial \hat{\xi}_i^h}{\partial q_k} = \sum_h n^h b^h \xi_i^h - \sum_h n^h \xi_i^h + \sum_h n^h t_y^h \frac{\partial \hat{\xi}_y^h}{\partial q_i}, \tag{9}$$

with Hicksian (compensated) demand indexed by a hat. From (7),

$$\text{cov}(\mathbf{b}, \boldsymbol{\xi}_i) = \sum_h n^h b^h \xi_i^h - \sum_h n^h \xi_i^h,$$

so that the optimal discouragement on good i appearing in the left-hand side of (9) can be rewritten as given in Proposition 1.

Proposition 1. *The discouragement index on (clean or dirty) good i is*

$$\sum_{j \neq y} t_j \frac{\partial \hat{\xi}_i}{\partial q_j} + t_y \frac{\partial \hat{\xi}_i}{\partial q_y} = \operatorname{cov}(\mathbf{b}, \boldsymbol{\xi}_i) + \sum_h n^h t_y^h \frac{\partial \hat{\xi}_y^h}{\partial q_i}. \tag{10}$$

In the absence of externality, we have $t_y^h = 0$ for all h, so that the last sum in (10) is zero for every good i. Let (t_i^{R}) be the Ramsey tax rates that would be optimal in this situation, i.e., the tax rates satisfying

$$\sum_{j \neq y} t_j^{\mathrm{R}} \frac{\partial \hat{\xi}_i}{\partial q_j} + t_y^{\mathrm{R}} \frac{\partial \hat{\xi}_i}{\partial q_y} = \operatorname{cov}(\mathbf{b}, \boldsymbol{\xi}_i) \tag{11}$$

for all i. Formula (11) is the usual Diamond and Mirrlees (1971) many-person Ramsey recommendation to equalize the discouragement index of good i in the left-hand side of (11) and the 'distributive factor' of this good, measured by the covariance $\operatorname{cov}(\mathbf{b}, \boldsymbol{\xi}_i)$. Demand for good i should then be discouraged by the tax system when consumers who like this good (those types h that have a high consumption ξ_i^h of good i) also have a low social valuation (a low b^h).

Externalities enter (10) through the last sum,

$$\sum_h n^h t_y^h \frac{\partial \hat{\xi}_y^h}{\partial q_i},$$

which represents the marginal social damage caused by the change in fuel consumption following a small change in the price of good i. This sum is positive if the dirty good is a Hicksian substitute to good i for the types of consumers causing the greatest social damage. A lower tax on good i then yields a lower consumption of the dirty good from these agents, and so a lower social damage. The sole environmental considerations then recommend to encourage the demand for good i. On the contrary, the sum will be negative if the dirty good is a Hicksian complement to good i for these agents.

4.2 A scope for the targeting principle

Proposition 1 suggests that every tax should typically depart from Ramsey recommendations in order to exploit complementarity and substitutability with the dirty good. We know however that Sandmo targeting principle would apply in our framework in the absence of local externalities, i.e., only the tax on the dirty good should then depart from its many-person Ramsey level. This section identifies circumstances where the targeting principle still holds in the presence of local externalities. To this aim it is useful to refer to

$$\mathrm{cov}\left(\mathbf{t}_y, \mathbf{s}_i\right) = \sum_h n^h t_y^h s_i^h - \sum_h n^h t_y^h,$$

where $\mathbf{t}_y$ is a vector with t_y^h as h-th component, and $\mathbf{s}_i$ is a vector whose h-th component

$$s_i^h = \frac{\partial \hat{\xi}_y^h}{\partial q_i} \Bigg/ \frac{\partial \hat{\xi}_y}{\partial q_i}$$

is the relative sensitivity of type h fuel consumption with respect to the price of good i. The formula (10) for optimal taxes then rewrites

$$\sum_{j \neq y} t_j \frac{\partial \hat{\xi}_i}{\partial q_j} + \left(t_y - \sum_h n^h t_y^h - \mathrm{cov}\left(\mathbf{t}_y, \mathbf{s}_i\right) \right) \frac{\partial \hat{\xi}_i}{\partial q_y} = \mathrm{cov}(\mathbf{b}, \boldsymbol{\xi}_i). \tag{12}$$

The scope of the targeting principle immediately follows from (12).

Proposition 2. *The targeting principle holds if* $\mathrm{cov}\left(\mathbf{t}_y, \mathbf{s}_i\right)$ *is independent of* i,

$$\mathrm{cov}\left(\mathbf{t}_y, \mathbf{s}_i\right) = \phi \textit{ for all } i. \tag{13}$$

Then the taxes on clean goods should be set to their Ramsey levels, i.e., $t_j = t_j^{\mathrm{R}}$ *for every clean good* j*, while the tax on the dirty good* y *is*

$$t_y = t_y^{\mathrm{R}} + \sum_h n^h t_y^h + \phi. \tag{14}$$

We refer to (13) as a 'sensitivity-neutral' condition. By rewriting this condition as

$$\sum_h t_y^h \frac{\partial \hat{\xi}_y^h}{\partial q_i} = \left(\phi + \sum_h n^h t_y^h \right) \frac{\partial \hat{\xi}_y}{\partial q_i}, \tag{15}$$

we see that it is satisfied when the reaction of the social damage to a change in the price of good i (in the left-hand-side of (15)) can be expressed as a given proportion, independent of the good i under consideration, of the reaction of the aggregate fuel consumption.

The sensitivity-neutral is satisfied in the two polar cases where the personalized Pigovian taxes (t_y^h) are uniform across types, which happens if the externality is global 'atmospheric', or if agents have the same preferences (u^h is independent of h) since then they all have the same demand function for the dirty good. In each of these two cases, the covariance ϕ in (13) is zero but the sensitivity-neutral can also be satisfied with a non-zero ϕ. For instance it is readily checked that $\phi > 0$ with $u^h(\mathbf{x}, y, \ell) = u(\mathbf{x}, y) - f^h(\ell)$ and $u(.)$ homothetic, if the high income earners also are the greatest polluters.

Provided that the sensitivity-neutral condition holds, the tax on the dirty good should be adjusted from its many-person Ramsey level in order to reflect both the average social damage in the population,

$$\sum_h n^h t_y^h$$

and the heterogeneity driven by local externalities captured by ϕ. The fuel tax should be set above the average social damage when the fuel consumption of the households implying the greatest social damage is the most sensitive to a change in the fuel tax, $\phi > 0$.

If an accurate estimate of the social damage $\mathbf{t}_y$ caused by the dirty good consumption were available, (15) could be used to assess the empirical validity of the sensitivity-neutral condition. This strategy would be closely in line with Parry and Small (2005) effort for collecting data about all possible external effects from fuel consumption. Otherwise, if an accurate estimate of the social damage $\mathbf{t}_y$ instead is lacking, this strategy is difficult to pursue. Our empirical illustration develops an alternative strategy to test for the validity of the sensitivity-neutral condition (15) based on the recovered perceived damage by the government of France.

5 An illustration on data from France

5.1 Empirical strategy

Our aim is to provide a decomposition of the fuel tax in France in line with Proposition 2. To this purpose we proceed in two steps:

1. We recover the social valuations (b^h) and the personalized Pigovian fuel tax rates $\left(t_y^h\right)$ that would make current observed tax rates optimal and thus satisfy (7) and (10). To this purpose we estimate a complete demand system on 10 broad categories of consumption goods including fuel. Demand is assumed to fit an Alomost Ideal Demand System (AIDS) formulation which is a flexible enough function to approximate at the second-order any demand system (Barnett and Seck, 2008), and thus is enough to deal suitably with the first-order conditions (7) and (10) in the neighborhood of the observed taxes.

2. Given the recovered Pigovian taxes $\left(t_y^h\right)$ and the AIDS price elasticities, one can compute $\operatorname{cov}(\mathbf{t}_y, \mathbf{s}_i)$ and assess the empirical validity of the sensitivity-neutral condition (13). If valid, the computation yields an estimate of the statistics ϕ. Given the actual fuel tax t_y formula (14) can then be used to get the Ramsey component t_y^{R}. This yields a decomposition of the actual fuel tax t_y into a many-person Ramsey and a Pigovian part adjusted for household heterogeneity ϕ in the damage their fuel consumption is causing.

In the first step we use consumption microdata from the French consumer expenditure 'Budget de Famille' survey to estimate AIDS elasticities.[2] We rewrite the first-order conditions (10) in Proposition 1 in function of budget shares and price elasticities,

$$-\sum_k \frac{t_k^{\text{val}}}{1+t_k^{\text{val}}} \sum_h n^h \frac{q_k \xi_k^h}{q_i \xi_i} \hat{\varepsilon}_{ki}^h = 1 - \sum_h n^h b^h \frac{q_i \xi_i^h}{q_i \xi_i} - \sum_h n^h \frac{t_y^h}{q_y} \frac{q_y \xi_y^h}{q_i \xi_i} \hat{\varepsilon}_{yi}^h, \tag{16}$$

where

$$\hat{\varepsilon}_{ki}^h = \frac{q_i}{\xi_k^h} \frac{\partial \hat{\xi}_k^h}{\partial q_i} \text{ for all } k,\ i \text{ and } h$$

is the type h price elasticity of compensated demand for good k with respect to the price of good i, and excise taxes (t_i) are related to valorem tax rates (t_i^{val}) by

$$\frac{t_i}{q_i} = \frac{t_i^{\text{val}}}{1+t_i^{\text{val}}}. \tag{17}$$

Given expenditures in the current (observed) situation and AIDS price elasticities, the system of equations formed by (7) and (16) is linear in the unknown social valuations (b^h) and the Pigovian tax rates $\left(t_y^h/q_y\right)$ for all h. Estimates $(\hat{b}^h)$ and $\left(\hat{t}_y^h/q_y\right)$ of these unknown parameters are obtained by minimizing the sum of the squared differences between both sides of (7) and (16). As a by-product of (8), we can also get an estimated type h intrinsic social valuation

$$\frac{\beta^h}{\lambda} \frac{\partial v^h}{\partial m^h} = \hat{b}^h - \sum_i \frac{t_i^{\text{val}}}{1+t_i^{\text{val}}} \frac{q_i \xi_i^h}{m^h} \varepsilon_{im}^h + \frac{\hat{t}_y^h}{q_y} \frac{q_y \xi_y^h}{m^h} \tag{18}$$

where $m^h \equiv \ell^h + T^h$ is her disposable income.

At this stage we will have all the information needed to start the second step of our empirical analysis and assess the empirical relevance of the sensitivity-neutral condition (13). To this aim, note that the writing of (13) in the form (15) can also be expressed in terms of expenditures and price elasticities,

$$\sum_h n^h \frac{t_y^h}{q_y} \frac{q_y \xi_y^h}{q_i \xi_i} \hat{\varepsilon}_{yi}^h = \left(\sum_h n^h \frac{t_y^h}{q_y} + \frac{\phi}{q_y} \right) \sum_h n^h \frac{q_y \xi_y^h}{q_i \xi_i} \hat{\varepsilon}_{yi}^h. \tag{19}$$

Given expenditures and price elasticities, once Pigovian taxes (t_y^h) are replaced with their recovered values $(\hat{t}_y^h)$, the only remaining unknown ϕ/q_y in (19) can be estimated by running an OLS regression

$$\sum_h n^h \frac{\hat{t}_y^h}{q_y} \frac{q_y \xi_y^h}{q_i \xi_i} \hat{\varepsilon}_{yi}^h = \varphi_0 + \varphi_1 \sum_h n^h \frac{q_y \xi_y^h}{q_i \xi_i} \hat{\varepsilon}_{yi}^h + \zeta_i \tag{20}$$

[2]An early estimation of the AIDS on the Budget de Famille survey can be found in Nichele and Robin (1993).

in a sample with I (the number of consumption categories) observations, with ζ_i a residual. The assumption that (15) holds for every good is considered as being satisfied if the model (20) provides us with a good fit to the data with a zero OLS estimate $\hat{\varphi}_0$ of φ_0. Under this condition we can decompose the optimal fuel tax t_y as in (14).

5.2 Data

Our data comes from the French consumer expenditure survey 'Budget de Famille' realized by the National Institute of Statistics (INSEE) in 2011. The survey reports household final expenditures on consumption items disaggregated at the 5-digit COICOP international classification, as well as information on various household demographic and spatial characteristics. Households were surveyed from October 2010 to September 2011. They were divided into six different groups and all the households in the same group were surveyed during the same time wave. This yields price variability over time and space sufficient to estimate demand functions accurately.

Our initial sample consists of $10,342$ households living in continental France. From this sample we select observations where the family head is between 18 and 80 years old, is not self-employed, and we remove observations in the bottom and top 1% of the income (total expenditures) distribution. We are eventually left with a dataset of $8,722$ observations.

Local pollution through NO_2 mostly concerns densely populated and urbanized areas of France.[3] We therefore form two groups of households referring to the size of the population of the area where they live (`tau` variable of the survey) with a population threshold of $500,000$ inhabitants. By convention, 'urban' households live in the most populated areas while the remaining households are 'rural.' With this threshold urban areas comprise the 17 largest French cities, the threshold corresponding approximately to the population in the urban area of Avignon in 2010. The variation across space of the mean NO_2 and PM10 concentration levels are very well explained by this population threshold.[4]

Household characteristics and the time wave when they are surveyed are reported in Tables `Menage` and `Depmen` of the survey while Table `C05` gives us household expenditures for every 5-digit COICOP category. Categories that are considered as less flexible are treated as given household demographic characteristics (see, e.g., Blundell, Pashardes and Weber, 1993, for a similar treatment). This applies to items reported as durables in the COICOP international classification, as well as the whole 2-digit COICOP category Housing, water, electricity, gas and other fuels (COICOP category 04), which mostly comprises rents paid by tenants. The French survey does not provide imputed rents for landlords but it reports in an original category numbered 13 various housing related payments that do not enter the usual COICOP categories, including landlord expenditures, e.g., mortgage interest. These payments are included into fixed (landlord) expenditures to treat tenants and landlords symmetrically. Finally prices about Health (COICOP category 06) and Education

[3] NO_2 concentration is highly correlated with local external effects from fuel consumption since NO_2 in the air primarily is due to the burning of fuel.

[4] See Appendix B for more details.

(COICOP category 10), which are mostly publicly provided in France, are often missing and cannot be accurately computed. These two categories are therefore also considered as fixed expenditures. We are eventually left with 10 broad 2-digit COICOP categories: Food (01), Alcoholic beverages, tobacco and narcotics (02), Clothing and footwear (03), Furnishings, household equipment and routine household maintenance (05), fuel (0722), Transport (07 except 0722), Communication (08), Leisure and Culture (09), Restaurants and hotels (11) and Other goods and services (12).

Prices are computed from the table `Carnets` which reports both quantities and expenditures on disaggregated fine 5-digit COICOP items for every household. We abstract from issues related to quality measurement and directly compute Stone price indexes from unit values (the ratios of expenditure to quantity). For every aggregate consumption category, the indexes are computed as a function of the region (`zeat` variable) broken down by population size[5] (`tau` variable), and wave of the survey.[6]

Tax data for every 5-digit COICOP item are obtained from the Institut des Politiques Publiques (Meslin, 2012). In France most items are subject to the VAT or excise taxes. The standard (high) rate of VAT in 2011 was 19.6% while the reduced (low) rate was 5.5%.[7] Both VAT and an excise tax called TICPE (Taxe Intérieure de Consommation sur les Produits Energétiques) apply to fuel: the sum of the net of tax (producer) price and the TICPE is subject to the standard rate of VAT. The amount of TICPE in fact varies according to the fuel type, an information that is missing in the survey. In 2010 the tax rates on the main fuel types stand between 115% for diesel and 160% for (unleaded) petrol; in 2011 the global world rise in the price of energy has implied an increase in the net of tax (producer) prices and so, given the amount of TICPE, implied lower fuel taxes ranging from 97% to 133%. We find a mean fuel tax rate over the overall period equal to 131%.

[5]The survey considers 11 brackets but prices are often missing in sparsely populated rural areas, so that we have consolidated the three bottom brackets into only one bracket comprising areas with $10,000$ inhabitants at most. The other brackets are 25-40 (thousands of inhabitants), 40-50, 50-100, 100-200, 200-500, at least 500, and Paris.

[6]A great deal of attention has been devoted to cleaning price data. We remove observations in `Carnets` where either the quantity and/or the unit (in kg, liter or unit) is missing. We also remove those where the operation cannot be tracked because the shop where the purchase took place is not filled. To deal with reporting errors, we do not consider observations that correspond to a unit that represents less than 5% of the reported units per 5-digit COICOP category. In the case of fuel, for instance, most households report consumption in liters, but some report units, which sometimes correspond to liters ($40-50$ units for a fuel tank) and sometimes to one fuel tank (1 unit), both with the same (tax included) price around $50-60$ euros. We also remove price and quantity observations in the bottom or top one percent of the observations for every 5-digit category, for each wave and `zeat`×`tau` area. There still remain 1.5% of household observations where some prices are missing. They are usually found in areas with a low number of inhabitants so that some items are not bought at all during the time window of the survey. In these few cases we compute the price indexes at the `zeat` level.

[7]The resulting tax rates for the 2-digit flexible categories are 5.9% for Food, 66% for Alcohol, 19.6% for Clothing, 19.3% for Furnishings, 15.2% for Transport (other than fuel), 131% for fuel (COICOP 0722), 6% for Communication, 11% for Culture, 5.5% for Restaurants, and 19.6% for Other goods and services.

5.3 Descriptive statistics

Table 1: Rural and urban households in France[1]

	rural	urban
Number of households surveyed	5,137	3,412
Number of households represented[2]	25,854	19,771
Average number of persons per household	2.264	2.254
Average number of units of consumption per household	1.55	1.545
Average age of the head of the household	50.34	47.73
Average household income per year	31,647	36,781
Average total household expenditures per year	25,452	28,447
Average total household flexible expenditures per year	16,172	17,927

1. Computed from the 2011 Budget de Famille survey
2. They obtain from the actual number of surveyed households using the `pondmen` weights provided in the survey. These are used to compute the profile (n^h), e.g., $n^h = 25,854/(25,854 + 19,771) \simeq 57\,\%$.

As shown in Table 1 family structures are similar for rural and urban households. Urban households are younger, richer, and they save more than rural households. They have also higher fixed expenditures (mostly because of housing) so that the total expenditures for flexible categories tend to be similar.

Table 2: budget shares of flexible categories of goods[1]

	rural	urban
Food and non-alcoholic beverages (01)	25.5	24.4
Alcoholic beverages, tobacco and narcotics (02)	5.3	4.3
Clothing (03)	7.2	7.5
Furnishings, household equipment and routine household maintenance (05)	3.0	3.4
Transport (except fuels) (07 except 0722)	5.0	7.2
fuels and lubricants for personal transport equipment (0722)	9.2	6.2
Communication (08)	5.2	5.2
Recreation and culture (09)	9.9	10.7
Restaurants and hotels (11)	8.8	11.1
Miscellaneous goods and services (12)	20.9	20.0

Note 1. Budget shares in the total expenditures for flexible categories.

The budget shares of flexible categories given in Table 3 are about identical for the two types of households. The main differences concern the structure of the original COICOP Transport category (which is a consolidated category with both our Transport and Fuel categories). This original category represents about $14-15$ percent of the budget of every household, but rural households actually devote a much larger share to fuel than urban households. Instead urban households consume more Transport (except fuel), through, e.g., the use of public transportation services.

Table 3: Price and income elasticities for rural households

	pFood	pAlco	pClot	pFurn	pTran	pFuel	pComm	pCult	pRest	pOthe	Income
qFood	-0.767	0.047	0.121[1]	0.013	0.050	0.073	0.089	0.101	0.063	0.209	1.041[2]
qAlco	0.215	-0.830	0.092	0.022	0.058	0.059	0.075	0.066	0.009	0.236	1.160
qClot	0.462	0.076	-1.006	0.002	-0.002	0.028	0.062	0.103	0.069	0.204	0.958
qFurn	0.117	0.043	0.005	-0.782	0.064	0.042	0.009	0.043	0.182	0.278	1.505
qTran	0.274	0.068	-0.003	0.039	-0.877	0.184	0.000	0.061	-0.001	0.255	1.317
qFuel	0.204	0.036	0.021	0.013	0.094	-0.799	0.044	0.063	0.051	0.272	1.251
qComm	0.437	0.080	0.080	0.005	0.000	0.078	-0.941	0.093	0.068	0.100	0.207
qCult	0.279	0.040	0.075	0.013	0.031	0.062	0.052	-0.820	0.049	0.219	1.063
qRest	0.216	0.007	0.061	0.069	0.000	0.063	0.047	0.061	-0.754	0.230	1.333
qOthe	0.260	0.064	0.067	0.039	0.058	0.122	0.025	0.099	0.084	-0.818	0.714

Note 1. The compensated price elasticity of Food with respect to Clothing price is 0.121.

Note 2. The income elasticity of Food is 1.041.

Table 4: Price and income elasticities for urban households

	pFood	pAlco	pClot	pFurn	pTran	pFuel	pComm	pCult	pRest	pOthe	Income
qFood	-0.927	0.162	0.082[1]	0.024	0.076	0.076	0.069	0.115	0.099	0.225	0.907[2]
qAlco	0.879	-0.985	-0.034	0.001	0.008	0.070	0.073	0.054	-0.263	0.198	1.172
qClot	0.287	-0.022	-0.761	0.034	0.047	0.005	0.102	0.085	0.119	0.104	0.930
qFurn	0.182	0.001	0.075	-0.865	0.114	0.078	0.108	0.207	-0.104	0.204	1.539
qTran	0.267	0.005	0.047	0.052	-0.839	0.107	0.010	0.083	0.133	0.137	1.198
qFuel	0.303	0.052	0.006	0.040	0.122	-1.004	0.028	-0.029	0.162	0.319	1.322
qComm	0.319	0.063	0.136	0.065	0.013	0.032	-0.933	0.093	0.125	0.089	0.168
qCult	0.286	0.025	0.061	0.067	0.059	-0.018	0.050	-0.864	0.173	0.162	1.132
qRest	0.236	-0.116	0.081	-0.032	0.091	0.097	0.064	0.166	-0.775	0.188	1.315
qOthe	0.292	0.047	0.039	0.034	0.051	0.103	0.025	0.084	0.102	-0.777	0.831

Note 1. The compensated price elasticity of Food with respect to Clothing price is 0.082.

Note 2. The income elasticity of Food is 0.907.

Tables 3 and 4 report the estimated AIDS elasticities that enter the formula in Propositions 1 and 2. They show that most fuel compensated cross price elasticities are positive, i.e., fuel tends to be a Hicksian substitute to the other goods. The formula for optimal taxes given in Proposition 1 thus suggests that the consumption of goods other than fuel should be encouraged, if any, compared to the situation where there would be no externality from fuel.

5.4 Empirical results

5.4.1 Social valuations and personalized Pigovian taxes

Table 5 reports the values of the estimates $(\hat{b}^h)$ and $\left(\hat{t}_y^h/q_y\right)$ that minimize of the sum of the squared differences between both sides of (7) and (16). It also uses (18) to provide an estimate for the intrinsic components

$$\frac{\beta^h}{\lambda}\frac{\partial v^h}{\partial m^h}$$

that enter the social valuations (b^h).

Table 5: Social valuations and personalized Pigovian tax rates

	rural	urban
Social valuation $(\hat{b}_h)$	1.18	0.81
Pigovian tax rates $(\hat{t}_y^h/p_y)$	78 %	163 %
Intrinsic valuation[1]	1.04	0.70
Income effect	0.17	0.15
Pigovian contribution to social valuation	0.03	0.04

Note 1. By (18), Social valuation - Income effect + Pigovian contribution.

Redistribution clearly goes from urban to rural households: the total social gain from a 1 euro income transfer to a rural household equals 1.18 euro and so yields a net social gain of 0.18 euro whereas the same transfer toward a urban household costs 0.19 euro to the society. In view of (18) the social valuations may give a blurred picture of the redistribution in France. However the recovered intrinsic social valuations display a similar pattern where rural are relatively favored by the tax system: the society would be neutral regarding the transfer of 1 euro to one rural household whereas this same transfer would cost 0.30 euro if benefiting a urban household.

The income effects in (18) make the overall social valuations $(\hat{b}_h)$ above the intrinsic social valuations since agents are also valuable to the government as sources of tax revenues. The recovered Pigovian taxes in the second row of Table 5 represent the values of the social damages that would make observed current taxes optimal. Such damages clearly matter to

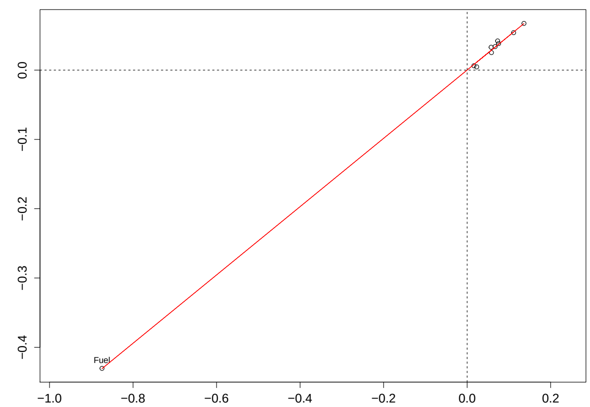

Figure 1: with fuel

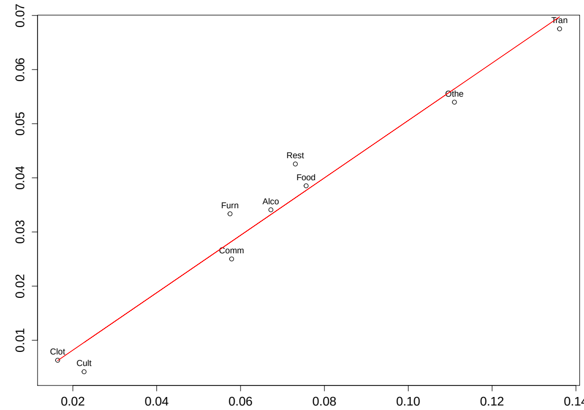

Figure 2: without fuel

the society, both in rural and urban areas, as signaled by the very high levels of Pigovian taxes. Using the number of rural and urban households (n^h) reported in Table 1 and the Pigovian tax rates ($\hat{t}_y^h/p_y$) in Table 5, we find an average social damage from fuel equal to

$$\sum_h n^h \frac{\hat{t}_y^h}{p_y} = 115\,\%.$$

A large part of the 131 percentage points of the fuel tax thus is imputable to global and the average local externalities over the population. We also find evidence of huge heterogeneity in the social damages perceived by the French government: Pigovian taxes are twice as large in urban areas as they are in rural areas. One could have expected that this huge spread would reduce a lot the intrinsic social valuation of urban agents compared to that of rural agents. This is not the case: as reported in Table 5, the own Pigovian contributions to social valuations in (18),

$$\frac{\hat{t}_y^h}{q_y} \frac{q_y \xi_y^h}{m^h},$$

are about identical across households and close to 0. This is due to the fact that the greatest damage due to urban households comes together with their much lower fuel consumption. This suggests that the high perceived differences in the social damages between rural and urban people may not necessarily justify a specific adjustment ϕ of optimal taxes in (14).

5.4.2 Targeting principle

We know from Proposition 2 that the validity of the targeting principle relies on the sensitivity-neutral condition (13) or (15) evaluated in the current (observed) situation. We now have all the information needed to assess (15) using the model (20): the distribution of households (n^h) is reported in Table 1, the budget shares are in Table 2, the compensated price elasticities in Tables 3 and 4, and the Pigovian taxes in Table 5.

We first plot the sum in the left-hand side of (19) for every category of goods in the vertical axis of Figures 1 and 2 against the last sum in the right-hand side of (19) that appears in the horizontal axis. Figure 2 abstracts from the outlier representative Fuel point. The fit of (20) in Figure 1 and 2 is impressive. The reaction of aggregate social damage to a change in the price of good i (in the vertical axis) is proportional to the reaction of aggregate fuel consumption to the same price change (in the horizontal axis), whatever i is. The OLS estimate $\hat{\varphi}_0$ of φ_0 in Table 6 indeed is 0 while $\hat{\varphi}_1$ is highly significant.

Table 6: ESTIMATION RESULTS OF THE MODEL (20)

	$\sum_h n^h \frac{t_y^h}{q_y} \frac{q_y \xi_y^h}{q_j \xi_j} \hat{\varepsilon}_{yj}^h = \varphi_0 + \varphi_1 \sum_h n^h \frac{q_y \xi_y^h}{q_j \xi_j} \hat{\varepsilon}_{yj}^h + \zeta_j$
`Constant` $\hat{\varphi}_0$	1.211×10^{-4}
	(1.231×10^{-3})
`Slope` $\hat{\varphi}_1$	0.493^{***}
	(4.306×10^{-3})
Number of observations	10
Notes:	Adjusted R-squared: 0.99
	*** Significant at the 1 percent level.

We conclude that the data does not reject the empirical validity of (15) and so the French government does not find it socially profitable to adjust the overall tax system in response to the presence of a heterogeneous welfare impact of local pollution across rural and urban areas. The targeting principle applies with the fuel tax being the only one to be adjusted to account for the external effects implied by fuel consumption. As a result, one can use the expression of the $\hat{\varphi}_1$ to obtain an estimated value $\hat{\phi}$ of ϕ. From (19) and (20) we have

$$\hat{\varphi}_1 = \frac{\hat{\phi}}{q_y} + \sum_h n^h \frac{t_y^h}{q_y} \Leftrightarrow \frac{\hat{\phi}}{q_y} = \hat{\varphi}_1 - \sum_h n^h \frac{t_y^h}{q_y} = 0.493 - 0.496 = -0.003.$$

Although the government cares about heterogeneity of damages from pollution, as revealed by the large 85 percentage point difference between the two Pigovian taxes in Table 5, we find that only the average Pigovian tax eventually matters in the correction of the fuel tax from its many-person Ramsey level. Indeed one can safely set $\hat{\phi} = 0$. At first sight this is surprising since fuel consumption from urban households (who cause the greatest social damage) is more responsive to the fuel price than fuel consumption from rural households. However, as already seen, this is compensated in practice by the lower fuel consumption of urban households.

We are now in a position to get our final decomposition of the fuel tax into the various contributions exhibited in Proposition 2. Switching to ad valorem taxes and using again $q_y = p_y(1 + t_y^{\text{val}})$, the formula (14) finally gives

$$\frac{\hat{t}_y^{\text{R}}}{p_y} = t_y^{\text{val}} - \left(1 + t_y^{\text{val}}\right) \sum_h n^h \frac{\hat{t}_y^h}{q_y} - \left(1 + t_y^{\text{val}}\right) \frac{\hat{\phi}}{q_y} \simeq 1.31 - 1.15 = 0.16.$$

The many-person Ramsey tax on fuel thus equals 16 percent, a level that is close to the standard rate of VAT (19.6 %). This is consistent with the standard view of VAT on clean goods as dealing with equity and efficiency such as summarized by the many-person Ramsey considerations. In France most of the fuel tax rate of 131% is imputable to externality considerations summarized by a simple population weighted average of Pigovian taxes over rural and urban households.

5.5 Actual and second-best optimal taxes

Our empirical analysis relies on the assumption that the government chooses a tax on fuel that maximizes social welfare of French households. As argued by Coate and Morris (1995) or Alesina and Passarelli (2014), political economy and lobbying considerations may lead to the adoption of inefficient environmental policies. In the US several studies find a fuel tax below its optimal level (West, 2004; Parry and small, 2005; Bento, Goulder, Jacobsen, and Haefen, 2009; Borck and Brueckner, 2016). Sometimes actual fuel taxes can also be found above their optimal level (Parry and small, 2005). In this section we provide two different assessments of our assumption of optimal taxes in France.

The first assessment relies on Parry and Small's (2005) methodology. We recover the distribution (t_y^h) of the social damage from fuel consumption using data collected from public administrative reports.[8] This yields Pigovian taxes reported in the first column of table 7. These taxes are close to the Table 5 estimated Pigovian taxes under the assumption of optimal consumption taxes (for convenience they are also given in the second column of Table 7). Hence, considering a redistributive stance similar to the one recovered in Table 5, Parry and Small's (2005) methodology leads to the conclusion that 2011 actual and optimal consumption taxes were located close to each other in France.

Since, at the optimum, the first-order conditions for optimal taxes make the differences between both sides of (7) and (15) equal to 0, a second assessment of the validity of our assumption of optimal taxes consists to check that the sum of the squared differences between both sides of (7) and (15) when evaluated at $\hat{t}_y^h$ and $\hat{b}^h$ remains close to 0. With our data we find that a residual value of 0.018. We have reproduced a bootstrap exercise

[8] Details about data sources and conversion operations are provided in Appendix A.

Table 7: PIGOVIAN TAXES

	Direct from administrative report[1]	Our estimate of t_y^h
Urban[2]	160%-174%	163%
Rural	32%-103%	78%

Note 1. Source: Gressier and Bureau (2003), table page 25
Note 2. population density greater than 420 inhabitants per km^2

100 times starting from tax rates randomly drawn between the minimum and maximum actual tax rates (0.055 and 1.31), i.e., we have estimated the taxes $\tilde{t}_y^h$ and $\tilde{b}^h$ that minimize the same sum of squares assuming such random taxes. The 100 draws average sum of the squared differences between both sides of (7) and (15) is equal to 0.103, which is more than 5 times higher than 0.018. Again the empirical validity of the assumption of optimal taxes in France does not seem to be rejected by the data.

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Appendix

A Direct external costs from administrative reports

In this appendix we apply Parry and Small's (2005) methodology to France. We report in table 8 the constant (real) external costs of passenger vehicles computed by Gressier and Bureau (2003).

Table 8: External costs of passenger cars[1]

	Urban[2] (French administration)	Rural/dispersed urban (French administration)
GhG	0.6[3]	0.6
Air pollution	2.9	0.1-1.5
Accident	0.8	0.8
Noise	0.52	0-0.52
Congestion	2.5-3.5	0-1.5

Note 1. Source: Gressier and Bureau (2003), table page 25.
Note 2. Population density greater than 420 inhabitants per km^2.
Note 3. In euro (base year: 2000) per 100 km.

External costs of GhG and air pollution[9] in the Bureau and Gressier report are based on a value of 7.41 liters per 100km in 2000. We use this value to convert external costs from euros per 100km to euros per liter. We use the French GDP growth rate to update these external costs to 2011. This gives external costs in euros per liter for year 2011 that are reported on the first two rows of Table 9.

Available external costs for security, noise and congestion are expressed as distance rather than fuel related. In order to convert these costs to euros per liter, we consider that only 40% of the long-run price responsiveness of fuel consumption is due to changes in vehicle travel, the other 60% being imputed to fuel efficiency (Parry and Small, 2005). We thus multiply the external cost of noise, congestion and accident by 0.4 in order to get the corresponding component in the Pigovian tax. We use the French GDP growth rate to update these external costs to 2011. We use an average fuel consumption per 100km of 7 liters in 2011[10] to convert these external costs from euros per 100km to euros per liter. The corresponding values are reported in the third to fifth rows of Table 9. The total cost from fuel consumption is finally converted from euro per liter to tax rates using an average

[9]Unlike Parry et Small (2005) we assume that air pollution is fuel-related rather than distance-related. The particulate emissions standards of motor engines are indeed in emissions per km but recent public release scandals about emissions show that these standards are not met in general conditions and that particulate emissions are more plausibly related to the amount of fuel consumed.

[10]https://www.economie.gouv.fr/files/rapport-prix-marges-consommation-carburants.pdf

pump price (including tax) was 1.4 euro per liter[11] in 2011 and an ad valorem fuel tax 131%. This gives the pigovian tax in Table 7.

Table 9: Pigovian tax components from direct external costs

	Urban	Rural/disperse urban
GhG	0.114	0.114
Air pollution	0.554	0.019-0.287
Accident	0.064	0.064
Noise	0.042	0-0.042
Congestion	0.202-0.283	0-0.121
Total (euros per liter)	0.976-1.057	0.197-0.628
Pigovian tax rate	160%-174%	32%-103%

[11] https://www.economie.gouv.fr/files/rapport-prix-marges-consommation-carburants.pdf

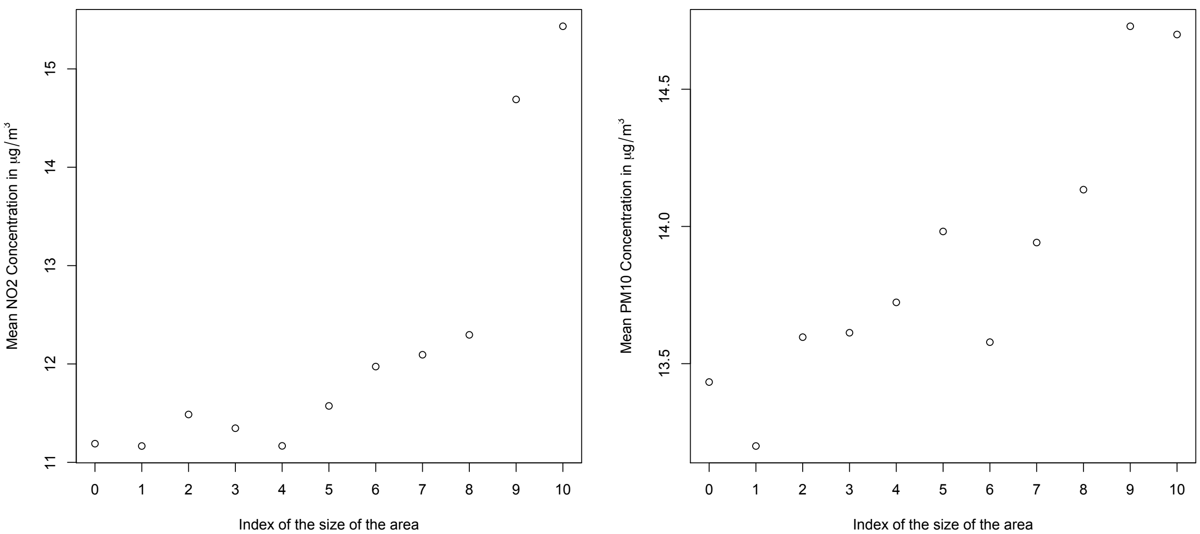

Figure 3: Mean NO_2 (left hand panel) and PM10 (right hand panel) concentration by `tau` index

B Rural and urban areas from NO_2 concentration

The available data on NO_2 and PM10 in France gives the daily prediction of the surface concentrations between 12/22/2017 and 01/22/2018 by PREV'AIR. The data are available in the form of maps covering metropolitan France at a spatial resolution of about 10km. We map these data with coordinates of localities (Communes). We then use INSEE dataset 'Base des Aires Urbaines' to get the `tau` variable corresponding to each Commune in the Budget de Famille survey.[12] Figure 3 plots the mean of NO_2 and PM10 concentration values in all the Communes that belong to an area of a given population size (`tau` variable of the survey). There is a clear jump in average NO_2 and PM10 concentration corresponding to a threshold of 500,000 inhabitants in the area that separates areas with `tau` equal to 09 and 10 (Paris) from smaller areas. The break is confirmed by running linear regressions of NO_2 and PM10 mean concentrations in the Commune on the dummy variables equal to 0 below and one above each possible value of the `tau` variable (see Table 10). The highest R^2 is found for a threshold of 500,000 inhabitants in the area.

Figure 4 gives the whole distribution of frequency of NO_2 and PM10 concentration values for Communes within urban and rural clusters.

[12] Here, unlike Section 5.2, we refer to the original 11 category classification of the survey and keep small areas separate. 00 (non-urban area); 01 (below $4,999$ inhabitants); 02 (from $5,000$ to $9,999$); 03 ($10,000$ to $24,999$); 04 ($25,000$ to $39,999$); 05 ($30,000$ to $49,999$); 06 ($50,000$ to $99,999$); 07 ($100,000$ to $199,000$); 08 ($200,000$ to $499,999$); 09 (above $500,000$ inhabitants, Paris excepted); 10 (Paris area).

Table 10: NO_2 concentrations

	Mean NO_2 concentration in the Commune:								
More than 15,000 inh. in the area	1.530*** (0.031)								
More than 20,000 inh. in the area		1.530*** (0.031)							
More than 25,000 inh. in the area			1.740*** (0.031)						
More than 35,000 inh. in the area				1.770*** (0.031)					
More than 50,000 inh. in the area					1.857*** (0.031)				
More than 100,000 inh. in the area						1.936*** (0.031)			
More than 200,000 inh. in the area							2.108*** (0.032)		
More than 500,000 inh. in the area								3.481*** (0.043)	
Paris area									3.66 *** (0.070)
Constant	11.19*** (0.022)	11.19*** (0.020)	11.20*** (0.020)	11.20*** (0.020)	11.21*** (0.019)	11.29*** (0.018)	11.37*** (0.017)	11.48*** (0.016)	11.77*** (0.016)
Observations	35,453	35,453	35,453	35,453	35,453	35,453	35,453	35,453	35,453
R^2	0.065	0.082	0.085	0.092	0.098	0.107	0.120	0.158	0.071
Note:	*p<0.1; **p<0.05; ***p<0.01								

Table 11: PM10 concentrations

	Mean PM10 concentration in the Commune:								
More than 15,000 inh. in the area	0.394*** (0.027)								
More than 20,000 inh. in the area		0.478*** (0.027)							
More than 25,000 inh. in the area			0.484*** (0.027)						
More than 35,000 inh. in the area				0.481*** (0.028)					
More than 50,000 inh. in the area					0.478*** (0.028)				
More than 100,000 inh. in the area						0.554*** (0.029)			
More than 200,000 inh. in the area							0.581*** (0.031)		
More than 500,000 inh. in the area								0.753*** (0.040)	
Paris area									0.502*** (0.0)
Constant	13.04*** (0.019)	13.03*** (0.018)	13.03*** (0.018)	13.04*** (0.018)	13.06*** (0.018)	13.06*** (0.017)	13.09*** (0.016)	13.14*** (0.014)	13.22*** (0.014)
Observations	35,453	35,453	35,453	35,453	35,453	35,453	35,453	35,453	35,453
R^2	0.006	0.009	0.009	0.009	0.009	0.011	0.011	0.011	0.002
Note:	*p<0.1; **p<0.05; ***p<0.01								

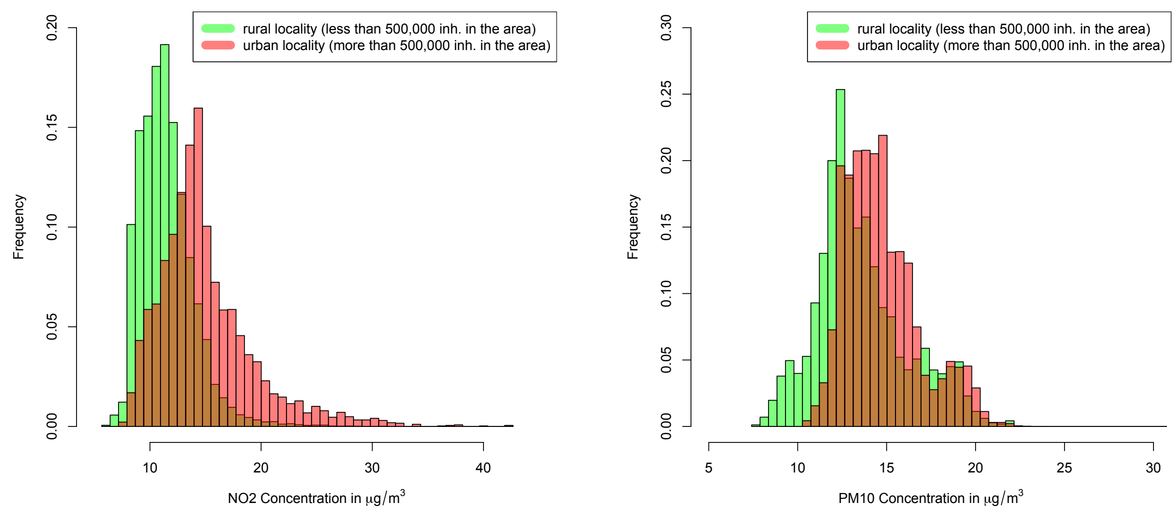

Figure 4: Frequency of NO_2 and PM10 concentration values in the Communes of urban and rural areas