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The Role of Elasticity in Environmental Externality Internalization in the Transport Sector

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Abstract

The economic theory prescribes the taxation of more elastic sectors in order to internalize negative externalities in production. However, taxation in road transport can be welfare damaging, especially if it is too high: we try to model the optimal method to correct for external costs due to pollution in road transport.

The purpose of this paper is to analyze the welfare effects associated with different elasticities and the (in)capability of impose differentiated taxation. We use a theoretical model to show what happens under different charging mechanism, with a particular focus on which group is best to tax when differentiation is possible. We also provide some numerical example with application to the Italian case for the optimal level of externality taxation and the double-dividend obtainable by actually applying it. We conclude that –in some cases- taxing high elasticity sectors when externalities are involved is socially more efficient that taxing inelastic sectors. In plain words: heavy taxation on road transport seems to be good for state revenues, but far less so for the environment, in relation with the taxation of other polluting sectors.

Keywords: environmental externality, optimal taxation

JEL codes: R48, Q50

1. Introduction

The issue of environment-related taxation is of dominant importance in general, but more so within the transport sector. This, since the more used mode of transport, road, is by far the more heavily taxed among every polluting sector, and *per se* this is a crucial factor both for the welfare of families, and for the costs and the efficiency of production and commercial distribution of goods. This paper underlines some particular welfare aspect of environment taxation, that may be defined as the "inversion of the Ramsey-Boiteaux rule" in case of external costs, and translate these results in an policy-oriented elaboration, focusing on the issue of a more efficient and equitable form of environmental policy dealing with transport.

The paper is structured as follows. In Section 2 a brief literature review is provided, in Section 3 a simple model is presented, while in Section 4 the implications for the transport sector are discussed. Section 5 concludes.

2. Literature review

Starting from Pigou (1920), the problem of internalization of negative externalities has become a central one in environmental economics. He prescribed the use of corrective taxes to equalize social and private marginal costs, reaching allocative efficiency. However, even if corrective, these taxes are distortionary, since the internalization of the externality is obtained through the erosion of the tax base generated by the increase of the tax rate. Thus, it is a central problem to eliminate the externality and, at the same time, not to create a too large excess burden of taxation (given that taxes distort behaviors).

In order to minimize this distortion coming from the tax revenue collection, the Ramsey-Boiteau principle[3] prescribed the optimal tax rate the government should apply to an agent in order to allow it a given mark-up, to avoid a substantial change in the behavior. This mark-up, however, when the taxed individuals differ in their demand, was inversely proportional to the elasticity of demand[4].

Nevertheless, when an externality occurs, private and social marginal costs diverge, generating a welfare loss; this possibility is not taken into account in Ramsey's mechanism. The idea of raising a tax that contemporarily reduces the externality and generates revenue (that could be used to provide public goods) is at the basis of the "double dividend" hypothesis[5].

Several papers, as Sadmo (1975) and Oum and Tretheway (1988) introduced a production externality in the discussion on the optimal taxation rule, in case of single (with independent demands) or multiple (with inter-dependent demand) goods, respectively, even if the "double

[3] See Ramsey (1927) and Boiteux (1956).

[4] Note that this is also due to the fact that he assumed that it is better to tax all goods at low level instead of concentrating high taxes on few goods.

[5] See Goulder (1995).

dividend" is not made explicit. In the latter case, the Ramsey rule is increased to incorporate a fraction of the external costs.

However, these papers where more focused on the optimal mark-up to be left to a monopolist firm in order to maximize social welfare. In case of congestion or pollution the focus changes into one of optimal taxation for demand (of the activity generating the externality) management in order to maximize welfare. Another element that should be taken into consideration is the level of elasticity of consumer demand to environmental taxes: the *ex-post* and *ex-ante* empirical estimates are quite scarce (OECD, 2000, 2001).

The present paper is concerned with the level of social surplus increase obtained when second-best pricing is available and the regulator decides to tax only a portion of those who produce the externality-generating activity. For example, in case of pollution[6] and road use, we can divide users in groups depending on the characteristics of the vehicle they drive. It is true that if one could differentiate for the group characteristics, first best could be obtained through Pigouvian taxes; however, sometimes only second-best charging mechanisms are available. We want to demonstrate that in this case it is better, for social welfare maximization, to charge those whose elasticity of demand is higher.

3. The model

In this Section, following Verhoef et al. (1995), we build a very simple model for an environmental externality optimal taxation.

Suppose there are 2 groups of consumers, denoted by $i=1,2$, producing a given quantity N_i of polluting activity, that are characterized by different demand elasticities. Moreover, they have different marginal private cost c_i, and marginal external cost $E_i'(N_i)$. We will analyze the different possibilities for the regulator in order to reduce the (negative) externality-generating activity. Starting from the classic case in which both groups are taxed (with differentiated or

[6] We limit ourselves here to pollution-related exernalities, for reasons of simplicity.

undifferentiated fee), we will deal with the specific case, in which we are particularly interested, of taxing the activity of a single group (i.e. an extreme case of differentiation).

3.1 Two-group taxation

Firstly, we find the optimal per-unit common fee (*f*), by maximizing the social welfare under a break-even constraint. The optimization problem can be solved thanks to the following Lagrangian:

$$L = \int_0^{N_1} D_1(n_1)dn_1 + \int_0^{N_2} D_2(n_2)dn_2 - E_1(n_1) - E_2(n_2) - c_1N_1 - c_2N_2 + \lambda_1[D_1(N_1)N_1 - c_1N_1 - fN_1] + +\lambda_2[D_2(N_2)N_2 - c_2N_2 - fN_2] \quad (1)$$

where $D_i(N_i)$ represents the inverse demand function for group *i*. The objective function is composed by the total benefits for group 1 and group 2 generated by the activity net of the total environmental external costs and of the total private costs. For simplicity, we assume this last function as linear, so that marginal and average private costs coincide. The terms in parentheses are the constraints for the two groups: the benefits coming from the activity should at least equal the costs, including the environmental fee. The first-order conditions are the following:

$$\frac{\partial L}{\partial N_1}: D_1(N_1) - E_1'(N_1) - c_1 + \lambda_1[D_1'(N_1)N_1 + D_1(N_1) - c_1 - f] = 0 \quad (1a)$$

$$\frac{\partial L}{\partial N_1}: D_2(N_2) - E_2'(N_2) - c_2 + \lambda_2[D_2'(N_2)N_2 + D_2(N_1) - c_2 - f] = 0 \quad (1b)$$

$$\frac{\partial L}{\partial \lambda_1}: D_1(N_1)N_1 - c_1N_1 + fN_1 = 0 \quad (1c)$$

$$\frac{\partial L}{\partial \lambda_2}: D_2(N_2)N_2 - c_2N_2 + fN_2 = 0 \quad (1d)$$

$$\frac{\partial L}{\partial f}: -\lambda_1N_1 - \lambda_2N_2 = 0 \quad (1e)$$

From the maximization problem, we can have two cases, depending on the values taken by the Lagrangian multipliers:

- if λ_i=0, the maximization is obtained through differentiated tariffs: $f=E_i'(n_i)$, that is, the Pigou-first best case, where each group pays a fee which is equal to the marginal external cost.

- if λ_i>0, the maximization is obtained through undifferentiated tariffs: through (1c) and (1d) the optimal common fee is obtained as:

$$f = \sum_i \frac{\frac{E'_i(N_i)}{D'_i(N_i)N_i}}{\sum_i \frac{1}{D'_i(N_i)N_i}} \quad \text{with } i=1,\ 2 \tag{2}$$

and from this together with equations (1a) and (1b) we obtain that the multipliers can be defined as

$$\lambda_i = -\frac{D_i(N_i) - c_i - E'_i(n_i)}{D'_i(N_i)N_i}.$$

This common fee not only is an average of the marginal external cost produced by the two groups (instead of making each of them pay their specific external cost as in the first best case), but it also weights them by taking into account the quantities produced (N_i) and, more importantly, the slopes of the demand curves ($D'_i(N_i)$). It is fundamental to include this last element, given that flatter curves are those which, at parity of deviation between social and private costs, generate the greater loss, given that the deviation in the quantities from the optimum is higher. This sensitivity is represented by the elasticity of demand, that is in our model is: $\eta_i = \frac{1}{dD_i/dN_i}\frac{D_i}{N_i} = \frac{dD_m}{dN_m}\frac{D_m}{N_m}$, we can rewrite (2) as:

$$f = \sum_i \frac{\frac{\eta_i E'_i(N_i)}{D_i(N_i)}}{\sum_i \frac{\eta_i}{D_i(N_i)}} \quad \text{with } i=1,\ 2 \tag{3}$$

This is a second-best case which can be obtained by taxing with the same fee both polluting groups. This optimal fee is directly proportional to the marginal cost of externality and the elasticity of demand, while is inversely related to the demand function, which represent both the numerosity of the group and its willingness to pay.

3.2 A third-best charging mechanism: only one group is taxed

When the first best is not achievable, and the policy-makers decide to levy a tax on the polluting activity on one group only (for hypothesis, group 1), the problem of social welfare maximization under a break-even constraint changes slightly, leading to the following Lagrangian:

$$L = \int_0^{N_1} D_1(n_1)dn_1 + \int_0^{N_2} D_2(n_2)dn_2 - E_1(n_1) - E_2(n_2) - c_1N_1 - c_2N_2 + \lambda_1[D_1(N_1)N_1 - c_1N_1 - fN_1] + +\lambda_2[D_2(N_2)N_2 - c_2N_2] \quad (4)$$

The first-order conditions are:

$$\frac{\partial L}{\partial N_1}: D_1(N_1) - E_1^{'}(N_1) - c_1 + \lambda_1[D_1{'}(N_1)N_1 + D_1(N_1) - c_1 - f] = 0 \quad (4a)$$

$$\frac{\partial L}{\partial N_1}: D_2(N_2) - E_2^{'}(N_2) - c_2 + \lambda_2[D_2{'}(N_2)N_2 + D_2(N_1) - c_2] = 0 \quad (4b)$$

$$\frac{\partial L}{\partial \lambda_1}: D_1(N_1)N_1 - c_1N_1 + fN_1 = 0 \quad (4c)$$

$$\frac{\partial L}{\partial \lambda_2}: D_2(N_2)N_2 - c_2N_2 = 0 \quad (4d)$$

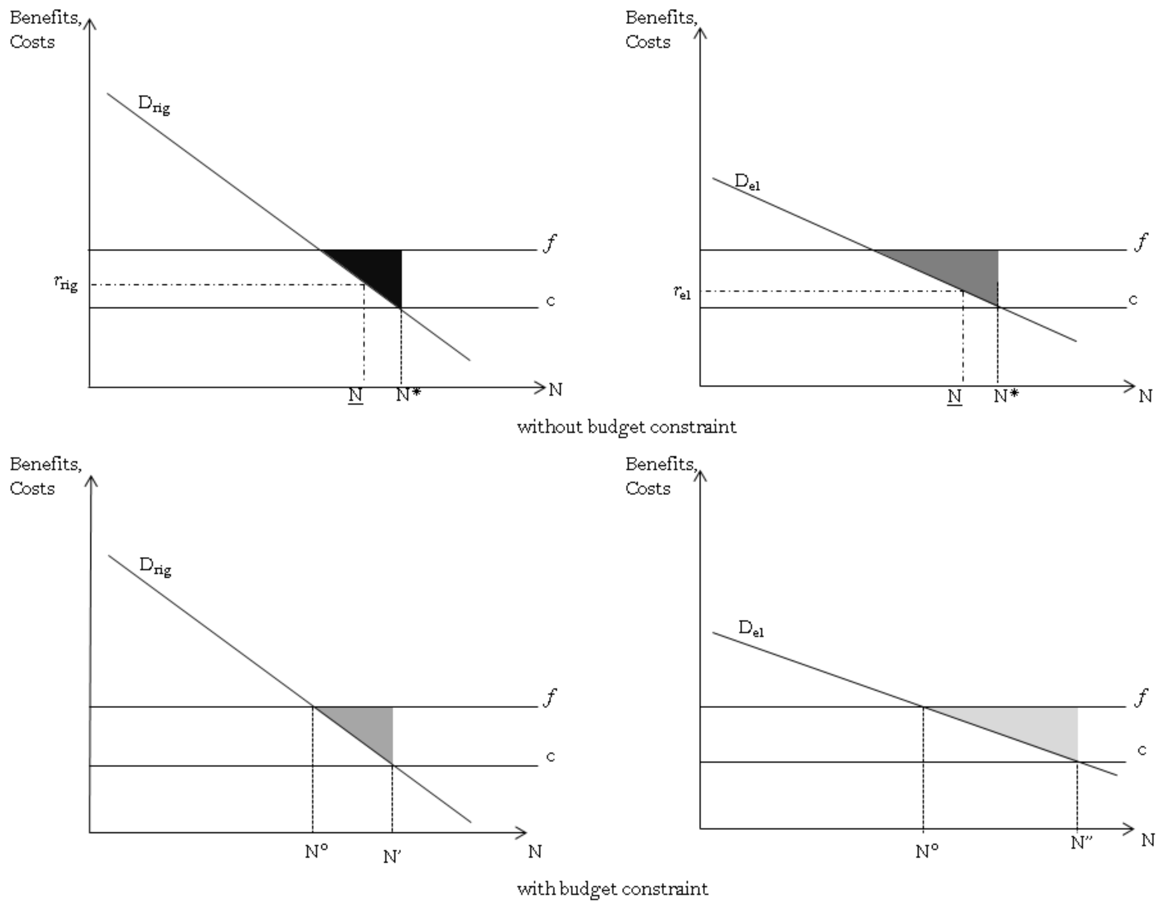
$$\frac{\partial L}{\partial f}: -\lambda_1 N_1 = 0 \quad (4e)$$

- For the group which is taxed (group 1) λ_1=0 (4e), so from (4a) and (4c) we obtain: $f=E_1'(n_1)$, that is, the Pigou-first best case taxation.
- For the group which is not taxed (group 2), λ_2>0: from (4b) and (4d) we obtain that $\lambda_2 = \frac{E'_2(n_2)}{D'_2(N_2)N_2} = \frac{E'_2(n_2)\eta_2}{D_2(N_2)}$.

  This is the shadow cost (in terms of net consumer surplus) of not taxing that group: given that is directly proportional to the elasticity, this hints that it would be better to tax the sector with higher elasticity.

This is easy to show also graphically (see Figure 1). The gain in internalizing the externality (i.e. in terms of consumer surplus loss saved) is higher the with more elastic demand. The first two graphs compare the effect of raising a Pigouvian tax to completely internalize the externality, in absence of governmental budget constraint. This increase, which raises the perceived cost up to *f* in both cases, generates a decrease in the consumer surplus that is much higher in case of elastic (upper right graph) than rigid (upper left graph) demand. The second pair of graphs illustrate the situation under binding governmental budget constraints. If the government wants to achieve a given quantity of produced output $N°$ (once again obtained by raising the perceived cost from c to f), starting from the no-tax situation (i.e. N' when the demand function is rigid, N'' when the demand function is elastic), the amount of surplus loss eliminated is higher with elastic demand, given that $N''>N'$.

Figure 1: The welfare effects of a decrease in the polluting activity in presence of users with rigid or elastic demand, when the government has not or has a budget constraint.



Starting from the Figure above, suppose that $N=\underline{N}<N^*$ (that is, the number of trips in lower than the one in which marginal private costs and demand meet): in this case $D_{rig}(\underline{N})<D_{el}(\underline{N})$ and $E_{rig}(\underline{N}\})=E_{el}(\underline{N})$.

- The gain in internalizing the externality with rigid demand is: $[E_{rig}(\underline{N})]^2 * \underline{N}\ \eta_{rig} /[2\ D_{rig}(\underline{N})]$
- The gain in internalizing the externality with elastic demand is: $[E_{el}(\underline{N})]^2 * \underline{N}\ \eta_{el} /[2\ D_{el}(\underline{N})]$

Given that $[E_{el}(\underline{N})]^2 * \underline{N}/2$ is constant, we can just compare η/D. Given that $\eta_{rig} < \eta_{el}$ and $D_{rig} > D_{el}$, we can confirm that there are higher gains in internalizing externalities coming from individuals with more elastic demand. Note also that when the same amount of quantity is produced, a lower tariff is required to the individuals, and a greater area of surplus loss is absorbed.

In plain words again, we have demonstrate something reasonable also in intuitive terms: for the environment, it is better to tax sectors that will reduce more easily their polluting emissions. The budget constraint that we assume here means that we deal with one polluting sector related to other ones, but without changing the structure of the entire public budget.

3.2.1 A numerical example

We will provide a rough estimate for Italy, assuming a fixed revenue constraint, a fixed taxation per unit of oil product (identical to the present level of taxation for gasoline, that is 0.85208 €/liter[7]) imposed to a sector with an elasticity double that the one assumed for the road sector (e.g. -0.6 instead of -0.3) will double the reduction in quantities (10 billion liters now, down from 11.529 billion that we can assume without taxation and given the elasticity we have assumed[8], generating around 1.35 billion of surplus gain and 8.86 billions of revenues). The reduction of quantities obtained by taxing the "other sector" and keeping the same revenues from the tax (this means inducing a production of 10 billions of liters) with double elasticity (i.e. -0.6 in the present case), will be around 16.57 billion liters[9], generating a gain of surplus of nearly 5,82 billion.

4. Applications and implications for the transport sector

The transport sector is probably the one more implicated in the consequences of the relation between the elasticity of demand and the efficiency of the environmental taxation, that we have

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[7] This tax level is computed as the sum of excise and the VAT part that is computed on this excise (i.e. which can not be assumed as "neutral"). The data are the statistics on energy diffused by the Ministry of Economic Development; we took the most recent data, that refer to the average national prices for February, 2012.

[8] $-0.3 = [(x - 10000000000)/10000000000]/[(0.85208 - 1.7378)/1.7378]$.

[9] $-0.6 = [(10000000000 - x)/x]/[(1.7378 - 0.85208)/0.85208]$.

seen above. This, due both to the low elasticity of its largest component (the road mode), and to the relatively high level of taxation of this mode, mainly in Europe and Japan. Let's review the taxation first-best strategy: a carbon tax (and a related tax for other pollutants).

We are definitely very far from this situation across the different polluting sectors. But actually we also are very far from a second-best situation (i.e., one with an "average" taxation, identical for all the polluters). Some heavy polluters are explicitly subsidized, for others the tax is negligible, and for others still it is very high, and probably above the efficient level. Transport is the more evident case of the latter situation. In other sectors, fossil fuels are taxed either far less, or non taxed at all. Historical and political reasons explain this fiscal asymmetry: when cars were few and expensive, income-distribution targets were in favor of this type of taxation. After mass motorization, the political reasons for maintaining a high tax level on gasoline shifted toward keeping an abundant and secure source of revenues. Furthermore, the rigidity of demand of road transport indicated a reduced deadweight loss, following the traditional Ramsey-Boiteaux rule, that is valid only without considering the environmental issue. But the rigidity of demand has another meaning: it is related to a very high willingness to pay. So a "secondary" political reason intervened: the social reactions against this tax were reduced, since cars and trucks were sold and used anyway. Finally, the environmental growing conscience contributed to make this taxation even more politically acceptable (in a sense, the State was able to create a "guilt complex" in road users, much more than in other polluting sectors, in order to secure the continuity of its large fiscal revenues).

As we have demonstrated above, from the point of view of environmental effectiveness and efficiency, it is far from optimal to tax sectors with rigid demand (i.e., the Ramsey-Boiteaux rule is inverted in case of Pigouvian environmental taxes). And we have seen that with mass motorization the social "merit" of this tax is also much reduced.

So now it is the case to elaborate on the rigidity of road transport demand, in order to shed some light on this phenomenon. First of all, historical and empirical evidence suggests that transport demand is very rigid indeed. The technical costs of reducing emissions of moving (i.e. small) motors is high: the larger the source of emission (i.e. energy production, industry etc.), the more simple and effective at the margin is the intervention, given the economies of scale of abatement. Consequently, the Intergovernmental Panel for Climate Change (IPCC) recognizes that transport generates 23% of the total GHG emissions, but it reduces the target to 9% of the recommended total reduction (see Kahn Ribeiro et al., 2007). In second place, transport is a special sector in terms of "complement costs" for the users.

Let's see another simple numerical example (using just rough orders of magnitudes). The perceived cost of time in Europe is in the order of 10,34 €/hour[10]; a commuter that travels by car 10 km/day and consumes 1 liter of gasoline spends 1,74€; if the shift from the car mode to public transport implies for him/her a loss even of only 15 minutes per day, even with a free public service he/she will not shift mode (2,585€ is the value of the time loss).

Time has a dominant value in developed countries, and is a basic complement (perceived) cost for travel. And this fact has been proved from the actual experience of sharp changes of the gasoline price: the two subsequent oil price shocks in the Seventies of the past century have generate a relevant decline in the British Termal Unit (BTU) content per unit of GDP, while the mass motorization trend has remained more or less unvaried.

A form of elasticity has actually emerged, that is not inter-modal (from road transport to other modes), but intra-modal. The unit gasoline consumption per horsepower generated has somewhat declined, even if far less so per vehicle, due to the increase of accessories (mainly servo-mechanisms and air conditioning). But overall Green House Gases (GHG) emissions of the transport sector have increased, much more than in other sectors. And road transport has increased its dominance, even if other land modes (railways, buses) have been in general heavily subsidized.

[10] We take the average between the perceived cost of time (VTPI, 2012) in road passenger transport in Europe for business (€ 21.00 per person hour), commuting/private (€ 6.00 per person hour), and leisure/holiday (€ 4.00 per person hour).

A first consideration emerges: elasticity to gasoline taxation is already maximized via the subsidies to public transport, with very limited results (without these subsidies, the demand for road transport would be even more rigid). A second consideration concerns the equity issue of this taxation: if the principle “polluters pay” has an evident equity content. Taxing different polluters in such an unbalanced way is definitely unfair, since transport by car is no longer reserved for the rich. A third consideration concerns environmental efficiency (i.e. gain or losses of social surplus): taxing more elastic polluting sectors will show much larger social benefits (following the IPCC, the main sectors involved are energy production and energy consumption outside the transport sector).

Actually, a further efficiency issue emerges in transport: if the larger component of polluting transport (cars) is overtaxed in relation of the external environmental costs that this sector generates, we face a surplus deadweight loss. Obviously this is true for every taxation, but the issue is its relative magnitude compared to other sectors. Let’s assume that VAT is the standard indirect taxation: overtaxing one polluter above others in order to meet a state revenue constraint, is inefficient even if its demand is more rigid than others. In fact, taxing polluters in proportion to their external costs generates only surplus gains, while taxing more rigid demand generates only lower surplus losses (see Figure 1). If we add to this picture a high marginal opportunity cost of public funds related to the fiscal crisis of many States, reduction of subsidies of public transport (especially of railways) seems also a logical choice, given the very limited role it plays in total mobility (in the order of 10% traffic units in Europe). Subsidies, by the way, are mainly absorbed by public transport with very low patronage: well utilized public services requires limited subsidies even now. Apparently, a problem remains unsolved in this recommended policy: road congestion. A reduction of public transport and an increase of road transport will increase congestion. True, but with strong limits. Even a heavy reduction of public transport (let’s say an unlikely 20%), will generate a small amount of road traffic increase, in the order of 2%. This seems a dimension that can easily be dealt via a limited increase of road capacity, and this result can also be met through proper congestion charging, without any burden for the state, and in an highly efficient and equitable way (we cannot enter in further technical details here on this issue).

4.1 Is Italian gasoline taxation too high?

However, keeping the numbers we used in Section 3.2.1 in mind, the present level of taxation is inefficient (i.e. too high). Once again, taking the data for Italy: the marginal private cost we take as a reference is 1.12016 €/liter[11].

Now, let's assume an efficient level of taxation (i.e. excise) for the internalization of environmental[12] external costs: 0.25833 €/liter[13]. Thus, the optimal selling price of gasoline, computed using this Pigouvian environmental tax is 1.37849 €/liter. Increasing the price above this level generates a surplus loss (the so-called deadweight loss of taxation): this surplus loss is at present, given the -0.3 elasticity, in the order of 111 millions (which will also be the gain in surplus obtainable by shifting to the right tax, generating a double dividend), which erodes one third of the surplus gains obtained by taxing the environmental externality[14] (see Figure 2).

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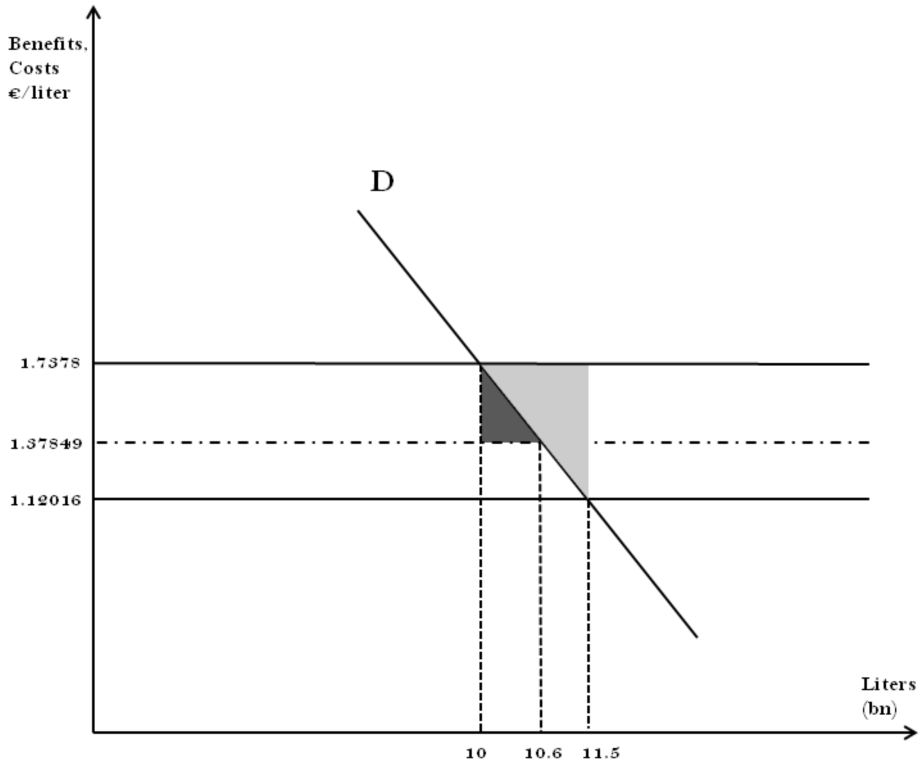
[11] The final price is 1.7378 €/liter, while the net price (out of VAT and the excise) is 0.732 €/liter. adding the "neutral" portion of the 21% VAT on this value only (in Italy part of VAT is computed on the excise) the marginal cost becomes 0.88572 €/liter. Finally, since we are dealing with environmental costs, we include in the private marginal costs the marginal cost of accidents and congestion (Maibach et al., 2008) of 0.23444€/liter, taking as reference the marginal unit costs in an interurban context, off-peak, daily.

[12] They include: noise, air pollution, climate change, up- and down-stream processes, soil and water pollution.

[13] This cost is calculated following Maibach et al., 2008.

[14] Starting from $-0.3 = [(x - 10000000000)/10000000000]/[(1.37849 - 1.7378)/1.7378]$, we obtain that the liters of gasoline consumed by decreasing the excise down to its optimal level would be 10,6 billions of liters; the deadweight loss is computed as $(10620300000 - 10000000000) * (1.7378 - 1.37849)/2 = 111440000$, while the gain is $(11066200000 - 10000000000) * (1.7378 - 1.12016)/2 = 329263884$, with 11066200000 obtained from $-0.3 = [(x - 10000000000)/10000000000]/(1.12016 - 1.7378)/1.7378]$. These calculations are done under the hypothesis of linear demand function.

Figure 2: The beneficial welfare effect of an optimal taxation of an environmental externality and the deadweight loss due to over-taxation.



5. Concluding remarks and future research

The theory that has been presented here seems to be rather straightforward, up to be on the intuitive side: taxing high elasticity sectors when externalities are involved is socially more efficient that taxing inelastic sectors, everything being equal. In this way, surplus losses are minimized: the Ramsey-Boiteaux rule is actually inverted. This can be seen also as a form of the much-discussed "double dividend" concept.

A shift of part of the present high taxation away from road transport, that in Europe and in Japan is heavily taxed, on polluting sectors that are more elastic (i.e. have more alternative goods) seems to be strongly recommended.

The main political objection to this can be twofold. The first is "internal" to the transport sector: its rigid demand is due to the limits of alternatives, so it would be better to create solid alternatives, and the sector will become more elastic. But this has already been done by subsidies to public transport (specially rail), with negligible results, and high public costs. A second, "external" objection states that taxing elastic sectors implies by definition a sharp reduction of their production, this involving in turn employment losses. But in fact there are sectors extremely energy-consuming, that are not labor-intensive. The examples are in several sectors, underlined also by the IPCC: energy production, and furthermore metal and cement production. Useless to say, a higher taxation is not only involving a reduction of quantities produced, but also a strong incentive to innovate the relevant technologies.

A further consideration is related to the risks of an increase of road congestion: but the same rigid demand that generates limited environment benefits when taxed, will limit the increase of road transport when taxation is reduced. And direct pricing of congestion (see the London case) is a much more efficient and equitable tool for dealing with this issue, than an indirect intervention through gasoline taxation, that affects indifferently congested and uncongested situations.

Moreover, as we have seen, even the social objectives of this taxation has become at least ambiguous: in the USA, the strong bi-partisan political resistance to increase gasoline taxes is related to avoid the adverse impacts on low income commuters. And the flexibility in space and time of the modern labor market is also at stakes here, if it is not possible to elaborate more here on this issue.

Further research is needed obviously on the main issue analyzed here: the elasticity of demand, both static and dynamic, in the different polluting sectors, taking also into account the potential development of the related technologies.

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