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Working Paper

The Political Economy of Cordon Tolls

CESifo Working Paper, No. 5558

Provided in Cooperation with:

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Suggested Citation: De Borger, Bruno; Russo, Antonio (2015) : The Political Economy of Cordon Tolls, CESifo Working Paper, No. 5558, Center for Economic Studies and ifo Institute (CESifo), Munich

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CESIFO WORKING PAPER NO. 5558

CATEGORY 1: PUBLIC FINANCE

OCTOBER 2015

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ISSN 2364-1428

CESifo

Center for Economic Studies & Ifo Institute

The Political Economy of Cordon Tolls

Abstract

This paper studies the political economy of cordon tolls, the most common form of road pricing in cities. We consider a monocentric city inhabited by renters and resident-landowners. A cordon toll raises the rental price of land within the cordon, and it reduces rents outside this area. Hence, the toll redistributes welfare between renters and landowners, and between owners of land in different locations. Assuming majority voting we show that the equilibrium toll is below the socially optimal level – possibly even zero -- unless the majority of residents owns land within the cordon. Second, if residents have heterogeneous wages, the baseline results still hold, unless the poor live in the center and own a large share of land within the cordon. Third, moving the cordon further away from the city center shifts the political power from renters to landowners and from residents in the suburbs towards those living closer to the center. Finally, under reasonable conditions, it is easier to get a majority in favor of a toll close to the city center than a cordon further out in the suburbs. These results are consistent with several stylized facts, including (i) the low political acceptability of cordon tolls, (ii) the observation that existing (and contemplated) toll schemes predominantly encompass a small area around the city center.

JEL-Code: R410, D780, H230.

Keywords: cordon tolls, road pricing, voting, monocentric city.

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We thank Jan Brueckner, Moez Kilani, Jos van Ommeren and seminar participants at the University of Lille, the 2014 Urban Economics Association conference in Washington DC, the 2015 ITEA conference in Oslo and the 2015 ERSa meeting in Lisbon for useful comments. All errors are ours.

1. Introduction

Road congestion is one of the major problems faced by city governments around the world. To force drivers to internalize the external costs of automobile traffic, economists have long been advocating the implementation of road pricing measures. Of course, first-best road pricing policies require sophisticated, distance-based pricing instruments that allow charging road users as a function of congestion and pollution levels. Unfortunately, in urban areas such instruments are difficult to implement, as each car's path would have to be monitored to compute the relevant charges. City governments have therefore focused on less ambitious but feasible second-best policies: the urban road pricing schemes that currently exist (or have recently been contemplated) are *cordon tolls*. The idea is to place a 'cordon' around the city center and to charge drivers entering the area so defined. It has been implemented in London, Oslo, Stockholm, Milan and Singapore. Two examples are given on Figure 1.

Although the issue is also on the political agenda in many other cities throughout Europe and the US, governments often appear unable or unwilling to implement road pricing measures. The list of examples where cordon tolls have been discussed but not introduced is much longer than the few examples of successful introduction given before, and it includes New York, San Francisco, a variety of towns in the UK (for example, Birmingham, Edinburgh and Manchester), several cities in Belgium, the Netherlands, etc. Although economists have shown their positive welfare effects, political acceptability of urban road pricing measures is still a major challenge (Small and Verhoef (2007)).¹ To better understand why this is the case, this paper develops a simple political economy model of cordon pricing.

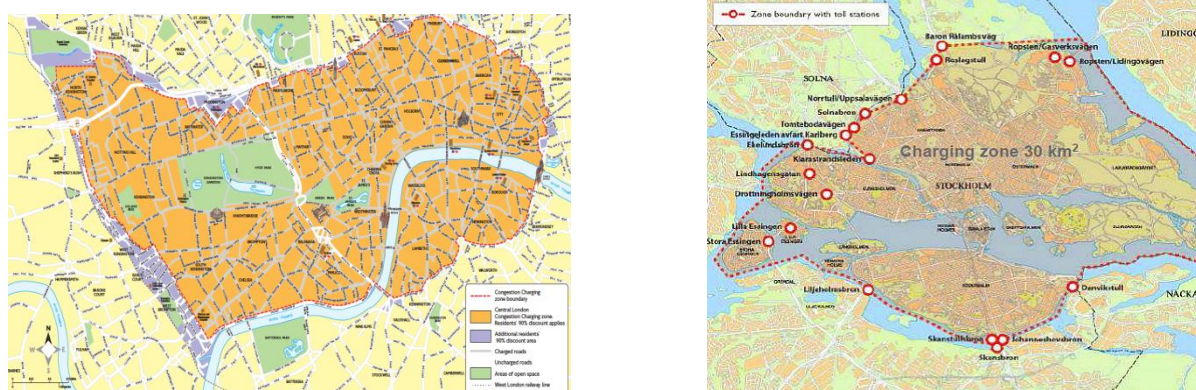


Figure 1: Road pricing in London (left) and Stockholm (right).

¹ The literature sometimes refers to cordon tolling as “second best” road pricing because it is not distance-based. According to previous findings, cordon tolls can achieve a large fraction of the welfare gains attainable with first-best pricing (see, e.g., Mun et al. (2003) and Verhoef (2005)).

We consider a monocentric city and distinguish three zones: the city center where all employment is located, a midcity region and a suburban zone. The morning commute has drivers from the midcity and the suburban region travel to the center. The road system is congestible. Building upon the framework developed by Brueckner and Helsley (2011) and extended in Brueckner (2015), we model the cordon toll as a tax on all cars entering an area that encompasses the city center. The toll affects the desirability of living in the different urban zones. Indeed, in equilibrium, land rents (and population density) within the cordon increase with the toll, and they decrease outside the tolled zone.

In the baseline model, we study majority voting on a cordon toll placed in the immediate proximity of the city center, taking into account the implications of landownership arrangements. Not surprisingly, we find that the extent to which city residents support the toll depends not only on whether they own land, but also on where the land they own is located.² Assuming that total land rent increases with the toll, we show that the voting equilibrium yields a toll equal to or higher than the optimal level only if the majority of voters owns land within the cordon, and the share of land they own is large enough. If any of these two conditions does not hold, the government adopts a toll below the optimum, or even no toll at all.³ The intuition is as follows. The toll affects land rents within the city and redistributes welfare between renters and landowners. Furthermore, because land rents increase with the toll only inside the cordon, there is also redistribution within the group of landowners. Whereas the socially optimal toll is determined by considering the welfare of landowners in the entire city, a voter forms her policy preferences considering only the effect of the toll on the value of the parcel of land she owns (if any). Consequently, individuals who do not own any land prefer a toll lower than optimal. The same goes for individuals who own land outside the cordon, since the toll reduces the value of their asset. The only individuals who may prefer a toll higher or equal than the socially optimal one are those who own land within the cordon.

Although there are other potential explanations, these findings are consistent with the low political support cordon tolls have in reality. Tolling systems are generally designed to include a small fraction of the city around the center, where land tends to be scarce and expensive. It is therefore unlikely that the majority of residents own land there. This is indirectly confirmed by available data: for instance, in most large US urban areas, residents in

² In a similar vein, Bento *et al.* (2006) study anti-sprawl policies in the monocentric model, distinguishing landowners according to where they own land.

³ These results may not hold if total land rent decreases with the toll. However, as we argue in Section 3, this case can be regarded as more of a theoretical curiosity than a real possibility. Hence, we focus primarily on the case where average land rent increases with the toll. This is in line with the findings of previous literature (see, e.g., Verhoef (2005, Table 1), Safirova *et al.* (2006, p.11), and Tikoudis *et al.* (2015, fig.2)).

central cities are much less likely to own their home than residents in the suburbs (Gleaser, 2011).⁴ This observation applies also to several European cities. For example, whereas about 60% of residents in the outer suburbs of Paris (“Grande Couronne”) own their home, more than 60% of residents in the central city are renters (INSEE, 2010).⁵

Next, we extend the model to allow for wage differences between voters. Different wages (and, hence, opportunity costs of time) imply different preferences towards road congestion. We distinguish two groups, rich and poor individuals, and assume the poor are the majority. We reconsider voting on a cordon toll in the presence of the typical income-location pattern of European cities, where income tends to decrease with distance from the city center. We also model the opposite polar case, where income increases with proximity to the suburbs (the stylized income-location pattern of most American cities). We show that the baseline results still hold, as long as the poor do not own a large share of land within the cordon. In fact, it is even harder to obtain a majority for the optimal toll, since poor individuals are, all else equal, less willing to pay to reduce congestion than rich ones.

Finally, we study the political economy of toll location. In the few cities where cordon tolls have been implemented, toll location decisions have probably been made based on technical feasibility arguments. As a consequence, the cordon is typically limited to a fairly small zone surrounding the city center. However, where the cordon toll is located does matter for welfare.⁶ Moreover, adoption of a cordon toll is ultimately a political decision so that, when better technology becomes available, the question arises whether it is easier to get a political majority for a toll close to the center or further out in the suburbs. We find that moving the cordon from the center towards the suburbs shifts the political power from renters towards landowners. Moreover, under plausible conditions, we show that it is easier to get a political majority for a toll close to the city center. In sum, though highly stylized, the results are consistent with the casual observation that not only existing but also contemplated toll schemes predominantly encompass a small area around the city center.

⁴ Gleaser (2011, p. 20) reports that “According to the 2006–2008 American Community Survey, 76 percent of Manhattan residents rent but 64 percent of the residents in suburban Westchester County own their own homes. In Boston, 62 percent of residents rent, but 65 percent of residents in suburban Middlesex County own. In Chicago, 51 percent of residents rent, but 62 percent of the residents in Cook County own.” Furthermore, “...in Los Angeles 61 percent of city residents rent, but 62 percent in Orange County own. In Atlanta, 49 percent of city residents rent, but 59 percent of Clinton County residents own.”

⁵ Another example is Brussels: about 30% of homes in central Brussels are owned by the tenant, whereas the average percentage in the surrounding provinces of Vlaams-Brabant is about 70% (see http://census2011.fgov.be/data/fresult/buildingsownerliving_fr.html).

⁶ For instance, the larger the area encompassed by the cordon, the smaller the portion of trips that pay the toll. Thus, a wide cordon may be less effective in reducing congestion than a narrow one. Furthermore, the location of the cordon will affect population density. See Mun et al. (2003) for a study of optimal toll location in a monocentric city.

Our paper is at the intersection of two strands of previous literature. First, it fits within the growing literature on the political economy of urban transportation policy. Few papers in this literature explicitly model the urban land market.⁷ Exceptions include Brueckner and Selod (2006), who study the political economy of transport systems in a monocentric city, focusing on the trade-off between the monetary and time costs in choosing a system. In a similar setup, Borck and Wrede (2005, 2008) study the political economy of commuting subsidies. Using a majority voting framework (with two types of individuals, rich and poor), they describe conditions under which support for a commuting subsidy can be expected. Our paper differs by explicitly modeling road congestion. Furthermore, their focus is on commuting taxes (or commuting subsidies) as per kilometer charges. The implied discontinuous nature of cordon tolling leads to remarkably different implications, as we show below.

Second, our paper contributes to the literature on the economics of cordon tolling in urban areas. For example, Mun, Konishi and Yoshikawa (2003) studied a monocentric city with uniform residential densities and no explicit housing and land markets. They show that an optimally located second best cordon toll yields almost as much benefit as the first best Pigovian toll. The analysis is extended in Mun, Konishi and Yoshikawa (2005), who find that the welfare effects of the cordon come closer to first best as the city approaches the monocentric type. Verhoef (2005) allows for endogenous rents, residential densities and labor supply, but still finds cordon tolls to be close to first-best. More recently, Tikoudis, Verhoef and van Ommeren (2015) extended the model further to consider different toll rebate rules. In a model distinguishing three urban zones (the center, the midcity and the suburbs), Brueckner (2015) emphasizes that a cordon around the city center has an effect on land rents and population density which is non-monotonic in distance from the center. He shows that the absence of a toll when entering the midcity implies that the optimal second-best toll on entering the city center is higher than the first-best toll.

Not surprisingly, a number of papers have developed large-scale numerical models to study the implications of cordon tolling. For example, Safirova et al. (2006) analyze tolling in a model calibrated on Washington, D.C. De Lara et al. (2013) contains a very detailed simulation analysis that is richer than earlier literature in many respects; for example, they optimize road width at any distance from the center. Anas and Hiramatsu (2013) present a careful analysis of cordon tolling in a general equilibrium model applied to the Chicago

⁷ See, e.g., Marcucci et al. (2005), De Borger and Proost (2012, 2015) and Russo (2013) for political economy studies that do not consider the land market.

setting. Finally, a limited number of papers has evaluated the impact of the real world cordon tolling experiences in London, Stockholm and Milan (see, e.g., Santos (2008), Eliasson et al. (2009) and Rotaris et al. (2010)).

Remarkably, although political acceptability is a key obstacle to implementation, the above studies have not considered the political economy of toll introduction. Of course, governments have to respond to voters when choosing whether, how and where to introduce a toll. Our paper is a first attempt to study these issues in some detail.

A brief overview of the rest of the paper follows. In Section 2, we present the structure of the baseline model. Section 3 derives the voting outcomes. In Section 4 we extend the baseline model to capture differences in income between voters, allowing for different location patterns. In section 5 we discuss the political economy of toll location. Extensions and conclusions are discussed in Section 6.

2. Cordon tolling: a basic model

In this section, we introduce the idea of a cordon toll in a simple model of an urban area, allowing the toll to affect land rents and population location decisions. We first present the structure of the model and discuss the main ingredients. We then analyze the impact of a cordon toll on traffic levels and land rents throughout the urban area. Finally, as a benchmark for comparison with the voting outcomes derived in later sections, we derive and interpret the socially optimal second best cordon toll.

2.1 Setup of the model

We adopt the spatial structure of the model used in Brueckner (2015). Specifically, the city consists of three ‘islands’ or zones: a central island C where the employment center (CBD) is located, a midcity island M and a suburban island S (which includes the city boundary). The spatial structure is illustrated in Figure 2. We normalize the size of C and M to one⁸. By contrast, there is no space constraint in the suburban zone S , where supply of land is elastic at a constant rental price, normalized at zero.

⁸ We considered an alternative setup in which the size of the midcity, relative to the city center, is variable. Although more realistic, this complicated the interpretation and did not fundamentally change the results.

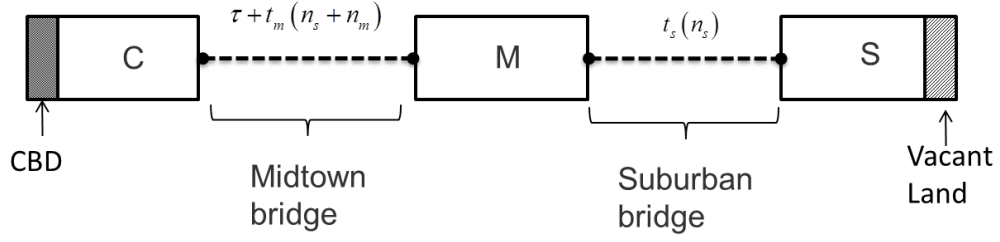


Figure 2: Spatial setup and commuting costs

The total population of the urban area is assumed to be exogenous; it is denoted N , where

$$N = n_c + n_m + n_s \quad (1)$$

In this expression, n_c, n_m, n_s refer to the number of individuals that is residing in C, M and S , respectively.⁹ Whereas N is fixed, the population of the three islands is endogenous: as will become clear, the cordon toll affects population density in the three zones and, hence, land rents. We further assume all individuals are commuters to the central city CBD. Travel demands are inelastic and all trips take place by car.¹⁰

A midcity bridge connects islands C and M , whereas a suburban bridge connects M to S . Both are congestible; the time costs of crossing the bridges (expressed in monetary terms) are

$$t_m(n_m + n_s) \text{ and } t_s(n_s), \text{ with } t'_m(.) > 0, t'_s(.) > 0.$$

Here $n_m + n_s$ is the total number of commuters crossing the midtown bridge, and n_s is the number of commuters crossing the suburban bridge. Following a simple but ingenious suggestion of Brueckner (2015), the idea of a cordon toll is implemented by assuming that a toll τ is imposed on users of the midcity bridge, whereas there is no toll on the suburban bridge. As is the case in the real-world examples of cordon tolling (London, Stockholm, etc.), the toll is paid by all traffic entering the central city zone. Note that the absence of a toll on the suburban bridge is a restriction on the set of instruments at the government's disposal. Commuting costs are also illustrated on Figure 2.

It is assumed that people living in the central city, the midcity and the suburbs care about two goods: their consumption of residential land, denoted q_j ($j=c, m, s$), and a

⁹ Throughout the paper, we use capital C, M and S to refer to the three urban zones. We use subscripts c, m and s when referring to population, housing consumption etc. in a given zone.

¹⁰ In the concluding section, we discuss how our results would change in the presence of alternative commuting modes (e.g. public transport), and of residents that do not commute to the CBD.

composite good e_j , treated as the numeraire. Preferences are specified by the quasi-linear utility function

$$u(q_j, e_j) = e_j + v(q_j) \quad ; j = c, m, s$$

where $v(\cdot)$ is increasing and concave.

We assume individuals can only spend time working or commuting. Due to differences in commuting costs, the budget and time constraints of an individual also depend on where she lives. Assuming a fixed wage, normalized at one, and an exogenously given working time Y , we combine budget and time constraints for people living in C , M and S , respectively. The resulting constraints can be written as:

$$\begin{aligned} e_c + r_c \cdot q_c &= Y + L + R^i \\ e_m + r_m \cdot q_m + \tau + t_m(n_s + n_m) &= Y + L + R^i \\ e_s + \tau + t_m(n_s + n_m) + t_s(n_s) &= Y + L + R^i \end{aligned}$$

The left-hand side captures expenditures; r_m and r_c are the rental prices of land in M and C , respectively (recall that the price of land in S is normalized at zero, ($r_s = 0$)). Of course, the expenditure side of the constraint depends on residential location. If the individual lives on island C , she does not have to cross any bridge to commute to and from the CBD . Thus, her commuting cost is zero, but she pays r_c per unit of land. An individual living in M has to sustain the cost of traveling across the midtown bridge, $\tau + t_m(n_s + n_m)$, and pays rent r_m . Finally, someone living in S has to sustain the additional commuting cost $t_s(n_s)$ but can rent land at no cost. As we will show below, in equilibrium $0 < r_m < r_c$. The choice of location is thus driven by the familiar trade-off between commuting costs and land prices.

The right-hand side of the budget constraint captures the individual's income. Labor income Y is exogenous and the same for all urban residents. This assumption will be relaxed in an extension below (see Section 4). Toll revenues are assumed to be redistributed lump-sum and uniformly to all residents. Hence, the individual's toll revenue L equals

$$L = \tau \left(\frac{n_s + n_m}{N} \right).$$

Finally, R^i represents rental income from land-ownership.¹¹ The sensitivity of land rents with respect to the cordon toll implies that voter preferences towards toll introduction may depend fundamentally on whether and where they own land. Consequently, land ownership arrangements will play an important role in voting on cordon tolls. Note that income from land ownership does not depend on where the individual lives but on whether and where she owns land, indexed by the superscript i . Specifically, to define R^i , we consider three types of residents:

- Residents owning land in C . The size of this group is denoted N^c . We denote the exogenous share of total land rent r_c in C that accrues to one such individual by β_c . Note that this share is at most $\frac{1}{N^c}$; hence, $\beta_c \in (0; \frac{1}{N^c}]$. Income from land-ownership for such an individual is $R^c = \beta_c r_c$.
- Residents owning land in M . The size of this group is N^m , and the share of total land rent r_m received by one such individual is denoted $\beta_m \in (0; \frac{1}{N^m}]$. Hence, $R^m = \beta_m r_m$.
- Residents that do not receive any income from land ownership. This group includes both owners of land on island S (where rent is normalized at 0) and residents that do not own any land. We denote the size of this combined third group by N^p . For this group, rental income is zero: $R^p = 0$. For brevity, from now on we refer to this group as “pure renters”.

Before proceeding, note the following characteristics of the specification of land ownership arrangements. First, in terms of policy preferences with respect to the cordon toll, we can treat owners of land in S and those who do not own any land at all as one group. The reason is that land rent is exogenous in S (normalized at zero) and is therefore not affected by changes in the road toll. Hence, any resident owning land there would have the same policy preferences towards the toll as a pure renter. Second, our specification allows residents to own land in a different zone than the one they live in, but assumes they own land in one zone only.¹² This simplifying assumption saves on notation and complexity without affecting the nature of the results. Third, the model captures the possibility of absentee landownership. To see this, take landownership in C as an example. Given the definitions above, the total fraction of land rent

¹¹ If the individual resides on a parcel of land she owns, it is assumed she ‘pays’ a rent to herself. This is in line with earlier literature considering resident-landowners.

¹² A special case of this specification is that all landowners own the land they live on.

in C that accrues to urban residents is given by $\beta_c N^c$. It follows that $(1 - \beta_c N^c)$ is the fraction of land owned by absentee landlords not living in the urban area. Finally, observe that N^i and land ownership shares β_i are exogenous. Of course, we have $\sum_{i=c,m,p} N^i = N$.

2.2 The impact of the cordon toll on the urban equilibrium

The effects of the toll on the urban equilibrium are easily described. Using the budget constraint to replace e_j in the utility function we obtain the utility of an individual of type i conditionally on residing in zone j . Denoting this utility by U_j^i , we have:

$$U_c^i = v(q_c) + Y + R^i - r_c q_c + \frac{\tau(n_s + n_m)}{N} \quad (2)$$

$$U_m^i = v(q_m) + Y + R^i - r_m q_m - \tau - t_m(n_s + n_m) + \frac{\tau(n_s + n_m)}{N} \quad (3)$$

$$U_s^i = v(q_s) + Y + R^i - \tau - t_m(n_s + n_m) - t_s(n_s) + \frac{\tau(n_s + n_m)}{N}. \quad (4)$$

Maximizing utilities with respect to q_j , we find that optimal land consumption satisfies¹³:

$$v'(q_j) = r_j, \quad j = c, m, s. \quad (5)$$

Due to quasi-linearity of preferences, individual land consumption only depends on the rental price of land. Equilibrium in this model also requires that space on islands C and M be fully occupied. Hence

$$n_c q_c = 1 \quad \text{and} \quad n_m q_m = 1. \quad (6)$$

Finally, assuming free mobility between zones, the standard equilibrium condition requires that utility for each individual be invariant with respect to location, i.e.

$$U_c^i = U_m^i = U_s^i = U^i; \quad i = c, m, p \quad (7)$$

Equilibrium utility depends on whether and where an individual owns land, but not on where she lives. We also have, using (2)-(4) and (7), that:

¹³ Note that individual land consumption of residents of the suburban zone S is not affected by the cordon toll. We have normalized rent in this area (at zero to save on notation); individual land consumption remains fixed throughout the analysis.

$$U^c = U^p + R^c \quad \text{and} \quad U^m = U^p + R^m.$$

The utility of a resident-landowner in the center C or the midcity zone M is identical to that of a pure renter up to the land-ownership income R^c or R^m .

Using (7) in (2)-(4) implies:

$$v(q_m) - r_m q_m - (v(q_c) - r_c q_c) = \tau + t_m (n_s + n_m) \quad (8)$$

$$v(q_s) - (v(q_m) - r_m q_m) = t_s (n_s). \quad (9)$$

Given that the right hand side of (8) and (9) is strictly positive, that $v(\cdot)$ is a concave function and using (2)-(4), it is easily shown that $q_c < q_m < q_s$ (and $0 < r_m < r_c$) in equilibrium. Lot size increases away from the center, whereas the rental price of land decreases. The meaning of (8) and (9) is then obvious: the extra surplus an individual gets from occupying a larger (and cheaper) lot of land on the midtown island, compared to the central island, is ‘compensated’ by the generalized cost of commuting across the midtown bridge. Similarly, the difference between surplus from occupying a larger lot of land on the suburban island, compared to the midtown island, is equal to the cost of crossing the suburban bridge.

To fully characterize the equilibrium, we establish how changing the cordon toll affects the density of population and land rents in the three zones. First, use (1), (5) and (6) to obtain

$$\frac{dn_s}{d\tau} = -\frac{dn_c}{d\tau} - \frac{dn_m}{d\tau} = Z_c \frac{dr_c}{d\tau} + Z_m \frac{dr_m}{d\tau} \quad \frac{d(n_s + n_m)}{d\tau} = -\frac{dn_c}{d\tau} = Z_c \frac{dr_c}{d\tau} \quad (10)$$

where $Z_c \equiv \frac{1}{q_c^2 v_c''} < 0$ and $Z_m \equiv \frac{1}{q_m^2 v_m''} < 0$. In these expressions, v_c'' is the second derivative of $v(q_c)$ computed in q_c (similar for v_m''). Differentiating (8) and (9), using (10) and rearranging, we find:

$$\begin{aligned} [q_c - (t'_m + t'_s) Z_c] \frac{dr_c}{d\tau} - [t'_s Z_m] \frac{dr_m}{d\tau} &= 1 \\ -[t'_s Z_c] \frac{dr_c}{d\tau} + [q_m - t'_s Z_m] \frac{dr_m}{d\tau} &= 0 \end{aligned}$$

Finally, solving this system we obtain the effect of the toll on land rents in the different zones:

$$\frac{dr_c}{d\tau} = \frac{1}{\Delta} [q_m - t'_s Z_m] \quad \text{and} \quad \frac{dr_m}{d\tau} = \frac{1}{\Delta} [t'_s Z_c], \quad (11)$$

where

$$\Delta \equiv [q_c - t'_m Z_c][q_m - t'_s Z_m] - q_m t'_s Z_c > 0. \quad (12)$$

This shows that

$$\frac{dr_c}{d\tau} > 0 \quad \text{and} \quad \frac{dr_m}{d\tau} < 0. \quad (13)$$

These findings are intuitive. Increasing the toll on the midtown bridge raises land rents in C but reduces them in M . The size of both effects depends on the congestibility of the two bridges. For example, (11) suggests that the effect of the toll on land rent in zone M increases with the congestibility (t'_s) of the suburban bridge. This follows from the fact that land rent in M reflects only the cost of crossing the suburban bridge. Similarly, high congestibility of the midcity bridge (i.e., a large t'_m) reduces the positive effect of the toll on land rent in C . The intuition is as follows. High congestibility implies that the reduction in traffic that comes with a higher toll brings a relatively strong reduction in the time cost of crossing the midtown bridge. As a result, the net effect of the toll on the generalized travel cost on that bridge is smaller. Finally, there is no effect on land rent in S , which is constant by assumption.

The implications for population density in the different zones easily follow. Expressions (11) and (10) imply, after straightforward algebra, that $\frac{dn_c}{d\tau} > 0$, $\frac{dn_m}{d\tau} < 0$, and $\frac{dn_s}{d\tau} < 0$. The intuition is that the toll can be avoided only by residing on island C , which gives incentive to individuals in both M and S to move there. However, individuals in S have no incentive to move to M , as this would not exempt them from paying the toll. Hence, population decreases in both M and S , and so does congestion on both bridges.

2.3. The second best optimal cordon toll

Before turning to the political economy analysis, as a benchmark we first determine the welfare-maximizing cordon toll. Of course, given the absence of a toll on the suburban

bridge, this gives a second-best optimum.¹⁴ The utilitarian social welfare function we use consists of the sum of all utilities of the urban population (including land rent accruing to residents) plus land rent accruing to absentee landowners. Note that rental income from land ownership of residents is captured in utility (see (2)-(4) above). The fractions of rental income on land in C and M that accrue to absentee landlords is given by $(1 - \beta_c N^c)$ and $(1 - \beta_m N^m)$, respectively. We can therefore write the utilitarian social welfare function as follows:

$$SW = \sum_{i=c,m,p} N^i U^i + (1 - \beta_c N^c) r_c + (1 - \beta_m N^m) r_m. \quad (14)$$

Note that we have dropped the location index from the utility specification of residents in each group because, by (7), in equilibrium utility is invariant with respect to location.

Substituting (2)-(4) in (14) and maximizing social welfare we obtain the following expression for the optimal cordon toll (the derivation is in Appendix 1):¹⁵

$$\tau^{SB} = t'_m \cdot (n_m + n_s) + \frac{q_m t'_s n_s}{q_m - t'_s Z_m} \quad (15)$$

Of course, this is not a closed-form solution, because populations and land consumption in the various zones depend on the toll. But the structure of the toll expression is clear. The first term on the right-hand side is the marginal external congestion cost: it is the increase in the cost of crossing the bridge for a small increase in traffic (t'_m) times the number of users ($n_m + n_s$). Since the second term on the right hand side is strictly positive, the optimal (second best) cordon toll exceeds the marginal external cost on the midcity bridge, where it is levied: it internalizes some of the external cost of congestion on the suburban bridge. This internalization is imperfect, however, because the toll is levied also on commuters who do not use this bridge. Using a slightly different setup, a similar result is derived in Brueckner (2015, see Proposition 1), to which we refer for a more detailed discussion.

3. Voting on the cordon toll

We keep the political process to decide on the toll as simple as possible. We adopt a standard majority voting procedure so that, under appropriate conditions, the median voter is decisive. We proceed in two steps. We first determine the most-preferred tolls by each of the three groups of urban residents (pure renters and resident-landowners on the central and

¹⁴ We ignore the first-best policy, which, as shown by Brueckner (2015), consists of Pigouvian tolls on each bridge. This result holds also in our model.

¹⁵ We assume throughout that second order conditions are satisfied.

midcity island), and we compare the toll expressions to the socially optimal cordon toll in (15). We then characterize the majority voting equilibrium.

3.1. Most-preferred tolls by residents

In this subsection, we determine the most-preferred tolls for each group $i = c, m, p$. The fact that in equilibrium all individuals belonging to the same group must have the same utility, regardless of location, facilitates the analysis. Indeed, equations (8) and (9) imply that the effects of the toll on commuting costs are fully capitalized in land rents.¹⁶ Therefore, maximizing (2), (3) or (4) with respect to the toll leads to the same result (for a given $i = c, m, p$).

Consider first what pure renters (i.e., residents receiving no rental income) would like. Maximizing (2) with respect to the toll, taking into account that $R^p = 0$, the first-order condition can be written as:

$$\frac{dU^p}{d\tau} = -q_c \frac{dr_c}{d\tau} + \frac{n_m + n_s}{N} + \frac{\tau}{N} \frac{d(n_m + n_s)}{d\tau} = 0.$$

To solve for the most-preferred toll by renters, denoted τ^p , we use similar steps as for the derivation of (15). We outline these steps in Appendix 1. There are different ways to write the expression for this toll. Given that we are interested in deviations from the second best optimum, a particularly appealing one is the following:

$$\tau^p = t'_m \cdot (n_m + n_s) + \frac{q_m t'_s n_s}{q_m - t'_s Z_m} + \frac{\Phi}{N} \left(\frac{dr_c}{d\tau} + \frac{dr_m}{d\tau} \right), \quad (16)$$

Here

$$\Phi \equiv \frac{\Delta N}{Z_c (q_m - t'_s Z_m)} < 0$$

and Δ has been defined in (12) above.

It is instructive to compare (16) to the expression for the second best toll in (15). Of course, one should be careful when making such comparisons, since one has to evaluate toll rules at different values of the endogenous variables, such as population and land consumption. However, intuition suggests that the comparison among toll rules is a useful exercise (numerical analysis below confirms that differences in toll rules translate into

¹⁶ Differentiating (8) and (9) we have $q_c \frac{dr_c}{d\tau} - q_m \frac{dr_m}{d\tau} = 1 + t'_m \frac{d(n_m + n_s)}{d\tau}$. The increase in differential land expenditures on island C and M following a toll increase is equal to the change in commuting costs on the midtown bridge. By the same token, we have $q_m \frac{dr_m}{d\tau} = t'_s \frac{dn_s}{d\tau}$.

differences in toll values). The sign of the last term on the right hand side of (16) is crucial. Given that $\Phi < 0$, it suggests that the toll τ^p renters would like is below the second best optimal toll τ^{SB} if and only if the cordon toll raises total land rent in the urban area, that is, if

$$\frac{dr_c}{d\tau} + \frac{dr_m}{d\tau} > 0. \quad (17)$$

Observe, however, that this inequality need not hold in general, given that $\frac{dr_c}{d\tau} > 0 > \frac{dr_m}{d\tau}$. See below for further discussion.

To grasp the intuition underlying the desired toll of pure renters, keep in mind that these individuals disregard the welfare of landowners. They therefore ignore the effect of the toll on the income generated by land ownership throughout the city. On the contrary, as suggested by (14), a welfare maximizing government does consider this effect. Because the toll affects land rents, it redistributes welfare between landowners and renters. As a result, pure renters want a toll smaller than the socially optimal one as long as total land rent increases with the toll (i.e., the redistribution favors landowners). By contrast, if total land rents decrease with the toll, renters prefer a toll above the socially optimal one.

Turn now to resident landowners. Their utility differs from that of pure renters in that they own a specific parcel of land. It follows from (2)-(4) and (7) that

$$\frac{dU^c}{d\tau} = \frac{dU^p}{d\tau} + \beta_c \frac{dr_c}{d\tau}, \quad \frac{dU^m}{d\tau} = \frac{dU^p}{d\tau} + \beta_m \frac{dr_m}{d\tau} \quad (18)$$

Following the same steps as above, we find the tolls wanted by landowners in C and M as, respectively:

$$\begin{aligned} \tau^c &= t'_m \cdot (n_m + n_s) + \frac{q_m t'_s n_s}{q_m - t'_s Z_m} + \Phi \left(\frac{dr_c}{d\tau} \left(\frac{1}{N} - \beta_c \right) + \frac{dr_m}{d\tau} \frac{1}{N} \right) \\ \tau^m &= t'_m \cdot (n_m + n_s) + \frac{q_m t'_s n_s}{q_m - t'_s Z_m} + \Phi \left(\frac{dr_c}{d\tau} \frac{1}{N} + \frac{dr_m}{d\tau} \left(\frac{1}{N} - \beta_m \right) \right). \end{aligned}$$

These expressions differ from (16) because resident-landowners internalize the effect of the toll on the rents generated by the parcel of land they own. Comparison with (16) suggests indeed that (subject again to the caveat that we compare expressions, not toll levels):

$$\tau^c > \tau^p > \tau^m. \quad (19)$$

That is, the most preferred toll is highest for individuals owning land in C , and lowest for land owners in M . The intuition is straightforward. The toll increases land rents in the center C and reduces rents in the midcity zone M . Therefore, it not only redistributes welfare *between* renters and landowners, but also *within* the group of landowners, favoring those who own land inside the cordon at the expense of those who own land outside. As a result, the former

prefer a larger toll than the latter. Finally, pure renters, who do not own any land, want an intermediate toll between τ^c and τ^m .

The strength of the described effects depends of course on how much land is owned by resident-landowners, captured by the β_i parameters. Consider a landowner in C . As the expressions above suggest, if β_c tends to zero (i.e., land on C is entirely owned by absentee landlords) her most preferred toll converges to τ^p . By contrast, if β_c tends to $\frac{1}{N^c}$ (i.e., land on C is entirely owned by urban residents), then τ^c is significantly larger than τ^p , possibly even larger than τ^{SB} . In contrast, τ^m decreases with β_m , because $\frac{dr_m}{d\tau} < 0$.

3.2. The majority voting equilibrium

We turn to the characterization of the majority voting equilibrium, which is the toll wanted by the Condorcet winner.

Of course, if one of the groups $i=c,m,p$ consists of more than half the total population, the equilibrium yields that group's most-preferred toll. More interesting is the case in which no group has an absolute majority. In Appendix 2, we use the results of Gans and Smart (1996) to show that policy preferences satisfy the single crossing property, so that a majority voting equilibrium exists and coincides with the most preferred toll by the group that wants the median toll. Given earlier results, this group is group p , the pure renters. We have:

LEMMA 1: *The majority voting equilibrium is*

- τ^i if $N^i > \frac{N}{2}$ where $i = c, m, p$
- τ^p otherwise

As the pure renter is the median voter, an important policy question is whether she will support the socially optimal toll. As shown above, they will not do so if land rent is increasing in the toll. It is therefore useful to investigate the sign of $\frac{dr_c}{d\tau} + \frac{dr_m}{d\tau}$, to find out whether or not (17) holds. At first sight, intuition suggests that it does. Indeed, the increase in population density in the central island that follows a marginal increase in τ is always greater than the

corresponding decrease in density in the midtown island.¹⁷ Furthermore, because $\frac{dn_s}{d\tau} < 0$, the geographical size of the city and overall land consumption decrease with the toll. In general, however, the sign of $\frac{dr_c}{d\tau} + \frac{dr_m}{d\tau}$ is ambiguous. Consequently, the second best toll may be below or above the toll resulting from the political decision process.

To get additional insight, using (11) and the definitions of Z_c, Z_m , we have

$$\frac{dr_c}{d\tau} + \frac{dr_m}{d\tau} > 0 \Leftrightarrow q_m - t'_s \left(\frac{1}{q_m^2 v_m''} - \frac{1}{q_c^2 v_c''} \right) > 0 \quad (20)$$

The sign of the term in brackets is generally ambiguous. It depends on the functional forms of $v(q)$ and $t'_s(\cdot)$, and on equilibrium lot sizes, which depend in turn on the toll itself.¹⁸ Do note that $q_c < q_m$ and $v_c'' < 0, v_m'' < 0$. Using $n_j q_j = 1$ ($j = c, m$) and assuming a constant second derivative of the utility function for simplicity, we have

$$\left(\frac{1}{q_m^2 v_m''} - \frac{1}{q_c^2 v_c''} \right) = \frac{1}{v''} (n_m^2 - n_c^2)$$

Since $v'' < 0$ and because equilibrium population density in the midcity is smaller than in the city center, this expression is positive. This suggests that (20) will hold unless the suburban bridge is highly congestible (as captured by t'_s). In that case, average land rents would decline with the toll, and the median voter may want a toll that exceeds the second-best optimal one.¹⁹

In light of this ambiguity, in the following we consider both the case in which total land rents increase with the toll and that in which they decrease. However, we do focus our attention primarily on the former case. First, as argued above, total land rents may decrease with the toll only if congestion is heavily concentrated on the suburban bridge. Furthermore, most of the literature on cordon tolling in monocentric cities (that relies on models calibrated

¹⁷ We have $\frac{dn_c}{d\tau} = -\left(\frac{dn_m}{d\tau} + \frac{dn_s}{d\tau}\right)$, implying that $\frac{dn_c}{d\tau} > \left|\frac{dn_m}{d\tau}\right|$ given that $\frac{dn_s}{d\tau} < 0$.

¹⁸ Consider some examples. Let $v(q) = \rho \ln(q)$; it then easily follows that the term between brackets in (20) is zero, so that the inequality certainly holds. Alternatively, let $v(q) = q^\rho$, $\rho < 1$. Then the expression between brackets is positive, so that (20) may not hold if the suburban bridge is highly congestible.

¹⁹ Note that when there is no congestion at all on that bridge ($t'_s = 0$), the toll would increase rents in C but leave rents in M unaffected (see (11)). However, a positive t'_s may imply that the toll reduces the rental price of land in the midcity zone M proportionally more than it raises it in C . As a consequence, when t'_s is large, a marginal increase in the toll may reduce total land rent.

using data from real cities) finds that a cordon toll increases total land rents (see, e.g., Verhoef (2005, Table 1), Safirova et al. (2006, p.11), and Tikoudis et al. (2015, fig.2)).²⁰

Following the previous discussion and using Lemma 1, we can state the following Proposition:

PROPOSITION 1

- a. Assume the cordon toll raises total land rents in the urban area. The equilibrium toll is below the socially optimal one, unless landowners in C are at least half the total population and own large shares of land.*
- b. Assume the cordon toll reduces total land rents. The equilibrium toll exceeds the socially optimal one, unless landowners in M are at least half the total population and own large shares of land.*

The intuition is easy. First, if the toll increases total land rents, it redistributes welfare from renters to landowners. As a result, pure renters want a toll smaller than the optimal one. Furthermore, the toll redistributes welfare from individuals owning land outside the cordon to those who own land inside. It follows that only residents who own land in C will support a toll higher than optimal, and only if the share they own is not too small. All other groups want a toll below the optimum: pure renters can always count on the support of landowners in M (where the toll reduces rents) when demanding a toll below τ^{SB} .

Second, if the suburban bridge is highly congestible, total land rents in the urban area may decline with the toll. In that rather extreme case, a pure renter may want a toll above the social optimum, and, by the same forces illustrated above, this also applies to a resident-landowner in the central island. The only voters that may want a toll below the optimum are landowners in M .

Proposition 1 suggests that, unless the most severe congestion problems are not situated relatively close to the center but much further in the suburbs, the cordon toll will be below the social optimum. Although there are other potential explanations for why city governments rarely manage (or even try) to implement tolls, Proposition 1 is consistent with this observation. In almost all the real-world examples mentioned in the introduction, implemented and contemplated cordon tolls cover an area that encompasses the most central area of the city, with a high density of business and commercial buildings, as well as several

²⁰ Unfortunately, there is little empirical evidence on the long run effects of cordon tolls on urban land markets. In a study based on Milan, D’Arcangelo and Percoco (2015) find small but positive effects on total rents.

amenities (e.g. parks or historical buildings). Land within the cordon is therefore generally scarce and highly expensive. Hence, it seems unlikely that residents that own land within that area constitute the majority of the population. Available data seems to corroborate this conjecture: for instance, according to Gleaser (2011, p.20), in most large US urban areas, residents in central cities are much less likely to own the home they live in than residents in the suburbs.²¹ A similar pattern characterizes other large urban areas outside the US, e.g. Paris.²² Given the absence of a majority owning land within the cordon, Proposition 1 suggests that the political process will then induce the government to underprice congestion. In fact, the expressions given before do not exclude that the majority may prefer not to adopt any toll at all. Numerical analysis reported in Section 6 illustrates this possibility.²³

4. Accounting for wage differences

In this section, we extend the model to account for wage differences between individuals. This may be quite relevant: wages typically are a reasonable proxy for the willingness-to-pay to reduce road congestion, so we expect individuals earning different wages to have different preferences towards toll introduction.

For simplicity, we will consider only two wage levels, assuming individuals earn either a high or a low wage. People are indexed by $w = h, l$; we will refer to the former group as “the rich” and to the latter as “the poor”. We denote by x^w ($w = h, l$) the hourly wage, with $x^l < x^h$. We let Y be the total time endowment per period (say, per month), assumed to be the same for both types. Individuals can only spend time working or commuting. Consequently, the opportunity cost of commuting time to the individual is exactly equal to the individual’s wage; the rich then automatically have a higher opportunity cost of time than the poor.

We also retain several other assumptions from the baseline model. For example, individuals have the same quasilinear utility function introduced above, defined on land consumption and a general consumption good. The consequence is that land consumption is

²¹ He reports that 76 percent of Manhattan residents rent but 64 percent of the residents in Westchester County own their homes. In Boston, 62 percent of residents rent, but 65 percent of residents in suburban Middlesex County own. In Chicago, 51 percent of residents rent, but 62 percent of the residents in Cook County own.

²² Specifically, whereas about 33% of residents in central Paris own their home, about 43% of residents in the inner suburban belt own (“Petite Couronne”) and more than 60% own in the outer (“Grande Couronne”) suburban belt (INSEE, 2010).

²³ In our model, some voters are at the same time renters and landowners. However, one can obtain the outcome described in Proposition 1 (toll below second best) under different assumptions. For instance, one could assume all voters receive an identical share of land rents. Unless all rents accrue to residents, they will vote for a toll below the optimum. Even if they do not vote, landowners could influence the political equilibrium by lobbying the government. We could expect those who own land in C to lobby in favor of the toll, while those who own land in M to lobby against it. See Bento *et al.* (2006) for a study of land regulation policy adopting a related approach.

determined by $v'(q_j) = r_j$, $j = c, m, s$; hence, it is independent of income.²⁴ Moreover, as in the baseline model, we divide residents of the urban area (now taking account of whether they are rich or poor) in three subgroups according to landownership: rich and poor resident-landowners in C and in M , and voters not receiving any income from land ownership. We denote by $R^{i,w} = \beta_i^w r_i$ ($i = c, m; w = h, l$) the rental income of a rich or poor voter owning land in the midcity or the central city, where $\beta_c^h, \beta_c^l; \beta_m^h, \beta_m^l$ are the shares of land rent in C and M that accrues to one such individual. As before, $\beta_i^w \in (0, \frac{1}{N^{i,w}}]$ and members of group p earn zero rental income, that is $R^{p,h} = R^{p,l} = 0$. Finally, we assume that, in any zone, the share of land owned by a poor individual is never greater than that owned by a rich individual. That is, $\beta_i^h \geq \beta_i^l$, for $i = c, m$.

The total number of high and low income people is denoted by N^w ($w = h, l$). We assume the majority of the population is poor: $N^h < N^l$. As residents of each income type may own land in the various urban zones or be a pure renter, we have $N^w = N^{c,w} + N^{m,w} + N^{p,w}$ ($w = h, l$), where $N^{i,w}$ ($i = c, m, p; w = h, l$) is the number of urban residents of type i that belong to a particular income class. By definition we also have $N = N^h + N^l$.

We take income-location patterns as given. In what follows, we consider two different examples of such patterns. In the first, high-income types live in the city's most central locations, while the low-income types live farther away. Loosely speaking, this is representative of the income/location pattern in many European cities (Paris, Amsterdam, London), where income tends to decrease with distance from the CBD. As a second example, we let high-income individuals reside in the suburbs; this setup can be considered a very stylized representation of many US cities.

4.1. Scenario Rich in Center (the “European” city)

There are several equilibrium location patterns consistent with the scenario “rich in the center”. To see this, suppose there is one zone where both rich and poor individuals live, and denote it $k \in \{C, M, S\}$. Then, the rich must outbid the poor for land on any zone closer to the CBD than k , and vice-versa. This is due to the larger opportunity cost of commuting time of

²⁴ The assumption is admittedly restrictive, but relaxing it complicates the analysis quite substantially without affecting the main insights from the model. We provide in an appendix (available upon request) an alternative version of the model that explicitly allows high and low income types to consume different quantities of housing. This model leads to essentially the same results as that presented here.

the rich, which implies that, *ceteris paribus*, they are willing to pay more for land close to the CBD than the poor.²⁵ Further note that, in our model, there will always be one (and only one) island where both types reside. The reason is that land on S is supplied perfectly elastically: even if the rich group $w=h$ is numerous enough to fully occupy C and M , it can never occupy S entirely.

Of course, which of the three islands is shared by rich and poor depends on the size of the rich group, N^h . Although not critical for the results, in what follows we will assume the rich group is large enough to occupy the entire zone C , but not large enough to occupy the entire midcity zone M . That is, $k = M$. The income-location pattern we study in this subsection is therefore as illustrated in Figure 3. Specifically, we assume the midcity M is jointly inhabited by poor and rich, whereas the other areas are exclusively inhabited by one group only; in the central city C only rich people live, whereas in the suburbs S we only have poor people.²⁶ Formally, this means that parameter values are such that $N^h q_c = 1$ and $N^h q_m < 1$. Finally, to simplify the presentation below, we assume that low-wage types do not own any land in zone C (where none of them resides): $\beta_c^l = 0$.

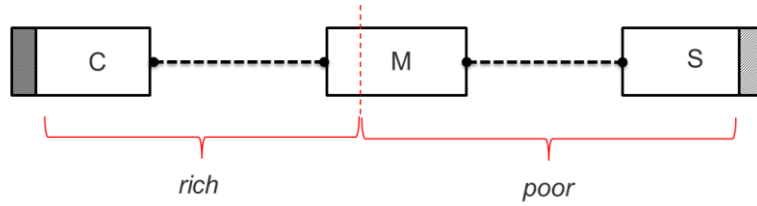


Figure 3: The Rich in Center case

Using similar substitutions as in the baseline model, it is straightforward to obtain the utilities of rich and poor individuals, conditional on location and land ownership, and taking into account the income-location pattern assumed. We find:

$$U_c^{i,h} = v(q_c) + x^h \cdot Y - r_c q_c + R^{i,h} + L \quad (21)$$

$$U_m^{i,h} = v(q_m) + x^h \cdot (Y - t_m(n_s + n_m)) - \tau - r_m q_m + R^{i,h} + L \quad (22)$$

²⁵Generally, a necessary condition for this equilibrium to arise is that the elasticity of land consumption with respect to income is small enough. However, the latter is zero in this model by quasi-linearity of the utility function.

²⁶ The assumption underlying Figure 3 is made purely for ease of exposition. Little would change in the results if we assumed that both rich and poor individuals occupy island C , while M and S are entirely occupied by the poor.

$$U_m^{i,l} = v(q_m) + x^l \cdot (Y - t_m(n_s + n_m)) - \tau - r_m q_m + R^{i,l} + L \quad (23)$$

$$U_s^{i,l} = v(q_s) + x^l \cdot (Y - t_m(n_s + n_m) - t_s(n_s)) - \tau + R^{i,l} + L. \quad (24)$$

Free mobility implies that in equilibrium we must have:

$$U_c^{i,h} = U_m^{i,h} = U^{i,h} \quad \text{and} \quad U_m^{i,l} = U_s^{i,l} = U^{i,l}, \quad i = c, m, p. \quad (25)$$

This implies that utility differs only depending on (i) whether and where residents own land and (ii) their wage. Finally, space on both the central and midcity island has to be fully occupied. Hence

$$n_c^h q_c = n_c q_c = 1, \quad (n_m^h + n_m^l) q_m = n_m q_m = 1, \quad (26)$$

where n_c^h (resp. n_m^h) is the number of rich individuals in C (resp. M), and n_m^l is the number of poor residents in M . Observe that, given our assumption, all individuals living in C are rich.

The conditions (21) - (25) imply

$$v(q_m) - r_m q_m - (v(q_c) - r_c q_c) = \tau + x^h t_m(n_s + n_m) \quad (27)$$

$$v(q_s) - (v(q_m) - r_m q_m) = x^l t_s(n_s). \quad (28)$$

These equations have the same interpretation as (8) and (9), except that the cost of crossing bridges is multiplied by the values of time of high and low income residents, x^w ($w = h, l$).

From (27)-(28), following the same procedure as in Section 2.2, we derive

$$\frac{dr_c}{d\tau} = \frac{1}{\Sigma} [q_m - x^l t'_s Z_m] > 0 \quad \frac{dr_m}{d\tau} = \frac{1}{\Sigma} [x^l t'_s Z_c] < 0, \quad (29)$$

where

$$\Sigma = [q_c - x^h t'_m Z_c] [q_m - x^l t'_s Z_m] - q_m x^l t'_s Z_c > 0.$$

The optimal second-best toll

Social welfare is defined as before, but captures the fact that there are two wage levels.

It can be written as:

$$SW = \sum_{i=m,p} N^{i,l} U^{i,l} + \sum_{i=c,m,p} N^{i,h} U^{i,h} + \left(1 - \sum_{w=h,l} \beta_c^w N^{c,w}\right) r_c + \left(1 - \sum_{w=h,l} \beta_m^w N^{m,w}\right) r_m \quad (30)$$

By (25), we do not distinguish individual utility according to residential location.

In Appendix 3 we maximize social welfare with respect to τ and show that -- following similar steps as in the baseline model -- the second best optimal toll can be written as:

$$\tau^{SB} = t'_m \cdot \left[x^l \cdot N^l + x^h \cdot (n_m + n_s - N^l) \right] + \frac{x^l \cdot (q_m t'_s n_s)}{q_m - x^l \cdot (t'_s Z_m)} \quad (31)$$

The second-best toll has the same structure as in the baseline model; the only difference is due to the different values of time of the rich and the poor. For example, the marginal external cost of congestion on the midtown bridge (the first term on the RHS) takes into account the different time values of poor and rich commuters that are crossing the bridge. Note that all poor individuals (N^l) and the rich who reside in M (their number equals $n_m + n_s - N^l$, viz., the population of M and S minus the number of poor individuals) cross the midcity bridge. The correction term for congestion on the suburban bridge (second term on the RHS) evaluates time losses by the time value of a poor individual: only residents of S cross this bridge, and they are all poor.

Most preferred tolls

Consider the most preferred tolls of different types of individuals. We start with the rich. We show in Appendix 3 that the toll a rich pure renter prefers, denoted $\tau^{p,h}$, can be written as:

$$\begin{aligned} \tau^{p,h} = t'_m \cdot \left[x^l N^l + x^h (n_m + n_s - N^l) \right] &+ \frac{x^l \cdot (q_m t'_s n_s)}{q_m - x^l \cdot (t'_s Z_m)} \\ &+ \Omega \left(\frac{dr_c}{d\tau} \frac{1}{N} + \frac{dr_m}{d\tau} \frac{1}{N} \right) + (x^h - x^l) t'_m N^l \end{aligned} \quad (32)$$

The definition of Ω is given in Appendix 3; it suffices here to note that $\Omega < 0$. In (32), there are two additional terms with respect to the second-best toll. The third term on the RHS is by now familiar: it accounts for the fact that pure renters ignore the effect of the toll on the income of landowners. The final term accounts for the fact that high-wage types have a larger value of time than the average commuter on the midtown bridge does. Contrary to the second best toll, the rich evaluate their time losses on the midcity bridge at their own high time value. This gives them an incentive to ask for a higher toll.

Similarly, for rich individuals owning land on C and M we find the following desired toll expressions:

$$\begin{aligned}\tau^{c,h} = t'_m \cdot & \left[x^l N^l + x^h (n_m + n_s - N^l) \right] + \frac{x^l \cdot (q_m t'_s n_s)}{q_m - x^l \cdot (t'_s Z_m)} \\ & + \Omega \left(\frac{dr_c}{d\tau} \left(\frac{1}{N} - \beta_c^h \right) + \frac{dr_m}{d\tau} \frac{1}{N} \right) + (x^h - x^l) t'_m N^l\end{aligned}\quad (33)$$

$$\begin{aligned}\tau^{m,h} = t'_m \cdot & \left[x^l N^l + x^h (n_m + n_s - N^l) \right] + \frac{x^l \cdot (q_m t'_s n_s)}{q_m - x^l \cdot (t'_s Z_m)} \\ & + \Omega \left(\frac{dr_c}{d\tau} \left(\frac{1}{N} - \beta_m^h \right) + \frac{dr_m}{d\tau} \frac{1}{N} \right) + (x^h - x^l) t'_m N^l.\end{aligned}\quad (34)$$

These formulas differ from $\tau^{p,h}$ only because landowners internalize the effect of the rent generated by their parcel of land.

Turn now to poor individuals, and recall that they are either pure renters or landowners in M . We show in Appendix 3 that for poor pure renters we have the following preferred toll:

$$\begin{aligned}\tau^{p,l} = t'_m \cdot & \left[x^l N^l + x^h (n_m + n_s - N^l) \right] + \frac{x^l \cdot (q_m t'_s n_s)}{q_m - x^l \cdot (t'_s Z_m)} \\ & + \Omega \left(\frac{dr_c}{d\tau} \frac{1}{N} + \frac{dr_m}{d\tau} \frac{1}{N} \right) - (x^h - x^l) t'_m N^h\end{aligned}\quad (35)$$

Direct comparison of (32) and (35) suggests that $\tau^{p,l} < \tau^{p,h}$: the rich indeed prefer a higher toll. Finally, for a poor landowner in M we find

$$\begin{aligned}\tau^{m,l} = t'_m \cdot & \left[x^l N^l + x^h (n_m + n_s - N^l) \right] + \frac{x^l \cdot (q_m t'_s n_s)}{q_m - x^l \cdot (t'_s Z_m)} \\ & + \Omega \left(\frac{dr_c}{d\tau} \frac{1}{N} + \frac{dr_m}{d\tau} \left(\frac{1}{N} - \beta_m^l \right) \right) - (x^h - x^l) t'_m N^h.\end{aligned}\quad (36)$$

Majority voting and comparison with the second best toll

The first step towards characterization of the political equilibrium is to compare the formulas for the most preferred tolls by each group. To simplify the discussion, we will assume in what follows that total land rents increase with the toll, i.e. $\frac{dr_c}{d\tau} + \frac{dr_m}{d\tau} > 0$ (this condition was discussed in Section 3.2). Comparison of the toll rules established above then suggests that

$$\tau^{m,l} < \tau^{p,l} < \tau^{SB}, \quad (37)$$

$$\tau^{m,h} < \tau^{p,h} < \tau^{c,h}. \quad (38)$$

As (37) suggests, all poor individuals want a toll smaller than the second best optimal one. This can be understood by noting that (i) their value of travel time is smaller than that of the average commuter on the midtown bridge; (ii) they either completely disregard the effect of the toll on average land rents (if they are pure renters) or they only internalize the negative effect on the value of land on the midtown island (if they own land there). For the rich, the picture is mixed (see (38)). The relation between most-preferred tolls is the same as in the baseline model, but the relation between these tolls and the optimal one is ambiguous. Rich people value time savings more than average, but landowners in M suffer a loss in income when the toll goes up. Finally, rich landowners in C want a toll larger than the optimal one if either the difference in time values $(x^h - x^l)$, or the share of land they own β_c^h , are large enough.

Characterization of the majority voting equilibrium is made difficult by the fact that policy preferences in this scenario do not necessarily satisfy the single-crossing property (we discuss this property in Appendix 3). Nevertheless, we prove a less ambitious but useful result:²⁷

LEMMA 2: *In the rich in center scenario, if a majority voting equilibrium exists, it does not exceed the most preferred toll by a poor renter $\tau^{p,l}$.*

The intuition can be explained as follows. Because $\frac{dr_m}{d\tau} < 0$, we have $\frac{dU^{m,l}}{d\tau} < \frac{dU^{p,l}}{d\tau}$ for any τ . This means that if poor renters prefer a certain toll level to a larger one, the same goes for poor landowners in M . By definition, poor pure renters strictly prefer $\tau^{p,l}$ to any larger toll. Therefore, this must also be the case for poor landowners in M . Consequently, because these two groups taken together constitute the majority of the population by assumption (recall that $N^h < N^l$), $\tau^{p,l}$ cannot be beaten by any larger toll in a pairwise majority voting context.

In light of Lemma 2, and using (37), we can state the following proposition:

²⁷ We cannot show that a voting equilibrium always exists. Still, it is not difficult to come up with sufficient conditions for existence. A trivial one is that either $N^{m,l}$ or $N^{p,l}$ are larger or equal to $\frac{N}{2}$. A different condition

is that $\frac{dU^{p,l}}{d\tau} < \frac{dU^{m,h}}{d\tau}$ for any τ (which would ensure single crossing, see Appendix 3).

PROPOSITION 2: *Consider the “Rich in center” case. Assume average land rents increase with the toll and that the majority of the urban population is poor. If a majority voting equilibrium exists, it is such that the toll is strictly below the optimal level.*

This result corroborates the findings of Proposition 1. Introducing income heterogeneity, under the reasonable condition that more poor than rich individuals populate the city, we find that the toll implemented by majority voting is below the optimal one, at least as long as total land rents increase with the toll. If the latter condition does not hold, Proposition 2 may not hold for the same reasons as in the baseline model.

4.2. Scenario “Poor in center” (the “American” city)

Consider now the case in which the rich live farther from the center than the poor. This income-location pattern characterizes many North American cities. In this scenario, the poor live in all three zones, while the rich only live in the suburbs. To capture the possibility that some poor residents in C may own the land upon which their home is built, we relax the assumption that $\beta_c^l = 0$. That is, we allow poor individuals to own some land in the center. We will refer to this second setting as the “Poor in Center” scenario.

As pointed out in the “Rich in Center” case, if the rich and poor have identical preferences, the former would always outbid the latter for land close to the CBD. Hence, to obtain an equilibrium “Poor in Center” pattern, an additional assumption is needed. Following earlier literature (see, for example, Brueckner and Selod (2006)), we assume the rich have a “taste for location”, whereby they get some extra utility γ when living on the suburban island. If this utility is large enough, they will outbid the poor (only) on S . But since land is elastically supplied in S , the rich can never occupy it entirely. We assume the number of poor people is large enough that both the central and the midcity islands are fully occupied by the poor, and both rich and poor live on S . We provide an illustration in Figure 4.

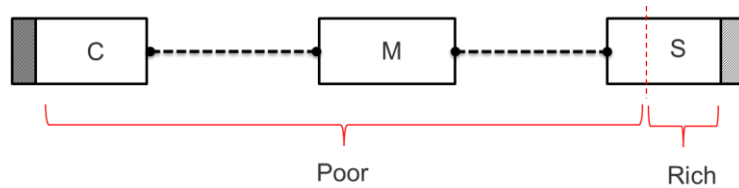


Figure 4: The Poor in Center case

Because a rich individual only resides on island S by assumption (but may own land on any island), her utility is

$$U^{i,h} = v(q_s) + x^h \cdot (Y - t_m(n_s + n_m) - t_s(n_s)) + R^{i,h} + L - \tau + \gamma \quad i = c, m, p \quad (39)$$

The last term γ is the rich's "taste for location", i.e. the type-specific extra utility from living in S (assumed large enough so that the rich's utility when living in S is strictly larger than on any other island).

The utility of a poor individual is, depending on location,

$$U_c^{i,l} = v(q_c) - r_c q_c + R^{i,l} + L, \quad (40)$$

$$U_m^{i,l} = v(q_m) + x^l (Y - t_m(n_s + n_m)) - \tau - r_m q_m + R^{i,l} + L, \quad (41)$$

$$U_s^{i,l} = v(q_s) + x^l (Y - t_m(n_s + n_m) - t_s(n_s)) - \tau + R^{i,l} + L, \quad (42)$$

again with $i=c,m,p$.

The analytics and the results of this case are quite similar to the previous one; we therefore relegate them to Appendix 4 to avoid unnecessary repetition, and just summarize the results. The socially optimal cordon toll in this scenario has the following form:

$$\tau^{SB} = t'_m \left(x^h \cdot N^h + x^l \cdot (n_m + n_s - N^h) \right) + \frac{t'_s q_m \left(x^l (n_s - N^h) + x^h N^h \right)}{q_m - t'_s x^l Z_m}. \quad (43)$$

As in the "rich in center" scenario, the optimal toll accounts for the value of time of both rich and poor commuters. Observe however that in this scenario all types use both bridges.

As in the case where income decreases with distance from the CBD , the poor tend to prefer a smaller toll than the rich because of their lower opportunity cost of time. However, if land on the central island belongs predominantly to poor individuals, they may decisively tilt the equilibrium in favor of a toll above the optimum. Indeed, we show in Appendix 4 that the only case in which the toll can be above the social optimum is when poor individuals owning land within the cordon (hence, in C) constitute an absolute majority, and the share of land they own there is sufficiently large. This is quite unlikely. Given that land close to the CBD is generally expensive, a more plausible scenario is that, even if many of the poor live in the center, they do not own much land there. This leads to an equilibrium toll smaller than optimal. We summarize in the following proposition.

PROPOSITION 3: *Consider the "Poor in center" scenario. Assume average land rents increase with the toll and that the majority of the city population is poor. If a majority voting equilibrium exists, the toll is strictly below the optimal level if either (i)*

$(N_m^l + N_p^l) \geq \frac{N}{2}$, i.e. *the number of poor landowners in C is small, or (ii) if β_c^l is small, i.e. the share of land rents in C that accrues to poor landowners is small.*

Although the conditions under which a toll above the social optimum is obtained are different than when the rich live in the center, in a qualitative sense Proposition 3 again corroborates earlier findings. As before, it suggests that a toll below the social optimum is highly plausible.

5. The Political Economy of Toll Location

So far, we have studied the political economy of imposing a cordon toll on the midcity bridge, focusing on the comparison between the optimal toll and the voting equilibrium. As a final part of our analysis, we investigate the political economy of *toll location*. Specifically, we study whether tolling the midtown bridge (i.e., placing the cordon relatively close to the CBD) is preferable to tolling the suburban bridge (i.e., placing the cordon farther away from the center). Furthermore, we investigate whether, and under what conditions, the majority of voters prefers a toll on the midtown bridge to one on the suburban bridge. To study these questions, we return to the setup where voters have identical wages (as in section 3).

Toll location is a policy-relevant issue. In reality, the choice of toll location is often determined by technical feasibility. But, making abstraction of technical issues, where the toll is located bears important implications on social welfare: it determines how many road users pay the toll and by how much congestion will decline. Moreover, the adoption of a toll is ultimately a political decision. Hence, it is important to understand whether, and under which conditions, the majority of voters favors a cordon close to the city center over one placed further out. In order to avoid repetition, we present here only the main results of the analysis, and relegate the derivations to Appendix 5.

5.1. A suburban cordon toll

Consider a toll placed on the suburban bridge and denote it by τ_s . We will refer to this toll as the “suburban toll.” Assume there is no toll on the midtown bridge. We first determine how land rents in C and M change with respect to the suburban toll. We show in Appendix 5 that:

$$\frac{dr_c}{d\tau_s} = \frac{1}{\Delta} q_m > 0; \quad \frac{dr_m}{d\tau_s} = \frac{1}{\Delta} (q_c - t_m' Z_c) > 0, \quad (44)$$

where Δ was defined in (12). Unlike the toll on the midtown bridge, a higher suburban toll raises land rents both in the midcity M and in the city center C . This is intuitive, given that only commuters from the suburban zone S pay the toll.

The second best suburban toll is (see Appendix 5 for the derivation):

$$\tau_s^{SB} = t_s' n_s + \frac{t_m'(n_s + n_m)(Z_c q_m)}{Z_c q_m + Z_m(q_c - t_m' Z_c)} \quad (45)$$

Both the numerator and the denominator of the final term on the right hand side are negative. This suggests that τ_s^{SB} exceeds the first best toll on the suburban bridge, for the same reasons as in our baseline model: a single toll is used to control congestion on both bridges.

The most-preferred suburban tolls by different groups of residents are derived in Appendix 5 as well. First, for residents not receiving any income from landownership (the group indexed by p), we find

$$\tau_s^p = t_s' n_s + \frac{t_m'(n_s + n_m)(Z_c q_m)}{Z_c q_m + Z_m(q_c - t_m' Z_c)} + \frac{\Psi}{N} \left[\frac{dr_c}{d\tau_s} + \frac{dr_m}{d\tau_s} \right], \quad (46)$$

where
$$\Psi = \frac{\Delta N}{Z_c q_m + Z_m(q_c - t_m' Z_c)} < 0.$$

Note the similarity of this rule to (16) (the corresponding toll residents of type p wanted on the midcity bridge). The first two terms capture the second best optimal suburban toll, the last term captures the impact of the toll on average land rent. But, unlike in the case of the midcity toll, the effect on land rents is positive in both C and M . Hence, the final term on the right hand side of (46) is necessarily negative. This suggests that the toll that renters want is unambiguously below the optimal level.

Turn now to resident-landowners in C and M . We find that their most-preferred tolls are, respectively:

$$\tau_s^c = t_s' n_s + \frac{t_m'(n_s + n_m)(Z_c q_m)}{Z_c q_m + Z_m(q_c - t_m' Z_c)} + \Psi \left[\frac{dr_c}{d\tau_s} \left(\frac{1}{N} - \beta_c \right) + \frac{dr_m}{d\tau_s} \frac{1}{N} \right], \quad (47)$$

$$\tau_s^m = t_s' n_s + \frac{t_m'(n_s + n_m)(Z_c q_m)}{Z_c q_m + Z_m(q_c - t_m' Z_c)} + \Psi \left[\frac{dr_c}{d\tau_s} \frac{1}{N} + \frac{dr_m}{d\tau_s} \left(\frac{1}{N} - \beta_m \right) \right]. \quad (48)$$

As a result, the most preferred toll by a resident-landowner in C or M can be above the second best optimal toll if and only if the share of land owned is large enough.

The comparison of toll formulas suggests the following relations (subject to the same caveat as before):

$$\begin{aligned}\tau_s^c &> \tau_s^p; \quad \tau_s^m > \tau_s^p \\ \tau_s^c &\geq \text{or} \leq \tau_s^m \\ \tau_s^{SB} &\geq \tau_s^p\end{aligned}$$

Both owners land in M and C prefer a higher suburban toll than pure renters, who prefer a toll smaller than the second best optimum. The above expressions also imply that landowners in C and M may support a toll above τ_s^{SB} only if they own large enough shares of land.

Unless one group is the absolute majority of the population, it is not straightforward to establish existence of a voting equilibrium, because preferences do not necessarily satisfy the single crossing property (see Appendix 5).²⁸ We can show, however, that – if an equilibrium exists -- the decisive voter belongs to either group $i=c$ or $i=m$. We can therefore state the following.

LEMMA 3: Voting on the suburban toll:

- if $N^i > \frac{N}{2}$, where $i=c, m, p$, the majority voting equilibrium is τ_s^i
- otherwise, if an equilibrium exists, it is either τ_s^c or τ_s^m .

Recall from Lemma 1 that if the cordon is placed on the midtown bridge, and if no group constitutes an absolute majority, the decisive voter belongs to group p . Remember that this group consists of all individuals receiving zero rental income, viz., renters and landowners in the suburban zone S . Hence, from a political economy viewpoint, a first interesting finding is that moving the location of the cordon further from the city center shifts political power between different groups of residents. Indeed, we find that resident-landowners in C or M are decisive when the toll is on the suburban bridge. In other words, shifting the cordon away from the center moves the political decision maker (i) closer to the center (from owners in S towards owners in the midcity and the city center) or (ii) from renters to resident-owners. We summarize as follows.

PROPOSITION 4: Shifting the cordon from the midcity to the suburbs implies that decision power shifts from renters and resident-landowners in the suburbs to resident-landowners in either the central or midcity island.

²⁸ In order to avoid technicalities that are inessential for our arguments, we do not fully characterize the conditions under which single-crossing holds. We provide a discussion of these conditions in Appendix 5.

5.2. Cordon location: a toll on the midcity or the suburban bridge?

In this section, we study the choice of toll location. We first look at the socially optimal location of the appropriate second best optimal toll, then we discuss the political economy of toll location. To clearly distinguish the two tolls we denote them by τ_m and τ_s , respectively. Figure 5 provides an illustration.



Figure 5: Tolls on the midtown and suburban bridge

The social viewpoint

Consider the second best optimal toll on the midtown and the suburban bridge (described, respectively, in (15) and (45)). It is difficult to compare such tolls due to the fact that the relevant formulas need to be evaluated at different land consumption and population levels. One general statement can be made, however. Depending on the congestibility of the two bridges, both the midcity toll and the suburban toll may be socially preferable. To see this, it suffices to consider some extreme cases. Suppose the midcity bridge is not congested at all, so that $t'_m = 0$. It then immediately follows from (45) that the second-best optimal toll on the suburban bridge is

$$\tau_s^{SB} = t'_s \cdot n_s$$

Under the described assumptions, implementing this second best toll on the suburban bridge alone is also the first-best outcome. Indeed, if the midcity bridge is not congestible, the first best is $\tau_m^{FB} = 0; \tau_s^{FB} = t'_s \cdot n_s$. Alternatively, if the suburban bridge is not congestible (hence, $t'_s = 0$), the second best toll on the midcity bridge alone is $\tau_m^{SB} = t'_m \cdot (n_m + n_s)$. This is the first-best outcome under the conditions described ($\tau_m^{FB} = t'_m \cdot (n_m + n_s); \tau_s^{FB} = 0$).

Therefore, not surprisingly, whether it is socially preferable to introduce a (second-best optimal) toll on the midcity or suburban bridge depends on the relative congestibility of the two bridges. If the suburban bridge is not very congestible but the midcity bridge is, it is socially preferable to place the cordon at bridge *M*. In the opposite case, tolling the suburban bridge is preferable.

Voting on toll location

We now turn to the political economy analysis. The question we ask is the following: will voters favor a cordon toll close to the city center (bridge M) over one further away in the suburbs (bridge S)? Intuitively, with local landownership, depending on cordon location different coalitions may form in favor or against the toll. In the case of a midcity toll, central city landowners may support it because it raises the value of the land they own, whereas midcity and suburban landowners, as well as renters, may oppose it. If the cordon is placed at the suburban bridge, renters and suburban landowners may oppose it, whereas landowners in C and M may support it (provided they own a sufficiently large share of land).

Unfortunately, it is impossible to make general statements about whether a second best toll implemented on the midtown bridge is more likely to obtain a majority than a second best toll on the suburban bridge. The level of these tolls may differ widely, and one would have to evaluate all equilibrium quantities (i.e., populations, land consumption, etc.) at different toll levels. We therefore study a less ambitious but, we believe, equally interesting question. Consider an initial situation with no toll on any bridge. Suppose then that the government contemplates imposing a small toll, on either the midcity or the suburban bridge. Which location will voters prefer? Note that a zero toll is a relevant reference point: in practically all cities that have recently adopted (or contemplated adopting) a cordon toll (e.g., London, Stockholm, Milan, Manchester, New York City), there was no pre-existing road pricing system.

We first analyze how pure renters would view the introduction of a small toll on either the midcity or the suburban bridge. Consider a pure renter and assume she lives in the suburban zone S . As usual, this is without loss of generality because her equilibrium utility is independent of where she lives: focusing on a resident in zone C or M would yield identical results.

Suppose that a small toll τ_m is imposed on the midcity bridge. The renter's utility is then given by:

$$U^p = v(q_s) + Y - \tau_m - t_m(n_m + n_s) - t_s(n_s) + \frac{\tau_m \cdot (n_m + n_s)}{N}.$$

The populations determining congestion and toll revenues are evaluated at the equilibrium consistent with the small midcity toll that is imposed. Denoting the generalized commuting cost of a resident in S by $GC_s(\tau_m)$, utility can be reformulated as

$$U^p = v(q_s) + Y - GC_s(\tau_m) + \frac{\tau_m \cdot (n_m + n_s)}{N}; \quad GC_s(\tau_m) = \tau_m + t_m(n_m + n_s) + t_s(n_s)$$

Note that q_s is independent of the toll, so that the effect of a marginal toll increase at the midtown bridge (evaluated at a zero initial toll) reads:

$$\left. \frac{dU^p}{d\tau_m} \right|_{\tau_m=0} = -\frac{dGC_s(\tau_m)}{d\tau_m} + \frac{n_m + n_s}{N} = -\left[\frac{q_c(q_m - t'_s Z_m)}{\Delta} \right] + \frac{n_m + n_s}{N} \quad (49)$$

The last equality is obtained by differentiating the generalized cost and using (10), (11) and (12). The term between square brackets on the right hand side of (49) is positive. Expression (49) therefore tells us that the effect of the toll on a renter residing in S is ambiguous: the toll raises the generalized cost of commuting, but it also generates revenues redistributed by the government.

A similar reasoning can be applied to determine the effect of a small toll τ_s on the suburban bridge on the renter's utility. Given that she resides on S , her utility can in this case be written as:

$$U^p = v(q_s) + Y - t_m(n_m + n_s) - \tau_s - t_s(n_s) + \frac{\tau_s \cdot n_s}{N}.$$

Denoting the generalized cost as $GC_s(\tau_s) = t_m(n_m + n_s) + \tau_s + t_s(n_s)$ -- where the n_j ($j = c, m, s$) are the equilibrium populations given the small suburban toll -- a similar exercise as before shows that the marginal utility of a small toll at the suburban bridge, evaluated at the zero toll reference, is:

$$\left. \frac{dU^p}{d\tau_s} \right|_{\tau_s=0} = -\frac{dGC_s(\tau_s)}{d\tau_s} + \frac{n_s}{N} = -\left(\frac{q_c q_m}{\Delta} \right) + \frac{n_s}{N}. \quad (50)$$

Again, the last equality follows from using (10), (11) and (12). The effect of the suburban toll on renter utility can be either positive or negative, for the same reasons as in the case of the midcity toll.

Subtracting (50) from (49), we easily derive:

$$\left. \frac{dU^p}{d\tau_m} \right|_{\tau_m=0} - \left. \frac{dU^p}{d\tau_s} \right|_{\tau_s=0} = -\left(\frac{dGC_s(\tau_m)}{d\tau_m} - \frac{dGC_s(\tau_s)}{d\tau_s} \right) + \frac{n_m}{N} = \frac{t'_s q_c Z_m}{\Delta} + \frac{n_m}{N}. \quad (51)$$

The sign of the right-hand side is ambiguous in general (the first term is negative, the second positive), but its interpretation is clear. The final term reflects the extra toll revenues generated by a small midcity toll (relative to a suburban toll). The first term captures the difference in the extra commuting costs for suburban residents when the suburban toll (and not the midcity toll) is introduced. Interestingly, this term is negative. This implies that, in equilibrium, a small midtown toll raises the generalized cost of commuting from zone S to the CBD more than a small suburban toll does; we have

$$\frac{dGC_s(\tau_m)}{d\tau_m} - \frac{dGC_s(\tau_s)}{d\tau_s} = -\frac{t'_s q_c Z_m}{\Delta} > 0. \quad (52)$$

Surprisingly, therefore, the suburban toll has the largest effect on total congestion (i.e., on total time losses at the two bridges together). This seems counterintuitive, because the midcity toll affects more people; it discourages traffic originating in M and S , whereas the suburban toll only discourages traffic originating in S . To understand this result, note that the midcity toll reduces congestion on the midcity bridge more than the suburban toll does (the downward effect on the number of users -- $n_m + n_s$ -- is larger in the former case). By contrast, the suburban toll reduces congestion more on the suburban bridge (it has a larger negative effect on n_s , the number of commuters originating from S). But do note that the effect of reducing travel originating in S on overall time losses at the two bridges together is more important than reducing demand originating in M . The reason is simply that commuters from S use both bridges, unlike individuals living in M . As a result, the overall congestion reduction is larger with a suburban toll.

To understand what drives the renter's preference for tolling at a particular location, we use the definition of Δ as given by (12) and rewrite (51) as:

$$\left. \frac{dU^p}{d\tau_m} \right|_{\tau_m=0} - \left. \frac{dU^p}{d\tau_s} \right|_{\tau_s=0} = \frac{t'_s q_c Z_m}{[q_c - t'_m Z_c][q_m - t'_s Z_m] - t'_s q_m Z_c} + \frac{n_m}{N} \quad (53)$$

It is easily shown that the first term on the right hand side is between -1 and 0, whereas the second term is between 0 and 1. The absolute value of the first term – as shown above, it captures the different effects of the tolls on the generalized commuting costs from S to the center – depends on the relative congestibility of the two bridges. Although all quantities in (53) depend on t'_m and t'_s , the expression suggests that greater congestibility of the midtown bridge (i.e., t'_m) reduces the importance of the first term, whereas greater congestibility of the suburban bridge (i.e., t'_s) increases it. As mentioned before, the second term in (53) captures the extra toll revenue when tolling the midcity bridge.

Interpretation of (53) is then straightforward. Suppose the suburban bridge is not very congestible relative to the midcity bridge (i.e., t'_s small relative to t'_m). Low congestibility of bridge S implies that the effect of the suburban and the midtown toll on the generalized cost of commuting from the suburbs to the center is almost the same. Renters will then obviously tend to prefer the midtown toll, because this yields larger redistributed toll revenues; the size

of this effect depends on how many residents live in the midcity zone M . Under the described conditions, the first term in (53) is small relative to the second, and the overall effect is positive.

Alternatively, let the suburban bridge be much more congestible than the midcity bridge (t'_s is large relative to t'_m). In that case, tolling the midtown bridge raises the generalized commuting cost significantly more than having the toll in the suburbs: the former has much less effect on commuters from S than the suburban toll. If the midcity population is small so that the extra redistributed toll revenues from the midcity toll are relatively small, renters will then tend to prefer a toll on the suburban bridge. In terms of (53), the first term is negative and large in absolute value, the second term is small.

In sum, renters will prefer the midcity toll when, loosely speaking, the urban congestion problem is situated mostly on the midcity bridge (i.e., t'_m large relative to t'_s) and the midcity population is large. They will prefer the suburban toll only if the midcity is not too populated and the most pressing congestion problem is situated at the suburban level. This suggests that in many realistic cases pure renters will prefer the midtown toll. In most cities, congestion upon entering the center is indeed quite severe and, unless one defined the midcity in a rather awkward way, the population of the midcity is substantial.

Finally, consider resident-landowners in C or M . Recall that tolling the midtown or the suburban bridge has different effects on the rental prices of land. Indeed, land rents increase only within the tolled area. Therefore, landowners in C benefit when a small toll is introduced on either bridge; landowners on M see rents rise if the toll is on the suburban bridge, but they suffer an income loss if the midtown bridge is tolled.

As we did for pure renters, we can find the differential utility effect of the two tolls on landowners in C and M ; they are given by, respectively:

$$\left. \frac{dU^c}{d\tau_m} \right|_{\tau_m=0} - \left. \frac{dU^c}{d\tau_s} \right|_{\tau_s=0} = \frac{t'_s q_c Z_m}{\Delta} + \frac{n_m}{N} - \frac{t'_s \beta_c Z_m}{\Delta} \quad (54)$$

$$\left. \frac{dU^m}{d\tau_m} \right|_{\tau_m=0} - \left. \frac{dU^m}{d\tau_s} \right|_{\tau_s=0} = \frac{t'_s q_c Z_m}{\Delta} + \frac{n_m}{N} - \frac{\beta_m (q_c - (t'_s + t'_m) Z_c)}{\Delta} \quad (55)$$

Depending on parameter values, landowners may prefer the midcity or suburban toll. Landowners in C are more likely to favor the midcity toll the more land they own. On the contrary, owners of large parcels of land in M are more likely to prefer the toll on the suburban bridge.

Comparison of (54)-(55) with (51) yields:

$$\left. \frac{dU^c}{d\tau_m} \right|_{\tau_m=0} - \left. \frac{dU^c}{d\tau_s} \right|_{\tau_s=0} > \left. \frac{dU^p}{d\tau_m} \right|_{\tau_m=0} - \left. \frac{dU^p}{d\tau_s} \right|_{\tau_s=0}$$

$$\left. \frac{dU^m}{d\tau_m} \right|_{\tau_m=0} - \left. \frac{dU^m}{d\tau_s} \right|_{\tau_s=0} < \left. \frac{dU^p}{d\tau_m} \right|_{\tau_m=0} - \left. \frac{dU^p}{d\tau_s} \right|_{\tau_s=0}$$

These observations have simple but powerful implications. Suppose that no group has an absolute majority and that pure renters prefer a small midtown toll over a toll on the suburban bridge; we argued before that this is quite likely to be the case. Then the above inequalities show that owners of land in C will also (in fact, even more strongly) prefer the midtown toll. Under the described conditions, therefore, a coalition of renters and landowners in C will lead to a majority in favor of the toll on the midcity bridge. Alternatively, consider the less likely case that pure renters prefer the suburban toll. As argued above, this will only be the case if the midcity population in the zero toll situation is small and congestion is primarily concentrated in the suburban area. If pure renters prefer the suburban toll, the above inequalities suggest that landowners in M will also certainly prefer the suburban toll. A coalition majority consisting of renters and resident-landowners in M then leads to implementation of the cordon at the suburban bridge.

We summarize our findings as follows.

PROPOSITION 5: *Consider introducing a small toll on either the midtown or suburban bridge, and assume no group has an absolute majority.*

- a. Unless congestion problems are primarily concentrated in the suburban zone, a majority coalition of renters and landowners in the center prefer to have the cordon at the midcity bridge.*
- b. If congestion problems are primarily concentrated in the suburbs and the midcity population is small, a majority coalition of renters and landowners in the midcity may exist that prefers the toll on the suburban bridge.*

Proposition 5 suggests that local governments may place cordons relatively close to the city center for reasons that go beyond technical feasibility. Unless congestion is mostly concentrated in the suburbs (a condition which seems unlikely in modern cities), it is easier to get voters to support introduction of a cordon toll placed relatively close to the *CBD* than one placed further outside. This finding is in accordance with the stylized fact that existing (and

contemplated) toll schemes in reality predominantly encompass a relatively small area around the city center (see the examples of London, Stockholm, Milan, etc.).

6. A numerical example

In this section, we provide a small numerical example. It is not based on observed information, and its only purpose is to illustrate the theoretical results. For simplicity, we assume equal wages throughout.

The total population is fixed at $N=3$. The sizes of the three groups are given as $N^c = N^m = N^p = 1$. In the suburban region, we normalize both the price and the consumption of land at 1, $r_s = q_s = 1$.²⁹ We use the following specification for the utility function of a resident of group j ($j=c,m,p$) living in zone i ($i=c,m,s$):

$$U^j = v(q_i^j) + e_i^j = \ln(q_i^j) + e_i^j.$$

Note that this implies (for $j=c,m$) that $v'(q_j) = \frac{1}{q_j}$; $v''(q_j) = -\frac{1}{(q_j)^2}$. The congestion functions are simply proportional to traffic levels, both on the mid-city and the suburban bridge:

$$\begin{aligned} t_m(n_m + n_s) &= \delta_m \cdot (n_m + n_s) \\ t_s(n_s) &= \delta_s \cdot n_s \end{aligned}$$

The first-order condition for land consumption and the normalizations $n_c q_c = n_m q_m = 1$ imply that $r_j = n_j$ ($j=c,m$).

We first present results for the toll on the midcity bridge. Consider Table 1. The first row reports results for the situation without congestion. In the no-congestion (in essence, setting $\delta_m = \delta_s = 0$) and no-toll ($\tau = 0$) equilibrium it is easy to show that we have:

$$q_j = n_j = r_j = 1 \quad (j=c,m,s).$$

We further report the equilibrium populations, the utilities of landowners in C and M and of pure renters, and total social welfare. The other rows then give the outcomes for different alternatives under a common set of parameters, given by ($\beta_c = \beta_m = 1/3$; $\delta_m = \delta_s = 0.1$). We

²⁹ We normalized rent in zone S at 1 (and not at zero as in the theory section) to facilitate the numerical calculations. As rents and individual land consumption in S are unaffected by the tolls, this has no consequences for the nature of the results.

report, consecutively, the case with congestion but a zero toll, the second-best optimum, and the outcomes under the desired toll levels by each of the three groups (c, m, p) of residents.

The case without toll ($\tau = 0$) but allowing for some congestion on both bridges raises land prices in the central city quite substantially. Note that land prices in the mid-city also moderately rise. The reason is that congestion makes the central city more attractive relative to the mid-city and suburban areas but, as more people move to the central city, housing consumption declines and this reduces utility. The trade-off between housing consumption and time losses due to congestion limits the increase in central city population, and population in M also rises. Consumption of land in areas M and C declines, and the population in the suburban area S is strongly reduced.

Now consider the second-best optimal toll and the desired tolls by the three population groups. The second-best toll is positive; it amounts to 0.195 per cordon crossing. The toll further raises the central city population at the expense of areas M and S . The toll wanted by people owning land in the central city exceeds the second best toll: the central city becomes a more attractive place to live, raising its population, and land owners benefit from increasing land rents. Land consumption per household declines.

Interestingly, both the toll wanted by the mid-city landowners and pure renters are negative. In practice they want a zero toll (restricting the toll at zero produces the solution of the second row of the table). For a positive toll, the mid-city people would see their land rents slightly decline and they would face the toll on the mid-city bridge; hence, they prefer no such toll. The pure renters also prefer not to pay the toll at all, as they have no benefits from such a toll except lower congestion, but this is out-weighted by the toll payments. In sum, the political equilibrium would be a zero toll, despite a substantial second-best optimal toll.

	r_c	r_m	n_c	n_m	n_s	q_c	q_m	U^c	U^m	U^p	SW	$Toll$
No congestion $\delta_m = \delta_s = 0$	1	1	1	1	1	1	1	1.33	1.33	1	5	0
Congestion, no toll $\delta_m = \delta_s = 0.1$	1.21	1.07	1.21	1.07	0.71	0.83	0.93	1.19	1.11	1.09	4.61	0
Second best τ^{SB}	1.48	1.05	1.48	1.05	0.48	0.68	0.95	1.20	1.05	1.04	4.65	0.195

Owners C (τ^c)	1.56	1.04	1.56	1.04	0.40	0.64	0.96	1.21	1.02	1.01	4.63	0.275
Owners M (τ^m)												<0
Pure renters (τ^p)												<0

Table 1: a toll on the midcity bridge

In Table 2 we evaluate the second-best toll and the desired tolls for the three groups of residents for different relative congestibility of the midcity and suburban bridges. The second-best toll is very sensitive to variations in the relative congestibility: the toll at the midcity bridge is much lower when bridge S is the most congestible. The toll wanted by landowners in C hardly depends on relative congestibility: they consistently want a high toll.

	τ_m^c	τ_m^m	τ_m^p	τ_m^{SB}
$\delta_m = \delta_s = 0.1$	0.275	<0	<0	0.195
$\delta_m = 0.2; \delta_s = 0$	0.262	<0	<0	0.262
$\delta_m = 0; \delta_s = 0.2$	0.259	<0	<0	0.102

Table 2: congestion and tolls on the midcity bridge

In sum, the results of Tables 1 and 2 imply that the political equilibrium in this simple example is a zero toll. Remember that the desired toll by pure renters is independent of the land ownership parameters β_c, β_m . Moreover, the toll wanted by the renter/median voter is zero for a wide range of congestion parameters.

Next look at the results for tolling the suburban bridge. They are summarized in Tables 3 and 4. These have the same structure as Tables 1 and 2 above, with one exception. As shown in the theoretical sections, the median voter is no longer a pure renter; instead, it turns out that the resident owning land in M is the median voter. The toll such a person wants strongly depends on the landownership parameters; we therefore report results for two very

different parameter sets: the parameters used in the base scenario ($\beta_c = \beta_m = 1/3$) and the set ($\beta_c = \beta_m = 2/3$).

Results are easily summarized. Consider Table 3. At low ownership shares, all groups want a zero toll, despite a positive second best optimal toll (note that the latter is much lower than the optimal toll on the midcity bridge). However, at high ownership shares, the median voter (resident of group m) wants a positive toll, which is not much below second-best optimal. The β_c, β_m matter a lot here. For sufficiently high values, the median voter would vote in favor of the second best optimal toll, unlike in the case of the midcity bridge. When β_c, β_m are low, the second best toll is not accepted anywhere.

	r_c	r_m	n_c	n_m	n_s	q_c	q_m	U^c	U^m	U^p	SW	$Toll$
No congestion $\delta_m = \delta_s = 0$	1	1	1	1	1	1	1	1.33	1.33	1	5	0
Congestion, no toll $\delta_m = \delta_s = 0.1$	1.21	1.07	1.21	1.07	0.71	0.83	0.93	1.19	1.11	0.75	4.61	0
Second best (τ^{SB})	1.39	1.16	1.39	1.16	0.45	0.72	0.86	1.15	1.10	0.69	4.67	0.127
$\beta_c = \beta_m = 1/3$												
Owners C (τ^c)												<0
Owners M (τ^m)												<0
Pure renters (τ^p)												<0
$\beta_c = \beta_m = 2/3$												
Owners C (τ^c)	1.39	1.19	1.39	1.19	0.42	0.72	0.84	1.62	1.48	0.68	4.64	0.134
Owners M (τ^m)	1.37	1.16	1.37	1.16	0.47	0.73	0.86	1.61	1.48	0.70	4.63	0.108
Pure renters (τ^p)												<0

Table 3: a toll on the suburban bridge

Table 4 has the results for various congestion parameters. At low land ownership shares, varying congestion still implies zero tolls throughout. At higher land ownership shares the table further confirms what we found before for the midcity bridge, viz. that the second best toll is more sensitive to congestion than the toll wanted by the residents.

	τ_m^c	τ_m^m	τ_m^p	τ_m^{SB}
$\beta_c = \beta_m = 1/3; \delta_m = \delta_s = 0.1$	<0	<0	<0	0.127
$\beta_c = \beta_m = 1/3; \delta_m = 0.2; \delta_s = 0$	<0	<0	<0	0.147
$\beta_c = \beta_m = 1/3; \delta_m = 0; \delta_s = 0.2$	<0	<0	<0	0.102
$\beta_c = \beta_m = 2/3; \delta_m = \delta_s = 0.1$	0.134	0.108	<0	0.127
$\beta_c = \beta_m = 2/3; \delta_m = 0.2; \delta_s = 0$	0.149	0.102	<0	0.147
$\beta_c = \beta_m = 2/3; \delta_m = 0; \delta_s = 0.2$	0.107	0.101	<0	0.102

Table 4: congestion and tolling the suburban bridge

Finally, in Table 5 we illustrate the results on toll location. For different parameter settings we report, for each of the three resident types – landowners in the center and the midcity (residents of groups c and m , respectively) and pure renters (group p) -- the utility difference of a marginal toll on bridge M and bridge S . The relevant expression were given by (51), (54) and (55). A positive value means that the relevant group prefers a marginal toll on bridge M . Note that we recalibrated the zero toll situation for each set of parameters. This explains the different starting values of the populations reported in the table. The results show that given the utility specification and for a very wide range of congestion function parameters, we always find that the toll on M is preferred by landowners in C as well as by pure renters. Unless midcity residents have an absolute majority this implies residents would vote for the midcity toll if they were asked to chose between a small toll on the midcity or the suburban bridge.

	n_c	n_m	n_s	$\left. \frac{dU^p}{d\tau_m} \right _{\tau_m=0} - \left. \frac{dU^p}{d\tau_s} \right _{\tau_s=0}$	$\left. \frac{dU^c}{d\tau_m} \right _{\tau_m=0} - \left. \frac{dU^c}{d\tau_s} \right _{\tau_s=0}$	$\left. \frac{dU^m}{d\tau_m} \right _{\tau_m=0} - \left. \frac{dU^m}{d\tau_s} \right _{\tau_s=0}$	Decision
$\delta_m = 0.1$ $\delta_s = 0.1$	1.27	1.07	0.68	0.278	0.312	-0.047	Majority prefers toll on bridge M
$\delta_m = 0.2$ $\delta_s = 0$	1.38	1	0.62	0.333	0.333	0	Majority prefers toll on bridge M
$\delta_m = 0$ $\delta_s = 0.2$	1.16	1.15	0.69	0.231	0.290	-0.081	Majority prefers toll on bridge M

Table 5: illustrating toll location

7. Concluding remarks

This paper studied the political economy of cordon tolls in urban areas. We considered a city inhabited by renters and resident-landowners commuting to a central business district. Introduction of the toll affects the price of land both within and outside the cordon, redistributing welfare not only between renters and landowners, but also within the group of landowners. The majority voting equilibrium therefore strongly depends on whether and where urban residents own land. We showed that the equilibrium toll is below the socially optimal level unless the majority of residents owns land within the cordon. In all other cases the government implements a toll smaller than the optimal level, or even no toll at all. If residents have heterogeneous wages, the baseline results still hold, unless the poor live in the center and own a large share of land within the cordon. Interestingly, moving the cordon further away from the city center shifts the political power from the suburbs towards the center, and from renters to landowners. Moreover, we found that -- under plausible conditions -- it is easier to get a political majority for a small toll close to the city center than a cordon further out in the suburbs. Our results are not inconsistent with a number of empirical observations.

The analysis can be extended in several interesting directions. First, we have assumed that all residents in the city commute to the *CBD*, and they all commute by car. This obviously need not be the case. Assume commuters can travel by car or use public transportation (or bike to their destination). Suppose also that commuting costs by public transport increase with distance more rapidly than commuting costs by car, and that there is a

fixed cost of car ownership.³⁰ In equilibrium, residents living close enough to the *CBD* will then use public transport, while the others commute by car. The results of the model then hinge on how fast the cost of using public transport increases with distance from the *CBD*, relative to the cost of using cars. For example, let the increase be quite steep, so that only residents in the central island find public transport convenient. As in the baseline model, only by residing within the cordon would an individual avoid a toll placed on the midtown bridge. Thus, the results of the model would be essentially identical to those of section 3. If residents of both *C* and *M* use public transport and only residents in *S* go by car, the results would be more involved. Nevertheless, in a more general model, one would expect that, even if the share of people using public transport does not steeply decline outside of the cordon area, the toll would increase density and land prices relatively close to the *CBD* (even if outside the cordon), but decrease them farther away. As a result, it is unlikely that the results would not differ substantially from those of our basic model.

Second, one could also extend the baseline model assuming that some individuals simply do not commute to the *CBD*. Even if non-users are a majority, one can reasonably conjecture that, if a large share of them are renters or owns land outside the cordon area, there may not be sufficient political support to implement the toll.³¹

Finally, we assumed that the government redistributes toll revenues via a uniform lump sum transfer. One could of course study alternative uses of revenues. For instance, the government may invest revenues to expand the capacity of the two bridges. By making roads less congestible, this could mitigate (but not eliminate) the effect of the toll on land rents. Although the opposition to tolls by renters and landowners outside the cordon could be weakened, our qualitative results would not be overturned.

³⁰ This is a rather crude assumption, but it is reasonable, as it captures the fact that travel time costs by car are generally smaller than by public transport. The assumption is also in line with previous literature. See, e.g., Borck and Wrede (2008) and Su and De Salvo (2008).

³¹ As previously shown by Borck and Wrede (2008), if commuting taxes (like the cordon toll) affect land rents, the majority may oppose them even if it does not use the taxed mode. The effects of the toll on the land market may therefore contribute to explain the rather puzzling fact that, in several cities that recently rejected proposals for cordon tolls (e.g. Edinburgh, Manchester and New York City), commuters traveling by car to the designated cordon area were not a majority.

References

- Anas, A., Hiramatsu, T., 2013. The economics of cordon tolling: General equilibrium and welfare analysis, *Economics of Transportation* 2, 18-37.
- Bento, A.M., Franco, S.F., Kaffine, D. (2006). The efficiency and distributional impacts of alternative anti-sprawl policies. *Journal of Urban Economics* 59, 121–141.
- Borck, R. and M. Wrede (2005). Political Economy of Commuting Subsidies, *Journal of Urban Economics*, 57, 478–499.
- Borck, R. and M. Wrede (2008). Commuting Subsidies with Two Transport Modes, *Journal of Urban Economics*, 63, 841–848.
- Brueckner, J.K. and H. Selod (2006), The political economy of urban transport-system choice, *Journal of Public Economics* 90, 983-1005.
- Brueckner (2011). Lectures in urban economics. MIT Press.
- Brueckner J. (2015). Cordon Tolling in a City with Congested Bridges. *Economics of Transportation*, 3, 235-242
- D’Arcangelo F. and M. Percoco (2015). Housing rent and road pricing in Milan: Evidence from a geographical discontinuity approach. *Transport Policy*, 44, 108–116
- De Borger, B., and S. Proost (2012). A political economy model of road pricing. *Journal of Urban Economics*, 71, 79-92
- De Borger B. and S. Proost (2015). The political economy of pricing and provision of congestible public goods in a federal state. Working Paper, University of Antwerp.
- De Lara, M., de Palma, A., Kilani, M., Piperno, S., 2013. Congestion pricing and long term urban form: Application to Paris region. *Regional Science and Urban Economics* 43, 282-295.
- Eliasson J. (2008). A cost–benefit analysis of the Stockholm congestion charging system. *Transportation Research A*. 43(4):468-480.
- Eurostat (2014), Distribution of population by tenure status, type of household and income group. Available at: <http://appsso.eurostat.ec.europa.eu/nui/show.do>
- Gans, J., and Smart, M. (1996). Majority voting with single-crossing of preferences. *Journal of Public Economics*, 59, 219-238.
- Marcucci, E., Marini, M., and Ticchi, D. (2005). Road pricing as a citizen-candidate game. *European Transport*, 31: 28-45
- Mun, S., Konishi, K., Yoshikawa, K. (2003). Optimal cordon pricing. *Journal of Urban Economics* 54, 21-38.

- Mun, S., Konishi, K., Yoshikawa, K., (2005). Optimal cordon pricing in a non-monocentric city. *Transportation Research A*, 39, 723–736
- Rotaris L., Danielis R., Marcucci E. and J. Massiani (2010). The urban road pricing scheme to curb pollution in Milan, Italy: Description, impacts and preliminary cost–benefit analysis assessment. *Transportation Research A*, Volume 44, 359–375
- Russo A. (2013). Voting on road congestion policy. *Regional Science and Urban Economics* 43 (2013), 707-724
- Santos, G. (2008) The London congestion charging scheme. *Brookings Wharton Papers on Urban Affairs*: 2008: 177-234.
- Safirova E., Houde S., Coleman C., Harrington W. and D. Abram Lipman (2006). Long-Term Consequences of Congestion Pricing. Resources For the Future DP 06-42
- Small, K.A., Verhoef, E.T., 2007. The Economics of Urban Transporation. Routledge, Abington, UK.
- Su Q. and J. S. De Salvo (2008). The effect of transportation subsidies on urban sprawl. *Journal of Regional Science*, 48 (3), 567–594
- Tikoudis I., Verhoef E. and J. van Ommeren J. (2015). On revenue recycling and the welfare effects of second-best congestion pricing in a monocentric city. *Journal of Urban Economics*, 89, 32-47
- US Census Bureau (2012). American Community Survey 2012.
- Verhoef, E.T., (2005). Second-best congestion pricing schemes in the monocentric city. *Journal of Urban Economics* 58, 367-388.

Appendix 1: Derivation of second best and most-preferred tolls

We begin with the derivation of τ^{SB} . Replacing from (2) with $R^p = 0$, we can rewrite (14) as

$$SW = N \left[\left(v(q_c) + y - r_c q_c + \frac{\tau(n_s + n_m)}{N} \right) + \frac{r_c + r_m}{N} \right]$$

The first-order condition is

$$N \left[-q_c \frac{dr_c}{d\tau} + \frac{n_m + n_s}{N} + \frac{\tau}{N} \frac{d(n_m + n_s)}{d\tau} + \left(\frac{dr_c}{d\tau} + \frac{dr_m}{d\tau} \right) \frac{1}{N} \right] = 0$$

Using (10) in this expression, we find

$$\frac{\tau}{N} \left(\frac{dr_c}{d\tau} Z_c \right) = -\frac{\frac{dr_c}{d\tau} + \frac{dr_m}{d\tau}}{N} + q_c \frac{dr_c}{d\tau} - \frac{n_s + n_m}{N}.$$

Rearranging and using (1) and (6), we have

$$\tau = \frac{(n_s + n_m)}{Z_c} \left(q_c - \frac{1}{\frac{dr_c}{d\tau}} \right) - \frac{\frac{dr_m}{d\tau}}{Z_c \frac{dr_c}{d\tau}}.$$

Finally, using (11), the definition of Z_c, Z_m , and (6), we find (15).

Next we derive (16). We start from the first-order condition of a pure renter (as before, we apply the equilibrium condition requiring that utility be invariant with respect to location):

$$\frac{dU^p}{d\tau} = -q_c \frac{dr_c}{d\tau} + \frac{n_m + n_s}{N} + \frac{\tau}{N} \frac{d(n_m + n_s)}{d\tau} = 0,$$

Using (10), this can be rewritten as

$$\tau = \frac{q_c N}{Z_c} - \frac{(n_s + n_m)}{Z_c \frac{dr_c}{d\tau}}.$$

Further using (10) and (11), this yields

$$\tau = t'_m (n_m + n_s) + \frac{t'_s n_s q_m}{q_m - t'_s Z_m} + \frac{1}{Z_c} + \frac{t'_s}{q_m - t'_s Z_m}.$$

To obtain (16), recall the expressions for $\frac{dr_c}{d\tau}$ and $\frac{dr_m}{d\tau}$ in (11), and apply the definition of Φ given in the text.

Finally, the derivation of τ^c and τ^m follow almost identical steps as for the derivation of (16), except that $\frac{dU^c}{d\tau} = \frac{dU^p}{d\tau} + \beta_c \frac{dr_c}{d\tau}$ and $\frac{dU^m}{d\tau} = \frac{dU^p}{d\tau} + \beta_m \frac{dr_m}{d\tau}$.

Appendix 2: Proof of existence of a voting equilibrium

Define the following marginal rate of substitution

$$\Gamma_i \equiv \frac{\frac{dU^i}{d\tau}}{\frac{dU^i}{dL}} \quad i = c, m, p,$$

where $L = \frac{\tau(n_s + n_m)}{N}$. Gans and Smart (1996) prove that the ‘single crossing’ property is satisfied if Γ_i is monotonic with respect to the types i (when evaluated at any τ). It is easily shown that this condition holds in the present setup. To see this, note that

(i) for any τ we have

$$\frac{dU^p}{d\tau} = \frac{dU^c}{d\tau} - \beta_c \frac{dr_c}{d\tau} = \frac{dU^m}{d\tau} - \beta_m \frac{dr_m}{d\tau} \Rightarrow \frac{dU^m}{d\tau} \leq \frac{dU^p}{d\tau} \leq \frac{dU^c}{d\tau}$$

(ii) for any τ , we have $\frac{dU^i}{dL} = 1$ ($i = c, m, p$).

This shows the existence of a majority voting equilibrium. Moreover, the equilibrium is such that the median voter is decisive. Here, this voter is an individual in group $i=p$.

Appendix 3: Analysis of the case “rich in center”

Second best toll

Using (21) - (25) with $R^{p,w} = 0$, $w=h,l$, we can rewrite (30) as

$$SW = N^h (v(q_c) - r_c q_c) + N^l (v(q_s) - \tau - x^l (t_m(n_s + n_m) + t_s(n_s))) + \\ + \tau(n_s + n_m) + r_c + r_m + Y(N^l x^l + N^h x^h)$$

The first-order condition is

$$N^h \left(-q_c \frac{dr_c}{d\tau} \right) + N^l \left(-1 - x^l \left(t'_m \frac{d(n_m + n_s)}{d\tau} + t'_s \frac{dn_s}{d\tau} \right) \right) + n_m + n_s + \tau \frac{d(n_m + n_s)}{d\tau} + \left(\frac{dr_c}{d\tau} + \frac{dr_m}{d\tau} \right) = 0$$

(A3.1)

Using identity (1), equilibrium conditions $v'(q_j) = r_j$, (26) and (10), we can rewrite (A3.1) as:

$$\tau \left(\frac{dr_c}{d\tau} Z_c \right) = - \left(\frac{dr_c}{d\tau} + \frac{dr_m}{d\tau} \right) - (n_s + n_m) + N^h q_c \frac{dr_c}{d\tau} + N^l \left(1 + x^l \left(t'_m \left(\frac{dr_c}{d\tau} Z_c \right) + t'_s \left(\frac{dr_c}{d\tau} Z_c + \frac{dr_m}{d\tau} Z_m \right) \right) \right).$$

Making use of (26), this equation can be further rewritten as follows:

$$\tau = (N^h - n_c) \frac{q_c}{Z_c} + (N^l - n_m - n_s) \frac{1}{\frac{dr_c}{d\tau} Z_c} - \frac{\frac{dr_m}{d\tau}}{\frac{dr_c}{d\tau} Z_c} + N^l x^l \left(t'_m + t'_s \left(1 + \frac{\frac{dr_m}{d\tau} Z_m}{\frac{dr_c}{d\tau} Z_c} \right) \right).$$

Using the definition of Z_c, Z_m and expressions (26), and (29) in this expression, we find after some algebra:

$$\tau = t'_m (x^h (n_m + n_s - N^l) + x^l N^l) + \left(\frac{t'_s x^l}{q_m - x^l t'_s Z_m} \right) (n_s q_m - N^l q_m + x^l N^l t'_s Z_m) + x^l N^l t'_s,$$

which simplifies to (31).

Preferred tolls of the rich

Consider an individual in group p, h . Observe that, by (25), there is no loss of generality in proceeding as if rich pure renters all reside on C . The first order condition for this individual reads

$$\frac{dU^{p,h}}{d\tau} = -q_c \frac{dr_c}{d\tau} + \frac{n_m + n_s}{N} + \frac{\tau}{N} \frac{d(n_m + n_s)}{d\tau} = 0.$$

Using the definition of Z_c, Z_m and (26), this can be rearranged as follows

$$\tau = \frac{Nq_c}{Z_c} - (n_m + n_s) \frac{1}{\frac{dr_c}{d\tau} Z_c}$$

Using (29), we have, again after rearrangements

$$\tau = \frac{1}{Z_c} + x^h t'_m (n_m + n_s) + \frac{x^l t'_s (n_m + n_s) q_m}{q_m - x^l t'_s Z_m}. \quad (\text{A3.2})$$

Define

$$\Omega \equiv \frac{\Sigma N}{Z_c (q_m - x^l t'_s Z_m)} < 0,$$

where Σ has been defined in the text. Rearranging (A3.2) and using this definition, we obtain (32).

Finally, recognizing that $U^{c,h} = U^{p,h} + R^{c,h}$ and $U^{m,h} = U^{p,h} + R^{m,h}$, one can follow similar steps to get (33) and (34).

Preferred tolls of the poor

Consider an individual in group p, l . As before, by (25), there is no loss of generality in proceeding as if poor pure renters all reside on S . We can therefore write the first order condition for a poor renter as

$$\frac{dU^{p,l}}{d\tau} = -\left(1 + x^l t'_m \frac{d(n_m + n_s)}{d\tau} + x^l t'_m \frac{dn_s}{d\tau}\right) + \frac{n_m + n_s}{N} + \frac{\tau}{N} \frac{d(n_m + n_s)}{d\tau} = 0. \quad (\text{A3.3})$$

In order to facilitate comparison with the preferences of the rich, it is useful to rewrite this expression as follows. Differentiating (27) we have $q_m \frac{dr_m}{d\tau} = q_c \frac{dr_c}{d\tau} - \left(1 + x^h t'_m \frac{d(n_m + n_s)}{d\tau}\right)$.

Similarly, differentiating (28) we get $x^l t'_s \frac{dn_s}{d\tau} = q_m \frac{dr_m}{d\tau}$. Replacing the term $q_m \frac{dr_m}{d\tau}$ in the previous expression and rearranging, we can rewrite (A3.3) as

$$\frac{dU^l_p}{d\tau} = -q_c \frac{dr_c}{d\tau} + (x^l - x^h) t'_m \left(\frac{d(n_m + n_s)}{d\tau} \right) + \frac{n_m + n_s}{N} + \frac{\tau}{N} \frac{d(n_m + n_s)}{d\tau} = 0.$$

Solving for the toll, and using the same steps as for the derivation of (32), we find (35). Finally, recognizing that $U^{m,l} = U^{p,l} + R^{m,l}$, one can follow similar steps to derive (36).

Existence of a voting equilibrium

Characterization of the majority voting equilibrium is made difficult by the fact that policy preferences in this scenario do not necessarily satisfy the single-crossing property. Note the following relations:

$$\frac{dU^w_p}{d\tau} = \frac{dU^w_m}{d\tau} - \beta^w_m \frac{dr_m}{d\tau} = \frac{dU^w_c}{d\tau} - \beta^w_c \frac{dr_c}{d\tau} \quad (\text{for any } w=l, h, \text{ and } \tau)$$

This allows us to obtain

$$\frac{dU^h_m}{d\tau} < \frac{dU^h_p}{d\tau} < \frac{dU^h_c}{d\tau} \quad \text{and} \quad \frac{dU^l_m}{d\tau} < \frac{dU^l_p}{d\tau} \quad \text{for any } \tau.$$

Hence, Single Crossing (SC) holds within each wage class. Because $x^h > x^l$, it is also easily established that

$$\frac{dU^l_p}{d\tau} < \frac{dU^h_p}{d\tau}.$$

However, to establish SC over the entire population, we have to establish that the relation between $\frac{dU_p^l}{d\tau}$ and $\frac{dU_m^h}{d\tau}$ has the same sign for any τ ; unfortunately, this relation is ambiguous in general. A poor pure renter may obtain larger utility from a marginal increase in the toll than a rich landowner on M ; this will be the case if the latter owns a large enough share of land and the difference in wages between rich and poor is not too large. If either $\frac{dU_p^l}{d\tau} < \frac{dU_m^h}{d\tau}$ for all τ , or if $\frac{dU_p^l}{d\tau} > \frac{dU_m^h}{d\tau}$ for all τ , then SC holds. Assume it is the case. From Gans and Smart (1996), one can establish that a majority voting equilibrium exists and the median voter is a member of either group $i=p,l$, $i=p,m$ or group $i=h,m$ (the latter is possible only if $\frac{dU_p^l}{d\tau} > \frac{dU_m^h}{d\tau}$ for all τ).

Appendix 4: The “Poor in center” case

The second-best optimal toll

The usual equilibrium conditions apply, including

$$n_c^l q_c = n_c q_c = 1, \quad n_m^l q_m = n_m q_m = 1 \quad (\text{A4.1})$$

and

$$U_c^{i,l} = U_m^{i,l} = U_s^{i,l} \quad i = c, m, p. \quad (\text{A4.2})$$

Using these expressions, the condition $v'(q_j) = r_j$, and following the same steps as in the baseline model, we get

$$\frac{dr_c}{d\tau} = \frac{1}{\Delta} [q_m - x^l t'_s Z_m] > 0 \quad \frac{dr_m}{d\tau} = \frac{1}{\Delta} [x^l t'_s Z_c] < 0, \quad (\text{A4.3})$$

where

$$\Delta \equiv [q_c - x^l t'_m Z_c] [q_m - x^l t'_s Z_m] - q_m x^l t'_s Z_c > 0.$$

The social welfare function is

$$SW = \sum_{i=c,m,p} N^{i,l} U^{i,l} + \sum_{i=c,m,p} N^{i,h} U^{i,h} + \left(1 - \sum_{w=h,l} \beta_c^w N^{c,w}\right) r_c + \left(1 - \sum_{w=h,l} \beta_m^w N^{m,w}\right) r_m$$

Substituting the relevant utility specifications, we get

$$\begin{aligned}
SW = & N \left\{ \frac{N^l}{N} \left(v(q_s) + x^l \cdot (Y - t_m(n_s + n_m) - t_s(n_s)) + \frac{\tau(n_m + n_s)}{N} - \tau \right) + \right. \\
& + \frac{N^h}{N} \left(v(q_s) + x^h \cdot (Y - t_m(n_s + n_m) - t_s(n_s)) + \frac{\tau(n_m + n_s)}{N} - \tau + \gamma \right) \Big\} \\
& + Y(N^l x^l + N^h x^h) + r_m + r_c.
\end{aligned}$$

The first order condition is

$$\begin{aligned}
& N^l \left(-x^l \left(t'_m \frac{d(n_s + n_m)}{d\tau} + t'_s \frac{dn_s}{d\tau} \right) - 1 \right) + N^h \left(-x^h \left(t'_m \frac{d(n_s + n_m)}{d\tau} + t'_s \frac{dn_s}{d\tau} \right) - 1 \right) + \\
& + (n_m + n_s) + \tau \frac{d(n_s + n_m)}{d\tau} + \left(\frac{dr_c}{d\tau} + \frac{dr_m}{d\tau} \right) = 0
\end{aligned} \tag{A4.4}$$

Using (10), the definitions of Z_c, Z_m and rearranging, we can reformulate (A4.4) as

$$\tau \left(\frac{dr_c}{d\tau} Z_c \right) = - \left(\frac{dr_c}{d\tau} + \frac{dr_m}{d\tau} \right) - (n_s + n_m) + N + (N^l x^l + N^h x^h) \left(t'_m \left(\frac{dr_c}{d\tau} Z_c \right) + t'_s \left(\frac{dr_c}{d\tau} Z_c + \frac{dr_m}{d\tau} Z_m \right) \right)$$

Hence, using $\frac{dr_m}{d\tau} = \frac{1}{\Delta} [x^l t'_s Z_c]$ from (A4.3), we find

$$\tau = \frac{n_c}{Z_c \frac{dr_c}{d\tau}} + (N^l x^l + N^h x^h) \left(t'_m + t'_s + t'_s \frac{Z_m t'_s x^l}{(q_m - t'_s x^l Z_m)} \right) - \frac{t'_s x^l}{(q_m - t'_s x^l Z_m)} - \frac{1}{Z_c}.$$

Further replacing $\frac{dr_c}{d\tau}$ (see (A4.3)) in the above expression, after some rearrangements, we obtain (43) in the text.

Preferred tolls by poor individuals

Consider a poor pure renter. By (A4.2), there is no loss of generality in assuming that she resides in S . With $R^{p,l} = 0$, starting from (42), the first order condition reads

$$\frac{dU^{p,l}}{d\tau} = - \left(1 + x^l t'_m \frac{d(n_m + n_s)}{d\tau} + x^l t'_s \frac{dn_s}{d\tau} \right) + \frac{n_m + n_s}{N} + \frac{\tau}{N} \frac{d(n_m + n_s)}{d\tau} = 0$$

Using the definition of Z_c, Z_m and (A4.1), this can be rearranged as follows

$$\tau = \frac{n_c}{Z_c \frac{dr_c}{d\tau}} + N x^l \left(t'_m + t'_s + t'_s \frac{Z_m \frac{dr_m}{d\tau}}{\frac{dr_c}{d\tau} Z_c} \right).$$

Using (A4.3) and rearranging, we can rewrite this as

$$\tau = \frac{1}{Z_c} + x^l t'_m (n_m + n_s) + x^l t'_s (n_m + n_s) + \frac{(x^l t'_s)^2 Z_m (n_m + n_s)}{q_m - x^l t'_s Z_m}. \quad (\text{A4.5})$$

Define

$$\Omega \equiv \frac{\Delta N}{Z_c (q_m - x^l t'_s Z_m)} < 0,$$

where Δ has been defined in (12). Using this definition and rearranging, (A4.5) becomes

$$\begin{aligned} \tau^{p,l} = & t'_m \left(x^h N^h + x^l (n_m + n_s - N^h) \right) + \frac{t'_s q_m \left(x^l (n_s - N^h) + x^h N^h \right)}{q_m - t'_s x^l Z_m} + \\ & + (x^l - x^h) N^h \left(t'_m + \frac{t'_s q_m}{q_m - t'_s x^l Z_m} \right) + \Omega \left(\frac{dr_c}{d\tau} \frac{1}{N} + \frac{dr_m}{d\tau} \frac{1}{N} \right). \end{aligned}$$

Finally, recognizing that $U^{c,l} = U^{p,l} + R^{c,l}$ and that $U^{m,l} = U^{p,l} + R^{m,l}$, one can follow similar steps to get

$$\begin{aligned} \tau^{c,l} = & t'_m \left(x^h N^h + x^l (n_m + n_s - N^h) \right) + \frac{t'_s q_m \left(x^l (n_s - N^h) + x^h N^h \right)}{q_m - t'_s x^l Z_m} + \\ & + (x^l - x^h) N^h \left(t'_m + \frac{t'_s q_m}{q_m - t'_s x^l Z_m} \right) + \Omega \left(\frac{dr_c}{d\tau} \left(\frac{1}{N} - \beta_c^l \right) + \frac{dr_m}{d\tau} \frac{1}{N} \right) \end{aligned}$$

and

$$\begin{aligned} \tau^{m,l} = & t'_m \left(x^h N^h + x^l (n_m + n_s - N^h) \right) + \frac{t'_s q_m \left(x^l (n_s - N^h) + x^h N^h \right)}{q_m - t'_s x^l Z_m} + \\ & + (x^l - x^h) N^h \left(t'_m + \frac{t'_s q_m}{q_m - t'_s x^l Z_m} \right) + \Omega \left(\frac{dr_c}{d\tau} \frac{1}{N} + \frac{dr_m}{d\tau} \left(\frac{1}{N} - \beta_m^l \right) \right). \end{aligned}$$

The most-preferred tolls by the poor have a similar interpretation to those seen in the “Rich in Center” scenario. They contain the “second best” terms, plus positive correction terms that account for the wage difference between rich and poor. Finally, we have the familiar terms that account for the extent to which a poor individual internalizes the effect of the toll on land rents (depending on if and where she owns land).

Most preferred toll for the rich

Consider a rich pure renter. Starting from (39), with $R^{p,h} = 0$, the first order condition reads

$$\frac{dU^{p,h}}{d\tau} = - \left(1 + x^h t'_m \frac{d(n_m + n_s)}{d\tau} + x^h t'_s \frac{dn_s}{d\tau} \right) + \frac{n_m + n_s}{N} + \frac{\tau}{N} \frac{d(n_m + n_s)}{d\tau} = 0.$$

Following similar steps as for the derivation of $\tau^{p,l}$ above, we obtain

$$\begin{aligned}\tau^{p,h} &= t'_m \left(x^h \cdot N^h + x^l \cdot (n_m + n_s - N^h) \right) + \frac{t'_s q_m \left(x^l (n_s - N^h) + x^h N^h \right)}{q_m - t'_s x_l Z_m} \\ &+ (x^h - x^l) N^l \left(t'_m + \frac{t'_s q_m}{q_m - t'_s x^l Z_m} \right) + \Omega \left(\frac{dr_c}{d\tau} \frac{1}{N} + \frac{dr_m}{d\tau} \frac{1}{N} \right).\end{aligned}$$

And, recognizing that $U^{c,h} = U^{p,h} + R^{c,h}$ and $U^{m,h} = U^{p,h} + R^{m,h}$, we have

$$\begin{aligned}\tau^{c,h} &= t'_m \left(x^h \cdot N^h + x^l \cdot (n_m + n_s - N^h) \right) + \frac{t'_s q_m \left(x^l (n_s - N^h) + x^h N^h \right)}{q_m - t'_s x_l Z_m} \\ &+ (x^h - x^l) N^l \left(t'_m + \frac{t'_s q_m}{q_m - t'_s x^l Z_m} \right) + \Omega \left(\frac{dr_c}{d\tau} \left(\frac{1}{N} - \beta_c^h \right) + \frac{dr_m}{d\tau} \frac{1}{N} \right) \\ \tau^{m,h} &= t'_m \left(x^h \cdot N^h + x^l \cdot (n_m + n_s - N^h) \right) + \frac{t'_s q_m \left(x^l (n_s - N^h) + x^h N^h \right)}{q_m - t'_s x_l Z_m} \\ &+ (x^h - x^l) N^l \left(t'_m + \frac{t'_s q_m}{q_m - t'_s x^l Z_m} \right) + \Omega \left(\frac{dr_c}{d\tau} \frac{1}{N} + \frac{dr_m}{d\tau} \left(\frac{1}{N} - \beta_m^h \right) \right)\end{aligned}$$

Voting equilibrium and proof of Proposition 3.

We will again proceed assuming that $\frac{dr_c}{d\tau} > \left| \frac{dr_m}{d\tau} \right|$ holds. Under this assumption, comparison of toll rules derived above suggests the following

$$\tau^{m,l} < \tau^{p,l} < \min(\tau^{c,l}; \tau^{SB}), \quad \tau^{SB} > \tau^{c,l} \quad \tau^{m,h} < \tau^{p,h} < \tau^{c,h}.$$

The main difference with the “Rich in Center” case is that some poor individuals may own land on C . Their most-preferred toll cannot be immediately compared with the second best toll. This is because these individuals have smaller value of time than average, but may support a larger toll than optimal if they own a large share of land.

As was the case in the “Rich in Center” scenario, the single crossing condition does not always hold under our assumptions, which makes a complete characterization of the majority voting equilibrium quite involved (see Appendix 3).³²

Following the same logic as in Lemma 2, we just claim:

³² As in the Rich in Center scenario, it is not difficult to come up with sufficient conditions for existence.

LEMMA A.1: *In the poor in center scenario, if a majority voting equilibrium exists, then*

- *If $N^{m,l} + N^{p,l} < \frac{N}{2}$, the equilibrium cannot exceed $\tau^{c,l}$*
- *If $N^{m,l} + N^{p,l} \geq \frac{N}{2}$, the equilibrium cannot exceed $\tau^{p,l}$*

The logic is the same as for Lemma 2 (see the proof in section 4.1). Because

$$\frac{dU_m^l}{d\tau} < \frac{dU_p^l}{d\tau} < \frac{dU_c^l}{d\tau} \quad \forall \tau, \text{ all poor individuals prefer } \tau^{c,l} \text{ to any larger toll. Furthermore, poor}$$

landowners in M and pure renters prefer $\tau^{p,l}$ to any larger toll. Hence, given that poor individuals are the majority in the population, if an equilibrium exists, it cannot exceed $\tau^{c,l}$.

In addition, if poor landowners in M and renters are more than half the total population, i.e.,

$$N^{m,l} + N^{p,l} \geq \frac{N}{2}, \text{ the equilibrium cannot exceed } \tau^{p,l}.$$

We are now in a position to prove Proposition 3. If the number of poor landowners in C is small, i.e. such that $N^{m,l} + N^{p,l} \geq \frac{N}{2}$, then, if an equilibrium exists, it cannot exceed $\tau^{p,l}$.

Thus, the toll resulting from the political process is certainly below the second best optimum.

Otherwise, the upper bound is $\tau^{c,l}$. Observe that $\tau^{c,l}$ increases in β_c^l and tends to $\tau^{p,l}$ when

$$\beta_c^l \text{ tends to zero. Therefore, we can claim that when } N^{m,l} + N^{p,l} < \frac{N}{2}, \text{ but } \beta_c^l \text{ is sufficiently}$$

small, the voting equilibrium (if it exists) is such that the toll is below optimum. This proves Proposition 3.

Appendix 5: Analysis of a suburban toll

The effect of the suburban toll on land rents

We denote the suburban toll by τ_s . We first determine how land rents in C and M change with respect to this toll. The following equilibrium conditions must now hold (these are equivalent to (8) and (9) before):

$$v(q_s) - (v(q_c) - r_c \cdot q_c) = \tau_s + t_m(n_s + n_m) + t_s(n_s)$$

$$v(q_s) - (v(q_m) - r_m \cdot q_m) = \tau_s + t_s(n_s)$$

Totally differentiating these equations with respect to τ_s , and using the equilibrium conditions $v'(q_j) = r_j$ and (6), we obtain, using similar derivations as in the case of the midcity toll:

$$\frac{dr_c}{d\tau_s} = \frac{1}{\Delta} q_m > 0; \quad \frac{dr_m}{d\tau_s} = \frac{1}{\Delta} (q_c - t_m' Z_c) > 0 \quad (\text{A5.1})$$

Derivation of toll formulas

Using the fact that utility is independent of location, one way of formulating the government's problem is to maximize N times the utility of a renter living in C plus total land rents:

$$\text{Max}_{\tau_s} \quad N \left\{ y + v(q_c) - r_c q_c + \frac{\tau_s n_s}{N} + \frac{r_m + r_c}{N} \right\}$$

As in the baseline model, we have

$$\frac{dn_s}{d\tau_s} = -\frac{dn_c}{d\tau_s} - \frac{dn_m}{d\tau_s} = Z_c \frac{dr_c}{d\tau_s} + Z_m \frac{dr_m}{d\tau_s}, \quad \frac{d(n_s + n_m)}{d\tau_s} = -\frac{dn_c}{d\tau_s} = Z_c \frac{dr_c}{d\tau_s}.$$

Hence, the first order condition can be written as

$$\tau_s \left[(Z_c) \frac{dr_c}{d\tau_s} + (Z_m) \frac{dr_m}{d\tau_s} \right] = (Nq_c - 1) \frac{dr_c}{d\tau_s} - \frac{dr_m}{d\tau_s} - n_s.$$

Using (A5.1) and rearranging, the above gives

$$\tau_s^{SB} = t_s' n_s + \frac{t_m' (n_s + n_m) (Z_c q_m)}{Z_c q_m + Z_m (q_c - t_m' Z_c)}$$

To derive the most preferred suburban toll by a resident-landowner in C , using the fact that utility is invariant with respect to where people live, we can formulate her problem as follows:

$$\text{Max}_{\tau_s} \quad y + v(q_c) + (\beta_c - q_c) r_c + \frac{\tau_s (n_s)}{N}.$$

The first order condition can be written as

$$\frac{\tau_s}{N} \left[(Z_c) \frac{dr_c}{d\tau_s} + (Z_m) \frac{dr_m}{d\tau_s} \right] = (q_c - \beta_c) \frac{dr_c}{d\tau_s} - \frac{n_s}{N}.$$

Using (A5.1) and rearranging the toll rule can be found as

$$\tau_s^c = t_s' n_s + \frac{t_m' n_s q_m Z_c + q_c + q_m (1 - \beta_c N)}{Z_c q_m + Z_m (q_c - t_m' Z_c)},$$

manipulating this result, and using the definition of Ψ given in the text, we get (47). With similar steps we can derive the most preferred toll by consider pure renters. Using

$\frac{dU^p}{d\tau} = \frac{dU^c}{d\tau} - \beta_c \frac{dr_c}{d\tau}$, the most preferred suburban toll is

$$\tau_s^p = t_s' n_s + \frac{t_m' n_s q_m Z_c + q_c + q_m}{Z_c q_m + Z_m (q_c - t_m' Z_c)},$$

which rearranged using Ψ gives (46).

Finally, consider resident-landowners in M , i.e. group $i=m$. Noting that

$\frac{dU^m}{d\tau} = \frac{dU^s}{d\tau} + \beta_m \frac{dr_m}{d\tau}$, we find

$$\tau_s^m = t_s' n_s + \frac{t_m' n_s q_m Z_c + q_c + q_m - \beta_m N (q_c - t_m' Z_c)}{Z_c q_m + Z_m (q_c - t_m' Z_c)},$$

which can be rewritten as (48).

Existence of the voting equilibrium and proof of Lemma 3

We begin by arguing that preferences do not necessarily satisfy the single crossing (SC) property. As in Appendix 2, define

$$\Gamma_i \equiv \frac{\frac{dU^i}{d\tau_s}}{\frac{dU^i}{dL}} \quad i = c, m, p,$$

where $L = \frac{\tau(n_s + n_m)}{N}$. We know that

$$\frac{dU^c}{d\tau_s} = \frac{dU^p}{d\tau_s} + \beta_c \frac{dr_c}{d\tau_s}; \quad \frac{dU^m}{d\tau_s} = \frac{dU^p}{d\tau_s} + \beta_m \frac{dr_m}{d\tau_s}$$

where

$$\frac{dr_c}{d\tau_s} = \frac{1}{\Delta} (q_m) > 0; \quad \frac{dr_m}{d\tau_s} = \frac{1}{\Delta} (q_c - t_m' Z_m) > 0.$$

Note that $\frac{dU}{dL} = 1$ for all individuals.

It is immediately established that $\frac{dU^p}{d\tau_s} < \min\left[\frac{dU^c}{d\tau_s}, \frac{dU^m}{d\tau_s}\right]$ for all τ_s . Therefore, to

have SC, it must either be the case that $\beta_c \frac{dr_c}{d\tau_s} > \beta_m \frac{dr_m}{d\tau_s}$ for all τ_s , or that $\beta_c \frac{dr_c}{d\tau_s} < \beta_m \frac{dr_m}{d\tau_s}$

for all τ_s . Consider the first order condition in individual's utility maximization

$$v'(q_j) = r_j, \quad j = c, m, s.$$

Differentiating this equation with respect to q_j we have $v''(q_j) = \frac{dr_j}{dq_j}$, and further

differentiating with respect to τ_s we have

$$v'''(q_j) \frac{dq_j}{d\tau_s} = \frac{d^2 r_j}{dq_j d\tau_s}.$$

Assuming that $v'''(q_j) > 0$ for all q_j , the right hand side of the expression must be negative

when $j = c, m$ since $\frac{dq_j}{d\tau_s} < 0$. Finally, because, $q_c < q_m$, this implies that $\frac{dr_c}{d\tau_s} > \frac{dr_m}{d\tau_s}$. Hence,

when $\beta_c \geq \beta_m$, SC holds because $\beta_c \frac{dr_c}{d\tau_s} > \beta_m \frac{dr_m}{d\tau_s}$, and hence $\frac{dU^c}{d\tau_s} > \frac{dU^m}{d\tau_s} > \frac{dU^p}{d\tau_s}$, hold for

any τ_s . Then, a majority voting equilibrium exists and the landowner in M is decisive.

Assume now that $\beta_m > \beta_c$. If $\beta_m \frac{dr_m}{d\tau_s} > \beta_c \frac{dr_c}{d\tau_s}$ for any τ_s , SC holds, the equilibrium

exists and the landowner in C is decisive. However, SC may fail if $\beta_m \frac{dr_m}{d\tau_s} > \beta_c \frac{dr_c}{d\tau_s}$ for some

values of τ_s and $\beta_m \frac{dr_m}{d\tau_s} < \beta_c \frac{dr_c}{d\tau_s}$ for other values. Unfortunately, it is difficult to establish

conditions under which these inequalities hold, as this requires characterization of $\frac{d^2 r_m}{d\tau_s^2}$ and

$\frac{d^2 r_c}{d\tau_s^2}$. Given that the expressions for $\frac{dr_c}{d\tau_s}$ and $\frac{dr_m}{d\tau_s}$ are quite involved, and that r_c and r_m are

implicitly defined by a system of two equations, this characterization is cumbersome.