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The European road pricing game: how to enforce optimal pricing in high-transit countries under asymmetric information

by

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DISCUSSION PAPER

The European road pricing game: how to enforce optimal pricing in high-transit countries under asymmetric information.

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Abstract

A federal government tries to force local governments to implement welfare optimal tolling and investment. Welfare optimal tolling requires charging for marginal external costs. Local governments have an incentive to charge more than the marginal social cost whenever there is transit traffic. We analyse the pricing and investment issue in an asymmetric information setting where the local governments have better information than the federal government. The case of air pollution and of congestion are discussed.

Keywords: road pricing, federalism, asymmetric information, implementation congestion pricing

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1 Introduction

A standard result of transport economic theory is that efficiency requires prices equal to the marginal social cost (the extra costs to society associated with an additional trip made). This result, however, is only valid in a first-best setting and amendments to this simple rule are necessary in the presence of additional constraints. This paper focusses on one particular second-best constraint that has not yet been studied in detail in the context of transportation, namely the presence of incentive and information problems regarding external costs when there is more than one policy maker.

We know that when different levels of governments have conflicting objectives, this leads to uncoordinated and inefficient pricing policies. These kind of conflicting objectives can occur in the EU between the Commission and the member states or within one country between the federal government and the regions. While the upper level (EU, or country) is concerned with the welfare of all the citizens and wants social marginal cost based pricing, a lower level government (a member state or region) may prefer much higher transport charges to extract revenue from transit (this has been empirically validated for state gasoline taxes in the USA by Levinson (2001)).

In a White Paper of the European Commission (CEC, (1998)), the EU indeed acknowledges that pricing of transport infrastructure should relate to the marginal social cost associated with the use of the infrastructure, but the current interpretation (for tolling roads) is to impose a toll cap related to the infrastructure costs and not to the external costs. One of the arguments why the EU can not impose first-best marginal social cost pricing is that it may lack the necessary information about the marginal social cost of the different member states or that it is too costly to check the validity of the information received from the member state. If this is the case, the member states with a high fraction of transit users can pretend to have much higher external costs than in reality or claim that their region is substantially more affected by the adverse impacts from transport than the average. They can argue that their ecosystem is very vulnerable (e.g. Alpine and Pyreneen regions or Omberg in Sweden (see Sessa et al. (2009))) or that their urban planning is such that more people are exposed to air or noise pollution than in other regions (e.g. Frankfurt airport in Germany and Copenhague in Denmark (see Sessa et al. (2009))). Switzerland, for example, claims that the damage imposed by road traffic in the Alpine region is on average a factor of 2 higher than for a flat 'normal' area (Maibach et al. (2008))). There is in general no consensus on the magnitude of external costs and large differences can be found in the literature. In this paper we do not focus on the uncertainty in the magnitude of the external costs due to difficulties of measurement or definition, we do argue that how uncertain these values may be, it is very likely that a local authority will be better placed to gather the necessary information to estimate the real external costs and so will at least have more accurate estimates than a federal authority. Alternatively, it can have the legal presumption to know better the local conditions. When a lower level government has a better knowledge on the distribution of some costs than the higher level government we have a problem of asymmetric information The natural uncertainty on the magnitudes of external costs makes it even easier for a local government to exploit the problem of asymmetric information.

In the first part of this paper we investigate whether a federal authority can still implement optimal pricing under such asymmetry of information Under asymmetric information the federal authority can ask the regions to report their marginal external costs and implements pricing accordingly. We analyze the problem in a very simple setting; one link crossing a single state that is used by local and transit traffic[1]. This problem is very close to papers that deal with regulating firms (i.e. monopolies) when the regulator lacks some crucial information. Indeed, production costs are not always known by the regulator (or it is too costly to acquire the information) but are known by the firm. As a result firms will set their prices at an inefficient level to earn profits. In the case of a monopoly several regulation schemes are possible (see Laffont and Martimort (2002) and references therein) to minimize the excessive pricing, one of them being the compensation schemes. In such schemes, monetary transfers are given to a firm which reports a low production cost in order to induce the firms to reveal their true costs. Since transfers are typically seen as a cost to society, there will be a trade off between information revelation and efficiency. The policy maker will be willing to deviate from the first-best outcome in order to reduce the information rent (i.e. the monetary transfer needed to gather the true information). In our paper we make the simplifying assumption that transfers are between governments and are, as such, not considered as a real cost, this means that the higher level government will impose the first-best outcome and there will be no trade-off between efficiency and information. On the other hand we are concerned with transportation where the main external cost is congestion. This externality differs in one important way from other externalities: the social marginal cost depends explicitly on the level of use or demand and inversely, the level of use depends on the externality. For other externalities such as pollution or noise the level of the externality does not influence the level of use and the marginal social cost is independent of the demand. The presence of a congestion externality will alter the results significantly.

Transfer or compensation schemes are only one of the instruments available to the federal authority to minimize the welfare losses due to inefficient pricing. The transfer schemes, if one exists, will, however, be able to reduce the welfare losses to zero. Other instruments, such as, toll caps will perform less well but have the advantage of being more easy to implement. In this paper two different toll caps will be considered: one where the toll cap equals the toll that maximizes the expected welfare and the one used by the EU where the toll cap is equal to the average infrastructure costs.

The paper is organized as follows. In the second section we analyze the first best solution that can be achieved by an omniscient federal government that has to deal with local air pollution or road congestion. In the third section we

[1] By restricting ourselves to one single country we neglect strategic interactions when transit uses networks of several regions as studied in De Borger et al. (2005) and De Borger et al. (2007).

introduce a local government that has different tolling preferences and focuses on air pollution externalities only. Here we find that a revelation mechanism exists that allows the federal government to make the local government implement the first best pricing solution by a well designed transfer scheme. In the fourth section we concentrate on the more difficult case of congestion externalities. We show that, if the transit traffic share is sufficiently large, the federal government is unable to set up a transfer scheme that leads to first best results. In section five we illustrate the orders of magnitude of the inefficiencies associated to the asymmetric information problem and of a toll cap equal to a toll that maximizes the expected welfare. In the sixth section we generalize the model by including road capacity decisions and examine the solution advocated by the EU for roads: constrain the local road tolls to be smaller or equal to the average infrastructure costs. The last section sums up our findings and adds some caveats.

2 First-best pricing

As a benchmark case we analyze the setting where only local traffic is present. When only local traffic is present and neglecting political economy issues, both federal and local government will have the same objective and we get the standard first-best results. We discuss first the case of air pollution and then congestion.

2.1 Air pollution

We use a partial equilibrium model to analyze pricing decisions of a single (isolated) link crossing a country (or region). In this section there is only one kind of user, namely local users. The usage is denoted by X^L. In order to get explicit analytical results, we assume that the usage is determined by a linear downsloping inverse demand function $P_L\left(X^L\right)$

$$P_L\left(X^L\right) = a_L - b_L X^L, \quad a_L > 0, b_L > 0. \tag{1}$$

The objective function of both governments (local and federal) is the sum of the surplus of the users (first two terms in eq(2)), plus the toll revenues minus the external costs.

$$W = \int_0^{X^L} P_L\left(x\right) dx - \tau X^L + \tau X^L - e X^L \tag{2}$$

where τ is the toll levied on transportation, e the constant marginal external cost of one unit of X^L. Important in our analysis is that the marginal external cost is constant, does not affect the level of usage and has a purely local impact. Local air pollution damage could be an example, accident externalities imposed by cars on cyclists and pedestrians could be another.

In equilibrium, demand will be equal to the user cost. As we neglect here the other private resource costs, the user cost consists of the toll only. The equilibrium volume is then given by $X^L(\tau) = \frac{a_L - \tau}{b_L}$. An increase (or decrease) in the toll will reduce (or increase) the traffic volume:

$$\frac{\partial X^L}{\partial \tau} = -\frac{1}{b_L} < 0. \tag{3}$$

Both local and federal government will choose τ such as to maximize the social welfare function given in eq(2). The first order condition with respect to τ is[2]:

$$\frac{\partial W}{\partial \tau} = P\left(X^L\right)\frac{\partial X^L}{\partial \tau} - \tau\frac{\partial X^L}{\partial \tau} + (\tau - e)\frac{\partial X^L}{\partial \tau} = 0.$$

Using eq(1) and eq(3), the optimal toll is equal to the marginal environmental damage:

$$\tau^* = e.$$

As the marginal air pollution damage is constant, the Pigouvian tax solution is very simple.

2.2 Congestion

In the case of congestion, the marginal external cost depends on the usage level of the infrastructure. The user cost now equals the toll plus the time cost, where the time cost is an increasing function of the usage. The time cost and the discomfort of travel will in principle increase when a higher volume is loaded on the same infrastructure: average speed will decrease, in the train, passengers won't have a seat etc.. We assume that the user cost function is linear in the volume of transport[3]:

$$C\left(X^L\right) = \alpha + \beta X^L + \tau, \quad \alpha > 0, \beta > 0. \tag{4}$$

The objective function for both local and federal government is the sum of the surplus of the users minus the user cost (first two terms in eq(4)), plus the tax revenues (now the external costs are incorporated in the user cost function):

$$W = \int_0^{X^L} P_L(x)\,dx - C\left(X^L\right)X^L + \tau X^L. \tag{5}$$

In equilibrium, demand will equal the user cost ($P_L\left(X^L\right) = C\left(X^L\right)$), and the equilibrium volume is:

$$X^L = \frac{a_L - \alpha - \tau}{\beta + b_L}. \tag{6}$$

Contrarily to the case of air pollution, the level of congestion will now affect the level of usage (feedback effect). If the infrastructure is more easily congestible,

[2] The linear demand function ensure us that the second order conditions for a maximum are fulfilled and will not mention them in the rest of the chapter unless needed.

[3] The linear user cost function could be seen as the reduced form cost function of a simple bottleneck model with homogeneous users Arnott et al. (1993).

say the capacity of the infrastructure is smaller, β increases and the usage decreases:

$$\frac{\partial X^L}{\partial \beta} = -\frac{X^L}{\beta + b_L} < 0. \tag{7}$$

Again the governments will maximize the social welfare (now given by eq(5)) with respect to the toll. The first order condition is:

$$\frac{\partial W}{\partial \tau} = P\left(X^L\right)\frac{\partial X^L}{\partial \tau} - \frac{\partial C\left(X^L\right)}{\partial \tau}X^L - C\left(x^L\right)\frac{\partial X^L}{\partial \tau} + X^L + \tau\frac{\partial X^L}{\partial \tau} = 0,$$

and the optimal toll is (using eq(4), eq(7) and $P\left(X^L\right) = C\left(X\right)$);

$$\tau^* = \beta X^L. \tag{8}$$

As expected, the more congestible the infrastructure (the higher β), the higher the marginal external cost and the higher the optimal toll:

$$\frac{\partial \tau^*}{\partial \beta} = \frac{b_L\left(a_L - \alpha\right)}{\left(2\beta + b_L\right)^2} > 0.$$

3 Enforcing marginal social cost pricing when air pollution is the only externality

Introducing transit traffic will create a divergence between local and federal government objectives. Transit traffic is traffic by residents of another locality belonging to the federation. In order to concentrate on the asymmetric information issue we neglect the strategic interactions when transit traffic uses networks of several regions as studied in De Borger et al. (2005) and De Borger et al. (2007). The local government maximizes the surplus of the local users plus the revenue it can extract from transit. The federal government is interested in maximizing welfare of all users and wants therefore to control the tolling practices of the local government. To emphasize the difference in local decision making when transit traffic is present or not we ,first analyze the case where there is only transit traffic and generalize later to the case of transit and local traffic. As the type of external cost is crucial for the enforcement of first best pricing, we first focus on air pollution.

3.1 The case of only transit traffic

The local government collects the tolls paid by the transit users and is not interested in their welfare. Its objective function is therefore equal to the total toll revenue minus the (local) external cost caused by the traffic:

$$\Pi = \left(\tau - e\right)X^T, \tag{9}$$

where τ is the toll, e the constant marginal external cost and X^T the transit volume. The demand function for transit is assumed similar to that of local traffic used in the previous section:

$$P_T\left(X^T\right) = a_T - b_T X^T,\ a_T, b_T > 0. \tag{10}$$

The federal government, on the other hand, is concerned by the welfare of all citizens, including the transit users and will maximize an objective function similar to eq(2) where X^L is now replaced by X^T. The optimal toll from a federal point of view will therefore be again equal to the Pigouvian tax, namely

$$\tau^* = e.$$

3.1.1 The toll preferred by the local government

The local authority will charge a toll τ^N to the users of the facility that maximizes its welfare given in eq(9). This toll will solve the first order condition for τ which is

$$X^T + (\tau - e)\frac{\partial X^T}{\partial \tau} = 0,$$

implying

$$\tau^N = e + b_T X^T = \frac{e + a_T}{2}.$$

The toll increases with the marginal environmental damage. In fact the marginal environmental damage can be considered as a marginal cost for the local government. The toll charged by the local government τ^N exceeds the social marginal cost because the local government is able to raise revenues by charging transit users,

$$\tau^N > e = \tau^*.$$

Note that we need $a_T > e$ to ensure $X^T > 0$; the maximum willingness to pay for usage of the infrastructure must be at least the damage caused by usage. When the local government is free to set the toll equal to τ^N, its welfare is

$$\Pi = \frac{\left(a_T - e\right)^2}{4b_T} > 0,$$

deriving this expression with respect to the damage cost gives us

$$\frac{\partial \Pi}{\partial e} = -\frac{\left(a_T - e\right)}{2b_T},$$

which is negative since $a_T > e$: the higher the damage cost, the lower the local welfare. When $e = a_T$, then the local welfare is zero.

3.1.2 Federal toll regulation with asymmetric information

We now suppose that the marginal environmental damage e is unknown to the federal authority: it only knows that the region has either a low marginal environmental damage $\left(e = e^L\right)$ or a high one $\left(e = e^H > e^L\right)$. This uncertainty is not unrealistic. Some regions pretend their ecosystem is very vulnerable or that their urban planning is such that more people are exposed to air pollution than in other regions.

The game is the following: in the first stage, the regional government reports its marginal environmental cost $\tilde{e}^i \in \left\{e^L, e^H\right\}$ to the federal government. In the second stage, the federal government imposes a toll contingent on this report. To ensure truthful reporting we assume that the federal government can make a financial transfer to the regions. These financial transfers $M\left(\tilde{e}^i\right)$ will be such that a region always has the incentive to report its true marginal damage, i.e. the incentive constraints are satisfied. Note that this problem is similar to the problem of regulating a monopoly with unknown costs (see Baron and Myerson (1982)) but since we assume that the monetary transfers do not represent a real cost to society there will be no trade off between efficiency and paying "information rents". Whereas in the classic principal-agent problem the principal will be willing to deviate from the efficient outcome in order to pay less rent, here the principle (in casu the federal government) will always implement the first best tolls. Our aim is to check whether it is possible for the federal government to implement first-best tolls while ensuring truthful reporting.

The lower level government, knowing that it will have to charge a toll equal to its reported marginal damage, will choose to report a marginal damage $\tilde{e}^i$ such as to maximize following function:

$$\max_{\tilde{e}^j} \Pi\left(\tilde{e}^j, e^i\right) = \left[\tilde{e}^j - e^i\right] X^T\left(\tau = \tilde{e}^j\right) + M\left(\tilde{e}^j\right), \quad i, j = \{L, H\},$$

$\Pi\left(\tilde{e}^j, e^i\right)$ being the local welfare for a region with marginal damage e^i, reporting a marginal damage equal to $\tilde{e}^j$ and thus charging a toll equal to $\tilde{e}^j$.The transfer scheme $M\left(\tilde{e}^i\right)$ is such that it is beneficial for a region to report its true marginal damage. Since it is the difference between transfers that will be important we can set $M\left(\tilde{e}^H\right) = 0$ and $M\left(\tilde{e}^L\right) = M$ (M can in principle be negative) and the incentive compatibility constraints can be written as:

$$\Pi\left(\tilde{e}^H, e^H\right) \geq \Pi\left(\tilde{e}^L, e^H\right) + M, \tag{11}$$

$$\Pi\left(\tilde{e}^L, e^L\right) + M \geq \Pi\left(\tilde{e}^H, e^L\right). \tag{12}$$

These are the incentive compatibility (IC) constraints. The first constraint ensures that a region whose true marginal damage is high will prefer to report a high marginal damage $\tilde{e}^H$ and receive no financial transfer rather than to lie and report a low marginal damage and receive M. The second constraint ensures in the same way that a region with a low marginal damage will have no incentive to misreport its marginal damage.

Let us first look at the behavior of the local authority when there are no transfers. A region with low marginal damage will have an incentive to misreport its damage because it can increase its welfare by pretending to have a high marginal damage $\left(\Pi\left(\tilde{e}^H, e^L\right) > \Pi\left(\tilde{e}^L, e^L\right)\right)$. A region with high marginal damage, will, on the other hand, have an incentive to tell the truth since $\Pi\left(\tilde{e}^H, e^H\right) > \Pi\left(\tilde{e}^L, e^H\right)$. This is easily seen in 1.where $\Pi^I\left(\tau\right), I = L, H$ stands for the local welfare of a region with low/high marginal cost.

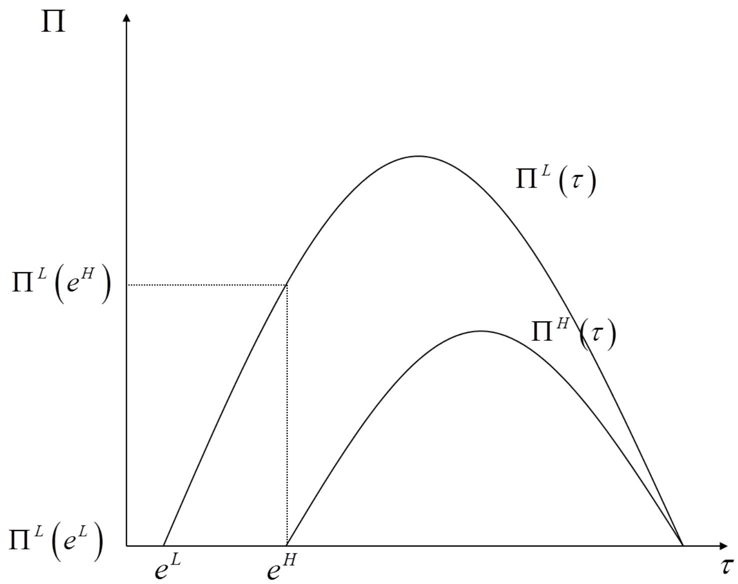

Figure 1: Local welfare functions with air pollution and only transit traffic.

In order for a region with a low marginal damage to tell the truth, it must be compensated with a financial transfer. The lowest transfer needed to induce truthtelling from such a region will be $M = \Pi\left(\tilde{e}^H, e^L\right) - \Pi\left(\tilde{e}^L, e^L\right)$. It remains to check wether the IC of the high marginal damage region (11) is satisfied. Using $\Pi\left(\tilde{e}^H, e^H\right) = \Pi\left(\tilde{e}^L, e^L\right) = 0$, (11) reduces to

$$\left(e^L - e^H\right)\left(e^H - e^L\right) < 0.$$

This is always true since $e^H > e^L$, which leads to the first proposition:

Proposition 1 *When there is only transit traffic and when the environmental damage is unknown to the federal government, the federal government can still implement the first-best tolls. For a region with low environmental damage* e^L *to report truthfully, it will, however, need a financial compensation equal to* $M = \left(e^H - e^L\right)X^T\left(e^H\right)$.

When the difference between the two marginal damages is large, the greater is the gain for a low damage region to pretend to have a high marginal damage and the larger the compensation for truthtelling needs to be.

If a transfer is not possible, the federal government could impose a cap on the toll. The most obvious cap is a cap that equals the toll that maximizes the expected federal welfare:

$$EW = \mathcal{P}W\left(\tau, e^{L}\right) + (1-\mathcal{P})\, W\left(\tau, e^{H}\right).$$

where p is the probability of a low mecc. The cap will then be equal to the expected environmental damage:

$$\tau^{*E} = \mathcal{P}e^{L} + (1-\mathcal{P})\, e^{H}$$

If this toll cap is set, a region with high mecc will always select a toll equal to the cap since $\tau^{*E} < \tau^{*H} < \tau^{NH}$ but note that in this case a region with high environmental cost will end up with a negative welfare and may prefer an extreme solution like closing down the road.

3.2 The case with transit and local traffic

When there is both local and transit traffic, the local government will only be concerned about the welfare of the local users and the revenues generated by the transit users. Its objective function is the sum of the surplus of the local users (two first terms), the total toll revenues and the total external costs:

$$\Pi = \int_0^{X^L} P^L(x)\, dx - \tau X^L + (\tau - e)\, X, \tag{13}$$

where $X = X^T + X^L$, the total amount of users. The federal government, on the other hand, takes into account the welfare of both local and transit users:

$$W = \int_0^{X^L} P^L(x)\, dx + \int_0^{X^T} P^T(x)\, dx - \tau X + (\tau - e)\, X.$$

The federal first-best toll is again $\tau^* = e$.

3.2.1 The toll preferred by the local government

Solving the first order condition of (13) with respect to τ yields the preferred toll τ^N, which is of the form

$$\tau^N = e - \frac{X^T}{\frac{\partial X}{\partial \tau}}.$$

Substituting $\frac{\partial X}{\partial \tau}$ in the expression for τ^N we get a toll level that is excessive:

$$\tau^N = e + \frac{b_L b_T}{b_L + b_T} X^T > \tau^*. \tag{14}$$

Moreover, the more transit users there are, the higher the locally preferred toll will be. Note that the presence of local users will partly protect the transit users of being excessively tolled since $b_T > \frac{b_L b_T}{b_L + b_T}$ and the toll levied when no local users are present will be even higher.

3.2.2 Federal toll regulation with asymmetric information

As in the case when there was only transit traffic, we now assume that the environmental damage is only known to the local government. Again the local government reports a marginal damage costs $\tilde{e}^i \in \left\{e^L, e^H\right\}$. Doing so it will have to implement a toll equal to $\tilde{e}^i$ and receive a financial transfer $M\left(\tilde{e}^i\right)$ which is zero for $\tilde{e}^i = e^H$ and equal to M when $\tilde{e}^i = e^L$. We saw that a region with high environmental damage will charge a toll that is higher than the corresponding marginal damage, which on its turn is larger than the first-best toll for low environmental damage:

$$\tau^{NH} > \tau^{*H} > \tau^{*L},$$

where $\tau^{*i} \equiv \tau^*\left(e^i\right), i = L, H$ and $\tau^{Ni} \equiv \tau^N\left(e^i\right), i = L, H.$ The local objective function is a parabolic function of the toll with a maximum for $\tau^{NH} = \tau^N\left(e^H\right)$, which implies that for a region with a high environmental damage there will be no incentive to lie since

$$\Pi\left(\tilde{e}^H, e^H\right) > \Pi\left(\tilde{e}^L, e^H\right).$$

Graphically, we have the following situation

The incentive compatibility constraint for a low damage region is

$$\Pi\left(\tilde{e}^H, e^L\right) = \Pi\left(\tilde{e}^L, e^L\right) + M.$$

In 2 we see that whether region with low damage will have an incentive to lie when no transfers are available depends on the relative position of the first-best toll in case of high damage $\left(\tau^{*H}\right)$ and the locally preferred toll for low damage $\left(\tau^{NL}\right)$. We can show that when the locally preferred toll satisfies following inequality

$$\tau^{NL} < e^L + \frac{e^H - e^L}{2},$$

then a low damage region will never have an incentive to lie about its marginal damage cost and the federal government can implement first best tolls without having to make any transfers, i.e. $M = 0$. Since the deviation of the locally preferred toll from the first-best toll depends on the volume of transit (see eq(14)), this inequality tells us that if transit traffic is not very important, then a low damage region will never have an incentive to lie about its marginal damage cost. If transit traffic is important enough, however, a region with low damage costs will have to be compensated in order to report truthfully, the transfer will be equal to $M = \Pi\left(\tilde{e}^H, e^L\right) - \Pi\left(\tilde{e}^L, e^L\right)$. This transfer could in principle induce a high damage region to mimic a low damage region in order

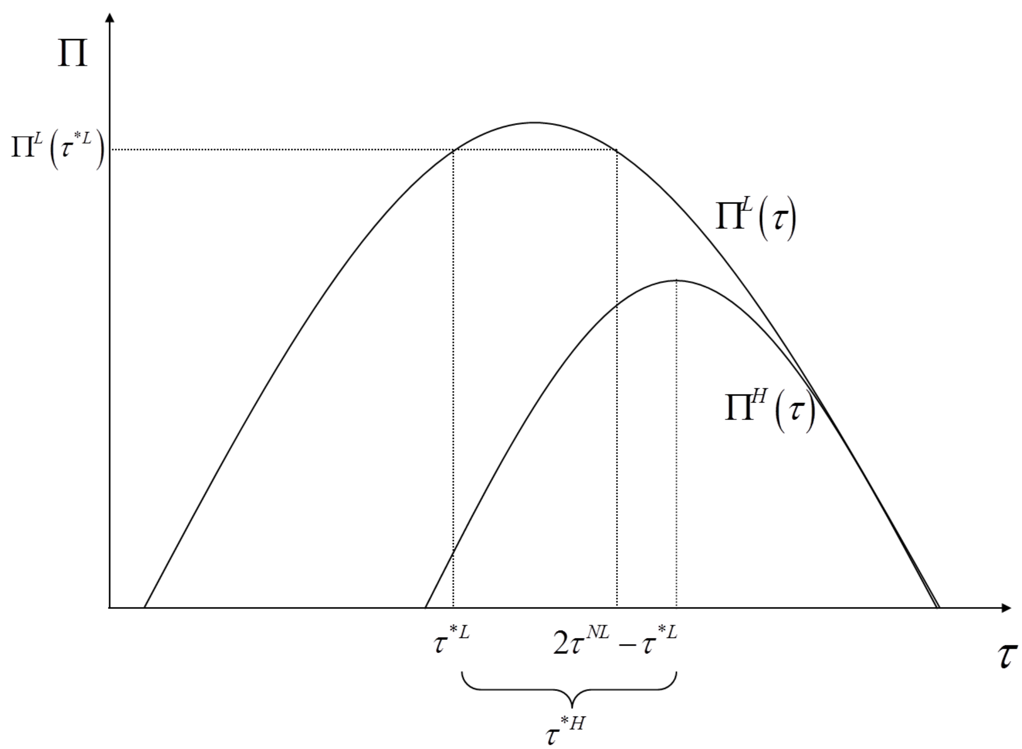

Figure 2: Local air pollution case: Local welfare with both local as transit users.

to receive the transfers. It is, however, easy to check that the IC constraints for a high damage region given by:

$$\Pi\left(\tilde{e}^H, e^H\right) > \Pi\left(\tilde{e}^L, e^H\right) + M,$$

are equivalent with

$$X\left(e^H\right) > X\left(e^L\right)$$

which is always the case since by assumption $e^H > e^L$.

Proposition 2 *When there is both local and transit traffic and the marginal environmental damage is unknown to the federal government, a truthful mechanism exists in which each region sets its toll equal to its marginal environmental damage.*

If

$$X^T\left(\tau^N, e^L\right) < \frac{\left(e^H - e^L\right)\left(b_L + b_T\right)}{2 b_L b_T},$$

no compensation is needed i.e. $M = 0$*,*

if this condition is not satisfied, then a financial compensation is needed in order to induce a "low cost" region to report its cost truthfully. This compensation must be equal to

$$M = \left[2 b_L\left(a_T - e^H\right) - b_T\left(e^H - e^L\right)\right] \frac{\left(e^H - e^L\right)}{2 b_L b_T}.$$

The larger the uncertainty on the marginal damage cost, the larger the difference between the two first-best tolls. For a low damage region to be willing to pretend to have a high marginal cost (and thus constraint to charge the τ^{*H}, the first-best toll given that the region has a high damage cost) it will need a lot of extra revenues from transit to compensate the loss of local consumer surplus loss. This will only be the case if there is a large fraction of transit. Conversely, the less transit there is, the less likely that any monetary compensation will be needed to induce truthful reporting.

As was the case where there was only transit, the toll that maximizes expected welfare from the federal point of view when no compensation can be paid is the expected environmental damage.

4 Enforcing marginal social cost pricing when congestion is the only externality

4.1 The case of only transit traffic

In the following sections we assume that congestion is the only externality present. A distinctive feature of congestion is that it, contrarily to externalities discussed in the previous sections, it affects the users of the infrastructure and will influence the demand levels. The local government is not interested in the welfare of the transit users, it will only be interested in the congestion costs of transit users in as far as they affect transit demand and the toll revenues. When only transit users are present the objective function of the local government is therefore very simple: it is equal to the total toll revenue

$$\Pi = \tau X^T, \tag{15}$$

where τ is the toll and X^T the transit volume. The federal first-best toll is $\tau^* = \beta X^T$ (see eq(8)).

4.1.1 The toll preferred by the local government

Solving the first order condition of eq(15) yields

$$\tau^N = \frac{a_T - \alpha}{2}, \tag{16}$$

the toll is independent of the congestion level. The local welfare will however depend on the level of congestion;

$$\Pi\left(\tau^N\right) = \frac{\left(a_T - \alpha\right)^2}{4\left(\beta + b_T\right)},$$

and the more congestible the infrastructure (the higher β), the lower the local welfare:

$$\frac{\partial \Pi}{\partial \beta} = \frac{-\left(a_T - \alpha\right)^2}{4\left(\beta + b_T\right)^2} < 0. \tag{17}$$

4.1.2 Federal toll regulation with asymmetric information

In this section we suppose that the federal government is not well informed about the marginal external costs of congestion. Again this is not an unrealistic assumption. The marginal external cost depends on values of time (so on composition of traffic). It also consists of schedule delay costs (see Arnott et al. [1]) so that observations on the length of queues etc. are insufficient information. The lack of information concerns the slope of the average user cost function, or more precisely, the parameter β. We assume that the federal government only knows that the slope of the user cost function can be either $\beta = \beta^L$ or $\beta = \beta^H$, where $\beta^H > \beta^L$. The larger the parameter β, the more easily congestible is the infrastructure and so we will refer to a region with $\beta = \beta^L$ as a region with "low marginal external congestion cost (mecc)" and to a region with $\beta = \beta^H$ as a region with "high mecc". As was the case in section 3.3.1 we will check whether with the help of financial transfers, it is possible to implement the first-best outcome.

The problem for the local government is to choose its reported mecc $\tilde{\beta}^i \in \left\{\beta^L, \beta^H\right\}$ such that it maximizes its welfare taking into account that it will be forced to charge the first best toll corresponding to the reported mecc $\left(\tau\left(\tilde{\beta}^j\right)\right)$:

$$\Pi\left(\tilde{\beta}^j, \beta^i\right) = \tau\left(\tilde{\beta}^j\right) X^T\left(\tau\left(\tilde{\beta}^j\right), \beta^i\right) + M\left(\tilde{\beta}^j\right),$$

where $\tau\left(\tilde{\beta}^j\right) = \tilde{\beta}^j X^T\left(\tau\left(\tilde{\beta}^j\right), \tilde{\beta}^j\right)$, the first-best toll given that the mecc is equal to the $\tilde{\beta}^j$. Again we can assume $M\left(\tilde{\beta}^H\right) = 0$ and $M\left(\tilde{\beta}^L\right) = M$, where M has to satisfy the incentive constraints:

$$\begin{aligned} \Pi\left(\tilde{\beta}^H, \beta^H\right) &\geq \Pi\left(\tilde{\beta}^L, \beta^H\right) + M \\ \Pi\left(\tilde{\beta}^L, \beta^L\right) + M &\geq \Pi\left(\tilde{\beta}^H, \beta^L\right). \end{aligned}$$

When no transfers are available, we can see in Figure 3 that a country with a low mecc will have an incentive to misreport its mecc. On the other hand, if a country has high mecc, it has an incentive to tell the truth and thus $M = \Pi\left(\tilde{\beta}^H, \beta^L\right) - \Pi\left(\tilde{\beta}^L, \beta^L\right) > 0$. A country with low mecc will need to be compensated to be truthful and the IC constraints reduce to

$$\Pi\left(\tilde{\beta}^H, \beta^H\right) - \Pi\left(\tilde{\beta}^L, \beta^H\right) > M.$$

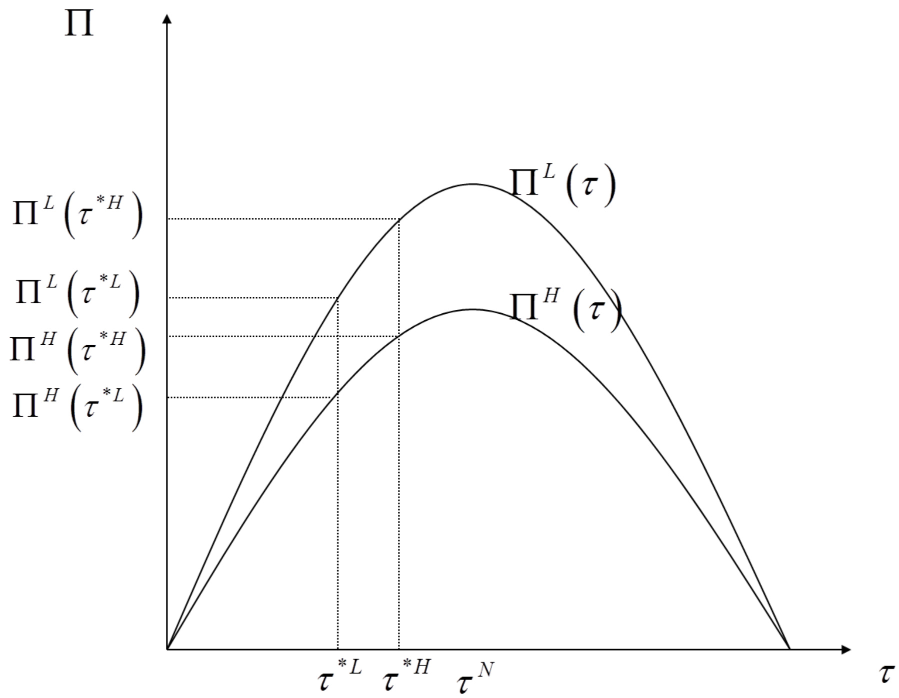

Figure 3: Local welfares for different road congestibility and tolls.

In Figure 3 we see that for an identical toll, the toll revenues of a region with low mecc will be higher than for a region that has a more easily congestible infrastructure since there will be more traffic using its infrastructure: $\Pi\left(\tau, \beta^L\right) \geq$

$\Pi\left(\tau,\beta^{H}\right)$ for all τ. Both welfare functions will be equal to zero when τ is 0 or equals α. These two properties imply that $\left|\frac{\partial^2\Pi\left(\tau,\beta^{H}\right)}{\partial\tau^2}\right| < \left|\frac{\partial^2\Pi\left(\tau,\beta^{L}\right)}{\partial\tau^2}\right|$, which on its turn implies that for every $M > 0$ and for every $0 \leq \tau_1 < \tau_2 \leq \alpha$:

$$\Pi\left(\tau_1,\beta^{L}\right) + M \geq \Pi\left(\tau_2,\beta^{L}\right) \Rightarrow \Pi\left(\tau_1,\beta^{H}\right) + M \geq \Pi\left(\tau_2,\beta^{H}\right),$$

where the equality on the right-hand side only holds when the left-hand side holds for equality. This property holds for every τ_1 and τ_2 and thus also for the special case where $\tau_1 = \tilde{\beta}^{L}$ and $\tau_2 = \tilde{\beta}^{H}$ and we see that there is a conflict with the IC constraints. This means that the federal government will not be able to find a transfer scheme that induces a region to declare its true mecc and implement the corresponding first-best toll, even if it has access to financial transfers. In fact the result holds for any pair of tolls and financial transfers M, and the federal government will never be able to induce a truthful report of the mecc. Note that the major difference with the air pollution type of externalities is that there the second derivative of the local welfare is constant. This difference reflects the fact that congestion has an influence on the demand levels, while air pollution does not.

Proposition 3 *When there is only transit traffic and the marginal external cost of congestion (mecc) is unknown to the federal government, no truthful mechanism exists that allows the federal government to implement marginal social cost pricing.*

In this case, when the federal government does not know whether the region has a low or high cost, it will not be able to impose first best tolling. One possibility is that it imposes a toll cap equal to the toll that would maximize the expected welfare. As long as this toll is inferior to the locally preferred toll, each region will choose to implement the cap.
The expected welfare is

$$EW = \mathcal{P}W\left(\tau,\beta^{L}\right) + (1-\mathcal{P})\,W\left(\tau,\beta^{H}\right).$$

The toll which maximizes the expected federal welfare is,

$$\tau^{*E} = \frac{1}{\mathcal{M}}\left[\mathcal{P}\tau^{*L}\frac{\partial X^{T}\left(\tau,\beta^{L}\right)}{\partial\tau} + (1-\mathcal{P})\,\tau^{*H}\frac{\partial X^{T}\left(\tau,\beta^{H}\right)}{\partial\tau}\right]. \qquad (18)$$

where $\mathcal{M} = \mathcal{P}\partial_\tau X^{T}\left(\tau,\beta^{L}\right) + (1-\mathcal{P})\,\partial_\tau X^{T}\left(\tau,\beta^{H}\right)$.It is easy to see that

$$\tau^{*E} < \tau^{*H}.$$

Since $\tau^{*H} < \tau^{N}$ independently of the mecc of the region, when this toll cap is imposed the local government will charge a toll equal to τ^{*E}.

4.2 The case with transit and local traffic

When there are also local users, the welfare function of the local government will be the sum of the user surplus of the local users (first two terms) plus the total toll revenues:

$$\Pi = \int_0^{X^L} P^L(x)\,dx - C(X)\,X^L + \tau X. \tag{19}$$

In contrast, the federal government will also take into account the user surplus of the transit users:

$$W = \int_0^{X^L} P^L(x)\,dx + \int_0^{X^T} P^T(x)\,dx - C(X)\,X + \tau X.$$

Equating the demand functions for transit and local users (equations eq(10) and eq(1) respectively) to the linear user cost function similar to eq(4), yields us the transit and local volumes in function of the mecc and the toll. Deriving the resulting expressions for the volumes with respect to the toll yields:

$$\frac{\partial X^L}{\partial \tau} = \frac{-b_T}{B} < 0, \qquad \text{and} \qquad \frac{\partial X^T}{\partial \tau} = \frac{-b_L}{B} < 0$$

where $B \equiv \beta(b_L + b_T) + b_L b_T$. As expected, both user volumes decrease when the toll increases.

4.2.1 The toll preferred by the local government

We obtain an expression for the locally preferred toll by solving the f.o.c. with respect to τ of eq(19):

$$\tau^N = \beta X^L - \frac{X^T}{\frac{\partial X}{\partial \tau}}.$$

Since $\frac{\partial X}{\partial \tau} < 0$,

$$\tau^N > \text{lmecc}$$

The toll exceeds the local marginal external cost, defined as the marginal external cost imposed on the locals, and the more transit there is, the larger will be the difference between the locally preferred toll and the federal optimal toll (see De Borger et al. [**?**])
Substituting $\frac{\partial X}{\partial \tau}$ in the expression of τ^N we get

$$\tau^N = \beta X(\tau,\beta) + \frac{b_T b_L}{b_T + b_L} X^T(\tau,\beta) \tag{20}$$

and so

$$\tau^N > \beta X(\tau,\beta) = \text{mecc}. \tag{21}$$

The toll charged by the local government exceeds the social marginal cost[4]. Deriving eq(20) with respect to β yields:

$$\frac{\partial \tau^N}{\partial \beta} = \frac{b_T}{(b_T + 2b_L)} X > 0.$$

For higher mecc (higher β) the local authority will charge a higher toll and so $\tau^N\left(\beta^H\right) > \tau^N\left(\beta^L\right)$ as expected.

4.2.2 Federal toll regulation with asymmetric information

Take now the case where the exact value of β $\left(\beta^L \text{ or } \beta^H\right)$ is unknown by the federal government.

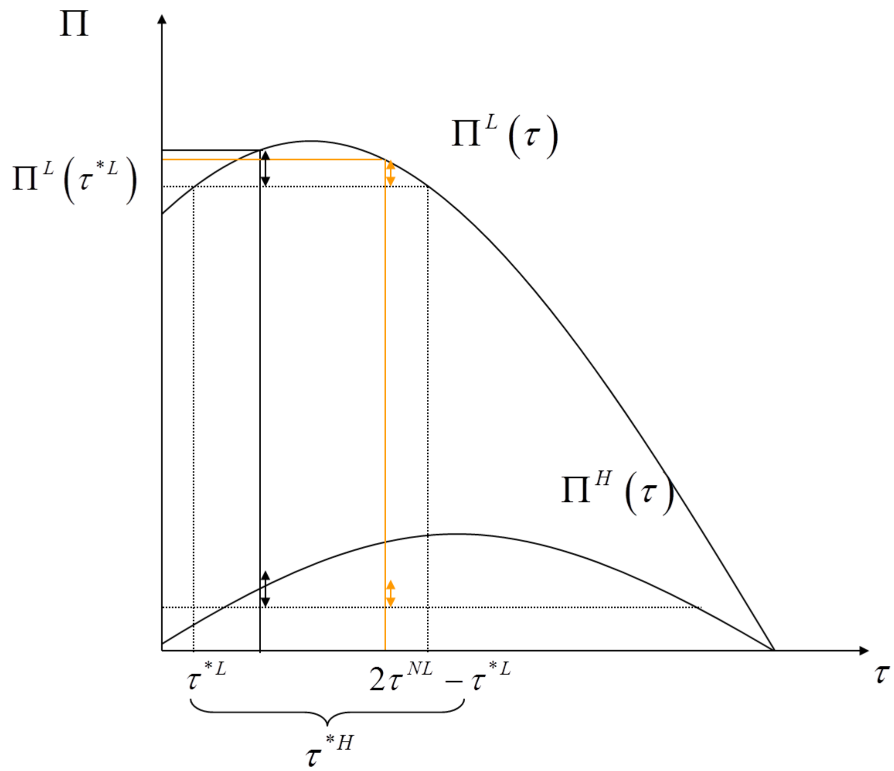

Figure 4: Local welfares for different congestion functions when there is local and transit traffic.

[4]Note that the volumes are, however, the volumes for $\tau = \tau^N$ and not the first-best volumes. It can be shown that the first-best toll is lower than the locally preferred toll whenever $\beta(b_T + b_L) + b_T b_L > 0$, which is always the case.

We see in Figure 4 that, as usual, a region with high mecc never has an incentive to lie since $\Pi\left(\tilde{\beta}^L, \beta^H\right) < \Pi\left(\tilde{\beta}^H, \beta^H\right)$, but a country with low mecc will in some cases have an incentive to lie when no transfers exists. Similarly to the case of air pollution type of externalities, when

$$\tau^{*H} > 2\tau^{NL} - \tau^{*L},$$

a low mecc region has no incentive to lie. This last condition can be rewritten:

$$X^T\left(\tau^{NL}, \beta^L\right) < \frac{A\left(\beta^H - \beta^L\right)(b_T + b_L)}{2\left(2\beta^H(b_T + b_L) + b_L b_T\right)(b_L b_T)}, \tag{22}$$

where $A \equiv a_T b_L + a_L b_T - (b_T + b_L)\,\alpha$ (for the derivation see Appendix). When there is an incentive for a low mecc region to mimic a region with high mecc, we will again have cases where the monetary transfers needed to induce truthtelling will be such that the IC for a high mecc region will be violated. This will happen when the share of transit is relatively high (in the next section we will show that for some parameters this will already be the case when half of the traffic is transit.). In other words; only when the transit share is small enough, the regions will declare their true mecc. If the transit share is larger, a region with low mecc will have an incentive to overstate its mecc.and compensation will be needed. When the share of transit is large, this compensation will induce a high mecc region to declare it has low mecc and it is impossible to implement the first-best outcome.

Proposition 4 *When there is both local and transit traffic and the marginal external congestion cost is unknown to the federal government, there are three cases*

1. *conditions (22) is satisfied: the federal government can set the toll equal to the mecc corresponding to the declared β*

2. *condition (22) is not satisfied but the share of transit is relatively low: the federal government can set toll equal to the mecc corresponding to the declared β but needs to make a financial transfer if a region declares it has a low mecc*

3. *condition (22) is not satisfied and the share of transit is relatively high: no mechanism exists where the federal government can induce a region to report its mecc truthfully and impose the corresponding first-best toll.*

5 Numerical Example

This section illustrates the results using a numerical example. In this example we put the maximum willingness to pay for any type of traffic equal to 5 $(a_L = a_T = 5)$. The demand functions are calibrated such that the total volume of traffic is equal to unity when the generalized price (without congestion) is equal to unity. The relative share of local and transit demand translates into different slopes of the aggregate local and transit demand functions: $b_L = \phi b_T$. For $\phi < 1$ the share of transit will be inferior to that of local traffic, for $\phi > 1$ the opposite is true. The values and probabilities[5] for the marginal external costs are:

	e_L	e_H	β_L	β_H
value	1	3.5	0.5	3
probability	0.8	0.2	0.8	0.2

Table 1: Marginal external costs and the probabilities

We will consider four scenarios: (i) no regulation is in place and the local government can freely choose their tolls, (ii) the federal government imposes first best tolls but relies on the reports of the local governments since it does not have the necessary information, (iii) the federal government has perfect knowledge of the value of the mecc and imposes the first best tolls and (iv) the federal government imposes a toll cap equal to the toll that maximizes the expected federal welfare. We will call the first scenario the "laissez fair" (LF) scenario, the second the "asymmetric information" (AI) scenario, the third one the "first best" (FB) scenario and the last one the "toll cap" (TC) scenario. We compute the expected welfares losses for the various scenarios. The value of information can be defined as the difference between expected welfare in the FB scenario and the expected welfare in the AI scenario.

5.1 Air pollution externality

In Table 2 we present the welfares for the federal and the local governments for different combinations of their true mecc and tolls (τ^{*H} is the first best toll when the mecc is high, τ^{*L} is the first best toll when the mecc is low and τ^N is the toll preferred by the local government). The relative amount of transit traffic will determine whether a low region will want to misreport its mecc or not. We will therefore consider three different values for the ultimate share of transit traffic, ϕ, in the first case 40% of the traffic is transit, in the second case 80% will be transit and finally in the last case all traffic is transit.

We see that a region with high mecc will never have an incentive to lie: if it does its welfare will be negative (the local welfare for $\left(e^H, \tau^{*L}\right)$ is in all three cases negative). The local welfares for a region with a low mecc when it is forced to implement the right first best toll (i.e. τ^{*L}) will exceed the local welfare given that the toll is the "wrong" first best toll (i.e. τ^{*H}) only when the share of transit is low (40%). In the other cases, a low mecc region will report a high mecc.

[5] We could take the case where the low or high outcome are equally probable but since the informational problem occurs when there is a chance of a low cost region to pretend to be high cost we assume that there is a higher chance for the region to have a real low mecc.

	40% transit		80% transit		100% transit	
	Welfares		Welfares		Welfares	
(mecc,toll)	Fed	Local	Fed	Local	Fed	Local
(e^H, τ^{*H})	0.28	0.17	0.28	0.06	0.28	0
(e^H, τ^{*L})	-0.50	-1.32	-0.5	-2.10	-0.5	-2.5
(e^H, τ^N)	0.26	0.20	0.23	0.16	0.21	0.14
(e^L, τ^{*L})	2	1.18	2	0.4	2	0
(e^L, τ^{*H})	1.22	1.10	1.22	0.99	1.22	0.94
(e^L, τ^N)	1.83	1.42	1.6	1.11	1.5	1

Table 2: Welfare when local air pollution is the only externality.

In Table 3 we report the monetary transfer needed to induce truthtelling, the value of information and the welfare losses of the different scenarios compared to the first best welfare.

share of transit	40%	80%	100%
transfer (M)	0	0.59	0.94
Value of Information	0	0.625	0.625
Welfare loss from asymmetric information	0%	38%	38%
Welfare loss from Laissez Faire	8.5%	20%	25%
Welfare loss from toll cap	7.5%	7.5%	7.5%

Table 3: Results for numerical example for air pollution and both local and transit traffic

We see that, when transfers are needed, the value of information is high, nearly 40% of the expected welfare. This reflects the large difference in the first best toll levels. In these cases it can be worthwhile to invest in better information. We can also see, however, that if the federal government would impose a cap equal to the expected mecc instead of trying to impose first best tolling relying on the information given by the local government, the welfare loss would be much lower, namely 7.5%, we see that, in this case even no regulation would perform better.

5.2 Congestion externality

Again the results will depend on the share of transit. We will consider four cases: in the first case the share of transit is approximately 13%, in the two next cases the total traffic will consists of 33% respectively 52% of transit. In the last columns we report the results for the case where traffic consists only of transit traffic.

In the first case where 13% of the traffic is transit no region has an incentive to lie. In the other cases the low region will want to pretend having a high mecc. The transfers needed to induce truthtelling, the value of info and welfare losses

	13% transit		33% transit		52% transit		100% transit	
	Welfares		Welfares		Welfares		Welfares	
(mecc,toll)	Fed	Local	Fed	Local	Fed	Local	Fed	Local
$\left(\beta^H, \tau^{*H}\right)$	1.25	1.18	1.25	1.08	1.25	0.99	1.25	0.75
$\left(\beta^H, \tau^{*L}\right)$	1.15	1.04	1.15	0.87	1.15	0.72	1.15	0.32
$\left(\beta^H, \tau^{N}\right)$	1.25	1.18	1.23	1.10	1.21	1.03	1.15	0.89
$\left(\beta^L, \tau^{*L}\right)$	2.5	2.24	2.5	1.83	2.5	1.45	2.5	0.50
$\left(\beta^L, \tau^{*H}\right)$	2.38	2.22	2.38	1.97	2.38	1.74	2.38	1.17
$\left(\beta^L, \tau^{N}\right)$	2.48	2.26	2.39	1.97	2.28	1.76	2.01	1.39

Table 4: Welfares for congestion and both local and transit traffic

are summarized in the next table:

share of transit	13%	33%	52%	100%
transfer (M)	0	0.14	0.29	0.67
Value of Information	0	0.1	0.1	0.1
Welfare loss from asymmetric information	0	4.4%	4.4%	4.4%
Welfare loss from Laissez Faire	0.8%	4%	8%	18.5%
Welfare loss from toll cap	0.76%	0.76%	0.76%	0.76%

Table 5: Results for numerical example for air pollution and both local and transit traffic

The transfers listed in the above table will give a low cost region the right incentives to report its true cost, but the transfer needed in the case half of the traffic is transit will however induce a region with a high mecc to pretend to be low. Indeed, charging the low first best toll and receiving the transfer will yield him a higher local welfare than charging the high first best toll (local welfare for $\left(\beta^H, \tau^{*H}\right) = 0.99$, while local welfare for $\left(\beta^H, \tau^{*L}\right)$ plus the transfer is $0.72 + 0.29 = 1.01$ which is larger). Imposing the first best tolls will thus not be possible. Instead of using transfers, the federal government can impose a toll cap. The welfare losses when imposing the toll cap are again quite low.

Table 5 gives one surprising insight. Although the possibility to exploit transit traffic is clearly there, the loss in welfare due to the asymmetric information remains relatively low in the case of congestion. The value of information is 4.4%. This is clearly lower than the 38% found as value of information in the case of air pollution. So although, in the case of congestion, no mechanism exists to attain the First Best, the loss in welfare remains low. The intuition is that the welfare loss when a region has a low mecc but reports a high mecc is a function of the square of the excessive toll (difference between high first best toll and low first best toll). In the case of air pollution the excessive toll can be quite high. When we deal with congestion, the high external congestion cost comes down to a lower "excessive toll" or market distortion because the first best tolls depends on the demand, which on its turn decreases with increasing toll. This feedback effect reduces the effective toll needed and the high first best tolls will be relatively smaller than in the case of an air pollution type externality. As the welfare loss is proportional to the square of the market distortion, the welfare loss associated to asymmetric info (and the value of info) is much larger in the case of air pollution than in the case of congestion.

6 The European solution: a toll cap equal to the average infrastructure costs

We have seen in the previous section that in the case of congestion (or any kind of externalities with feedback effects) when there is transit traffic, there is no obvious way to implement first-best tolling when there is some uncertainty about the magnitude of the externality. As announced in the introduction, the current practice in the EU is to constrain the toll level by a toll cap which equals the average infrastructure cost. In this section we analyze to what extent this practice makes sense. The advantage is that such a cap does not require any knowledge about the level of congestion and will therefore not rely on the reporting of the marginal external costs by the regional governments. The federal government needs only to know the total infrastructure costs and the toll revenues. Assuming constant returns to scale in road capacity costs, the total infrastructure costs (TC) are equal to

$$TC = \frac{k}{\beta},$$

where k is the unit cost of capacity and $1/\beta$ is the level of capacity. It is cheaper to provide a highly congested or badly serviced road (low capacity, high β). Note that both the unit cost of capacity and the level of capacity can be unknown to the federal government, we only assume that the total costs are known. The toll revenues collected by the regional government can not exceed the total infrastructure cost, so

$$\tau X < TC.$$

Note that the local government has now the freedom to choose not only the toll level τ but also the capacity level $1/\beta$. We will see, however, that this extra freedom generates first best results for the tolling and for capacity choices of the local government since it will always choose the optimal level of investment given the level of usage.

6.1 The case of only transit traffic

The objective functions now include the infrastructure costs which are born by the local government. With only transit traffic, the objective function equals the toll revenues minus the infrastructure costs:

$$\Pi = \tau X^T - \frac{k}{\beta}. \tag{23}$$

The federal welfare is given by

$$W = \int_0^{X^T} P(x)\,dx - C\left(X^T\right) X^T + \tau X^T - \frac{k}{\beta}. \tag{24}$$

6.1.1 The toll and investment level preferred by the federal government

It is interesting to see what would happen if the federal government had the possibility to choose toll and capacity. If this would be the case it would choose β and τ such as to maximize federal welfare. It will have to solve the following two f.o.c. simultaneously

$$\frac{\partial W}{\partial \tau} = 0 \quad \text{and} \quad \frac{\partial W}{\partial \beta} = 0.$$

The first f.o.c. yields the first-best toll

$$\tau^* = \beta X^T\left(\tau^*, \beta\right).$$

The f.o.c. for β can be rewritten as

$$\left[\tau - \beta X^T\right] \frac{\partial X^T}{\partial \beta} - X^T X^T + \frac{k}{\beta^2} = 0.$$

Using, $\tau = \beta X$ and the fact that β should be positive we have that:

$$\beta^* = \frac{\sqrt{k}}{X^T\left(\tau^*, \beta^*\right)}. \tag{25}$$

The higher the marginal infrastructure cost, the more congested the infrastructure will be since the government will invest less. The more transit, the more revenues can be extracted and the more can be invested. Substituting β^* back in the expression for the first-best toll we get

$$\tau^* = \sqrt{k}$$

and this produces the well known cost-recovery result.

6.1.2 The toll and investment level preferred by the local government

It is instructive to see what the local authority would choose as its capacity level $(1/\beta)$ and toll if it is not regulated. The local government solves the next two equations simultaneously:

$$\begin{aligned}\frac{\partial \Pi}{\partial \tau} &= X^T + \tau \frac{\partial X^T}{\partial \tau} = 0, \\ \frac{\partial \Pi}{\partial \beta} &= \tau \frac{\partial X^T}{\partial \beta} + \frac{k}{\beta^2} = 0.\end{aligned}$$

The first equation gives us the same result as before (see eq(16)):

$$\tau^N = \frac{(a_T - \alpha)}{2}.$$

Using the derivatives with respect to β; $\frac{\partial X^T}{\partial \beta} = -\frac{X^T}{b_T + \beta}$ and substituting the result of the f.o.c for $\tau = \frac{(a_T - \alpha)}{2} = \frac{X^T}{b_T + \beta}$ in the first order conditions for β, we get an expression for the capacity level preferred by the local government:

$$\beta^N = \frac{\sqrt{k}}{X^T \left(\tau^N, \beta^N\right)}.$$

This is the optimal capacity from the federal point of view (see eq.(25)) given the level of usage. This means that if the federal government could induce optimal charging, the regional government would automatically opt for the optimal investment level.

6.1.3 A toll cap equal to the average infrastructure cost

Now the local government has to observe the following constraint:

$$\tau X^T (\tau, \beta) \leq \frac{k}{\beta}.$$

The optimization problem for the local government becomes:

$$\max_{\tau, \beta} \quad \Pi \tag{26}$$

$$\text{s.t. } \tau X^T (\tau, \beta) - \frac{k}{\beta} \leq 0 \tag{27}$$

where Π is given in eq(23). It is clear that in this case the local government will choose toll and capacity levels such that the toll revenues exactly equal the infrastructure costs since otherwise it will have negative welfare and will choose not to invest at all. The local government will be indifferent to all pairs of tolls and capacity levels that yield zero welfare and that satisfy $\tau X^T (\tau, \beta) = k/\beta$. Using the equilibrium expression for $X^T = \frac{a_T - \alpha - \tau}{\beta + b_T}$, we see that the constraint reduces to:

$$\tau (a_T - \alpha - \tau) = k + \frac{k b_T}{\beta}.$$

so for every β in a feasible range there is a τ that satisfies the constraint and there is an infinity of solutions that satisfy this constraint but only one is optimal from a federal point of view.

6.2 The case of transit and local traffic

6.2.1 Federal price setting

The federal optimization problem yields the same result as in the case where there is only transit traffic but now the transit flow X^T is replaced by the total flow X :

$$\begin{aligned} \tau^* &= \beta^* X(\beta^*, \tau^*) \\ \beta^* &= \frac{\sqrt{k}}{X(\beta^*, \tau^*)} \end{aligned}$$

substituting β^* in τ^*, the first-best toll becomes

$$\tau^* = \sqrt{k}$$

6.2.2 Local pricing and investment strategy

Without regulation, the local authority would choose its investment level (β) and τ such as to maximize its welfare $\Pi - \frac{k}{\beta}$, where Π is given in eq(19). It has to solve the next two equations:

$$\begin{aligned} \frac{\partial \Pi}{\partial \tau} &= X + \tau \frac{\partial X}{\partial \tau} + P(X_L) \frac{\partial X^L}{\partial \tau} - \frac{\partial C}{\partial \tau} X^L - C \frac{\partial X^L}{\partial \tau} = 0 \\ \frac{\partial \Pi}{\partial \beta} &= P^L(X_L) \frac{\partial X^L}{\partial \beta} - \frac{\partial C}{\partial \beta} X^L - C \frac{\partial X^L}{\partial \beta} + \tau \frac{\partial X}{\partial \beta} + \frac{k}{\beta^2} = 0 \end{aligned}$$

The first equation gives us a toll

$$\tau^N = \beta X\left(\tau^N, \beta\right) + \frac{b_T b_L}{b_T + b_L} X^T\left(\tau^N, \beta\right)$$

The f.o.c. for β is

$$\left(\tau - \beta X^L\right) \frac{\partial X}{\partial \beta} - X X^L + \frac{k}{\beta^2} = 0$$

Substituting τ^N and using $\frac{\partial X}{\partial \tau} = \frac{1}{X} \frac{\partial X}{\partial \beta}$ gives

$$\beta^N = \frac{\sqrt{k}}{X\left(\tau^N, \beta^N\right)}$$

Again, the capacity will be set optimally. Note that the toll level is larger than the optimum so that flows are smaller. The local authority will thus not invest enough and charge too much.

With local traffic, the local government could in principle charge tolls smaller than the average infrastructure cost and still have positive welfare. Under the constraint, the optimization problem for the local government becomes:

$$\max_{\tau,\beta}\Pi, \tag{28}$$

$$\text{s.t. } \tau X - \frac{k}{\beta} \leq 0 \tag{29}$$

where Π is given by eq(19).

Define the Langragian

$$\mathcal{L} = \Pi - \lambda \left(\tau X - \frac{k}{\beta} \right)$$

then the Kuhn-Tucker conditions are

$$\frac{\partial \mathcal{L}}{\partial \tau} = 0 \tag{30}$$

$$\frac{\partial \mathcal{L}}{\partial \beta} = 0 \tag{31}$$

$$\lambda \geq 0, \tau X - \frac{k}{\beta} \leq 0 \text{and } \lambda \left(\frac{k}{\beta} - \tau X \right) = 0 \tag{32}$$

the first and the second equation give

$$\tau = \frac{B}{(b_T + b_L)} X - \frac{b_T b_L}{(1-\lambda)(b_T + b_L)} X^L \tag{33}$$

$$\frac{k}{\beta^2} = \left[\frac{b_T b_L}{(1-\lambda) A} \right] X X^L + \frac{(b_T + b_L)}{B} \tau X \tag{34}$$

where $B = \beta (b_T + b_L) + b_T b_L$.

The last equation is satisfied when either $\lambda = 0$ or $\frac{k}{\beta} - \tau X = 0$. It is easy to show that when $\lambda = 0$ (or when the constraint is not binding), that the toll revenues will always equal or exceed the infrastructure costs. So this leads us to conclude that the constraint is binding. If this is so, we have a unique solution:

$$\tau = \sqrt{k}, \quad \beta = \frac{\sqrt{k}}{X}, \tag{35}$$

which corresponds exactly to the first best solution[6]. This means that when the higher authority level has no knowledge about the marginal external congestion cost, it can still achieve the first-best by letting the local government decide about capacity levels and tolls, provided that the average infrastructure cost cap holds.

[6] the langargian multiplier λ is then equal to the proportion of the transit traffic in the overall traffic $\left(\lambda = \frac{X^T}{X} \right)$.

7 Conclusions

In this paper it is assumed that the federal government lacks information on the external costs created by traffic.The local government knows the external costs and uses this asymmetry in information to charge transit and local traffic more than the marginal external cost. We have shown that, if the external cost does not affect the use of the infrastructure (as in the case of some forms of air pollution), there exists a transfer scheme by which the federal government can induce the local government to charge the right tolls. If monetary transfers are not possible the federal authority can impose a toll cap equal to the expected value of the marginal external cost. When the external cost is of the congestion type so that the level of congestion affects the level of use, a transfer scheme to induce the local government to implement the right toll only exists if transit traffic is not sufficiently important. These results are summarized in Figure 5.

	Air pollution		**Congestion**		
	low transit	**high transit**	**low transit**	**medium transit**	**high transit**
Transit	with transfer		no mechanism exists		
Local and Transit	without transfer	with transfer	without transfer	with transfer	no mechanism exists

Figure 5: Conditions for which a mechanism exists that induces truthfull reporting of the marginal social costs

Stated differently: the classic solution to asymmetric information problems, namely proposing some transfer scheme to induce the lower level authority to report its true marginal external cost, breaks down in the case of congestion. The welfare loss due to this lack of information, however, turns out to be rather small when the externality is of the congestion type. The reason is that demand reacts to the toll and the first best toll reacts on the level of use, the level of first best tolls will be lower than when such feedback effects are not present. This reduces the welfare loss when charging the wrong first best toll (i.e. the first best toll for a high mecc when the true mecc is low). For the air pollution type of externality the excessive toll is high because, in our case, it did not depend on the volume of traffic.

In both cases one could also impose a toll cap that equals the toll that maximizes the expected welfare. In the numerical example used in this chapter, the welfare losses are substantially smaller with such a cap than when the federal government tries to impose the first best but relies on the local government signal. The current European regulation imposes a toll cap equal to the average infrastructure cost. This regulation turns out to perform well under certain circumstances: if there is only type of traffic and there are constant returns to scale in capacity extension, one can achieve a first best outcome for prices and investment by using the average infrastructure cost as toll cap.

In this paper we assumed that there is only one type of users and that they all contribute in the same way. When transit and local traffic have the same air pollution or congestion effect, there is only one parameter that is unknown to the federal government. The propositions derived in this paper can be generalized to the case of several types of users if their relative contribution to the externality is known. This would be the case if the relative emission rates of trucks and cars is known or if the relative congestion contribution of cars and trucks are known. Having different types of users does however most likely create problems to use the average infrastructure cost as toll cap. In this case the federal government does control neither the toll nor the investment levels. When there are more types of users the federal government can control easily the absence of discrimination between local and transit traffic for each type but this will be insufficient. Whenever the transit share of one type of users is larger, there will be an incentive for the local government to overcharge this group. This is a well known result in the tax exporting literature. The implication is that the first best character of a toll cap equal to the average infrastructure cost breaks down. To see this, take an extreme example and assume that all trucks except one are transit trucks but that all passenger cars are local traffic. Tolls for trucks will be inefficiently high and the toll cap can not prevent this and the powerful result that using toll caps equal to the average infrastructure cost is enough to ensure efficient pricing and investment breaks down.

This paper uses a very simple model and several extensions are worth studying. One extension is the use of more complex networks. The competition for transit traffic may limit the pricing power of local government levelsin the case of parallel networks as in De Borger et al. (2007). A second extension is to consider a wider range of instruments, besides transfer mechanisms and toll caps; one may also consider quality standards for roads or uniform fixed tariffs.

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A Derivation of condition (22)

The equilibrium volume are determined by the Wardrop equilibrium concept where

$$a_T - b_T X^T = \alpha + \beta \left(X^T + X^L\right) + \tau = a_L - b_L X^L$$

Solving this for X^T and X^L and using $X = X^T + X^L$ we get

$$X\left(\tau, \beta^A\right) = \frac{a_T b_L + a_L b_T - (b_T + b_L)\,\alpha}{B^A} - \frac{(b_T + b_L)}{B^A}\tau = \frac{A}{B^A} - \frac{(b_T + b_L)}{B^A}\tau \tag{36}$$

where $B^A \equiv \beta^A (b_L + b_T) + b_L b_T$ and $A \equiv a_T b_L + a_L b_T - (b_T + b_L)\,\alpha$.
From eq(8), eq(21) and solving the equilibrium volumes we know that

$$
\begin{aligned}
\tau^{*A} &= \beta^A X\left(\tau^{*A}, \beta^A\right) & (37)\\
\tau^{NA} &= \beta^A X\left(\tau^{NA}, \beta^A\right) + \frac{b_T b_L}{b_T + b_L} X^T\left(\tau^{NA}, \beta^A\right) & (38)
\end{aligned}
$$

Substituting eq(37) in eq(36) yields,

$$
X\left(\tau^{*A}, \beta^A\right) = \frac{A}{2\beta^A\left(b_T + b_L\right) + b_L b_T} \tag{39}
$$

Substituting eq(38) in eq(36) and using eq(39) we get

$$
X\left(\tau^{NA}, \beta^A\right) = X\left(\tau^{*A}, \beta^A\right) - \frac{b_T b_L}{2\beta^A\left(b_T + b_L\right) + b_L b_T} X^T\left(\tau^{NA}, \beta^A\right) \tag{40}
$$

With the help of these four last equations (first using eq(37) and eq(38), then substituting eq(40) and after rearranging the terms we substitute eq(39)) we get the result that the inequality $\tau^{*H} > 2\tau^{NL} - \tau^{*L}$ can be rewritten as

$$
X^T\left(\tau^{NL}, \beta^L\right) < \frac{A\left(\beta^H - \beta^L\right)\left(b_T + b_L\right)}{2\left(2\beta^H\left(b_T + b_L\right) + b_L b_T\right)\left(b_L b_T\right)}
$$