TSE working paper series

12-310

May 2012

Research Group : Public Economics

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Revised version November 2012

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Voting on Road Congestion Policy*

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This version: November 2012

Abstract

This paper studies the political economy of urban traffic policy. First, it examines how the institutional setup affects the policy adopted by local governments. A city council and a regional government (representing city and suburbs), elected by majority voting, decide respectively on parking fees and road toll. Both are below the optimum when median voters in city and suburbs prefer cars to public transport sufficiently more than the average. Moreover, even if the city government would have set an optimal road toll, the regional government blocks it when the median suburban voter prefers cars strongly enough. Letting the city control both parking and road pricing may therefore increase chances of adoption for the latter. However, this is not necessarily optimal: when local voters choose lower-than-optimal car charges, imperfect governmental coordination may reduce the inefficiency, producing higher charges than if one government controlled them both. Finally, we examine how the use of revenues affects acceptability of road pricing. Earmarking for public transport is welfare enhancing, compared to lump-sum redistribution, only if the city government is granted additional funds by the national government.

JEL CLASSIFICATION: R41, D78, H77, H23

KEYWORDS: Road pricing; parking charges; majority voting; multiple governments

*I thank Richard Arnott, Chiara Canta, Helmuth Cremer, Bruno De Borger, Philippe De Donder, Yinan Li, Robin Lindsey, Stef Proost, Paul Seabright, Emmanuel Thibault, Davide Ticchi and Wouter Vermeulen for useful comments and suggestions. I also thank audiences at the University of Antwerp, EUI, IEB Barcelona, Istanbul (PET 2010), Malaga (EEA 2012), Marseille (LAGV 2012), Tilburg and Toulouse. Finally, I thank the Scientific Committee of the 2012 Kuhmo-Nectar Conference in Berlin for awarding the "Best Paper by Junior Researcher Award" to this paper. All errors are mine.

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1 Introduction

Road congestion in major urban areas is an increasingly serious problem. Yet, even if economists have for long argued in its favor, road pricing in city centers is still rare. Many local politicians are reluctant to adopt it, fearing that voters will be opposed. Edinburgh, Manchester, New York City and Copenhagen have abandoned plans for urban road pricing in recent years, in spite of the fact that London, Stockholm and Milan have demonstrated both the political feasibility and effectiveness of the policy.

Political acceptability is perhaps the greatest obstacle to the implementation of road pricing. It is therefore important to understand what determines it. This is the objective of this paper. Of course, the number of factors that determine acceptability of road tolls can hardly be captured in a single model. Hence, we focus on three specific questions that, it seems, have not received much attention in previous literature. First, how does the institutional setup influence the choice of traffic policy made by local governments? Second, how is the political sustainability of pricing schemes affected by the way their revenues are utilized? Third, is the role of financial support by national governments crucial in improving local policymakers' attitudes regarding these schemes?

The relevance of the above issues is well illustrated by recent experience in the city of Copenhagen. In early 2012 the Danish government decided to withdraw a long-debated proposal for a central cordon toll. Mayors of surrounding municipalities strongly voiced their opposition to the scheme, with a seemingly important influence on its rejection. Most of them were unhappy because public transport fare reductions could not be implemented before the road toll was introduced. These were considered essential to provide a viable alternative to otherwise car-dependent commuters, but became unfeasible due to the national government‘s refusal to cover the projected shortfall in the local public transport operator‘s budget.[1]

The impact of policies that curb traffic in city centers can substantially depend on an individual‘s location within the urban area. Commuters living in suburbs are generally more likely to travel by car than those who live in central areas. This is linked to cities becoming sprawled as well as to the lack of alternative travel options. Also, the comfort, independence and travel flexibility that cars provide make them attractive compared to other modes.[2] These features are likely to be more relevant the longer the trips one has to take. Secondly, revenue redistribution is essential in determining winners and losers from road tolls. Suburban, car-

[1]see http://cphpost.dk/news/national/zealand-mayors-rebel-over-congestion-zone and http://cphpost.dk/news/local/update-congestion-charge-reportedly-taken-table

[2]Schlag (1995, p.8) claims that "the car serves at the same time as a status-symbol, pleasure time activity and an article of daily use. Most people regard freedom of choice on when and where to travel as a basic right". Commenting on a survey of commuters in Stuttgart he notes that "95% of participants agreed with the statement 'The car guarantees my independence' and that 75% with 'Driving a car is fun"'.

dependent voters may fear that they will not be fully compensated for higher travel costs, since at least some of the revenues benefit people not using the priced roads. Revenues may also be appropriated by a city administration that disregards suburbanites' welfare. As a consequence, policymakers representing suburban voters are unlikely to endorse central city road tolls. This happened not only in Copenhagen, but in other cities as well. Similar protests took place before the "Ecopass" road pricing scheme was introduced in Milan and most of the municipalities around Stockholm voted, in a consultative referendum, against the congestion charge.

This suggests that chances of adoption of road pricing may be diminished if it is under the control of governments representing more than just city voters. In recent cases of successful introduction of road tolls (i.e., London, Stockholm and Milan) city governments seem to have been decisive. Experience was less favorable in cities where they were not. As examples, one can mention Copenhagen as well as New York City where road pricing was approved by the City Council, but ultimately blocked by the State Assembly. A related case is that of parking fees. These have generally smaller influence over vehicle movement than tolls, but can have a similar discouraging effect on car trips terminating in the city center. Parking fees tend to generate significantly less political opposition than tolls, even in cities where the latter were discarded. Unlike road pricing, parking is traditionally managed exclusively by city governments. Again, the Copenhagen case is indicative: in the last seven years, the Danish capital's City Council has substantially raised central parking fees. The political process leading to their adoption seems to have been much smoother compared to that for road pricing. To continue, while road pricing did not find support at the State Assembly level, parking fees in Manhattan have been significantly increased by New York City's Department of Transportation.

To give a possible explanation to these facts, the first part of this paper investigates how the institutional setup affects the type of traffic policy adopted by local governments. We consider an urban area consisting of a Central Business District (CBD) and two residential areas: a city and the hinterland. Traffic policy consists of two monetary charges that one may be asked to pay when driving to the CBD: a parking fee and a road toll. Individuals differ in the utility they get from traveling by car relative to public transport (their default option). To capture modal choice patterns that are recurrent in reality, we assume the share of population preferring cars to public transport to be larger in the hinterland than in the city. First, we look at the case in which both parking and road pricing are under the control of the city government. A simple result emerges: when the median (decisive) city voter has sufficiently stronger (resp. weaker) preferences for cars than the average voter, car charges are smaller (larger) than optimal. Therefore, if the majority of the city population strongly values cars over public transportation, while the rest does not, the total car charge is below the optimum. This is consistent with a quite intuitive correlation between voters' reliance on cars and their unwillingness to accept traffic restraining policies.[3] We then look at a more complex setup where a city council and a regional government (the latter representing the city and its hinterland), both elected by majority voting, decide traffic policy. We assume, in particular, that the former controls parking fees, while the latter controls the road toll, consistently with the examples provided above. Intuitively, incentives for voters of city and hinterland are not the same. This is because of different preferences for travel modes but also because the city government can exploit tax-exporting possibilities when setting its own charge. By its nature, the regional government cannot do so. Consequently road pricing receives the smallest political support. In fact, when the median suburban voter has sufficiently stronger preferences for cars relative to public transport, road pricing is blocked by the regional government. This happens even if the city would have set a road toll at least as high as the optimum, if it could have decided on it just as it does for parking fees.

From a practical standpoint, the above findings suggest simply that if the objective is to increase chances of adoption for road pricing, city governments should be given the power to decide on it, as is generally the case for parking fees. However, we find that this is socially desirable only as long as the majority of city voters support socially optimal car charges. This is instead not true when both city and suburban populations oppose them, i.e. when the combination of parking fee and road toll results in a total car charge which is below the optimum. The reason is that the city and regional government do not perfectly coordinate when setting the respective charges. This produces a "double marginalization" phenomenon and the total charge on car trips ends up being at least as high as if it were entirely under the control of the city government. Interestingly, the "upward" bias produced by imperfect governmental coordination may partially correct the "downward" bias resulting from voters' preferences. In that case, we find, social welfare is at least as high with two non-coordinating governments than if a single one controlled the whole set of policy instruments.[4]

In the second part of the paper, we investigate a different question: how the use of revenues from proposed pricing schemes affects their public acceptability. In particular, we focus on the effects of using the money (entirely or in part) to finance a subsidy to public transportation, instead of redistributing it in the generic form of lump-sum transfers. It is commonly thought

[3] In most of the cities that recently implemented road pricing, the majority of peak-hour travelers were not drivers (at the time of the schemes' introduction). For instance, in London around 12% of trips to the charge zone were made by car (TfL (2003)). In Stockholm, only a third of commuters travelled by car (Armelius and Hulkrantz (2006)). In contrast, most cities in the U.S. and Australia travelers depend on cars to a large extent. Few local governments have shown determination to restrict it.

[4] A similar reasoning suggests that the possibility for the local government to exploit tax-exporting opportunities may actually be welfare enhancing.

that earmarking revenues for public transport improves public acceptability of road pricing. Yet, our results suggest that such an effect can be achieved only on one important condition: that the local government implementing the policy is granted extra funds to cover the costs of an improved public transport service. More precisely, we find that if the socially optimal road toll is not politically sustainable when revenues are redistributed in a less specific form, earmarking them for public transport induces voters to accept a toll closer to the optimal level only as long as these revenues are integrated by additional funds. In a nutshell, this is because improvements to public transport are funded by taxing the very "goods" (i.e., car trips to the city center) that are being discouraged. Consequently, the revenues collected may not be enough to fund the public transportation upgrades necessary to ensure political sustainability. The result suggests, therefore, that they should be part of "policy packages" that include not only earmarked revenues for public transportation, but also additional grants from central governments. Lack of financial support by the national government may have favored rejection of road pricing in Copenhagen. On the contrary, the successful introduction of the Stockholm Congestion Charge was accompanied by a public transport service expansion funded in part by the Swedish government.

The rest of the paper is organized as follows: Section 2 relates this work to existing literature. Section 3 presents the model. Section 4 studies voting on traffic policy. Proofs of all propositions and lemmas are provided in an Appendix. Section 5 presents a numerical illustration of the results. Section 6 concludes.

2 Related literature

There is a large body of literature studying road congestion policy from a normative perspective (see Small and Verhoef (2007)).[5] Political acceptability is one of the main issues holding back traffic restraining measures. Yet, there are, quite surprisingly, very few papers looking at traffic policy from a political economy perspective. To the best of my knowledge, only De Borger and Proost (2012) and Marcucci *et al.* (2005) study voting on road pricing. De Borger and Proost use a majority voting setup to study the role of voters' uncertainty on the cost of switching travel mode. Differently from them, we consider the presence of multiple governments and taxes. However, we neglect voter uncertainty. Marcucci *et al.* use a citizen-candidate game to model the political decision process on road pricing. A common finding of both papers is that using charge revenues to subsidize public transport can improve the

[5]Most of the literature focuses on road pricing and infrastructure. There is also a part of this literature looking at parking issues (e.g. Arnott and Inci (2006)). However, these papers take a purely normative perspective, also neglecting the presence of multiple governments involved in congestion policy.

acceptability of the optimal charge. Parry (2002) provides a normative analysis comparing the effects of congestion charges and public transport subsidies. Differently from them, our results point out the important role of extra funding from external governments. Another related paper is Dunkerley *et al.* (2010), studying the political economy of fuel taxes. They find that when aggregate income is high enough that drivers constitute the majority of the population, voting results in too low fuel charges and viceversa. The opposite happens for road capacity. While this result is similar to that of our paper, we consider individuals that are heterogeneous in preferences for alternative transport modes. We also study interactions between overlapping local governments, absent in their setup.

There is a growing literature that focuses on governmental competition in pricing of road networks. This literature does not use a political economy approach and considers governments as (local) welfare maximizers. De Borger *et al.* (2007) study the interaction of different governments in setting traffic policy on parallel and serial networks. They find that imperfect coordination among them can lead to significant deviations from the optimal pricing and investment scheme. As mentioned above, this is not necessarily the case in our model. In fact, imperfect coordination among the two governments may actually increase social welfare. Ubbels and Verhoef (2008) study the choice of pricing and capacity investments by a city and a hinterland government, each controlling one part of a two link road network leading to the city's Central Business District. Horizontal tax competition and tax exporting lead to higher tolls on the city than on the hinterland section of the network. These results, however, do not explain why car charges in city centers may face strong political opposition. This paper provides a possible explanation.

3 The model

The analysis below studies how local politicians choose traffic policy, given that they are elected by majority voting. We here describe the basic ingredients of the model. These are essential to understand how traffic policy affects the behavior and welfare of individuals and, in turn, how this determines the way in which their vote is cast.

Spatial structure. There is a "large" population (whose size is normalized to 1) living in an urban area. A first group of individuals, a fraction $\lambda \epsilon (0, 1)$ of the total, is assumed to live within the boundaries of a city's jurisdiction. A second group (the remaining $1 - \lambda$ fraction) lives in the city's hinterland. The city also includes a Central Business District (*CBD*), where no one lives but where all travel goes (e.g. for commuting purposes). We model the three areas as point sized islands, denoted *CBD*, *C* and *H* (Figure 1). Since our focus is on short-run effects of traffic policy, we assume residential locations to be fixed and ignore land market considerations.[6]

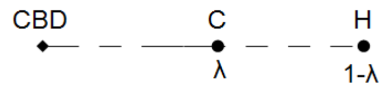


Figure 1: Spatial setting

Individuals. All individuals travel to *CBD*, on two alternative modes. We have trips by car, whose quantity is denoted by q, and trips by public transport, whose quantity is denoted as b. Both are non-negative continuous variables. A car trip consists of two complementary activities: driving to *CBD* and parking the car once there. This means that, per each car trip, an individual may have to pay two charges (should they exist): a road toll to enter the *CBD* and a parking charge (see below). Individuals also care for a consumption good n (a numeraire, whose price is fixed and normalized to one).

We assume (as in De Borger and Proost (2012)) that the decision of how much to travel at peak-hour is exogenous. For all individuals travel demand is fixed at a positive and large quantity Y, so $b + q = Y$. This is, for example, the case of commuters who need to reach the workplace (at peak hours) a given number of times during the year. This simplifies the analysis and is consistent with a short-run interpretation of the model: in the short run, individuals may find it hard to adjust their (total) travel demand, especially when travel is for work purposes. The choice of how to travel is however endogenous.[7]

The marginal utility of a trip by public transport is zero: public transport is a "default" travel mode to which the individual assigns all the trips she does not consider it worthwhile to take by car. The marginal utility of a car trip is increasing in the individual specific parameter $r \geq 0$. This captures the intensity of the individual‘s preference for cars relative to public transportation. For instance, the car generally allows greater independence of movement. Moreover, r can capture the relative quality of the two modes as it is perceived by the individual. For example, the individual may find public transport to be uncomfortable or unreliable: in that case, it is more likely that r is larger. Its value can also depend on the physical structure of the city (e.g. its density) and the place where the individual resides (see below).

[6]Fixed residential locations are a commonly found simplification in models studying commuting costs (e.g.,Gutiérrez-i-Puigarnau and van Ommeren (2010))

[7]In reality, not all the population travels at peak hours. This (e.g. unemployed or retired people) could easily be accounted for including a fraction of the population who does not derive any utility from peak hour travel, characterized by $r = 0$ and $Y = 0$.

Individuals have the following utility function[8]

$$U(q, n; r) = 2\,(qr)^{\frac{1}{2}} + n$$

The parameter r is exogenously distributed, in each population C and H, according to a CdF $F_C(r)$ for C and $F_H(r)$ for H, with the same support $\sigma = [0, r^u]$. We assume that $F_H(r) < F_C(r)$, for any $r \in \sigma$. Denoting $\hat{r}_C$ (resp. $\hat{r}_H$) as the median individual in C (resp. H), so $F_C(\hat{r}_C) = F_H(\hat{r}_H) = \frac{1}{2}$, this implies that $\hat{r}_C \leq \hat{r}_H$. The idea is that, all else equal, an individual living in H is more likely to find public transport less viable than one living in C. It is intuitive that, because of this assumption, people in suburbs will drive more frequently than people in the city in equilibrium. We denote the average value of r, for the entire population as

$$\bar{r} = \lambda \int_0^{r^u} r dF_C(r) + (1-\lambda) \int_0^{r^u} r dF_H(r)$$

We also denote

$$\hat{r} = \lambda \hat{r}_C + (1-\lambda)\,\hat{r}_H$$

the weighted average of r for the median individuals in the two subpopulations.

Travel options, costs and budgets. Consider individuals living in C. The monetary cost of a car trip from C to CBD is $p = t + d$, where t is the sum of charges on car trips set by local governments (i.e. parking and road pricing) and d is an exogenous resource cost (e.g fuel). T is the (monetary equivalent of) time cost of such a trip. We denote by A the generalized cost of a public transport trip. For an individual living in C, the budget constraint is

$$M + L^C \geq n + (p+T)\,q + Ab$$

where M is undifferentiated (exogenous) income and L^C is the (sum of) lump-sum transfers paid to people living in C. We assume that $p + T > A$ always holds. We ignore, for the moment, subsidies to public transport. They will be introduced below.

The time cost of a car trip T is a linear function of traffic volume Q (the aggregate amount of car trips).[9] This captures road congestion which, for simplicity, is assumed to develop only

[8]This functional form is convenient because of its tractability, allowing smooth aggregation of preferences. Linearity in consumption and costs of travel is however a common assumption in the literature on road pricing (see, e.g., De Borger and Proost (2012), de Palma *et al.* (2010), Arnott *et al.* (1993)).

[9]Linearity of the congestion function is commonly assumed in models of road pricing: see, e.g., De Borger and Proost (2012)

on the portion of the road network that links C to *CBD.* We have

$$T(Q) = \gamma Q$$

where $\gamma > 0$ is constant, so the partial derivative is $T_Q = \gamma$. When deciding on the number of car trips to be taken, individuals consider T as given: there is a congestion externality. A is instead assumed to be independent of the amount of traffic.

Individuals living in H have to sustain the additional cost of the trip from H to C. We denote by x the generalized cost of travel from H to C by car, and by x^b if by public transport. We make two simplifying assumptions: first, both are independent of traffic volumes as congestion on the road linking C to H is ignored. Second, we assume that, because of the low availability of public transport in suburban areas, $x < x^b$. Individuals wanting to reach the *CBD* by public transport thus optimally drive from H to a park-and-ride facility in C. Consequently, the extra cost of travel from H to C is simply x. There is, however, an inconvenience of switching modes that reduces the attractiveness of public transport for individuals in H, compared to those in C. The assumption that $F_H(r) < F_C(r)$, for any $r \in \sigma$, captures also this effect.[10]Given these assumptions, the budget constraint for an individual in H is:

$$M + L^H \geq n + (p + T + x)\, q + (A + x)\, b$$

where L^H is the lump-sum transfer paid to people in H.

Timing. The sequence of events is as follows

1. Local governments decide traffic policy variables (resulting in the total charge t). As we will illustrate below, governments are elected (and policies chosen) by majority voting. When casting their vote, voters perfectly anticipate their utility at the following stage.

2. Taking policy variables as given, individuals decide the amount of trips q, b and consumption n, maximizing $U(.)$.

[10] Of course, there may be costs of parking and switching modes at the facility, which we do not explicitly model. However, including them would complicate the analysis without affecting the main results. They would discourage people in H from using public transport to reach the *CBD* compared to people in *C,* inflating their demand for cars. Hence, suburban commuters would be hit harder by car charges. This is already the case since we assume $F_H(r) < F_C(r)$, for any $r \in \sigma$. Alternatively, suppose a trip from H to *CBD* had to be taken either entirely by car or entirely by public transport: it would still be reasonable to assume that the extra cost of travel for suburban commuters is such that $x < x^b$. Again, the consequence would be that of increasing suburban commuters' demand for car trips (all else equal) compared to city dwellers. This would make them even more unwilling to support car charges, thereby making the regional government less likely to adopt them (see Proposition 2). Our qualitative results would not change.

Individual behavior once policy variables are set. Suppose the total charge on car trips t is set. Individuals maximize their utility choosing the amount of trips q and b as well as consumption n (after receiving transfers from the governments). This leads to the demand function

$$q(t;r) = \frac{r}{(p+T-A)}$$

If $r=0$, the individual obtains the same utility from both car and a public transport trips. Since $p+T>A$ always holds, so she never uses the car. Recall that, for a traveler, $b+q=Y$, with total travel demand Y being fixed, so $b(t;r)=Y-q(t;r)$. By the linearity of $U(.)$ in n, trip quantities are independent of income (and transfers). Substituting $q(t;r)$ and $b(t;r)$ into $U(.)$ and using the individuals' budget constraint, we get, after simplification, the indirect utility functions

$$V_C(t;r) = \frac{r}{(p+T-A)} + M + L^C + AY \tag{1}$$

$$V_H(t;r) = \frac{r}{(p+T-A)} + M + L^H + (A-x)\,Y \tag{2}$$

for individuals living, respectively, in C and H. To obtain the aggregate demand for car trips $Q(t)$, we integrate $q(t;r)$ over σ, for both C and H, to get

$$Q(t) = q(t;\bar{r}) = \frac{\bar{r}}{(p+T-A)}$$

Thus, the aggregate amount of car trips in the economy coincides with that of the "average" individual, of type $r=\bar{r}$. It is easy to show that, even after accounting for feedback effects due to the reduction in T, we have $\frac{dQ}{dp}<0$. From now on, we will denote, in order to save on notation, $q(t;r)$ simply as $q(r)$. Similarly, $Q(t)$ will be simply denoted by Q

Governments and policy instruments. There are two local governments: a city government G_C and a regional government G_R. The city government represents only the population in C. It controls a non-negative monetary charge t_C (a component of the total car charge t), paid per each car trip by all drivers.

G_R is a regional government representing both people living in C and in H. It is assumed to control a non-negative per-car-trip charge t_R (another component of t), also paid by all drivers. To be consistent with the examples provided in the Introduction, we identify t_C as a parking charge and t_R as a cordon toll around the city's *CBD*. The total charge paid for a car trip to *CBD* is thus

$$t = t_C + t_R$$

We denote by π the vector of traffic policy variables

$$\pi = (t_C, t_R)$$

We assume lump-sum redistribution of charge revenues: the local governments G_C and G_R fully rebate to each individual *in their respective populations* an equal share of the charge revenues, using undifferentiated lump-sum transfers L_{G_C} and L_{G_R}.[11] The government budget constraints are thus

$$\lambda L_{G_C} = t_C Q \quad \text{and} \quad L_{G_R} = t_R Q$$

for G_C and G_R respectively. Recall that G_C represents only a fraction $\lambda \epsilon (0, 1)$ of the total population, the only one entitled to transfer L_C. The lump sum transfer paid to individuals residing in C is therefore

$$L^C = L_{G_C} + L_{G_R}$$

while it is just

$$L^H = L_{G_R}$$

if the individual resides in H. In Section 4.2 we will look at the possibility of redistributing revenues in alternative forms, specifically by financing public transportation.

Note that t_C and t_R are both modelled as per-unit taxes on car trips, paid by all individuals. [12] Indeed, in our model they enter demands for car and public transport travel in exactly the same way (only the total charge t matters). The key difference between them is the way in which local governments redistribute the revenues they generate. Of course, we are making a simplification as in reality parking fees and road tolls are imperfect substitutes. Yet, when one considers trips ending in the CBD, the discouraging effect of the two instruments is quite similar.

It is also useful to note that our setup entails fiscal externalities: first, there is tax-exporting at the city level, since all individuals pay t_C but only people in C are entitled to the revenues. Moreover, the two local governments may act strategically and imperfectly coordinate. As is quite standard, their effect is to inflate car charges set by local governments. However, their impact on social welfare is not necessarily negative and depends on voters' attitudes, as will be discussed below.

[11] We implicitly assume that, due to information asymmetries (individuals‘ preferences being unobservable), personalized transfers are not incentive compatible and, hence, unfeasible.

[12] In many cities, not all drivers pay for parking. This may be due to the limited powers of local governments (Bonsall and Young (2010)), but it may also be due to lack of political will. It seems therefore appropriate to study the governments' behavior allowing them, a priori, to charge parking fees for every trip to the *CBD*.

Social Welfare. We consider a utilitarian social welfare function $W(t)$. This is obtained by integrating (1) and (2) over σ, for both C and H. We have thus

$$\begin{aligned} W(t) &= \lambda \int_0^{r^u} V_C(t,T,A;r)dF_C(r) + (1-\lambda)\int_0^{r^u} V_H(t,T,A;r)dF_H(r) \\ &= \frac{\bar{r}}{(p+T-A)} + M + \lambda L_{G_C} + L_{G_R} + AY - xY(1-\lambda) \end{aligned}$$

which, replacing for λL_C and L_R gives

$$W(t) \quad = \quad \frac{\bar{r}}{(p+T-A)} + M - AY + tQ - xY(1-\lambda) \tag{3}$$

Only the sum of car charges matters from a pure welfare maximization perspective: t_C and t_R are perfectly equivalent instruments. Importantly, this is not the case from voters' perspective. Once again, this is because the three instruments affect governments' budgets in different ways. Hence, their impact on voters‘ welfare is uneven and crucially depends, *coeteris paribus*, on where they live.

As a benchmark, consider the case where t is set by a welfare-maximizing government, whose objective is just to maximize (3). We obtain the following simple result[13]

LEMMA: *Denote* $Q^{FB} \equiv Q\left(t^{FB}\right)$. *The welfare-maximizing policy* t^{FB} *is equal to the marginal external cost of a car trip:* $t^{FB} = \gamma Q^{FB}$.

4 Voting on traffic policy

We now introduce majority voting as the social choice process by which traffic policy is determined. Our focus will be first on the role of the institutional setup and secondly on the role of subsidies to public transportation (ignored in the first part).

4.1 The relation between institutional setup and traffic policy chosen by local governments

Our first objective is to study how the institutional setup influences the policy chosen by local governments. We proceed in the following way: first, we look at the choice of the city government, for any (given) charge set at the regional level. This also allows us to study

[13] Given quasilinear utility and a utilitarian social welfare function, there is an infinite set of first-best allocations differing in the distribution of n but not in trip quantities. This is why setting $t^{FB} = \gamma Q^{FB}$ is sufficient to implement any first best allocation, irrespectively of how income (consumption) is distributed in the urban area.

the special case in which the regional government has no say on traffic policy. It can easily be shown that, if the city government controlled the total charge t, this would be set at the same level as that of t_C when no charge is set at the regional level (i.e. $t_R = 0$). Hence, this case provides a useful reference to which we compare the equilibrium when both governments intervene in traffic policy. We then look at the equilibrium of the full voting procedure where t_C and t_R are simultaneously determined. In order to capture imperfect coordination between city and regional governments, we assume voting takes place following a Shepsle Procedure (Shepsle (1979)). This means that policy variables are simultaneously chosen, with each local government (elected by majority voting) taking as given the choice of the counterpart.[14]

4.1.1 Voting by the city on the charge t_C

Let us first look at the election at the city level. The single policy dimension the city government has to decide on is the car charge t_C, taking t_R as given. We now describe preferences for t_C for individuals living in C. We start from the indirect utility function (1) for a type-r traveler (written after replacing L_{G_C} and L_{G_R}):

$$V_C(\pi; r) = \frac{r}{(p + T - A)} + M + (s - A)\, Y + \frac{t_C Q}{\lambda} + t_R Q \tag{4}$$

To find the most-preferred charge $t_C^*(t_R; s, r)$ by the type-r individual, we maximize (4) with respect to t_C. The first-order derivative writes as

$$\frac{\partial V_C(\pi; r)}{\partial t_C} = -q(r) \cdot \left(1 + T_Q \frac{dQ}{dp}\right) + \frac{Q + t_C \frac{dQ}{dp}}{\lambda} + t_R \frac{dQ}{dp} \tag{5}$$

A marginal increase in t_C affects $V_C(\pi; r)$ in two ways: it raises (since $0 < 1 + T_Q \frac{dQ}{dp} < 1$) the generalized price of a car trip $p + T$. This affects individuals depending on the amount of driving $q(r)$. Secondly, it changes the amount of revenues from car charges t_C and t_R, as well as expenditures to finance public transport s. The relevance of effects on revenues is greater the smaller the size of the city population relative to the entire urban area's λ. This encourages city voters to raise t_C, due to a tax-exporting force (i.e. shifting the tax burden mostly on individuals who are not entitled to revenues). The most-preferred policy by an individual of type r, denoted $t_C^*(t_R; r)$, is such that (5) is equal to zero. Individuals' preferences on t_C satisfy the Single Crossing property, for any t_R (proof of this is embedded in the proof of Lemma 1, in the Appendix). This is the basis to establish the following

LEMMA 1: *When the city votes on the car charge t_C, for any given regional charge t_R,*

[14] To be more precise, each local government has a single policy variable to decide upon and chooses the Condorcet winner among them, given the policy chosen by the counterpart.

there exists a unique majority voting equilibrium $t_C\,(t_R)$*. It coincides with the most-preferred policy vector (given* t_R*) for the median voter in the city population,* $t_C^*(t_R;\hat{r}_C)$*. This is such that* $\frac{\partial t_C}{\partial \hat{r}_C}, \frac{\partial t_C}{\partial \lambda} < 0$ *and* $-1 < \frac{\partial t_C}{\partial t_R} \leq 0$*.*

The intuition is simple: the stronger an individual's preferences for cars (represented by $\hat{r}_C$) the more she will suffer from higher car charges. Smaller city size λ (relative to the total population) makes increasing the city-controlled charge more interesting. Lemma 1 also describes how the city government responds to a marginal increase in the road toll t_R. When facing an increase in the toll decided by the regional government, the city government reduces the charge it controls less than proportionally. This depends on the fact that a higher toll shrinks the tax base for both charges. However, city voters only partially internalize the effect on the latter.[15]

A simplified scenario: both car charges controlled by the city government

Before we introduce the full voting equilibrium, it is useful to consider a simplified setup in which the regional government G_R is not involved in traffic policy. Hence, there is no regionally-controlled car charge, so $t_R = 0$. This is interesting because t_C is set at the same level as the total charge t would be if the city administration had full control of both parking and road pricing (and of the revenues they generate). This is because the two charges are modelled as the same instruments and enter demand functions $q(\pi; r)$ and $b(\pi; r)$ in exactly the same way. The resulting car charge is $t^E = t_C\,(0)$, which we compare to the benchmark charge t^{FB} in the following

PROPOSITION 1: *Suppose that the city government controls both car charges and redistributes their revenues to city voters via a lump-sum transfer. If the median individual in the city population prefers car travel, compared to public transport, sufficiently more than the average individual, then the total car charge* t^E *is smaller than optimal. That is, if* $\hat{r}_C > \frac{\bar{r}}{\lambda}$*, then* $t^E = t_C\,(0)$ *is such that* $t^E < t^{FB}$*. Otherwise,* $t^E \geq t^{FB}$*.*

A scenario in which the majority of the city population is "car dependent" (with high r) and has strong preference for cars relative to public transport, while the rest of the population does not, is consistent with a left-skewed distribution of r, where $\hat{r}_C > \frac{\bar{r}}{\lambda}$. This, according to Proposition 1, will undermine political support for car charges. People who commute

[15] From the perspective of the city government, parking and congestion charge are strategic substitutes. Although this depends on the structure of our model, it is not an uncommon finding in the literature. There is also anecdotal evidence that the introduction of congestion charges has led to a reduction in parking charges (see "Congestion charge brings an unlikely benefit – parking in Central London at 20p an hour", http://www.timesonline.co.uk/tol/news/politics/article4144284.ece).

regularly by car at peak-hours stand to pay a high price if a charge on car trips is introduced. If, as can be expected, a part of the population can avoid it (because it travels by public transport or simply does not travel at all at peak-hours, e.g. the retired or unemployed), revenues collected are insufficient to compensate frequent drivers. If the latter are a majority, it is less likely that elected officials will support the optimal car charge.

We can argue that the distribution described above is consistent with travel patterns and modal shares characterizing cities that have shown little or no interest in congestion charging. For instance, in most U.S. and Australian cities more than 90% of peak hour trips are by car. It is thus likely that the majority of the population is of frequent peak-hour drivers. Few local governments there have been keen on introducing central city road pricing. The most significant exception is New York, where the share of peak-hour trips by public transport is much larger. Car-dependent cities can be found also in the European context. An example is Dublin. More than 60% of people in the Greater Dublin area use cars to get to work: Irish Transport Minister Dempsey stated in 2008 that "congestion pricing would be ruled out for at least eight more years".[16] On the other hand, among the cities that recently implemented road pricing, the majority of peak-hour trips were not taken by car at the time of the scheme introduction. For instance, in London the share of peak-hour trips by car was 12% (TfL (2003)). In Stockholm, only a third of commuters traveled by car to the central city (Armelius and Hulkrantz (2006)).

Proposition 1 also suggests that political support for car charges at the city level may also depend on the ability by the local government to "export" them. That is, make drivers that come from outside its jurisdiction pay. Such possibility is, intuitively, more interesting for the city government the smaller the relative size of its population λ, compared to the entire urban area. The volume of revenues that can be extracted from suburban commuters is larger and each city voter is entitled to a bigger share. Tax exporting by local governments is a fiscal externality and, generally, a welfare-diminishing phenomenon. Yet, interestingly, if voters do not support car taxes, the tax exporting possibility may actually be welfare-enhancing. We will have more to say about this below.

4.1.2 Voting on the charge t_R

Let us now move back to the more complex scenario with the regional government also involved in traffic policy, deciding on t_R. To describe the election at the regional level, it is important to distinguish between individuals in the city C and the hinterland H. The former will choose their most-preferred t_R (with t_C given) maximizing (4). A traveler living in H

[16] See http://www.independent.ie/national-news/congestion-levies-ruled-out-for-eight-years-by-dempsey-1298005.html

will instead maximize

$$V_H(\pi; r) = \frac{r}{(p + T - A)} + M + (A - x)\,Y + t_R Q \tag{6}$$

and, unlike individuals living in C, neglect the fact that a higher road toll t_R reduces the tax base for the city government. Moreover, t_R revenues are redistributed by the regional government to the entire urban area: there is no tax-exporting motive for the road toll. On the other hand, since $\hat{r}_C \leq \hat{r}_R$, we can expect the majority of the population in the hinterland to drive more often, to get to *CBD*, than that in the city. All else equal, this makes them more reluctant to accept the toll t_R than city-dwellers.

Existence of a (not necessarily unique) voting equilibrium for the road toll $t_R\,(t_C)$, for any t_C and s, is ensured by the fact that voters' preferences on t_R are single-peaked (this is shown in the Appendix). However, identification of the pivotal voter for the road toll is problematic. This is because individuals in city and suburbs face different budget constraints, as the former are entitled to transfers from both city and regional government, unlike the latter. Hence, on top of preferences, there are two dimensions of heterogeneity for voters at the regional level. In order to avoid excessive complications, we limit ourselves to prove that the equilibrium $t_R\,(t_C)$ belongs to the interval spanned by the most-preferred values $t_R^{C*}\,(t_C; \hat{r}_C)$ and $t_R^{H*}\,(t_C; \hat{r}_H)$ by the median individuals in, respectively, city and hinterland. Albeit partial, this is useful information to characterize the full equilibrium π^E below.

LEMMA 2: *For any city car charge t_C, denote $t_R^{C*}(t_C; \hat{r}_C)$ as the most-preferred road toll by the median individual in C. Denote $t_R^{H*}(t_C; \hat{r}_H)$ as the most-preferred road toll by the median individual in H. When the entire urban area's population votes on t_R, a majority voting equilibrium $t_R(t_C)$ exists and belongs to $I = \left[t_R^{C*}(t_C; \hat{r}_C), t_R^{H*}(t_C; \hat{r}_H)\right]$*

Note that this interval is not necessarily full: in particular, if $\hat{r}_H$ is large enough, the bounds of I coincide, as we will see below.

4.1.3 Equilibrium of the full voting procedure

We denote as $\pi^E = (t_C^E, t_R^E)$ the equilibrium policy vector resulting from the full voting procedure (with t_C and t_R being determined simultaneously). In order to provide a description of π^E, it is useful to begin by identifying intervals containing its components t_C^E and t_R^E.

LEMMA 3: *Define $\overline{\pi} = (\underline{t_C}, \overline{t_R})$ where $\overline{t_R} = t_R^{H*}(\underline{t_C}; \hat{r}_H)$ and $\underline{t_C} = t_C\left(\overline{t_R}\right)$. Define also $\underline{\pi} = (\bar{t}_C, \underline{t_R})$ where $\underline{t_R} = t_R^{C*}(\bar{t}_C, \hat{r}_C)$ and $\bar{t}_C = t_C\left(\underline{t_R}\right)$. The equilibrium policy vector π^E is such that $0 \leq \underline{t_C} \leq t_C^E \leq \overline{t_C}$ and $0 = \underline{t_R} \leq t_R^E \leq \overline{t_R}$. Moreover, $\overline{t_C} \leq t^E \leq \underline{t_C} + \overline{t_R}$.*

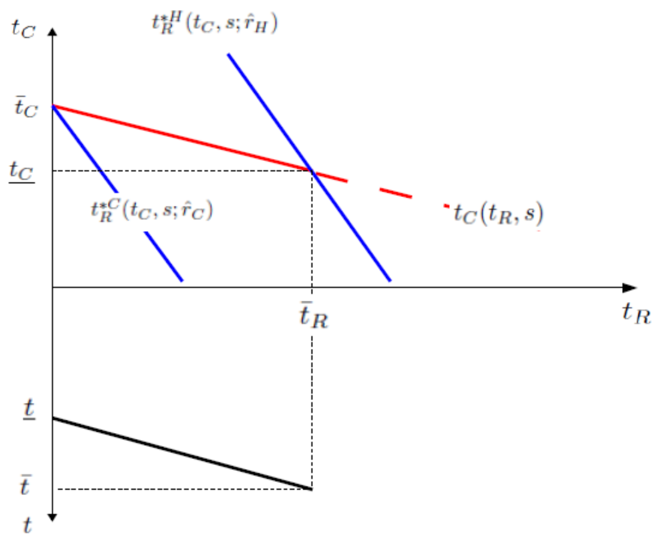


Figure 2: Depiction of the intervals for t_C^E, t_R^E and t^E

Figure 2 provides an illustration of the intervals in which t_C^E, t_R^E and their sum t^E lie. The red line depicts the best response function $t_C\left(t_R; s\right)$ for the city government. Given Lemma 1 and 2, the equilibrium couple $\left(t_C^E, t_R^E\right)$ (which may not be unique) necessarily belongs to the segment of the red line delimited by the blue lines, representing $t_R^{C*}(t_C, \hat{r}_C)$ and $t_R^{H*}(t_C; \hat{r}_H)$. Vector $\underline{\pi}$ (that would obtain if $t_R^E = t_R^{C*}(t_C; \hat{r}_C)$, i.e. the median city voter $\hat{r}_C$ were decisive at both the city and the regional votes) is such that the road toll is zero, i.e. $\underline{t_R} = 0$. The reason is that, with this institutional setup, if she was decisive both at the city and regional level, any city voter would make use only of the parking charge t_C, which guarantees her the largest share of revenues. To continue, since $-1 < \frac{\partial t_C}{\partial t_R} \leq 0$ (by Lemma 1), components of $\underline{\pi}$ mark the lower bound for road toll t_R^E, as well as the upper bound for the parking charge t_C^E. For the same reason, $\overline{t_C}$ also represents the lower bound on the total car charge $t^E = t_C^E + t_R^E$ in equilibrium. The opposite extremes are marked by vector $\overline{\pi}$, which we would obtain if the median individual in the hinterland population H were decisive in the vote on the road toll t_R, i.e. $t_R^E = t_R^{H*}(t_C; \hat{r}_C)$. Components of $\overline{\pi}$ also identify the upper bound for t^E.

We are now in a position to compare the equilibrium π^E and the welfare-maximizing policy vector π^{FB}. Before introducing the results, we need to define $r^+ \equiv \bar{r}\left(1 + \frac{1-\lambda}{1+T_Q \frac{dQ}{dp}(t^{FB})}\right)$.[17] Note that $r^+ > \bar{r}$. We have the following

PROPOSITION 2: *Suppose the city government controls the parking fee t_C and the re-*

[17]There is a unique r^+, given $\bar{r}$ and λ. There is therefore no endogeneity in the conditions on parameters presented below, as they come down to comparing a linear combination of $\hat{r}_C$ and $\hat{r}_H$ to a function of $\bar{r}$ and λ. All are exogenous parameters.

gional one controls the road toll t_R. Suppose revenues are rebated via lump-sum transfers. The equilibrium traffic policy vector $\pi^E = \left(t_C^E, t_R^E\right)$ is such that

- *If median voters in both city and hinterland prefer car travel, compared to public transport, sufficiently more than the average voter (i.e. $\hat{r}_C > \frac{\bar{r}}{\lambda}$ and $\hat{r} > r^+$ hold), the total car charge is lower than optimal $t_C^E + t_R^E < t^{FB}$*

- *The opposite, i.e. $t_C^E + t_R^E \geq t^{FB}$, happens if the median city voter does not prefer cars, compared to public transport, sufficiently more than average (i.e. $\hat{r}_C \leq \frac{\bar{r}}{\lambda}$). When this condition holds, if the city controlled both road toll and parking fee, the toll would be at least as high as optimal.*

- *Even then, if the median voter in the hinterland has sufficiently strong preferences for cars (i.e. $\hat{r}_H$ is high enough), no road toll is implemented by the regional government, i.e. $t_R^E = 0$*

- *The sum of parking fee and road toll t^E is at least as high as if the city government controlled them both*

Lemma 3 provided us with some bounds on the equilibrium values of policy variables. In particular, we obtained that $\overline{t_C} \leq t_C^E + t_R^E \leq \underline{t_C} + \overline{t_R}$. In the Appendix, we prove that, if $\hat{r} \geq r^+$ and $\hat{r}_C \geq \frac{\bar{r}}{\lambda}$, then $\underline{t_C} + \overline{t_R} < t^{FB}$. Therefore, $t_C^E + t_R^E < t^{FB}$. We also prove that, if $\hat{r}_C < \frac{\bar{r}}{\lambda}$, we have $\bar{t}_C \geq t^{FB}$. Thus, $t_C^E + t_R^E \geq t^{FB}$. Finally, we prove that, when $\hat{r} > r^+$, it is either the case that $\overline{t_R} > 0$ and $\underline{t_C} + \overline{t_R} < t^{FB}$, or $\overline{t_R} = 0$ and $\pi^E = \bar{\pi} = \underline{\pi}$. Given the bounds derived in Lemma 3, we can conclude that, when $\hat{r}_C < \frac{\bar{r}}{\lambda}$ and $\hat{r} > r^+$ are verified, we have a sufficient condition to have no road toll, i.e. $t_R^E = 0$. On the other hand, the parking charge is set at the highest acceptable level for the decisive city voter, i.e. $t_C^E = \bar{t}_C$. Note that what we just described is a sufficient, though not necessary, condition to have $t_R^E = 0$. All else given, a larger intensity of preferences for cars by the median individual in the hinterland $\hat{r}_H$, reduces $\bar{t}_R$ getting it closer to zero, as illustrated in Figure 3.

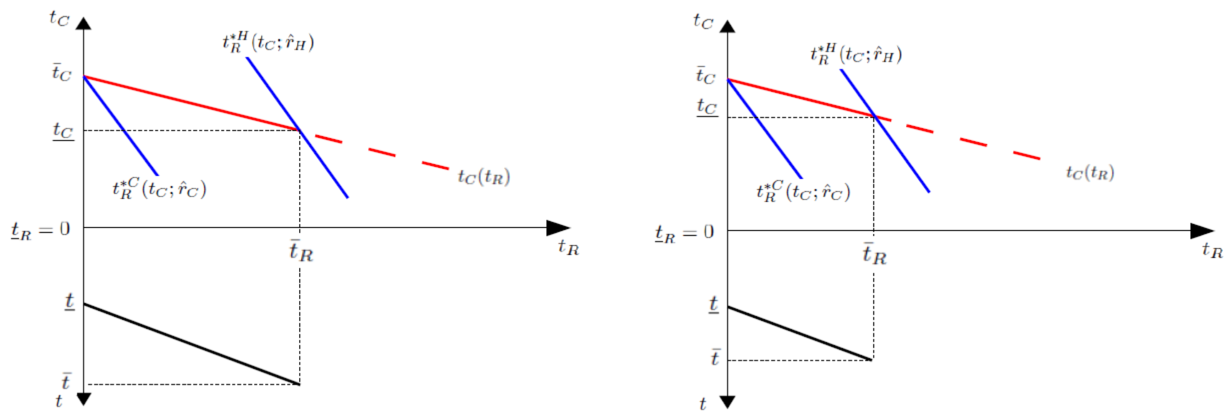


Figure 3: Change in the bounds of intervals for t_C^E, t_R^E and t^E as $\hat{r}_H$ is increased, all else equal. $\overline{t_R}$ is reduced while $\underline{t_C}$ increases. The upper bound for the total charge $\bar{t}$ is also smaller.

These findings suggest quite a negative perspective for road pricing. Suppose the majority of the city population prefers cars, relative to public transport, significantly more than average, so $\hat{r}_C > \frac{\bar{r}}{\lambda}$ holds. The city is, then, unwilling to support both the parking charge and the road toll. The same is likely to be true for the hinterland population, which is likely to have even stronger preferences for cars. In fact, even if the median city voter cares little more for car driving than for public transport (i.e., $\hat{r}_C < \frac{\bar{r}}{\lambda}$ holds), as long as the median individual in the suburban population has sufficiently strong preferences for cars, the road toll t_R collapses to zero. It may actually be that a sufficient condition for the city to choose a road toll at least as high as the optimum (if it could control it jointly with the parking charge) holds, yet the road toll is blocked by the regional government. As a response, the city government sets the parking charge at the highest level acceptable by its voters.

This suggests that an institutional setup where road pricing is under the control of regional authorities, rather than city governments, may not facilitate its adoption. Experience of cities presented in the Introduction seems quite consistent with this statement: in recent cases of successful implementation of road tolls (i.e., London, Stockholm and Milan), city governments have been decisive. In cases where they were not, outcomes have been less favorable. This was the case in Copenhagen (as discussed in the Introduction) as well as New York City where road pricing was approved by the City Council, but ultimately blocked by the State Assembly. On the other hand, parking charges, generally under exclusive control of city governments, are often used to discourage commuting to city centers and adopted through much smoother approval processes. This is true even in cities where road pricing was discarded. Again, Copenhagen seems like a fitting example: in the last seven years, the City Council has substantially raised central parking fees with the objective of discouraging car commuting.

The immediate implication of this finding is that, in order to improve chances of adoption of road tolls, city governments should be allowed to decide on them, as is the case for parking fees. However, our results suggest that letting the city government control both car charges is not always socially desirable. Indeed, we find that splitting control of traffic policy instruments among two governments is actually (weakly) preferable when both city and suburban populations oppose car charges. Interestingly, the reason is that the city and regional government do not coordinate. None of them fully takes into account the effect of a marginal increase of the charge it controls on the revenues generated by the charge set by the counterpart (a fiscal externality).[18] As a consequence, we have a phenomenon similar to the "double marginalization" studied in the industrial organization literature. Thus, car charges end up being at least as high as if both were under the control of the city government (last point of Proposition 2).

The above is a novel result in the literature on governmental interactions in pricing access to a given piece of infrastructure. Previous literature, neglecting the possibility that governments respond to heterogeneous voters, has argued that imperfect governmental coordination is generally detrimental to social welfare (De Borger *et al.* (2007), Ubbels and Verhoef (2008)). In our model, this is not necessarily true: the "upward" bias produced by imperfect coordination may partially correct the "downward" bias resulting from voters' preferences.

COROLLARY: *When the median individuals in both city and hinterland prefer car travel, compared to public transport, sufficiently more than the average voter (i.e.* $\hat{r}_C > \frac{\bar{r}}{\lambda}$ *and* $\hat{r} > r^+$*), social welfare when the (non-coordinating) city and regional government control, respectively, parking fee and road toll is at least as high as when the city government controls them both.*

4.2 The role of subsidies to public transportation

The analysis has so far neglected the possibility of using public transport subsidies to influence voters' attitudes towards car charges, such as road tolls. We here investigate such a question. We will first look at how exogenous provision of the subsidy may affect the voting equilibrium on t. As a second step, we will compare the equilibria obtained when revenues are redistributed in the generic form of a lump-sum transfer and when they are instead earmarked for the more specific purpose of financing public transport.

[18]The two-government setup is weakly prefereable because, if $t_R^E = 0$, the total car charge is the same in the two scenarios and so is welfare.

Modified setup. Since we do not focus on the institutional setup, we simplify the analysis on that front by assuming that there is a single car charge t (e.g. a proposed road toll) controlled by the city government. We disregard the presence of a regional government. Additional complexity comes from the presence of s, a (non-negative) subsidy to public transport, which, in the form of fare discounts or improved service, reduces A. The traffic policy vector π is now

$$\pi = (t; s)$$

For any individual, the budget constraint is thus

$$M + L \geq n + (p + T + x)\, q + (A - s + x)\, b$$

with $x = 0$ if the individual lives in C. The demand for car trips of a type-r individual is now

$$q(\pi; r) = \frac{r}{(p + T + s - A)}$$

while $b(\pi; r) = Y - q(\pi; r)$. We still have $q(\pi; \bar{r}) = Q(\pi)$. Note that p and s enter demands for car and public transport trips in exactly the same way. This is due to the assumptions of fixed transport demand and that trip costs enter utility linearly. We also have $\frac{dQ}{dp} = \frac{dQ}{ds} < 0$.

We assume the city government finances an (exogenously set) portion $0 < \alpha \leq 1$ of subsidy expenditures $s\,(Y - Q)$. Hence, only if $\alpha = 1$ the city finances the subsidy entirely out of her own budget. The remaining share $1 - \alpha$ is covered with money raised from general taxation at a nationwide level (assumed to put a negligible burden on the urban area's population): this essentially represents a grant from the national government.

In what follows we will consider two redistribution rules for the revenues generated by car charges: lump-sum redistribution and earmarking for public transportation. Under *lump-sum redistribution*, G_C uses (as in the previous Section) an undifferentiated lump-sum transfer L_{G_C} to rebate revenues to its voters. The city government's budget constraint is thus

$$\lambda L_{G_C} = t_C Q - \alpha s\,(Y - Q)$$

so that the indirect utility function (1) for a type-r individual (written after replacing L_{G_C} and $L_{G_R} = 0$ and redenoting t_C as t) is

$$V_C(\pi; r) = \frac{r}{(p + T - A + s)} + M + (s - A)\, Y + \frac{tQ - \alpha s\,(Y - Q)}{\lambda} \tag{7}$$

Under *earmarking* of for public transport, revenues from t are instead used to finance s: we have thus $L_{G_C} = 0$ and the budget balance condition

$$tQ = \alpha s(Y - Q)$$

has to hold.

The utilitarian social welfare function $W(\pi)$ is computed as in the previous section, except that we now need to subtract the cost of s which is not covered by G_C's budget, $(1-\alpha)\,s\,(Y-Q)$. We have thus

$$\begin{aligned} W(\pi) &= \lambda \int_0^{r^u} V_C(\pi, T, A; r) dF_C(r) + (1-\lambda) \int_0^{r^u} V_H(\pi, T, A; r) dF_H(r) - (1-\alpha)\, s\,(Y-Q) \\ &= \frac{\bar{r}}{(p+T+s-A)} + M + \lambda L_{G_C} + L_{G_R} + (s-A)\,Y - (1-\alpha)\, s\,(Y-Q) - xY\,(1-\lambda) \end{aligned}$$

which, replacing for λL_{G_C} (as computed above) and $L_{G_R} = 0$ (the regional government having no role here) gives (irrespectively of the rebate rule adopted)

$$W(\pi) = \frac{\bar{r}}{(p+T+s-A)} + M - AY + (t+s)\,Q - xY\,(1-\lambda) \tag{8}$$

As the reader can conjecture at this point, due to our assumption of fixed total trip quantity, only the sum of car charges and public transport subsidy $t + s$ matters from a pure welfare maximization perspective: t and s are perfectly equivalent instruments. Indeed, the benchmark policy vector $\pi^{FB} = \left(t^{FB}; s^{FB}\right)$ is now such that

$$(t+s)^{FB} = \gamma Q^{FB}$$

i.e., the first-best combination of car taxes and subsidies to public transport $(t+s)^{FB}$ is equal to the marginal external cost of a car trip.

4.2.1 The effect of providing a subsidy to public transport

We here study the effect of switching from a policy with no public transport subsidy (i.e. $s = 0$) to one where the subsidy is introduced (i.e. $s > 0$). We assume that revenues from the road toll, net of subsidy expenditures, are redistributed to the population through a lump-sum transfer. If the difference between charge revenues and costs of financing public transport is negative, the shortfall is covered via a lump-sum tax. The subsidy level is set exogenously.[19] Provision of public transport subsidies is often advocated to weaken voters'

[19] If we had let the city vote on s as well as t, as long as $\alpha = 1$, this would have resulted in $s = 0$ and, consequently, no change in t^E. This is because, to curb car traffic, city voters would rather make use of a car charge that produces extra revenues (being paid also by the people from H), than finance a subsidy to public

opposition to proposed road tolls. This is why we focus our attention on the case where, when $s = 0$, the city government chooses a charge t^E below the welfare-maximizing level t^{FB}. We obtain the following

PROPOSITION 3: *Suppose that, when revenues are redistributed lump-sum and no subsidy to public transport is provided, the voting equilibrium is such that the road toll t is lower than optimal. If a subsidy to public transport is provided, the toll gets closer to the optimum only if the subsidy is partially financed by the national government.*

Denote as t_0^E the voting equilibrium car charge with lump-sum revenue redistribution and no subsidy to public transport ($s = 0$). Suppose that there is insufficient political support for the car charge, that is $t^{FB} > t_0^E$. The equilibrium π^E is such that when user costs of public transport are reduced, setting $s > 0$, we have $(t+s)^{FB} > t^E(s) + s > t_0^E$ only if $\alpha < 1$.

We have argued above that charge t and subsidy to public transport s are perfectly substitutable instruments from the perspective of a welfare-maximizing government (see expression (3)). This is because, due to the fixed amount of trips assumption, t and s enter travel demands in exactly the same way. A marginal increase in s induces travelers to reduce car use to the advantage of public transport. This reduces, for each local voter, the extra (private) expenditures generated by an increase in the road toll. However, a larger subsidy not only increases governmental expenditures $s(Y - Q)$, but also reduces the tax base tQ. This has a negative impact on voters because the lump-sum transfer the government can pay back is diminished. Such a negative impact is fully internalized if the public transport subsidy is *entirely* financed by the city (i.e. $\alpha = 1$). In that case, a positive s leads to an equal reduction in the most-preferred charge t by any voter (with respect to the case in which the subsidy were not provided). When, instead, the subsidy is *only partially* financed by the city government (i.e. $\alpha < 1$), local voters do not fully internalize its impact on public finances. As a consequence, when s is provided, the equilibrium car charge is reduced less than proportionally. Hence, conditionally on s, t^E is higher than when $\alpha = 1$ and, most importantly, closer to the welfare optimum $(t+s)^{FB}$. See Figure 4 for an illustration.

Road pricing is usually proposed as part of "policy packages" that include subsidies to public transport. Proposition 3 suggests that, when combined with a proposal for a road toll, the subsidy to public transport has a welfare-enhancing effect only as long as its cost is not financed entirely by the local government. This provides an additional justification to the provision of grants for public transport from national to local governments: according to our result, these can be crucial in order to help relax political constraints on instruments such

transport that is used also by people in H. In order to have C choose a positive s, it would be necessary to have $\alpha < 1$. Therefore, the qualitative results would not change.

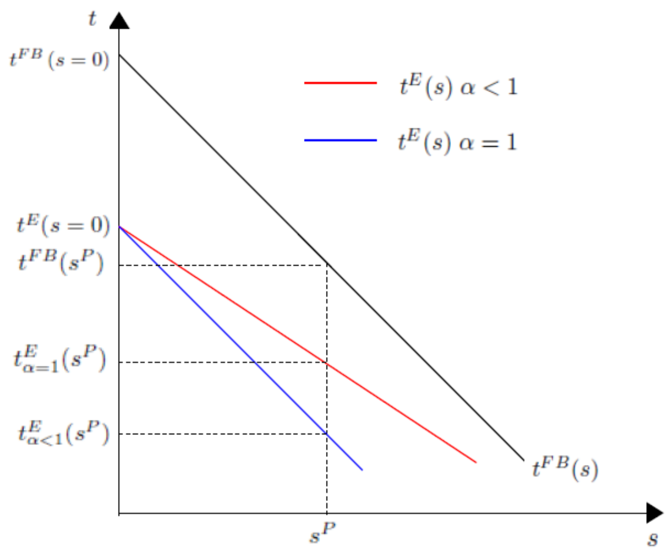


Figure 4: The black line $t^{FB}(s)$ depicts the first best values of t conditionally on s: it is downward sloping with a slope smaller than one in absolute value. The blue line $t^{E}_{\alpha=1}(s)$ depicts the equilibrium values of the car charge t conditionally on s when $\alpha = 1$. The red line depicts $t^{E}_{\alpha<1}(s)$ when $\alpha < 1$.

as road pricing. By choosing suboptimal car charges, (the majority of) city voters impose a negative externality on the rest of the population. In the absence of a direct instrument that aligns their interest with society's, a financial contribution from a higher government level corrects the "political" externality.

This result is also interesting from the perspective of second-best theory. Subsidizing public transport, the argument goes, is optimal in the presence of political constraints on a first best instrument, i.e. a pigouvian tax on car trips. Nevertheless, by endogenizing the political constraint on the road toll, we have obtained here that simple provision of the subsidy may not be useful. Extra funding for the local government may be required.

4.2.2 Earmarking of car charge revenues for public transportation

An often debated issue is whether earmarking revenues of road pricing for public transportation can improve public acceptability. To investigate it, we now compare voting equilibria on the road toll t under lump-sum redistribution (a generic form of rebate) and earmarking. The voting equilibrium under earmarking is denoted $\pi^{E}_{e} = \left(t^{E}_{e}; s^{E}_{e}\right)$. We have argued above that the first-best policy vector π^{FB} is such that the optimal combination of car charges and improvements to public transport is equal to the marginal external cost of a car trip, i.e. $(t+s)^{FB} = \gamma Q^{FB}$. Since there is an infinity of couples t, s whose sum is equal to $(t+s)^{FB}$, we have an infinite set of π^{FB} vectors. However, in the earmarking regime, the first-best vector π_e^{FB} is unique, since, in addition, it has to satisfy the budgetary-balance condition

$$BB: \quad t_e^{FB} Q_e^{FB} = \alpha s_e^{FB} \left(Y - Q_e^{FB} \right)$$

where $Q_e^{FB} \equiv Q\left(\pi_e^{FB}\right)$ and, again, α is the fraction of subsidy expenditures financed by the city government. We obtain the following

PROPOSITION 4: *Suppose that, when revenues are redistributed lump-sum, the voting equilibrium is such that the road toll is below the optimum. Earmarking revenues for (a subsidy to) public transport brings to an equilibrium such that, conditionally on the subsidy, the toll is closer to the optimum only if these revenues are topped up with extra funds by the national government.*

Denote as t_0^E the car charge obtained as a voting equilibrium with lump-sum revenue redistribution and no public transport subsidy ($s = 0$). Suppose that, in such case, there is insufficient political support for the car charge, that is $t^{FB} > t_0^E$. Earmarking car charge revenues to finance subsidies to public transport leads to an equilibrium $\pi_e^E = \left(t_e^E, s_e^E\right)$ such that $(t+s)^{FB} \geq t_e^E + s_e^E > t_0^E$ only if $\alpha < 1$. The intuition for this result is related to that of Proposition 3. With earmarking, lower cost of using public transport shrinks the tax base (i.e. car trips) from which revenues are drawn. Moreover, it increases expenditures for the city government, as demand for public transport goes up. Because of this, it turns out, the amount of funds actually available for public transport is insufficient to compensate voters opposing the car charge. When no extra funds are granted to the city government, conditionally on s, the difference between the optimal toll and the equilibrium one is the same as when revenues are rebated lump-sum. As a result, no change in social welfare is produced. On the contrary, when the subsidy to public transport is financed by both earmarked charge revenues and additional external funds, i.e. $\alpha < 1$, the equilibrium toll, conditionally on s, is closer to the welfare optimum. Therefore, social welfare goes up. See Figure 5 for an illustration.

Previous findings by De Borger and Proost (2012, Proposition 4) have suggested that earmarking revenues for public transportation can help soften voter‘s reluctance to accept socially-optimal road tolls. Our result differs in that is suggests that, in order to be welfare-enhancing, toll revenues have to be topped up by an external government.

As mentioned above, tangible financial support at the national level typically accompanies urban road pricing proposals. Our results may provide an additional justification for such practice. Indeed, price reductions to public transport in Copenhagen were unavailable, as compensation for the proposed road toll, also because the national government would not cover the projected shortfall for the local transit operator. On the other hand, the Swedish

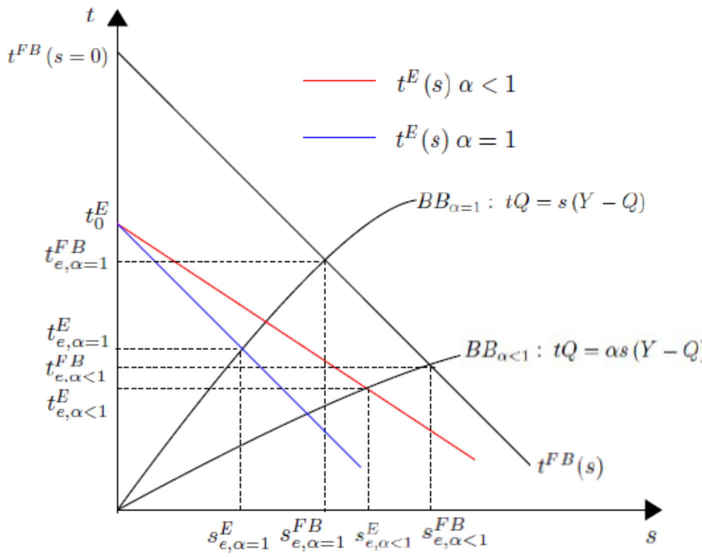


Figure 5: Comparison of equilibria under earmarking when charge revenues are topped up with extra funds by the central government (i.e. $\alpha < 1$) and when they are not ($\alpha = 1$)

government funded part of the public transport expansion in Stockholm before the road pricing trial. Furthermore, the British government set up the Urban Challenge Fund to support municipalities that implement road pricing. These examples suggest that supplementary financial support can be an important incentive to make road pricing appealing to local policymakers.

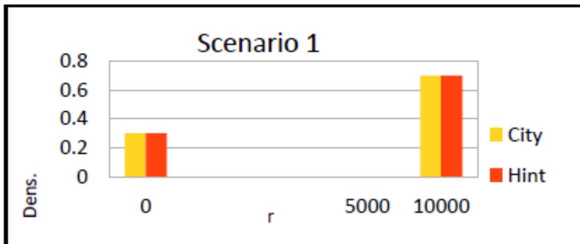
5 A numerical example

We here provide a numerical illustration of the results. We consider four scenarios, each characterized by distributions $F_C(r)$ and $F_H(r)$. These are very stylized, with a discrete support including only 3 values: 0, 5000 and 10000. Since suburban car dependence characterizes most cities, we chose to consider a population in H that is, for its majority, strongly attached to cars. $F_H(r)$ is such that 70% of the population has strong preferences for cars ($r = 10000$), while 30% does not care for driving ($r = 0$). The scenarios differ in $F_C(r)$, as we vary the fraction of the city population characterized by $r = 10000$. The distributions are depicted below. The remaining parameter values are as follows: $\lambda = 0.75$, $\alpha = 0.9$, $d = 20$, $Y = 100$, $\gamma = 1$.

In Scenario 1, $F_C(r)$ and $F_H(r)$ coincide. Focusing first on the $\rho = l$ and $s = 0$ regime, we can see that conditions ensuring too small car charge ($t^E < t^{FB}$), as seen in Proposition 2 are verified. Moreover, the portion of individuals with high valuation for cars in H is sufficiently large that the road toll is blocked, i.e. $t^E_R = 0$. When improvements to public transport are introduced (we consider $s = 0.1$) we obtain a reduction in the equilibrium car tax t^E smaller than the value of s. This indicates that, when the fraction of subsidy expenditures financed by the city is smaller than one, the local economy gets closer to the social optimum with respect to the case in which there are no interventions on public transport. A similar effect is observed when shifting to the earmarking ($\rho = e$) regime.

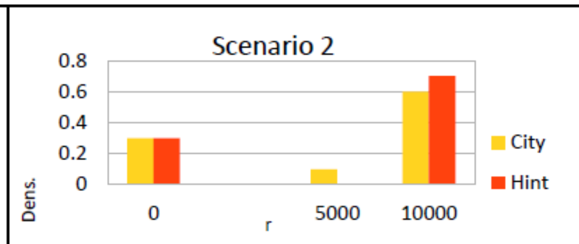
Scenario 2 and 3 present distributions of preferences in C such that the fraction of individuals strongly attached to cars is smaller than in Scenario 1. It is, nevertheless, still dominant. Thus, while the majority of the population is still made of frequent drivers, the total volume of car trips is smaller. Quite interestingly, this brings to charges which are even smaller, compared to the first best, than in Scenario 1. The reason for this is that the volume of funds that can be rebated to the population is smaller: the frequently-driving majority is even more penalized by the introduction of traffic restraint measures. In both scenarios there is no cordon toll and, in Scenario 3, the parking charge is also equal to zero. The role of s is the same as in Scenario 1. Switching to $\rho = e$ in Scenario 3 does not bring to any change in the equilibrium: this is due to the fact that, with a zero tax being the optimal choice of the city population, no funds for s are available even when earmarking is introduced.

Finally, in Scenario 4, people with strong valuation for cars do not represent the majority in the city anymore, while they still do in the hinterland. The result we obtain is that of a parking charge that is above the optimum. Yet, the equilibrium is still such that there is no road toll.



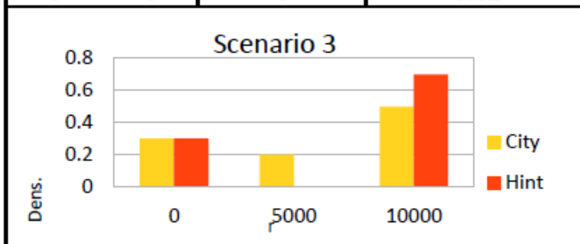
$r^\wedge_C$	$r^\wedge_H$	$r^\wedge$	$r+$	r/λ	$(t+s)^{FB}$
10000	10000	10000	8994	9333	1.61

ρ=l, s=0		ρ=l, s=0.1	ρ=e
t_C	$\underline{t}_C$	t_C^E	t^E_e
0.845	0.845	0.77	0.84
$\underline{t}_R$	t_R	t_R^E	s^E_e
0	0	0	0.02



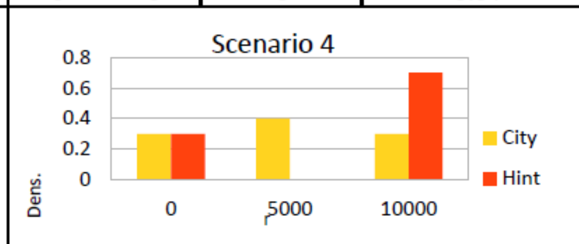
$r^\wedge_C$	$r^\wedge_H$	$r^\wedge$	$r+$	r/λ	$(t+s)^{FB}$
10000	10000	10000.	8342	8667	1.55

ρ=l, s=0		ρ=l, s=0.1	ρ=e
t_C	$\underline{t}_C$	t_C^E	t^E_e
0.2411	0.2411	0.15	0.25
$\underline{t}_R$	t_R	t_R^E	s^E_e
0	0	0	0.01



$r^\wedge_C$	$r^\wedge_H$	$r^\wedge$	$r+$	r/λ	$(t+s)^{FB}$
10000	10000	10000.	7691	8000	1.497

ρ=l, s=0		ρ=l, s=0.1	ρ=e
t_C	$\underline{t}_C$	t_C^E	t^E_e
0	0	0	0
$\underline{t}_R$	t_R	t_R^E	s^E_e
0	0	0	0



$r^\wedge_C$	$r^\wedge_H$	$r^\wedge$	$r+$	r/λ	$(t+s)^{FB}$
5000	10000	6250.	6392	5500.	1.288

ρ=l, s=0		ρ=l, s=0.1	ρ=e
t_C	$\underline{t}_C$	t_C^E	t^E_e
5.06	5.06	4.97	4.98
$\underline{t}_R$	t_R	t_R^E	s^E_e
0	0	0	0.11

6 Concluding remarks

In the first part of this work, we have studied how the institutional setup may influence traffic congestion policy. We have looked at a setup which seems to be quite commonplace in reality, with a regional government controlling a cordon toll and a city council controlling a parking charge. The political acceptability of a policy such as road pricing is enhanced by letting city governments decide whether to adopt it, just as it normally is the case for parking fees. Nevertheless, letting the city government control all traffic policy instruments is not always socially optimal. We found that a setup where two non-coordinating governments charge for access to the same piece of infrastructure (the congestible road) may be superior, in terms of social welfare, to one in which all car charges are under the control of the city government. In the second part of the paper, we have considered the role of public transport subsidies as a compensation for voters when a road toll is proposed: we have found that earmarking revenues of road pricing for public transport improvements can improve acceptability, although additional financial support from national governments is necessary.

Of course the results obtained rest on some important assumptions. Most importantly, we have focused only on short run effects of traffic policy, ignoring residential mobility and land markets. In the long run, these are obviously likely to impact the choices of local governments. While the study of long-run effects of traffic policy is beyond the scope of our analysis, we believe at least part of the forces we described would still be relevant. We plan to extend the research in this direction in future work.

Appendix

Remark Except for Proposition 4, all the following derivations are obtained assuming the public transport subsidy s to be set at an exogenous value (not necessarily zero). The proofs we provide are therefore valid conditionally on any s, and, clearly, also in the special case in which $s = 0$ (which we consider in the main text). Hence, the reader should look at all the proofs up to that of Proposition 3 by constraining $s = 0$.

LEMMA A: *When the C population votes on t_C, and when the C and H population vote on t_R, for every voting variable (taking the others as given) voters' preferences satisfy the Single Crossing Property*

PROOF: When the C population votes on t_C, given t_R and s, define

$$MRS^C_{t_C L_C}(\pi; r) \equiv \frac{\frac{\partial V^C(\pi;r)}{\partial t_C}}{\frac{\partial V^C(\pi;r)}{\partial L_C}} \qquad MRS^C_{K L_C}(\pi; r) \equiv \frac{\frac{\partial V^C(\pi;r)}{\partial K}}{\frac{\partial V^C(\pi;r)}{\partial L_C}}$$

and when the C and H population vote on t_R, given t_C and s, define

$$MRS^C_{t_R L_R}(\pi; r) \equiv \frac{\frac{\partial V^C(\pi;r)}{\partial t_R}}{\frac{\partial V^C(\pi;r)}{\partial L_R}} \qquad MRS^H_{t_R L_R}(\pi; r) \equiv \frac{\frac{\partial V^H(\pi;r)}{\partial t_R}}{\frac{\partial V^H(\pi;r)}{\partial L_R}}$$

Now $MRS^C_{t_C L_C} = MRS^C_{t_R L_R} = MRS^H_{t_R L_R} = -q(r) \cdot \left(1 + T_Q \frac{dQ}{dp}\right)$, for any π and r. Therefore ${}^{\partial MRS}/_{\partial r} = -\frac{\partial q(r)}{\partial r} \cdot \left(1 + T_Q \frac{dQ}{dp}\right) < 0$, since $\frac{\partial q}{\partial r} > 0$ and $1 + T_Q \frac{dQ}{dp} > 0$ for any π and r. Using the results of Gans and Smart (1996), the Single Crossing condition holds. ■

Derivation of the benchmark policy

The objective is

$$\max_{\{t,s\}} W(\pi)$$

The first order conditions are

$$\frac{\partial W}{\partial t} = \frac{\partial W}{\partial s} = -QT_Q \frac{dQ}{dp} + (t + s)\frac{dQ}{dp} = 0 \Rightarrow t + s = QT_Q$$

(Recall that $\frac{dp}{dt} = 1$). Let Π^{FB} be the set of stationary points of $W(\pi)$. We now verify that all elements of Π^{FB} are characterized by the same value of $(t + s)^{FB}$ (which is therefore unique).

We have
$$\frac{\partial^2 W}{\partial t^2} = \frac{\partial^2 W}{\partial s^2} = -\left(\frac{dQ}{dp}\right)^2 T_Q - QT_Q\frac{d^2 Q}{dp^2} + \frac{dQ}{dp} + (t+s)\,\frac{d^2 Q}{dp^2}$$

In the neighborhood of any element of Π^{FB} (for which the first order conditions above hold), this expressions simplifies to

$$\frac{\partial^2 W}{\partial t^2} = \frac{\partial^2 W}{\partial s^2} = \frac{dQ}{dp} - \left(\frac{dQ}{dp}\right)^2 T_Q < 0$$

Thus, given that $W(\pi)$ is a continuously differentiable function of π, there can exist a unique value of $(t+s)^{FB}$ and $W(\pi)$ is a strictly concave function of π. The benchmark policy of page 11 can simply be obtained by constraining $s = 0$.

Proof of Lemma 1

By Single Crossing, proved in Lemma A, we have existence of majority voting equilibria $t_C(t_R; s) = t_C^*(t_R; s, \hat{r}_C)$ (this follows from a result in Gans and Smart (1996)). We proceed assuming that $t_C^*(t_R; s, \hat{r}_C)$ is an interior maximizer of $V_C(\pi; \hat{r}_C)$, for given, t_R and s. This is always the case in equilibrium. We verify in Technical Appendix A that (for given t_R and s) any t_C satisfying the first order condition $\frac{\partial V_C(\pi;\hat{r}_C)}{\partial t_C} = 0$ also satisfies the second order condition. Thus, since $V_C(\pi; \hat{r}_C)$ is a continuously differentiable function of t_C, $t_C^*(t_R; s, \hat{r}_C)$ must be unique.

Let us now prove the comparative statics. In a neighborhood of $t_C(t_R; s)$, we can express t_C as function of $\hat{r}_C$,λ,t_R and s, using the Implicit Function Theorem. We have

$$\frac{\partial t_C}{\partial \hat{r}_C} = -\frac{\frac{\partial^2 V_C}{\partial t_C \partial \hat{r}_C}}{\frac{\partial^2 V_C}{\partial t_C^2}} \quad \frac{\partial t_C}{\partial \lambda} = -\frac{\frac{\partial^2 V_C}{\partial t_C \partial \lambda}}{\frac{\partial^2 V_C}{\partial t_C^2}} \quad \frac{\partial t_C}{\partial t_R} = -\frac{\frac{\partial^2 V_C}{\partial t_C \partial t_R}}{\frac{\partial^2 V_C}{\partial t_C^2}}$$

The denominator of all three expressions is $\frac{\partial^2 V_C}{\partial t_C^2} < 0$, by second order conditions (see Technical Appendix A). Let us look at $\frac{\partial^2 V_C}{\partial t_C \partial \hat{r}_C}$ and $\frac{\partial^2 V_C}{\partial t_C \partial \lambda}$. It can be easily verified that $\frac{\partial^2 V_C}{\partial t_C \partial \hat{r}_C} < 0$ and $\frac{\partial^2 V_C}{\partial t_C \partial \lambda} < 0$. Hence, $\frac{\partial t_C}{\partial \hat{r}_C} < 0$ and $\frac{\partial t_C}{\partial \lambda} < 0$, as stated in the text. Let us now focus on $\frac{\partial t_C}{\partial t_R}$. We prove in the Technical Appendix A that $\frac{\partial^2 V_C}{\partial t_C \partial t_R} < 0$ in the neighborhood of $t_C(t_R, s)$. As a consequence, $\frac{\partial t_C}{\partial t_R} > -1$ if and only if $\frac{\partial^2 V_C}{\partial t_C \partial t_R} < \frac{\partial^2 V_C}{\partial t_C^2}$. Since $\frac{\partial F_1}{\partial t_R} + \frac{dQ}{dp}(\frac{1}{\lambda} - 1) = \frac{\partial F_1}{\partial t_C}$ and $\frac{dQ}{dp}(\frac{1}{\lambda} - 1) < 0$, then the condition is verified. Thus, $0 > \frac{\partial t_C}{\partial t_R} > -1$.

Technical Appendix A

The second derivative of $V_C(\pi;\hat{r}_C)$ with respect to t_C is

$$\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_C^2} = -\frac{dq(\hat{r}_C)}{dp}\left(1+T_Q\frac{dQ}{dp}\right) - q(\hat{r}_C)\left(T_Q\frac{d^2Q}{dp^2}\right) + \frac{2\frac{dQ}{dp}+(t_C+\alpha s)\frac{d^2Q}{dp^2}}{\lambda} + t_R\frac{d^2Q}{dp^2}$$

in the neighborhood of interior (local) maximizers of V_C, using (5) (equated to zero), we can replace $-q(\hat{r}_C)T_Q + \frac{(t_C+\alpha s)}{\lambda} + t_R$ and rewrite the above expression as

$$\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_C^2} = -\frac{dq(\hat{r}_C)}{dp}\left(1+T_Q\frac{dQ}{dp}\right) + \frac{2\frac{dQ}{dp}}{\lambda} + \left(\frac{q(\hat{r}_C)-\frac{Q}{\lambda}}{dQ/dp}\right)\frac{d^2Q}{dp^2}$$

This expression can be simplified using $\frac{dQ}{dp}$, $\frac{dq(r)}{dp}$ and $\frac{d^2Q}{dp^2}$. We have

$$\frac{dq(r)}{dp} = -\frac{r}{\frac{1}{2}(p+T-A+s)^3+\bar{r}T_Q} \quad \text{and} \quad \frac{d^2Q}{dp^2} = \frac{3}{4}\bar{r}\cdot\frac{(p+T-A+s)^5}{\left(\frac{1}{2}(p+T-A+s)^3+\bar{r}T_Q\right)^3}$$

with $\frac{dQ}{dp} = \frac{dq(\bar{r})}{dp}$. Substituting into $\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_C^2}$ and rearranging, we have

$$\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_C^2} = \frac{\frac{1}{2}\left(\hat{r}_C-2\frac{\bar{r}}{\lambda}\right)(p+T-A+s)^3 - \frac{2}{\lambda}\bar{r}^2T_Q - \frac{3}{4}\left(\hat{r}_C-\frac{\bar{r}}{\lambda}\right)(p+T-A+s)^3}{\left(\frac{1}{2}(p+T-A+s)^3+\bar{r}T_Q\right)^2}$$

since the denominator is positive, the sign of $\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_C^2}$ depends on its numerator. Let us focus on it. One needs, first, to divide it by $(p+T-A+s)^3$ to obtain, using $T=T_QQ$ and $Q=\frac{\bar{r}}{(p+T-A+s)^2}$,

$$\frac{1}{2}\left(\hat{r}_C-2\frac{\bar{r}}{\lambda}\right) - \frac{2}{\lambda}\frac{\bar{r}T}{p+T-A+s} - \frac{3}{4}\left(\hat{r}_C-\frac{\bar{r}}{\lambda}\right)$$

Simple rearrangements allow us to write

$$\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_C^2} < 0 \Leftrightarrow \frac{T}{p+T-A+s} > -\frac{1}{8}\left(\frac{\hat{r}_C\lambda}{\bar{r}}+1\right)$$

The last expression being negative, the condition is always verified. This implies that second order condition are verified. Consider now

$$\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_C \partial t_R} = -\frac{dq(\hat{r}_C)}{dp}\left(1+T_Q\frac{dQ}{dp}\right) - q(\hat{r}_C)\left(T_Q\frac{d^2Q}{dp^2}\right) + \frac{\frac{dQ}{dp}+(t_C+\alpha s)\frac{d^2Q}{dp^2}}{\lambda} + t_R\frac{d^2Q}{dp^2} + \frac{dQ}{dp}$$

in the neighborhood of interior (local) maximizers of V_C, using (5) (equated to zero), we can write it as

$$\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_C \partial t_R} = -\frac{dq(\hat{r}_C)}{dp}\left(1 + T_Q \frac{dQ}{dp}\right) + \left(1 + \frac{1}{\lambda}\right)\frac{dQ}{dp} + \left(\frac{q(\hat{r}_C) - \frac{Q}{\lambda}}{dQ/dp}\right)\frac{d^2 Q}{dp^2}$$

following similar steps as above, we obtain

$$\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_C \partial t_R} < 0 \Leftrightarrow \frac{T}{p + T - A + s} > -\frac{1}{4}\frac{\hat{r}_C}{\bar{r}}\left(\frac{\lambda}{\lambda + 1}\right) + \left(\frac{3}{4(\lambda + 1)} - \frac{1}{2}\right)$$

which is always verified, given that $\hat{r}_C \in [0, 2\bar{r}]$, as long as (but not only if) $\lambda \geq \frac{1}{2}$.

Proof of Lemma 2

Proof of single-peakedness of tax preferences on t_R (given t_C and s)

The most-preferred $t_R^{C*}(t_C; s, r)$, given t_C and s, for an individual living in C, satisfies the following first order condition

$$\frac{\partial V_C(\pi; r)}{\partial t_R} = -q(r) \cdot \left(1 + T_Q \frac{dQ}{dp}\right) + \frac{(t_C + \alpha s)\frac{dQ}{dp}}{\lambda} + Q + t_R \frac{dQ}{dp} \leq 0$$

similarly, for an individual living in H, $t_R^{H*}(t_C; s, r)$ satisfies

$$\frac{\partial V_H(\pi; r)}{\partial t_R} = -q(r) \cdot \left(1 + T_Q \frac{dQ}{dp}\right) + t_R \frac{dQ}{dp} + Q \leq 0$$

If the latter is negative for all t_R, then clearly $t_R^{H*}(t_C; s, r) = 0$ and $V_H(\pi; r)$ is everywhere decreasing in t_R. The same can be said for $t_R^{C*}(t_C; s, r) = 0$ and $V_C(\pi; r)$. Single-peakedness would immediately follow. Consider the case in which, instead, there is at least one t_R such that the first order conditions above hold at equality (i.e. a stationary point of either V_C or V_H, given t_C and s). We prove in Technical Appendix B that such a point (for any r) would also satisfy second order conditions. This implies that any stationary point of $V_C(\pi; r)$ and $V_H(\pi; r)$ is a local maximizer. However, since these are continuously differentiable functions of t_R (given t_C and s, for any r), they can have at most one local maximizer. As a consequence, single-peakedness holds.

Technical Appendix B

The first derivative of $V_H(\pi; \hat{r}_H)$ with respect to t_R is

$$\frac{\partial V_H(\pi;\hat{r}_H)}{\partial t_R} = -q(\hat{r}_H)\left(1+T_Q\frac{dQ}{dp}\right)+t_R\frac{dQ}{dp}+Q$$

and the second derivative is

$$\frac{\partial^2 V_H(\pi;\hat{r}_H)}{\partial t_R^2} = -\frac{dq(\hat{r}_H)}{dp}\left(1+T_Q\frac{dQ}{dp}\right)-(\hat{r}_H)\left(T_Q\frac{d^2Q}{dp^2}\right)+2\frac{dQ}{dp}+t_R\frac{d^2Q}{dp^2}$$

The first derivative of $V_C(\pi; \hat{r}_C)$ with respect to t_R is

$$\frac{\partial V_C(\pi;\hat{r}_C)}{\partial t_R} = -q(\hat{r}_C)\left(1+T_Q\frac{dQ}{dp}\right)+\frac{(t_C+\alpha s)\frac{dQ}{dp}}{\lambda}+Q+t_R\frac{dQ}{dp}$$

and the second derivative is

$$\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_R^2} = -\frac{dq(\hat{r}_C)}{dp}\left(1+T_Q\frac{dQ}{dp}\right)-q(\hat{r}_C)\left(T_Q\frac{d^2Q}{dp^2}\right)+\frac{(t_C+\alpha s)\frac{d^2Q}{dp^2}}{\lambda}+2\frac{dQ}{dp}+t_R\frac{d^2Q}{dp^2}$$

In the neighborhood of interior (local) maximizers of $V_H(\pi;\hat{r}_H)$ and $V_C(\pi;\hat{r}_C)$, using, respectively $\frac{\partial V_H(\pi;\hat{r}_H)}{\partial t_R}=0$ and $\frac{\partial V_C(\pi;\hat{r}_C)}{\partial t_R}=0$, we can write $\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_R^2}$ and $\frac{\partial^2 V_H(\pi;\hat{r}_H)}{\partial t_R^2}$ as

$$\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_R^2} = -\frac{dq(\hat{r}_C)}{dp}\left(1+T_Q\frac{dQ}{dp}\right)+2\frac{dQ}{dp}+\left(\frac{q(\hat{r}_C)-Q}{dQ/dp}\right)\frac{d^2Q}{dp^2}$$

$$\frac{\partial^2 V_H(\pi;\hat{r}_H)}{\partial t_R^2} = -\frac{dq(\hat{r}_H)}{dp}\left(1+T_Q\frac{dQ}{dp}\right)+2\frac{dQ}{dp}+\left(\frac{q(\hat{r}_H)-Q}{dQ/dp}\right)\frac{d^2Q}{dp^2}$$

Following the steps of Technical Appendix A, rearrangements allow us to write that

$$\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_R^2} = \frac{\partial^2 V_H(\pi;\hat{r}_H)}{\partial t_R^2} < 0 \Leftrightarrow \frac{T}{p+T-A+s} > -\frac{1}{8}\left(\frac{\hat{r}_i}{\bar{r}}+1\right) \quad i=C,H$$

The last expression being negative, the condition is always verified. This implies that second order conditions are verified.

Proof that $t_R(t_C; s)$ lies in the interval $I = \left[t_R^{C*}(t_C; s, \hat{r}_C), t_R^{H*}(t_C; s, \hat{r}_H)\right]$

Suppose $t_R(t_C;s) < t_R^{H*}(t_C;s,\hat{r}_H) \le t_R^{C*}(t_C;s,\hat{r}_C)$. Given Lemma A, Single-Crossing of preferences for t_R implies that at least half of the H population would strictly prefer $t_R^{H*}(t_C;s,\hat{r}_H)$ to $t_R(t_C;s)$. The same has to be true for at least half of the individuals in C, given that $\hat{r}_C$ also prefers $t_R^{H*}(t_C; s, \hat{r}_H)$ to $t_R(t_C; s)$ by single-peakedness. Therefore, $t_R(t_C; s) < t_R^{H*}(t_C; s, \hat{r}_H) \leq t_R^{C*}(t_C; s, \hat{r}_C)$ is not possible. It cannot be a Condorcet Winner since at least half of the total population would prefer a t_R between $t_R^{H*}(t_C; s, \hat{r}_H)$ and $t_R^{C*}(t_C; s, \hat{r}_C)$ to $t_R(t_C; s)$. A similar reasoning shows that $t_R^{H*}(t_C; s, \hat{r}_H) \leq t_R^{C*}(t_C; s, \hat{r}_C) < t_R(t_C; s)$ is not possible either. The reasoning would be the same had we supposed $t_R^{H*}(t_C; s, \hat{r}_H) \geq t_R^{C*}(t_C; s, \hat{r}_C)$.

We now prove that $t_R^{H*}(t_C; s, \hat{r}_H) \geq t_R^{C*}(t_C; s, \hat{r}_C)$. Consider any equilibrium vector π^E. Since $t_C^E = t_C^*(t_R; s, \hat{r}_C)$, π^E must satisfy the first-order condition

$$\frac{\partial V_C(\pi; r)}{\partial t_C} = -q(\hat{r}_C)\left(1 + T_Q \frac{dQ}{dp}\right) + \frac{Q + (t_C + \alpha s)\frac{dQ}{dp}}{\lambda} + t_R \frac{dQ}{dp} \leq 0$$

which implies that, when evaluated at π^E,

$$\frac{\partial V_C(\pi; r)}{\partial t_R} = -q(\hat{r}_C)\left(1 + T_Q \frac{dQ}{dp}\right) + \frac{(t_C + \alpha s)\frac{dQ}{dp}}{\lambda} + Q + t_R \frac{dQ}{dp} < 0$$

since $\frac{Q}{\lambda} - Q > 0$. We have shown above that voters' preferences over t_R, given t_C and s, are single-peaked. Thus, both $\frac{\partial V_C(\pi;r)}{\partial t_R}$ and $\frac{\partial V_H(\pi;r)}{\partial t_R}$ are decreasing in t_R. Now, when evaluated at $t_R^{C*}(t_C; s, \hat{r}_C)$, $\frac{\partial V_C(\pi;r)}{\partial t_R} = 0$.[20] Therefore, if $\frac{\partial V_C(\pi;r)}{\partial t_R} < 0$ when evaluated at π^E, it must be the case that $t_R^E > t_R^{C*}(t_C; s, \hat{r}_C)$. Now consider the first-order derivative for individual $\hat{r}_H$

$$\frac{\partial V^H(\pi; r)}{\partial t_R} = -q(\hat{r}_H)\left(1 + T_Q \frac{dQ}{dp}\right) + Q + t_R \frac{dQ}{dp}$$

still evaluating at π^E. There are 2 possibilities: if $\frac{\partial V^H(\pi;r)}{\partial t_R} \geq 0$, t_R^E is smaller (or equal) than $t_R^{H*}(t_C, s; \hat{r}_H)$ because of single-peakedness. Then, surely $t_R^{H*}(t_C; s, \hat{r}_H) \geq t_R^E > t_R^{C*}(t_C; s, \hat{r}_C)$. If $\frac{\partial V^H(\pi;r)}{\partial t_R} < 0$, unless $t_R^E = 0$ (in which case $t_R^{H*}(t_C; s, \hat{r}_H) = t_R^{C*}(t_C; s, \hat{r}_C) = 0$), the π^E considered cannot be an equilibrium. This is because we would have

$$max\left(t_R^{C*}(t_C; s, \hat{r}_C); t_R^{H*}(t_C; s, \hat{r}_H)\right) < t_R^E$$

which is not possible, as proven above. The consequence of this reasoning is that there is no π^E such that $t_R^{C*}(t_C; s, \hat{r}_C) > 0$. We must always have that $t_R^{C*}(t_C; s, \hat{r}_C) = 0$. This also means that π^E must always be such that $t_R^{H*}(t_C; s, \hat{r}_H) \geq t_R^{C*}(t_C; s, \hat{r}_C)$.

[20] This is true unless $t_R^{C*}(t_C, s; \hat{r}_C) = 0$ as a corner solution. If it were the case, anyway, we would be sure that $t_R^{H*}(t_C; s, \hat{r}_H) \geq t_R^{C*}(t_C; s, \hat{r}_C)$.

Proof of Lemma 3

Let us begin from the case in which the most-preferred $t_R^{H*}(t_C; s, \hat{r}_H)$ is an interior maximizer, i.e. such that $\frac{\partial V^H(\pi;r)}{\partial t_R} = 0$. It is unique, by single-peakedness of voters preferences for t_R, proved in Lemma 2. It then has to satisfy

$$F: \quad \frac{\partial V^H(\pi; r)}{\partial t_R} = -q(\hat{r}_H)\left(1 + T_Q \frac{dQ}{dp}\right) + t_R \frac{dQ}{dp} + Q = 0$$

the Implicit Function Theorem tells us that $\frac{\partial t_R^{H*}(t_C;s,\hat{r}_H)}{\partial t_C} = -\frac{\frac{\partial F}{\partial t_C}}{\frac{\partial F}{\partial t_R}}$. Now, $\frac{\partial F}{\partial t_R} = \frac{\partial^2 V^H(\pi;r)}{\partial t_R^2} < 0$ when evaluated at $t_R^{H*}(t_C; s, \hat{r}_H)$. This is proven in Technical Appendix B. Moreover,

$$\frac{\partial F}{\partial t_C} = -\frac{dq(\hat{r}_H)}{dp}\left(1 + T_Q \frac{dQ}{dp}\right) - q(\hat{r}_H) T_Q \frac{d^2Q}{dp^2} + t_R \frac{d^2Q}{dp^2} + \frac{dQ}{dp}$$

When evaluated at $t_R^{H*}(t_C; s, \hat{r}_H)$, as we prove in Technical Appendix C, $\frac{\partial F}{\partial t_C} = \frac{\partial^2 V^H(\pi;r)}{\partial t_R \partial t_C} < 0$. Therefore, we get $\frac{\partial t_R^{H*}(t_C;s,\hat{r}_H)}{\partial t_C} < 0$. Focus now on the case in which $t_R^{H*}(t_C; s, \hat{r}_H) = 0$ as a corner solution. Then necessarily $\frac{\partial t_R^{H*}(t_C;s,\hat{r}_H)}{\partial t_C} = 0$.

Proof of uniqueness of $\bar{\pi}$ Let us begin from the case in which $\bar{\pi}$ is such that $t_R^{H*}(t_C; s, \hat{r}_H) = 0$ as a corner solution. Then $\bar{\pi} = (t_C(0; s), t_R = 0)$. Uniqueness of $\bar{\pi}$ follows from Lemma 1.

Consider now the case in which $t_R^{H*}(t_C; s, \hat{r}_H)$ is an interior maximizer of $V^H(\pi; r)$. $\bar{\pi}$ is such that the following conditions hold

$$F1: \quad \frac{\partial V_C(\pi;r)}{\partial t_C} = -q(\hat{r}_C)\left(1 + T_Q \frac{dQ}{dp}\right) + \frac{Q + (t_C + \alpha s)\frac{dQ}{dp}}{\lambda} + t_R \frac{dQ}{dp} = 0$$

$$F2: \quad \frac{\partial V_H(\pi;r)}{\partial t_R} = -q(\hat{r}_H)\left(1 + T_Q \frac{dQ}{dp}\right) + t_R \frac{dQ}{dp} + Q = 0$$

F1 implicitly defines t_C as a continuously differentiable function of t_R (as well as other policy parameters here treated as given). Similarly, *F2* implicitly defines t_R as a continuously differentiable function of t_C. By the Implicit Function Theorem, we have

$$\left.\frac{\partial t_R}{\partial t_C}\right._{F1} = -\frac{\frac{\partial F1}{\partial t_C}}{\frac{\partial F1}{\partial t_R}} = -\frac{-\frac{dq(\hat{r}_C)}{dp}\left(1 + T_Q \frac{dQ}{dp}\right) - q(\hat{r}_C) T_Q \frac{d^2Q}{dp^2} + \frac{2\frac{dQ}{dp} + (t_C + \alpha s)\frac{d^2Q}{dp^2}}{\lambda} + t_R \frac{d^2Q}{dp^2}}{-\frac{dq(\hat{r}_C)}{dp}\left(1 + T_Q \frac{dQ}{dp}\right) - q(\hat{r}_C) T_Q \frac{d^2Q}{dp^2} + \frac{\frac{dQ}{dp} + (t_C + \alpha s)\frac{d^2Q}{dp^2}}{\lambda} + t_R \frac{d^2Q}{dp^2} + \frac{dQ}{dp}}$$

$$\left.\frac{\partial t_R}{\partial t_C}\right._{F2} = -\frac{\frac{\partial F2}{\partial t_C}}{\frac{\partial F2}{\partial t_R}} = -\frac{-\frac{dq(\hat{r}_H)}{dp}\left(1 + T_Q \frac{dQ}{dp}\right) - q(\hat{r}_H) T_Q \frac{d^2Q}{dp^2} + t_R \frac{d^2Q}{dp^2} + \frac{dQ}{dp}}{-\frac{dq(\hat{r}_H)}{dp}\left(1 + T_Q \frac{dQ}{dp}\right) - q(\hat{r}_H) T_Q \frac{d^2Q}{dp^2} + t_R \frac{d^2Q}{dp^2} + 2\frac{dQ}{dp}}$$

We have shown in Technical Appendix A that $\frac{\partial F1}{\partial t_C} = \frac{\partial^2 V_C}{\partial t_C^2} < 0$ and $\frac{\partial F1}{\partial t_R} = \frac{\partial^2 V_C}{\partial t_C \partial t_R} < 0$, when evaluated in the neighborhood of $\bar{\pi}$. Note that $\frac{\partial F1}{\partial t_C} > \frac{\partial F1}{\partial t_R}$, since $\frac{2}{\lambda}\frac{dQ}{dp} < \left(1+\frac{1}{\lambda}\right)\frac{dQ}{dp}$. Let us now look at $\frac{\partial t_R}{\partial t_C}_{F2}$. We prove in Technical Appendix C that both $\frac{\partial F2}{\partial t_C} = \frac{\partial^2 V_H}{\partial t_C \partial t_R} < 0$ and $\frac{\partial F2}{\partial t_R} = \frac{\partial^2 V_H}{\partial t_R^2} < 0$, when evaluated in the neighborhood of $\bar{\pi}$. Moreover, given that $2\frac{dQ}{dp} < \frac{dQ}{dp}$, we have $\frac{\partial F2}{\partial t_C} < \frac{\partial F2}{\partial t_R}$. Thus, *F1* and *F2* define, in a neighborhood of $\bar{\pi}$, t_R as a strictly decreasing function of t_C. Now, $\bar{\pi}$ is necessarily such that both these functions cross on the (t_R, t_C) plane. Since we have (at couples satisfying both $F1$ and $F2$) that $\frac{\partial t_R}{\partial t_C}_{F1} < \frac{\partial t_R}{\partial t_C}_{F2} < 0$, it has to be the case that the first function crosses the second only from above. Since both are continuous, the crossing is unique. Therefore, $\underline{t_C}$ and $\bar{t_R}$ have to be unique.

Proof of uniqueness of $\underline{\pi}$ We have proven in Lemma 2 that $t_R^{C*}(t_C; s, \hat{r}_C) = 0$ at any π^E, including $\underline{\pi}$. So $\underline{\pi}$ is such that $\underline{t_R} = 0$, and, therefore, $\bar{t_C}$ coincides with $t_C\,(0; s)$. This is unique, as proven in Lemma 1.

Characterization of the bounds for t_C^E and t_R^E Recall from Lemma 1 that $-1 < \frac{\partial t_C}{\partial t_R} < 0$. Suppose that there existed a π^E such that $t_R^E > \bar{t_R}$ and, consequently, $t_C^E < \underline{t_C}$. Then $t_R^E > t_R^{H*}(t_C^E; s, \hat{r}_H)$. However, $t_R^E > t_R^{H*}(t_C^E; s, \hat{r}_H)$ is not possible since, as proven in Lemma 2, π^E must be such that $t_R^{H*}(t_C^E; s, \hat{r}_H) \geq t_R^E$. Similarly, we can prove that an equilibrium where $t_R^E < \underline{t_R} = 0$ and $t_C^E > \bar{t_C}$ is not possible. Finally, since $-1 < \frac{\partial t_C}{\partial t_R} < 0$, the bounds for $t_C^E + t_R^E$ must be given by $\bar{t_C} \leq t_C^E + t_R^E \leq \underline{t_C} + \overline{t_R}$.

Technical appendix C

We have

$$\frac{\partial^2 V_H\left(\pi; \hat{r}_H\right)}{\partial t_R \partial t_C} = -\frac{dq(\hat{r}_H)}{dp}\left(1 + T_Q\frac{dQ}{dp}\right) - q(\hat{r}_H)T_Q\frac{d^2Q}{dp^2} + t_R\frac{d^2Q}{dp^2} + \frac{dQ}{dp}$$

using the first order condition $\frac{\partial V_H(\pi;\hat{r}_H)}{\partial t_R} = 0$ (holding by assumption, since we are focusing on interior solutions), we can write it as

$$\frac{\partial^2 V_H\left(\pi; \hat{r}_H\right)}{\partial t_R \partial t_C} = -\frac{dq(\hat{r}_H)}{dp}\left(1 + T_Q\frac{dQ}{dp}\right) + \frac{dQ}{dp} + \left(\frac{q(\hat{r}_H) - Q}{dQ/dp}\right)\frac{d^2Q}{dp^2}$$

Using $\frac{dQ}{dp}$, $\frac{dq(r)}{dp}$ and $\frac{d^2Q}{dp^2}$, as in Technical Appendix A, similar rearrangements yield

$$\frac{\partial^2 V_H\left(\pi; \hat{r}_H\right)}{\partial t_R \partial t_C} < 0 \Leftrightarrow \frac{T}{p + T - A + s} > -\frac{1}{4}\left(\frac{\hat{r}_H}{2\bar{r}} - 1\right)$$

which is always verified since $\hat{r}_H \in [0, 2\bar{r}]$.

Proof of Proposition 1

Consider condition (5). When $s = 0$ and setting $t_R = 0$, this expression is the same as $\frac{\partial W(\pi)}{\partial t}$ if and only if $\hat{r}_C = \frac{\bar{r}}{\lambda}$. It is only in that case that $t_C^E = T_Q^{FB} Q^E$ (recall that $T_Q^{FB} = \gamma$). Since $t_C - T_Q^{FB} Q$ is strictly increasing in t_C, then it is only if $\hat{r}_C = \frac{\bar{r}}{\lambda}$ that $t_C^E = t^{FB}$. Since (by Lemma 1) t_C^E is decreasing in $\hat{r}_C$ and λ, the rest of the claim follows.

Proof of Proposition 2

To begin, let us focus on $\bar{\pi}$. Consider, first, the case in which $\bar{\pi}$ is such that $\underline{t_C}$ and $\bar{t_R}$ are interior maximizers of, respectively, $V_C(\bar{\pi}; r)$ and $V_H(\bar{\pi}; r)$. Conditions described as *F1 and F2* in the proof of Lemma 3 must thus hold at $\bar{\pi}$. Substituting $t_R \frac{dQ}{dp} = q(\hat{r}_H) \cdot \left(1 + T_Q \frac{dQ}{dp}\right) - Q$ from $F2$ into $F1$, multiplying both sides of the resulting expression by λ, and finally adding it to *F2* we obtain an equation that can replace $F1$. The result is the following equivalent system

$$\begin{aligned} F4:&\quad -q(\hat{r}) \cdot \left(1 + T_Q \tfrac{dQ}{dp}\right) + (t + \alpha s) \tfrac{dQ}{dp} + (2 - \lambda) Q = 0 \\ F2:&\quad -q(\hat{r}_H) \cdot \left(1 + T_Q \tfrac{dQ}{dp}\right) + t_R \tfrac{dQ}{dp} + Q = 0 \end{aligned}$$

where $\hat{r} = \hat{r}_C \lambda + (1 - \lambda) \hat{r}_H$. Importantly, *F4* contains terms that are function only of t, not of its components t_C, t_R. Thus, condition $F4$, by the Implicit Function Theorem, implicitly defines $\bar{t}$. Importantly, *F4* contains only terms that are function of $\bar{t}$, not of its components $\underline{t_C}$ and $\bar{t_R}$. We can use the Implicit Function Theorem to obtain that

$$\frac{\partial \bar{t}}{\partial \hat{r}} = -\frac{\frac{\partial F4}{\partial \hat{r}}}{\frac{\partial F4}{\partial \bar{t}}} \quad \frac{\partial \bar{t}}{\partial \lambda} = -\frac{\frac{\partial F4}{\partial \lambda}}{\frac{\partial F4}{\partial \bar{t}}}$$

We prove in Technical Appendix D that $\frac{\partial F4}{\partial \bar{t}} < 0$. The numerator of $\frac{\partial \bar{t}}{\partial \hat{r}}$ is $\frac{\partial F4}{\partial \hat{r}} < 0$. Hence, $\frac{\partial \bar{t}}{\partial \hat{r}} = -\frac{\frac{\partial F4}{\partial \hat{r}}}{\frac{\partial F4}{\partial \bar{t}}} < 0$. One can repeat the reasoning using λ as the independent variable, instead of $\hat{r}$, and obtain similar results.

Next, we prove that there exists a unique value $r^+ \equiv \bar{r}\left(1 + \frac{1-\lambda}{1+T_Q \frac{dQ(t^{FB})}{dp}}\right)$, such that if $\hat{r} = r^+$, then $\bar{\pi}$ is such that $\bar{t} = t^{FB}$. Take condition *F4* and add $Q T_Q \frac{dQ}{dp}$ to both sides. The equality obtained implies (since $q(r) = \frac{r}{(p+T-A+s)^2}$ and $q(\bar{r}) = Q$) that

$$\frac{(2-\lambda)\bar{r} - \hat{r}}{(p + T - A + s)^2} + (Q - q(\hat{r}))\, T_Q \frac{dQ}{dp} \gtreqless 0 \Leftrightarrow (t - T_Q Q) \frac{dQ}{dp} \lesseqgtr 0 \Leftrightarrow t - T_Q Q \gtreqless 0$$

We evaluate these expressions at $\bar{\pi}$. Now note that $h(\bar{t}) = \bar{t} - T_Q Q(\bar{\pi})$ (where $T_Q = \gamma$) is a strictly increasing function of $\bar{t}$. Then $h(\bar{t}) = 0$ if and only if $\bar{t} = T_Q Q(\bar{\pi})$. Therefore, we must have

$$\bar{t} = T_Q Q(\bar{\pi}) \Leftrightarrow \frac{(2-\lambda)\bar{r} - \hat{r}}{(p+T-A+s)^2} + (Q - q(\hat{r}))\, \bar{T_Q}\frac{dQ}{dp} = 0$$

One then needs to rearrange the second equality, using $q(r) = \frac{r}{(p+T-A+s)^2}$ and $q(\bar{r}) = Q$, to see that it is verified if and only if $\hat{r} = \bar{r}\left(1 + \frac{1-\lambda}{1+\bar{T_Q}\frac{dQ}{dp}}\right)$. If such a condition holds, we thus have $\bar{t} = t^{FB}$. One then needs to use $\frac{\partial \bar{t}}{\partial \hat{r}} < 0$, proven above, to see that $\bar{t} < t^{FB}$ if $\hat{r} \geq r^+$ and that $\bar{t} \geq t^{FB}$ and if $\hat{r} < r^+$.

To conclude the proof, consider the case in which $\bar{\pi}$ is such that $\bar{t_R} = 0$. In such a case, $\pi^E = \bar{\pi} = \underline{\pi}$. $\underline{\pi}$ coincides with $t_C\,(0; s)$, whose comparison to π^{FB} was provided in Proposition 1. By Lemma 3, $\bar{t_C} \leq \underline{t_C} + \bar{t_R}$. The last point of Proposition 2 follows. Proposition 1 also established that $\bar{t_C} \leq t^{FB}$ a if $\hat{r}_C < \frac{\bar{r}}{\lambda}$. This is why when $\hat{r} > r^+$ and $\hat{r}_C < \frac{\bar{r}}{\lambda}$, we can be sure that $\pi^E = \bar{\pi} = \underline{\pi}$, so $t_R^E = 0$.

Proof of Corollary to Proposition 2 Consider the case $\hat{r} > r^+$ and $\hat{r}_C > \frac{\bar{r}}{\lambda}$. Then $\bar{t}_C \leq t^E < t^{FB}$. $W\,(\pi)$ is a concave function of t, maximized (conditionally on $s = 0$) at $t = t^{FB}$. The claim follows from the last point in Proposition 2.

Technical appendix D

We intend to prove that condition

$$F_4 : -q(\hat{r}) \cdot \left(1 + T_Q\frac{dQ}{dp}\right) + (t + \alpha s)\frac{dQ}{dp} + (2-\lambda)Q \quad = 0$$

where $\hat{r} = \hat{r}_C\lambda + (1-\lambda)\,\hat{r}_H$ is such that, in the neighborhood of $\bar{\pi}$, its derivative $\frac{\partial F_4}{\partial t}$ is negative. This derivative is

$$-\frac{dq(\hat{r})}{dp} \cdot \left(1 + T_Q\frac{dQ}{dp}\right) + (3-\lambda)\frac{dQ}{dp} + (t + \alpha s - q(\hat{r})T_Q)\frac{d^2Q}{dp^2}$$

using *F4*, it can be written as

$$-\frac{dq(\hat{r})}{dp} \cdot \left(1 + T_Q\frac{dQ}{dp}\right) + (3-\lambda)\frac{dQ}{dp} + \left(\frac{q(\hat{r}) - (2-\lambda)\,Q}{dQ/dp}\right)\frac{d^2Q}{dp^2}$$

now using $\frac{dQ}{dp}$, $\frac{dq(r)}{dp}$ and $\frac{d^2Q}{dp^2}$, as in Technical Appendix A, similar rearrangements allow us to write that

$$\frac{\partial F4}{\partial t} < 0 \Leftrightarrow \frac{T}{p+T-A+s} > -\frac{\hat{r}}{4\bar{r}\,(3-\lambda)} + \frac{3}{4}\left(\frac{2-\lambda}{3-\lambda} - \frac{2}{3}\right)$$

which is always verified, since the right hand side is negative.

Proof of Proposition 3

We prove that $\frac{\partial t}{\partial s} > -1$. In the equilibrium, condition *F1* provided in the proof of Lemma 3 must be satisfied (i.e. $\frac{\partial V_C(\pi;\hat{r}_C)}{\partial t_C} = 0$), setting $t_R = 0$ and denoting now t_C as t. This condition defines $t_C\,(0; s)$ (which we may now denote as $t(s)$). Note also that here the vector of policy variables is $\pi = (t, s)$ and not $\pi = (t_C, t_R)$. The Implicit Function Theorem tells us that, in a neighborhood of $t(s)$

$$\frac{\partial t}{\partial s} = -\frac{\frac{\partial F1}{\partial s}}{\frac{\partial F1}{\partial t}}$$

where

$$\begin{aligned}
\frac{\partial F1}{\partial s} &= -\frac{dq(\hat{r}_C)}{dp}\left(1 + T_Q\frac{dQ}{dp}\right) - q\,(\hat{r}_C)\,T_Q\frac{d^2Q}{dp^2} + \frac{\frac{dQ}{dp} + t\frac{d^2Q}{dp^2} + \alpha s\frac{d^2Q}{dp^2} + \alpha\frac{dQ}{dp}}{\lambda} \\
\frac{\partial F1}{\partial t} &= -\frac{dq(\hat{r}_C)}{dp}\left(1 + T_Q\frac{dQ}{dp}\right) - q\,(\hat{r}_C)\,T_Q\frac{d^2Q}{dp^2} + \frac{2\frac{dQ}{dp} + t\frac{d^2Q}{dp^2} + \alpha s\frac{d^2Q}{dp^2}}{\lambda}
\end{aligned}$$

Now, $\frac{\partial F1}{\partial t_C} = \frac{\partial^2 V_C}{\partial t^2} < 0$ in the neighborhood of $t_C\,(0; s)$, as proven in Technical Appendix A. Therefore, $\frac{\partial t}{\partial s} > -1$ if and only if $\frac{\partial F1}{\partial s} > \frac{\partial F1}{\partial t}$. This condition is always verified in a neighborhood of $t_C\,(0; s)$. This is because, as we prove in Technical Appendix E, $\frac{\partial F1}{\partial s} = \frac{\partial^2 V_C}{\partial t_C \partial s} < 0$ if (though not only if) $\alpha \geq \frac{1}{2}$. If so, then $\frac{\partial F1}{\partial s} > \frac{\partial F1}{\partial t}$, since $\frac{\partial F1}{\partial t} = \frac{\partial F1}{\partial s} + \frac{(1-\alpha)}{\lambda}\frac{dQ}{dp}$. If instead $\frac{\partial F1}{\partial s} > 0$, then $\frac{\partial F1}{\partial s} > \frac{\partial F1}{\partial t}$ anyway.

Technical Appendix E

Consider

$$\frac{\partial^2 V_C\,(\pi; \hat{r}_C)}{\partial t_C \partial s} = -\frac{dq\,(\hat{r}_C)}{dp}\left(1 + T_Q\frac{dQ}{dp}\right) - q\,(\hat{r}_C)\left(T_Q\frac{d^2Q}{dp^2}\right) + \frac{(1+\alpha)\frac{dQ}{dp} + (t_C + \alpha s)\frac{d^2Q}{dp^2}}{\lambda} + t_R\frac{d^2Q}{dp^2}$$

in the neighborhood of interior (local) maximizers of $V_C\,(\pi; \hat{r}_C)$, using (5) (equated to zero), we can write it as

$$\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_C \partial t_R} = -\frac{dq(\hat{r}_C)}{dp}\left(1+T_Q\frac{dQ}{dp}\right)+\frac{(1+\alpha)}{\lambda}\frac{dQ}{dp}+\left(\frac{q(\hat{r}_C)-\frac{Q}{\lambda}}{dQ/dp}\right)\frac{d^2Q}{dp^2}$$

using $\frac{dQ}{dp}$, $\frac{dq(r)}{dp}$ and $\frac{d^2Q}{dp^2}$, as in Technical Appendix A and following similar steps we obtain

$$\frac{\partial^2 V_C(\pi;\hat{r}_C)}{\partial t_C \partial s} < 0 \Leftrightarrow \frac{T}{p+T-A+s} > -\frac{1}{4}\frac{\hat{r}_C}{\bar{r}}\left(\frac{\lambda}{1+\alpha}\right)+\left(\frac{3}{4(1+\alpha)}-\frac{1}{2}\right)$$

which is always verified at least as long as (but not only if) $\alpha \geq \frac{1}{2}$.

Proof of Proposition 4

Our strategy to identify π_e^E is the following. Suppose s could be set independently of t, as in the $\rho = l$ regime. Then we would be back to the setup of Lemma 1. We have proved there that, for each value of s, there exists an equilibrium $t^E(s)$ (where we set now $t = t_C$ as $t_R = 0$). Thus, by varying s, we can describe a set of equilibrium car charges $t^E(s)$. Let Σ be the set of $\left(t^E(s), s\right)$ couples. Among the elements of Σ, the equilibrium vector under earmarking $\pi_e^E = \left(t_e^E, s_e^E\right)$ is the unique one satisfying the budgetary rule

$$BB:\ tQ - \alpha s(Y-Q) = 0$$

We proceed assuming that vectors π_e^{FB} and π_e^E are such that BB describes s as an increasing function of t, so $\frac{\partial s}{\partial t}_{BB} > 0$.[21]

For a given value of s, $t^E(s) = t_C(0;s)$ is described by conditions named *F1* and *F2* in the proof of Lemma 1. In the proof of Proposition 3, we have argued that $t^E(s) = t_C(0;s)$ is such that $\frac{\partial t}{\partial s} > -1$. When adopting the BB rebate rule, there are two possibilities: if, for $s = 0$, π^E is such that $t_0^E = 0$, then imposing BB will leave the equilibrium unchanged. If, instead, when $s = 0$, π^E is such that $t_0^E > 0$, π_e^E must be such that both t_e^E and s_e^E are strictly positive. However, any vector in Σ is such that $\frac{\partial t}{\partial s} > -1$. Therefore, π_e^E must be such that $t_e^E + s_e^E > t_0^E$.

A priori, we cannot rule out the possibility that $t_e^E + s_e^E > t_e^{FB} + s_e^{FB}$. This will happen if α is small enough. However, G_W can always set α "large enough" (i.e. close enough to one) to make sure that $t_e^{FB} + s_e^{FB} > t_e^E + s_e^E > t_0^E$.

[21] Using the Implicit Function Theorem, one can show that this is true as long as $Q + t\frac{dQ}{dp} + \alpha s\frac{dQ}{dp} > 0$. That is, a marginal increase in the car tax produces an increase in the revenues generated by the tax itself (net of expenditures for s). Note that, in our setup, the highest possible value of t, in equilibrium, is the most-preferred by the individual for which $r = 0$. Since she never drives, this individual will simply choose t so as to maximize total (net) revenues $tQ - \alpha s(Y-Q)$. There is no reason for her to pick a tax such that marginal revenues are negative.

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