TOPIC 18
ENVIRONMENT AND
SUSTAINABLE MOBILITY

ILLUSTRATION OF GENERAL EQUILIBRIUM ASPECTS OF CONGESTION TAXES

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Abstract

A general equilibrium framework is presented for the optimal design of tax systems in the presence of congestion type of externalities caused by consumption and production. The government faces the dual objective of (i) controlling the externality and (ii) raising sufficient revenue, taking into account both equity and efficiency considerations.

INTRODUCTION

Several recent studies have advocated a strong increase of taxes on road use in order to cope with increasing congestion. These statements are mostly made in a partial equilibrium context. Only the benefits of a better allocation in the transport market are taken into account. The object of this paper is to analyze this problem in a general equilibrium context with a small illustrative model calibrated to Belgian data. The govemment is assumed to have the dual objective of correcting for the congestion externality and of raising revenue in an efficient and equitable way.

The use of a general equilibrium framework allows to analyse several dimensions that were hitherto not correctly addressed. What is missing in a partial equilibrium context is the incidence of the use of the congestion tax revenue, the incidence of tax changes on freight transport on consumers' welfare, the effects of parallel changes in other taxes and the public finance effects of the construction of new transport infrastructure. The more complete modelling context allows to treat two important questions. The first question is the determination of the optimal externality tax in a setting where the policy maker takes into account income distribution objectives and can re-optimise simultaneously a linear income tax. How will the optimal externality tax be affected by changes in the income inequality aversion? The second question is what has become known as the double dividend question. Given that an increase in externality taxes improves the allocation in the transport sector (first dividend), is it possible to realize a second dividend by using the extra tax revenue to reduce existing distortionary taxes eg on labour? And if this is the case, does this imply that the optimal externality tax should be higher than the Pigouvian tax? This question has been discussed extensively in the case of externality taxes (Goulder 1995; Bovenberg and Van der Ploeg 1994) but without paying attention to the income distribution objectives.

These aspects were studied in a theoretical general equilibrium framework by Mayeres and Proost (1995) who also discussed a number of empirical exercises. In this paper we want to give more background on the empirical illustration and present a number of additional exercises. After the presentation of the model and its calibration, we discuss the optimal taxes for an economy in which the initial income distribution is close to the optimal one. Next we present a number of sensitivity analyses.

THE MODEL

The empirical model was developed in Mayeres and Proost (1995). It describes a closed economy in which there are three goods. Good 1 is leisure which is the numeraire good. Good 2 represents a composite non-transport good. Good 3 is private road transport which causes congestion. The consumption vector of consumer i is $x^i = (x_1^i, x_2^i, x_3^i)$ where x_j^i denotes his consumption of good j. X_j is the total consumption of good j. The only externality is *congestion* caused by road transport. The congestion function is:

$$Z = \frac{1}{\left[1 - \frac{X_3+y_3}{X_3^*+R}\right]^{\chi}} \qquad \chi>1 \tag{1}$$

The level of congestion (Z) is determined by the ratio of total transport use by households (X_3) and firms (y_3) to the level of road capacity. Road capacity is given by the sum of the existing capacity of the road, represented by the traffic level at which average speed reduces to zero (X_3^*), and the additional capacity provided by the government (R). The contribution to congestion is assumed to be the same for households and firms. The parameter χ determines the elasticity of the congestion level to the total use of transport. For χ =1 the congestion function reduces to the inverse linear congestion function presented in Evans (1992).

The model includes five nonidentical *consumers* who differ only in their earning capacity e^i. They maximize their utility subject to their budget constraint. In doing so it is assumed that they ignore their own impact on the externality, ie they consider the congestion level to be exogenously given. The individual utility function of consumer i is assumed to be of the modified LES-type:

$$u^i(x_1^i, x_2^i, x_3^i, Z) = \sum_{j=1}^{2} \mu_j \ln(x_j^i - \lambda_j) + \frac{\mu_3}{Z^k} \ln(x_3^i - \lambda_3) \tag{2}$$

Usually λ_j is interpreted as the subsistence level and μ_j as the marginal budget share of good j. The parameter K is used to parameterize the aversion to congestion which rises with K. An increase in congestion reduces the attractiveness of transport by reducing the marginal budget share of that good. The budget constraint of the consumer is given by:

$$q_2 x_2^i + q_3 x_3^i = e^i(I - x_1^i) + T \tag{3}$$

I stands for the individual time endowment. The work performed by individual i is thus given by $(I-x_1{}^i)$. For this work he receives a wage denoted by e^i. The consumer price of good j is q_j. T is the uniform lump sum transfer made by the government to each household.

The *production sector* produces four final outputs: the composite non-transport good (good 2), the transport good (good 3), road infrastructure (R) and other public goods (REV). The production process is normalized such that all goods except road infrastructure are produced at identical costs. There is one intermediate output, freight transport y_3, which is used as an input in the production of the four other goods. Labour is used as an input both in intermediate and final production. The amount of labour used in both production processes is denoted by X_{I1} and X_{F1} respectively. The production function for freight transport is given by:

$$D\, y_3 - X_{I1} \leq 0 \tag{4}$$

The use of freight transport as input in the production of final goods contributes to congestion. In the final production, firms produce the four goods by combining labour and transport according to a modified CES function. The production possibilities are defined as (with $-1<\rho<\infty$ and $0\leq\Omega\leq1$):

$$(X_2 + X_3 + REV + \eta R) \leq \frac{F}{Z^H}\left[\Omega y_3^{-\rho} + (1-\Omega) X_{F1}^{-\rho}\right]^{-\frac{1}{\rho}} \tag{5}$$

In this expression F is an indicator of the general state of technology. The parameter Ω determines the relative factor shares in the product. The parameter ρ determines the elasticity of substitution ζ, which is defined as $1/(1+\rho)$. H represents the elasticity of the production costs with respect to congestion.

It is assumed that *the government* can use four instruments: the indirect taxes t_k on all goods except on the numeraire good leisure, which is taken to be untaxed, the excise θ_3 on the use of transport in production, the poll transfer T and R, the investments in road infrastructure. The government budget constraint is:

$$t_2 X_2 + t_3 X_3 + \theta_3 y_3 - 5T \geq \rho_2 (REV + R) \tag{6}$$

REV stands for the level of government revenue needed to pay for the public administration and for the supply of other public goods. The level of these remains fixed and does not need to be made explicit in the analysis. The government's objective function is represented by the following social welfare function:

$$W = \sum_i \frac{(V^i)^\varepsilon}{\varepsilon} \tag{7}$$

The parameter ε denotes the extent to which society is averse towards inequality. Besides the level of social welfare we also use the equivalent income (EI^i) to measure individual variations in welfare and the social equivalent gain (SG) to measure variations in social welfare between equilibria. The concept of equivalent income measures each household's welfare in terms of units of the numeraire good. Based on King (1983), equivalent income is defined here as that level of income which, at the reference price vector and the reference congestion level, allows one to reach the same level of utility as can be attained under the given price vector and level of congestion. In our exercise EI^i is always calculated with respect to the prices and congestion level associated with the initial equilibrium of the economy under consideration.

$$V^i (q_{initial}, Z_{initial}, EI^i) = V^i (q_{new}, Z_{new}, f^i_{new}) \tag{8}$$

In this expression f^i represents total income of household i and V^i is the indirect utility function. The change in individual welfare brought about by a change in the tax system can then be measured as the change in equivalent income. Using initial prices and level of congestion as reference, we obtain what has been termed by King (1983) the equivalent gain or loss (EG^i):

$$EG^i = EI^i_{new} - EI^i_{initial} \tag{9}$$

The social value of a tax change is given by the social equivalent gain (SG). This is the sum of money which, if equally distributed to all households in the initial equilibrium, would produce a social welfare equal to that obtained after the change in the tax system. Or, following King (1983)

$$W (EI^1_{initial} + SG, \cdots, EI^5_{initial} + SG) = W (EI^1_{new}, \cdots, EI^5_{new}) \tag{10}$$

THE INITIAL EQUILIBRIUM

The model is calibrated such as to represent an initial equilibrium with the currently existing consumer taxes, congestion taxes and excises for Belgium. The central values for the parameters and the corresponding initial equilibrium are presented in Table 1. In the central case the value of ε is assumed to be 6.75. For this value the existing income distribution will turn out to be very close to the optimal one and the main task for the government will be to correct for the congestion externality. Later, the outcome will be compared with the results for a different degree of inequality aversion. The central value for H and K is 0.0205 and 0.095 respectively. This gives a congestion elasticity of private transport use by consumers equal to -0.25 (comparable to the value put forward in Small 1983) and an elasticity of production costs with respect to congestion of 0.028. However, since we realize that both values are subject to uncertainty, we will discuss in a later section the sensitivity of the policy results to the values chosen.

Varying the aversion to congestion and the autonomous equilibrium mechanism

Table 2 shows how the initial equilibrium changes when the consumers have a higher degree of aversion to congestion (K) but holding the taxes t_2, t_3 and θ_3 constant at the initial level. The government budget is assumed to be balanced by adjusting the lump sum transfer. As the value of K increases and people become more averse to congestion, the total consumption of the private transport good decreases because of the negative feedback of congestion on the consumption of transport. This can be understood as a simple discomfort of transportation or as the implicit formulation of a quantitative rationing scheme. The decreased consumption of transport reduces congestion which will then mitigate the reduction of transport consumption. This process is called the autonomous equilibrium mechanism which operates in the absence of optimal congestion taxes or other policy instruments. The volume of freight transport is slightly reduced because of the decrease in overall output. The optimal policy response to the increased aversion to congestion will be discussed later.

Table 1 Calibration of the model

	Initial equilibrium: K = 0.095, S = 0.0205, ε = 6.75	
X_1	Cons. of leisure	2686
X_2	Cons. of composite commodity	11561
X_3	Cons. of passenger transport	1390
y_3	Freight transport	1348
R	New road capacity	0
$X_3^* + R$	Total road capacity	3500
Z	Congestion level	9.84
T	Poll transfer	2454.69
$p_2 = p_3 = p_R$	Producer price	1.126
p_1	Price of leisure	1
t_2	Excise on composite commodity	1.379
t_3	Excise on passenger transport	1.929
θ_3	Excise of freight transport	0.05
-Y	Congestion tax	0.55

Parameters used for calibration

Consumers		Producers	Congestion function	Government
K = 0.095	$e^1 = 1$	H = 0.0205	$\chi = 1.5$	REV = 5700
$\mu_1 = 0.10$	$e^2 = 3.5$			
$\mu_2 = 0.76$	$e^3 = 6.8$	D = 0.8		
$\mu_3 = 0.14$	$e^4 = 9.8$	F = 1.0708		
	$e^5 = 20$	$\Omega = 0.015$		
		$\rho = 0.5$		
$\lambda_1 = 400$	I = 1000	$\zeta = 1/(1+\rho) = 0.6667$		
$\lambda_2 = 3$		$\eta = 1$		
$\lambda_3 = 50$				

Table 2 The autonomous equilibrating mechanism

		Initial equilibrium	Optimum
H	Producers' aversion to congestion	0.0205	0.0205
K	Consumers' aversion to congestion	*0.095*	*0.14*
ε	Degree of inequality aversion	6.75	6.75
X_1	Cons. of leisure	2686	2693
X_2	Cons. of composite good	11561	11606
X_3	Cons. of passenger transport	1390	1299
y_3	Freight transport	1348	1346
R	New road capacity	0	0
$X_3^* + R$	Total road capacity	3500	3500
Z	Congestion level	9.84	8.28
T	Lump sum transfer	2454.69	2458.75
$p_2 = p_3 = p_R$	Producer price	1.126	1.122
p_1	Price of leisure	1	1
t_2	Excise composite commodity	1.379	1.379
t_3	Excise on passenger transport	1.929	1.929
θ_3	Excise on freight transport	0.05	0.05

OPTIMAL TAXES

The central case

The first part of Table 3 compares the initial equilibrium and the optimum for the central case. In the optimum the government chooses t_2, t_3, θ_3, R and T such that social welfare is maximized subject to the government's budget constraint and the production constraint. It is assumed that the activity which causes the externality is taxable. This amounts to assuming that perfect road pricing is possible. In reality however, political, informational, practical or other considerations may form an impediment. An extension of the model would therefore consist of introducing restrictions on the available price instruments. It is assumed that road capacity cannot be reduced below its initial level. Mayeres and Proost (1995) relaxes this assumption and thus allows to treat in a more thorough way the interaction between congestion taxes and transport infrastructure investments. As was pointed out before, the government has three main goals: controlling the level of the congestion externality and obtaining sufficient government revenue in an efficient and equitable way. It turns out that the existing tax system is far from optimal. The optimal congestion level is 73% lower than in the initial equilibrium. To achieve this result, the government makes use of two of the three available instruments. It is not optimal to invest in additional road capacity to alleviate congestion. This means that in the optimum the marginal social cost of an increase in capacity is higher than the social valuation of the corresponding decrease in congestion. Instead, the government increases the congestion tax on private transport use. The optimal congestion tax on the use of transport by consumers (-Y) is almost two and a half times as high as the initial one. Secondly, the government raises the excise on the use of transport by the production sector drastically. Despite the decrease in the tax base of the two externality taxes, total tax revenue from these sources rises. Since it is not optimal, given the value of the inequality aversion ε, to increase the poll subsidy substantially, the government is able to reduce the Ramsey part of the tax on good 2 and good 3 while maintaining a budget balance. The tax reform causes a rise in the implicit after-tax wage which results in an increase of the labour supply. The optimum is a Pareto improvement w.r.t. the initial situation. All individuals are better off.

Table 3 Comparison of the initial and the optimal equilibrium for ε = 6.75 and ε = 1 (K=0.095 and H=0.0205)

		Initial equilibrium	Optimum $\varepsilon = 6.75$	Optimum $\varepsilon = 1$
X_1	Cons. of leisure	2686	2679	3001
X_2	Cons. of composite good	11561	12266	11411
X_3	Cons. of passenger transport	1390	942	921
y_3	Freight transport	1348	746	738
R	New road capacity	0	0	0
$X_3^* + R$	Total road capacity	3500	3500	3500
Z	Congestion level	9.84	2.69	2.62
T	Lump sum transfer	2454.69	2466.23	4523.64
$p_2 = p_3 = p_R$	Producer price	1.126	1.163	1.158
p_1	Price of leisure	1	1	1
t_2	Excise composite commodity	1.379	1.164	2.039
t_3	Excise on passenger transport	1.929	3.893	5.460
-Y	Congestion tax	0.55	1.364	1.239
θ_3	Excise on freight transport	0.05	1.364	1.239
EG^1	Equivalent gain/loss		208	1086
EG^2			337	824
EG^3			520	483
EG^4			695	179
EG^5			1334	-827
SG	Social equivalent gain		552	608
G	Marginal cost of public funds		1.41	1.47

The move from the initial equilibrium to the optimum can be related to the double dividend discussion (Bovenberg and van der Ploeg 1994; Goulder 1994) which splits the welfare effects of an environmental tax reform into two benefits. The first dividend consists of the benefits of a reduction in the negative externality, when the poll transfer is used to recycle the extra tax revenue raised by the externality tax. The second dividend corresponds with the benefits of using the externality tax revenue for the reduction of existing distortionary taxes. Table 4 summarizes the results. The first dividend is computed by raising the price of the transport goods to the optimum level and by redistributing the proceeds by an increase in the poll transfer. All income groups gain from this policy change. However, this will not always be true, eg an individual who has a large consumption of transport but who is almost not affected by congestion, will experience a negative congestion dividend. The second dividend consists of the additional welfare gain achieved by replacing the increased poll transfer by a reduced level of distortionary taxes on good 2 (and implicitly on labour). There is a second-order positive effect on the level of congestion as the net congestion tax is also slightly increased. The total tax-recycling dividend is positive. However, the lower income groups who are better off with an increased poll transfer than with a lower tax on consumption (or labour), experience a welfare loss. *Comparing the first and the second dividend we see that the congestion dividend dominates the second dividend. This is due to the fact that in the initial equilibrium the distortions in the tax system on non-transport goods are limited.*

Table 4 **The move from the initial equilibrium to the optimum ($\varepsilon = 6.75$)**

$\varepsilon = 6.75$	Initial equilibrium	Congestion dividend	Congestion + tax recycling dividend
Government instruments			
t_2	1.379	1.379	1.164
t_3	1.929	3.893	3.893
θ_3	0.05	1.364	1.364
T	2455	2954	2466
Congestion level (Z)	9.84	2.80	2.69
Equivalent gain/loss			
Consumer 1		473	208
Consumer 2		491	337
Consumer 3		526	520
Consumer 4		564	695
Consumer 5		733	1334
Social equivalent gain/loss		543	552

The sensitivity of the optimal taxes with respect to the degree of inequality aversion

In the central case the existing income distribution turned out to be more or less optimal. However, when poorer households are given a higher welfare weight, this is no longer true. In the second part of Table 3 we compare the results for the central case with the optimal policy for a social welfare function which is more equity oriented (ε=1). The government will now not only try to control of the congestion externality but it will also aim at improving the existing income distribution. As before, the congestion taxes are raised. But the increase in the poll transfer made possible by the increased externality taxes is not high enough with respect to the income distribution objective of the government. The Ramsey part of the tax on good 2 and 3 needs to be raised further in order to make possible an even higher poll transfer. The resulting marginal cost of public funds is higher than for ε=6.75. Total labour supply decreases. This can be explained by the increase in the poll transfer T and by the lower implicit after-tax wage.

The mechanisms at work can be explained in Table 5 in which, as before, the move from the initial equilibrium to the optimum is split into two dividends. Again, the first dividend is positive for all income groups and dominates the total social equivalent gain. The second dividend now represents an important redistribution operation so that the highest income group is a net loser. *Comparing the tax reform operations for ε = 1 and ε = 6.75, we see that the optimal congestion* *taxes and optimal congestion levels are almost not affected by the degree of inequality aversion used by the policy maker.* This can be explained by the fact that the utility function is the same for all income groups so that all of them prefer lower congestion levels. However, it is important to note that the use of externality tax revenue and the ultimate welfare effect are determined to a large extent by the degree of income inequality aversion.

Table 5 **The move from the initial equilibrium to the optimum ($\varepsilon = 1$)**

$\varepsilon = 1$	Initial equilibrium	Congestion dividend	Congestion + tax recycling dividend
Government instruments			
t_2	1.379	1.379	2.04
t_3	1.929	5.46	5.46
θ_3	0.05	1.24	1.24
T	2455	3103	4524
Congestion level (Z)	9.84	2.41	2.62
Equivalent gain/loss			
Consumer 1		533	1086
Consumer 2		518	824
Consumer 3		510	483
Consumer 4		510	179
Consumer 5		552	-827
Social equivalent gain/loss		524	608

Additional sensitivity analyses

In this section we analyse the sensitivity of the results with respect to the households' aversion to congestion, the sensitivity of production costs towards congestion and the costs of road infrastructure. Each of these sensitivity analyses is performed for a given strong degree of inequality aversion, namely for $\varepsilon=1$.

The first part of Table 6 gives information on how the optimal policy should be adjusted if the degree of the individuals' aversion towards congestion changes. It summarizes the required change in the policy instruments if the degree of aversion to congestion appears to be smaller than what was assumed before, eg K = 0.05 instead of K = 0.095. As can be expected, the optimal level of congestion is higher. The Pigouvian tax component in the tax on good 3 and the excise on the use of transport in production no longer need to be as high as before. They can be reduced by 23.2% compared to the optimum for K=0.095. As a result the total use of transport by consumers and producers rises. Despite the increase in the tax base, tax revenue from these sources is reduced. In order to raise sufficient revenue the government needs to raise the consumer tax t_2. However, this decreases the tax base of this tax. So, on the whole, government revenue is reduced and the government needs to cut the poll transfers to the consumers.

The second part of Table 6 presents the results if the sensitivity of the production costs with respect to congestion changes. A higher value of H is associated with a larger impact of congestion on production. The results are similar to the ones obtained for an increased household aversion to congestion.

In the central case we have found that it is not optimal for the government to provide additional road infrastructure, since in the optimum the marginal costs of such a policy exceed the marginal benefits. Up to now it has been assumed that the production costs of a unit of road infrastructure are equal to those of other goods. What is the effect of relaxing this assumption and thus allowing the costs of road infrastructure to be lower than the costs for other goods? The parameter η gives the ratio of unit production costs of road infrastructure to those of other goods. We see that as η becomes smaller and investment in road infrastructure thus becomes relatively less expensive, it is optimal for the government to invest in road infrastructure. In the case of $\eta=0.4$ the government increases the road capacity by 509 units. Congestion is reduced by 75%. Transport use only needs to be reduced by 35%, whereas in the central case a reduction of 39.5% was called for. Moreover, marginal external congestion costs are lower than in the central case. These two considerations explain why the optimal externality taxes are lower than in the central case. The decrease in tax revenue due to lower externality taxes and more investment in road infrastructure is compensated by a slight increase in the distortionary taxes and by a reduction of the poll transfers.

Table 6 Additional sensitivity analyses

		Optimum for		Sensitivity analysis	
H	producers' aversion to congestion	0.0205	0.0205	*0.03*	0.0205
K	consumers' aversion to congestion	0.095	*0.05*	0.095	0.095
ε	degree of inequality aversion	1	1	1	1
η	relative infrastructure cost	1	1	1	*0.4*
X_1	Cons. of leisure	3001	2991	3000	2987
X_2	Cons. of composite good	11411	11301	11563	11253
X_3	Cons. of passenger transport	921	1066	972	998
y_3	Freight transport	738	815	769	793
R	New road capacity	0	0	0	509
$X_3^* + R$	Total road capacity	3500	3500	3500	4009
Z	Congestion level	2.62	3.18	2.81	2.43
T	Lump sum transfer	4523.64	4486.71	4513.31	4440.77
$p_2 = p_3$	Producer price	1.158	1.150	1.142	1.147
p_R	Producer price infrastructure	1.158	1.150	1.142	0.459
p_1	Price of leisure	1	1	1	1
t_2	Excise composite commodity	2.039	2.053	2.013	2.064
t_3	Excise on passenger transport	5.460	4.703	5.085	4.940
-Y	Congestion tax	1.239	0.952	1.112	1.027
θ_3	Excise on freight transport	1.239	0.952	1.112	1.027
EG^1	Equivalent gain/loss	1086	997	976	1066
EG^2		824	703	723	819
EG^3		483	320	396	501
EG^4		179	-26	104	217
EG^5		-827	-1187	-861	-719
SG	Social equivalent gain	608	455	514	620
G	Marginal cost of public funds	1.47	1.48	1.47	1.48

CONCLUSIONS

Using a general equilibrium framework has allowed us to analyse simultaneously the congestion taxes and the other instruments of which the government can make use. This dimension is absent in the partial equilibrium models which are generally used to study transport pricing. Moreover, income distribution aspects are taken into account explicitly. When determining the optimal policy for different degrees of inequality aversion, it is found that the optimal congestion tax is not very sensitive to the degree of inequality aversion of the policy maker. However, the inequality aversion is the most important factor in deciding on the use of the congestion tax revenue and on the accompanying changes in the tax system. Moreover, it is found that starting from a tax system that more or less realizes the equity objectives, the gains from using the externality tax revenues to reduce distortionary taxes are relatively small. In terms of the double dividend discussion, it can be said that the first dividend dominates.

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