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THE POLITICO-ECONOMIC LINK BETWEEN PUBLIC TRANSPORT AND ROAD PRICING: AN EX-ANTE STUDY OF THE STOCKHOLM ROAD-PRICING TRIAL[Ψ]

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Abstract

A full-scale road pricing seven months trial will be performed in Stockholm in 2006. The road tolls are bundled with major improvements of public transport. The trial will be followed by a local referendum. We conduct numerical simulations with a model of modal choice to estimate the welfare effects of road tolls on commuters crossing the toll zone. We find that in the absence of revenue recycling, few commuters gain from the road-toll reform. However, the fraction who gain rises considerably when public transport is improved as planned in Stockholm.

Key words: Congestion charges, road tolls, distributional effects, modal choice

JEL codes: R48, H23, H54

Running title: The Stockholm road-pricing trial

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1. Introduction

The development of urban road-pricing has vividly demonstrated to transport economists the hazards of giving policy recommendations based on the Kaldor-Hicks efficiency criterion; i.e. that a measure should be undertaken if there is a potential for winners to compensate those that may lose from it. Although road pricing persistently comes at the top of economists' lists of suggestions for dealing with traffic congestion to decision-makers responsible for transport policies, it has had a great difficulty in gaining their approval. Transport economists have therefore come to realise that is necessary to pay attention not just to the design of toll schemes, but also to how the revenues raised can be redistributed in ways that give the potential losers real and not just hypothetical compensation (Goodwin, 1989; Jones, 1991; Small, 1992; Schade and Schlag, 2000). Recent research has focused on precisely how road pricing should be bundled with compensatory benefits in order to maximise the chance of receiving public approval (Oberholzer-Gee and Weck-Hannemann, 2002; Raux and Souche, 2004; Jaensirisak et al., 2005; Kockelman and Kalmanje, 2005).[1]

It may come as some surprise that the first cities to adopt these pricing instruments for curbing road traffic congestion are not among those that are most dependent on car transport. Singapore, where congestion charges were levied as early as 1975, has a mass rapid transit network with 51 underground and above ground stations on the island, a light rapid transit network and frequent bus services. Urban road tolls based on pricing of traffic in congested zones have recently entered the political scene in several cities in northern Europe, beginning with Bergen (1986), Oslo (1990) and Trondheim (1991) in Norway, achieving a breakthrough in London (2003), and upcoming in the full-scale trial in Stockholm that will begin in January

2006. All these cities have well developed public transport services. Commuters in London and Stockholm who suffer from congestion in the streets have, unlike commuters in many other big cities, the choice of switching to public transit on extensive railway and subway networks. In Stockholm, a mere third of the commuters to the downtown area depend on car. By contrast, in big cities in the United States and in Australia, the auto accounts for 90 % and 80 %, respectively, of all travel (Kenworthy and Laube 2001).

One might think that many other metropolitan areas around the world with severe traffic congestion should have been eager to overcome the political difficulties of establishing urban road tolls. Furthermore, one might wonder why the city governments of London and Stockholm have chosen to recycle toll revenues heavily through public transport improvements. After all, motorists who pay tolls are more likely than public transport users to object to road pricing.[2] Motorists, however, are not given any significant direct compensation in the Stockholm plan. And in London, 80 % of the net revenues are used for public transport improvements.

Our study suggests an explanation for the link between acceptance of road pricing and the quality of public-transport, as well as for why urban road-tolls are bundled with benefits for public transport users. Using an economic model, calibrated for Stockholm, of the relation between modal choice and income distribution, we demonstrate the significant role of public-transport services in determining who gains and who loses from road pricing. We also use this model to estimate the potential for further enhancement of the share of winners from public transportation improvements.. In doing this, we extend the previously mentioned literature on

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[1] Another issue is how the overall efficiency of road-pricing schemes is affected by different ways of recycling revenues. Parry and Bento (2001) and Mayeres and Proost (2001) determine that considerable efficiency gains may accrue from reducing distortionary taxes in the labour market.

"benefits bundling" of road pricing by estimating effects within a model that takes into account travellers' endogenous behavioural responses to the tolls and benefits packages offered. A non-trivial limitation of this study, however, is that we do not take into account collection costs. These are substantial in the London case (Prud'homme and Bocarejo 2005), and will probably be so in Stockholm as well.[3] We also omit potentially significant social benefits of tolls from reductions of pollution, noise and accidents.

The paper is organised as follows. Section 2 describes the background to the road-pricing trial in Stockholm. Section 3 presents an analytical model of the relation between income distribution and commuters' choice between two congested travel modes: fast (car) and slow (public transport). Section 4 describes a numerical version of this model and the parameters that will be used. Section 5 presents results of the model simulations. Finally, implications and caveats are discussed in Section 6.

2. The Stockholm road-pricing trial

Stockholm, the capital of Sweden, is situated at the river mouth to the Baltic Sea of Sweden's largest lake, Lake Mälaren. The metropolitan area of Stockholm has a population of 2 million people,[4] and 3 millions live within a daily commuting distance. The downtown area, which is mostly surrounded by water, is 34 square kilometres and has 285,000 inhabitants. The city of

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[2] Only a fraction of the motorists will get full compensation for the toll payments from the travel-time reduction (see Section 3).

[3] However, we think that the conclusion that the London congestion charge is a "mini Concorde" (Prud'homme and Bocarejo, 2005, p.279) because of the current size of the collection costs is premature. There are several reasons for expecting that these costs can be considerably reduced in the future (e.g., use of better technologies for automatic payments Blythe, 2005), enhanced public acceptance and learning, etc.).

Stockholm is extremely mono-centric. Within the inner city there is a compact central business district with numerous workplaces within one kilometre walking distance from the central railway station.

Downtown Stockholm has suffered from traffic congestion for years. A large fraction of the morning rush hour traffic is directed to the central areas and is concentrated on a few main roads from the south and the north. The surrounding water makes it difficult, for technical, economical, and environmental reasons, to relieve the pressure on these central roads by building beltways. And the Stockholm region has long experienced higher economic and population growth rates, than has the rest of Sweden. Average traffic speed on the main roads to and from the downtown area during rush hours is more than 60 % below the limit, which is considered as severe congestion (Transek, 2004). The average rush-hour speed of city buses between the suburbs and downtown is 20-40 % below the average speed during evenings (SL, 2005). On one of the main routes, the average rush-hours speed of the city buses is just 12 km/hour, i.e. slower than a bicycle.

(Table 1 here)

2.1 Political background

Road pricing has been on the political agenda for Stockholm since the late 1960´s (Jansson, 1971; Ahlstrand, 2001). The coming trial and public vote are the latest events in a long series, involving heated public discussion, several government investigations (eg., Storstadskommittén, 1989) and extensive political logrolling at national and local levels. In the 1988 election, a local green party, the Stockholm Party (SP), won sufficient votes to hold

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[4] We will use this term for the County of Stockholm, which includes the city of Stockholm. The downtown area is a part of the city (i.e., the municipality of Stockholm). The municipality also

the balance in the city council. It offered to support either of the two party blocks to the left and right in exchange for a commitment to road tolls. The Social Democrats accepted, seized power and reciprocated by initiating a round of negotiations with the national government and neighbouring municipalities on a road infrastructure package for Stockholm. This resulted in an agreement on the construction of a circular belt of highways, mostly in tunnels, around the downtown area, that were to be partly funded by road tolls. Work started on some of the beltways, but the overall agreement was dissolved in 1997 and with it the toll funding.

However, efforts resumed when the national Green Party won a similar pivotal position in the national Parliamentary elections in September 2002. The Green and the Left Parties agreed to accept a 121-points program of policy reforms in exchange for their support of a Social Democratic government, one of the points being the implementation of a “full-scale” road tolling trial in Stockholm.

The government fulfilled its promise in April 2004 in a bill presenting a Law on congestion taxes. The Law is general, but has a supplement regulating the terms of a temporary full-scale trial in Stockholm. It was passed by the Parliament in June 2004. Unlike in the previous round, where road tolls were primarily seen as instruments for infrastructure funding, as in Norway, the focus is now on traffic control to reduce congestion, with Singapore and London as role models.

In the agreement with the Green and Left parties, the road-toll trial was described as a full-scale trial that would last for several years.[5] However, as the Social Democratic leadership in

includes several suburban areas.

[5] The term “trial” that is used officially does not imply that the scheme is designed primarily for research purposes. It is rather intended as a demonstration intended to affect public opinion in

Stockholm wanted to have this issue sorted out before the next election campaign, the city council decided to follow up the trial with a local referendum on the next election day, i.e., in September 2006. Since the trial would have to be completed before that date, the Social Democratic, Left and Green parties agreed to conduct the trial over a 14-month period from the beginning of June 2005 to the end of July 2006.

To get a road-toll system into operation at that time, the city council initiated procurement of an automatic toll-payment system in 2003 before the legislation on congestion taxes was passed. After an initial round, four consortia were invited to submit bids for the tender of equipment, software systems and operation services. These four bids were delivered in February 2004, but two of them were immediately dismissed for technical reasons. The two remaining bidders were consortia headed by the IBM and Combitech corporations, respectively. After the Law on congestion taxes was passed, the procurement was transferred from the city to the National Road Administration, Vägverket. On July 9, 2004, Vägverket declared that the IBM consortium would be awarded the tender.

Combitech, a Sweden-based company specialising in automatic vehicle-payment systems, did not want to give up this major contract on its own turf. The company appealed, and a first court decided the following month that the procurement should be redone, but courts of second and third instances overruled that decision in September and October. In February the court of final instance sent the case back to the third court, which on March 2 confirmed the decision to give the contract to IBM. A final appeal was dismissed on March 30, 2005, and Vägverket and IBM were able to start their preparations for the trial.

Stockholm. There is therefore no experimental design of the scheme, although a series of before and

Because of the delays, the political-alliance parties decided to postpone the start of the trial until January 3, 2006. Consequently, the duration of the trial was shortened from 14 to only seven months. Also, the public-transport component of the trial was split into a separate trial, starting earlier in the autumn of 2005.

In brief, the path to the road-pricing trial that will take place in Stockholm in 2006 has been very windy. The political process can be criticised on democratic grounds, the time for the set up and testing of the technical systems is very short, and the limited period between the end of the trial and the date of the referendum will not allow any profound evaluations to be made before voters make their decisions. The conditions for a favourable outcome to road pricing in the referendum are thus far from perfect.

2.2 The design of the 2006 road-pricing trial

As a result of these developments, the citizens of Stockholm[6] will decide in a referendum on September 17, 2006, whether road tolls[7] should be used to curb road traffic congestion and pollution in the downtown area of the city. In case of a yes outcome there will be a turnkey tolling system in place that can be started immediately, as the referendum is preceded by a full-scale trial, which will be performed from January 3 to July 31, 2006. In case of a no, the

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after measurements of assorted variables will provide interesting data for research.

[6] This refers to the referendum in the city of Stockholm that has been decided by the city council. However, several surrounding municipalities have announced plans to hold similar referenda the same day. The precise wording of the question of the Stockholm referendum is yet to be decided.

[7] The road tolls of Stockholm have different official names. In law, and by the national parliament, they are called ”congestion taxes”. This indicates that the main purpose of the tolls is to reduce congestion and that they are formally classified as taxes by the Swedish parliament. The city authorities have instead chosen to call the tolls ”environmental fees”, clearly in the hope that people are more inclined to accept user charges than taxes and more readily accept policies intended to alleviate pollution than reciprocal externalities within the road-traffic system.

Swedish government has spent considerable resources on a giant field-experiment data-gathering project for the benefit of the transport-research community.[8]

The overlapping "public-transport trial", which will start earlier on August 22, 2005, will also be concluded at the end of July 2006. This second trial involves an extension of public transport in the city with 197 new buses and 16 new bus lines aimed at providing fast alternatives for travelling at peak hours from the surrounding municipalities to the inner city. Furthermore, where capacity allows, service frequency will be increased on existing bus, underground and commuter train lines. A large number of new park-and-ride facilities will be built in the region and existing facilities will be made more attractive.

All costs will be paid entirely out of the national public budget, including toll-collection costs and the cost of the extended public-transport services.[9] The road tolls are paid directly to the government. Of course, it is not possible to finance the toll-collection system and the improvements of public-transport services from toll revenues during the limited period of the road-pricing trial. However, all intensified public-transport services will cease at the same time as the road-pricing trial,[10] thus conveying the message to the general public that the two parts of the trial are connected. [11] Clearly, the impression that both the city government and the national government want to make is that the continuation of the enhanced public-transport services depends on whether the road tolling is resumed after the referendum.

[8] The total expenditure is estimated at SEK 3.3 billions (€ 360 millions). However, a large part of it is devoted to investments in public transport, parking facilities, etc. and will not be lost in case of a negative fallout of the referendum. Also, the gross toll revenues during the trials – which are estimated at SEK 525 millions – can be used for similar or other purposes.

[9] There are no official estimates of the expected total cost, but the government has allocated SEK 3.2 billions (€ 340 millions) in its budget to expenditure related to the trial.

[10] It is not clear what will happen with buses and drivers, but probably they will to a large extent be integrated in the operation of regular services.

However, the government is not formally committed to redistribute revenues to the residents of Stockholm.

The road tolls will be collected at 19 toll stations on a cordon encircling the inner city as shown in the map in Figure 1. The zone within the cordon covers 90% of the downtown area (96% of the population), corresponding to a circular area with a 3 kilometre radius. The cordon is crossed on weekdays by 260,000 commuters living outside the zone, and 89,000 commuters living within it. The total number of vehicles traversing the cordon line on weekdays is approximately 550,000 per day.

(Figure 1 here)

The toll zone will thus have a single boundary. However, there are two openings for through traffic. One is the north-south “Essingeleden” highway which will be free of charge. The second opening is for vehicles passing directly from the island of Lidingö, situated just to the east of the inner city, through and out of the toll cordon within 30 minutes from the first passage.

Registration and payment will be implemented electronically without affecting the flow of traffic. All licence plates of passing vehicles will be photographed and this information will be stored for some time. The most convenient form of payment will be to load a free-of-charge transponder that can be mounted on the front window. Otherwise payment can be

[11] The “public-transport trial” was originally a part of the overall road-pricing trial, but was separated out as a result of the delay with the road tolls which came after the new buses had been ordered and drivers had been recruited.

made in several ways within five days after passage. After that time, a lower fee will be added, and after four weeks a penalty fee of SEK 500 will be charged.

As can be seen in Table 2, charges will be made for passage into and out of the inner city on weekdays from 6.30-18.29, with higher charges during peak periods. The highest one-way charge is SEK 20 (€ 2.1) and the maximum charge is SEK 60 (€ 6.4) per day and vehicle. Several categories of vehicles are exempted including motorcycles, taxis and cars not using fossil fuels.[12] Registration and payment will be implemented electronically without affecting the flow of traffic.

(Table 2 here)

2.3 Expected effects of the trial

The time profile of average weekday car-traffic flows is shown in Figure 2. The total of inbound and outbound traffic has marked peaks in the morning (7-9 AM) and afternoon (3.30 – 6 PM). The road tolls are expected to redistribute this traffic over the day, induce modal substitution, and to a limited extent reduce the number of trips.

(Figure 2 here)

[12] The following road user groups are exempt from congestion charges:
Emergency vehicles, Vehicles registered abroad, Diplomat vehicles, Military vehicles, Buses with a total weight of at least 14 tonnes, Eco-friendly vehicles (electric, ethanol, bio gas), Taxis, Disability and social services, etc. transportation service vehicles, and Motorcycles. Holders of disabled person's parking permits may apply for exemption for one vehicle.

According to model simulations[13] made on behalf of Stockholm City (Transek 2004), the road toll will considerably reduce the car traffic crossing the toll line on weekdays. Estimated reductions of car traffic (vkm/h) in the morning rush-hour and in mid-day are shown in Table 3. The car traffic in the inner city is estimated to fall by 20 % in peak time and 8 % in mid-day. A considerable reduction of congestion on the main routes is expected, although relatively long queues will remain. The average speed on these routes is currently 50-60 % below the speed corresponding to the speed limits. After the toll is imposed, this speed reduction is estimated to be around 40 %.

(Table 3 here)

The estimated effects on travel by different modes are shown in Table 4. The number of cars crossing the toll line during the peak hour on weekdays is estimated to decrease by 23 %. The number of car trips within the whole Stockholm metropolitan area is expected to fall by 3 %. Public transport usage and trips by foot or bike are expected to increase.

(Table 4 here)

2.4 Will road tolls be accepted?

Despite the considerable investments that have been made in designing and building a road-toll system, the future of congestion taxes in Stockholm is far from clear. Unlike in London, where the decision to levy congestion charges was taken by a mayor who had won an election

[13] The simulations were conducted early in 2004 before the exact timing of the trial was known. The computations were made by a model developed by Swedish traffic authorities called SamPers that includes an EMME/2 network model. A separate model was used to estimate dynamic effects. Also, the simulation results refer to the combined effects of both the road toll and a rise in the public transport fees that was to be decided by the city council at that time. The fee hike is a confounding effect that is likely to lead to an underestimation of the separate effects from the road toll. Moreover,

after openly stating his intention to do so, the decision to conduct the Stockholm trial was the result of political logrolling at the national level. To the anger of Stockholm citizens, this broke a vow by leader of the Social Democratic party in Stockholm not to introduce road tolls in the city if they won election.

Recent polls indicate a strong lead in the city of Stockholm for the non-socialist parties. Although these parties have voted against road tolls in the city council, they do not all reject tolls under all circumstances. Therefore, it seems likely that the future of congestion charges in Stockholm to a large extent rests on the outcome of the referendum, which will be held on the same day as the next election to both the national parliament and city council.

Two public opinion polls of Stockholm metropolitan area residents have been taken on behalf of the city of Stockholm. The most recent poll was undertaken by telephone in late November – early December 2004, and covered 1600 persons from 18-74[14] (USK, 2005). It showed that fifty percent of respondents indicated that they "were likely" to vote in the referendum against a permanent road toll, while 38 % "were likely" to vote yes. However, 53 % indicated that they supported the decision to perform the trial, while 43 % were against it.

Those commuting to the inner city mainly by car were generally against (62 % against vs. 33 % in that were positive) the decision to perform the trial, while 64 % of commuters mainly using public transport were positive. Only 19 % of the car users expected to vote yes to a

the simulations are based on the existing service level of public transport, so the effects of the supplementary measures of the "public-transport trial" are not included.

[14] The minimum age for voting in parliamentary elections in Sweden is 18.

permanent road toll (against 75 % that were likely to vote no), while 49 % of users of public transport believed they would vote yes (against 38 % for no).[15]

These results indicate that attitudes towards road pricing vary with the modal distribution of commuters. This observation is supported by a regression analysis of surveys made among citizens in four European cities (Athens, Como, Dresden and Oslo) in the EU-funded AFFORD project (Schade and Schlag, 2000). Indeed, transport mode was found to be the *only* socioeconomic variable that had a statistically significant influence on the willingness to accept urban road pricing. Jaensirisak et al. (2005) report similar results from a study of public acceptability of road pricing schemes in two UK cities. Based on result from a regression model for predicting voting behaviour, they predict that 18.6 % of the car users would be willing to accept a scheme involving a £3 daily charge, in contrast to 46 % of the non-car users. These figures are similar to those obtained in the 2004 opinion poll in Stockholm.[16]

The apparent linkage between mode choice and attitudes towards road pricing suggests that public acceptance can be enhanced by policy measures such as investments in public-transport infrastructure, operating subsidies for bus services, and other ways of using toll revenues. Naturally, the modal distribution is also affected by other factors such as the income distribution, the monetary costs of car use, congestion delays, etc. Also, the citizens participating in a referendum will consider several factors. Many voters are likely to trade off

[15] 49 % of the respondents indicated that their attitudes towards the decision to perform the trial were positively affected by the extension of public-transport services during the trial; while 56 % were positively affected by the fact that the lion's share of the toll revenues would be used for improvements of public transport within the region. However, only 37% declared that they had been aware of the considerable extension of public transport that will be made during the trial.

[16] £3 is close to the daily charge for two single trips in Stockholm, i.e. SEK 40. Jaensirisak et al. also report results for £1 and £2 charge levels, in which case a majority of non-car users are in favour of road-use charges.

their ideological preferences against the anticipated effects on their own economy.[17] Furthermore, the relation between the outcomes for different traveller categories and the general population of voters may be diffuse because of interdependencies within household and over the life cycle. For instant, voters who do not travel themselves may be indirectly affected by road tolls through the effects on other family members.

In this study, we conduct numerical simulations with a model of modal choice that is calibrated to represent the basic conditions of the Stockholm road-pricing trial. With this model we can estimate the potential effects on individual welfare from road tolls among commuters crossing the toll zone. In particular, we are able to estimate the proportions of commuters that will be negatively affected by road tolls under different assumptions on public-transport service levels. This exercise will therefore cast some light on the proportion of voters in the referendum that could be influenced by own benefits from the earmarked measures for improving public transport in Stockholm that is coupled to the road-pricing trial. However, a prediction of the outcome of the referendum is far beyond the scope of this study.

3. A model of modal choice for commuting trips

The numerical model that will be used is based on a modal-choice model developed by Armelius (2004). In this section the basic features of this model are reviewed.

The modal-choice model depicts an economy with a working population. The only travel is commuting (crossing a road-toll zone), the number of trips is fixed and there is no car pooling. The population has an exogenous after-tax wage-rate distribution. All individuals have a choice between a fast mode (car) and a slow mode (public transport) of travel to get to

[17] See Persson and Tabellini (2002, part II) for a review of the economic research on “special-interest

and from work. Each travel mode has a generalised cost consisting of a price (monetary expenditures including fuel, public transport fares, parking fees and road-tolls) and the value of travel time (i.e., commuting is produced in a household production function). The opportunity cost of travel time is equal to the net wage rate. Both modes suffer from congestion, which means that the generalised cost (or disutility) of each mode is increasing with the share of other commuters using the same mode.

For the present study it is assumed that peak-load pricing of public transport is not feasible. Hence, a road toll is the single instrument available to address congestion (or crowding) on the two modes.[18] We consider two cases: One, in which toll revenues are not recycled, and another where toll revenues are returned as equal lump-sum transfers to all commuters. One can think of the first either as a case where a central government uses a road toll to tax a local economy and spends the revenues in other parts of the country or a case where collection costs are equal to toll revenues. The second case is the other polar case where all revenues are redistributed. Reality is likely to be somewhere in between, for instance because of significant but not exhaustive collection costs.

Assume an economy consisting of N individuals. Individual i, $i=1,\ldots,N$, receives an exogenously given net wage y^i per time period, and derives utility from consumption, C^i. Everyone works the same amount of time (note that travel demand is assumed to be fixed; i.e. N is independent of the cost of travel). To get to work, individuals can choose between a fast mode (car) and a slow mode (public transport) ($j = f, s$), with travel times T_j. Disutility from travel time ($0 \le T_j \le 1$) is measured in consumption units by the value of time, equal to the

politics".

[18] This assumption is also made in Glazer and Niskanen (2000).

net wage rate. Each individual works eight hours a day (i. e. labour supply is fixed), and assuming that a person needs eight hours of sleep, has eight hours as leisure. The upper bound on T is thus set so that $T = 1$ would mean eight hours of travel time, and the lower bound, zero, would mean that getting to work each day takes no time at all. Utility is assumed to be a linear function:

$$U^i(C^i, T_j) = C^i - T_j y^i,\ i = 1, ..., N;\ j = f, s. \tag{1}$$

The consumer spends all her income on consumption, at a unit price, and travel, which has the price p_j

$$C^i = y^i - p_j\ . \tag{2}$$

We restrict our analysis to cases when the fast mode is faster than the slow mode ($T_f < T_s$), and the price of the fast mode is higher than the price of the slow mode ($p_f > p_s$). This implies that the relatively rich individuals will be car users. Travel times on each mode are assumed to be strictly increasing and differentiable functions of the number of people travelling by that mode ($T_j = T_j(n_j)$), where n_j is the number of individuals using mode j . Travels times are therefore assumed to be independent of travel volume on the other mode.[19]

The policy analysed is a congestion toll on the road network, t_f . The toll on the slow mode is constrained to zero. Substituting (2) into (1), utility is equal to

$$U^i(C^i, T_j) = (1 - T_j(n_j))y^i - p_j - t_j. \tag{3}$$

Assuming that y can take on values between 0 and plus infinity (with frequency distribution denoted by $F(y)$), there is a break point income level, $\hat{y}$, such that individuals with $y > \hat{y}$

[19] This is a reasonable assumption for commuter trains or subways, but not for buses since they compete with cars for road space. This means that our results may exaggerate the disutility to users of public transport from road pricing, as bus passengers get some compensation directly from faster bus services because of the reduction of congestion.

choose the fast mode (the car), and those with $y < \hat{y}$ choose the slow mode (public transport). An individual with income $\hat{y}$ is indifferent between the two modes so that by (3)

$$\hat{y} = \frac{p_f + t_f - p_s}{T_s(n_s) - T_f(n_f)}. \tag{4}$$

As shown by Armelius (2004), this is a unique equilibrium.[20]

The car-use category can be further divided into two groups: those who benefit from tolls and those who do not. Armelius (2004) proves that these groups are divided by the break point income level, $\tilde{y}$, at which the value of the travel time savings is equal to the toll:

$$\tilde{y} = \frac{t_f}{T_f\left[n_f^{nt}(y)\right] - T_f[n_f^t(y)]}, \tag{5}$$

where $n_f^{nt}(y)$ is the number of car users in the absence of tolls and $n_f^t(y)$ is the number of users with tolls (note that the slow mode users do not enter into this analysis). In conclusion, the locations of both switch point wage rates depend on the shape of the income distribution and the costs and speeds of the two travel modes.

4. A numerical application to the road-pricing trial in Stockholm

In the numerical version of the analytical model we use a quadratic congestion function[21] for travel time of the two modes, j =f, s,

$$T_j = \alpha_j + \beta_j \left(\frac{n_j}{N}\right)^2, \tag{6}$$

where $\alpha_f < \alpha_s$, $\beta_f > \beta_s$, $\beta_f > 0$, $\beta_f > \beta_s$, and $0 < \alpha_j + \beta_j (\frac{n_j}{N})^2 < 1$ for all values of n_j that fulfil the constraint $T_f < T_s$. For the slow mode, the sign of the parameter β_s depends on the

[20] If $p_f + t_f + p_s > 0$.

[21] Quadratic functions are used for analytical simplicity. Empirically, the appropriate functional form depends on the mode and, in the case of roads, on the number and width of traffic lanes, speed limits, mix of vehicle types, and various other factors. See, for example, Evans (1992) and Roess *et al.* (1998).

policy context. If public transport capacity is held fixed, β_s is likely to be positive because of an increase in congestion and/or discomfort due to crowding. However, if capacity is increased to hold crowding level constant, the generalised cost of travel is likely to decrease due to more frequent services, shorter walking distances from bus stops, etc (the so called Mohring effect).

Substituting (6) into (3), utility for a user of mode j will be

$$U^i = \left[1 - \alpha_j - \beta_j \left(\frac{n_j}{N}\right)^2\right] y^i - p_j - t_j , \tag{7}$$

where t_s is set to zero, as explained above.

The time period is set to one day. We use a log normal income distribution that is calibrated by the mean and the median of Swedish income distribution statistics. The average daily income in the Stockholm region is assumed to be SEK 896[22].

The congestion functions are calibrated using data from a large travel survey of the Stockholm metropolitan area in October 2004 (Trivector, 2005). As was shown above in Table 1, the survey finds that 33% of commuters to and from the future toll zone currently use car. Fifty-eight percent use public transport, and the remaining 9% use other modes. Here, we will assume that all non-car users travel by public transport. The survey indicates that commuters to the downtown area by car travel on average approximately 17 kilometres one-way, and users of other modes slightly less. The average one-way travel time is 44 minutes for users of public transport, and 30 minutes for car users. Using the car distance for both

[22]This value is obtained by dividing the average yearly income of SEK 291,000 (SCB, 2003) by 225 workdays, and then deducting taxes (30.8%) according to official income- and tax statistics. The log

categories, the average speeds are 23 km/hr and 34 km/hr, respectively, for the two modes. Free-flow speeds are assumed to be 27.2 km/hr and 50 km/hr, respectively.[23] Given that the share of commuters using car is 33%, and the remaining 67% use public transport, the initial congestion-function parameters shown in Table 5 can be computed.

(Table 5 here)

The out-of-pocket running expenditure of a car is assumed to be SEK 1.6 per km, which is the current level allowed by the Swedish tax authorities for tax-free compensation to employees using their own car in their work. Parking fees vary considerably, and many car commuters can park free of charge. A plausible range for the daily parking fee is SEK 0 – 100. This parameter is used to calibrate the initial modal division without road tolls. The resulting value is SEK 26, and the total daily cost of car usage in the absence of tolls works out to SEK 80. For the subway ticket price, we use the monthly fee divided by the number of days, which yields a daily cost of approximately SEK 20. The road toll is set at the peak one-way value to be levied of SEK 20 (SEK 40 per day). [24]

5. Simulation results

With these parameters, the simulation is carried out for 10,000 individuals. Equations (3), (6) and (7) are used to compute the modal division, average travel times, and utility of each individual. The simulations are made for three scenarios, each both without and with the road

normal distribution is calibrated to match the mean and median of empirical data for Sweden (SCB, 2003).

[23] These are educated guesses based on discussion with experienced modellers of the traffic in Stockholm. The free-flow assumption for public transport implies that the one-way travel time can be reduced from 44 minutes to 37.5 minutes. This assumption is further discussed in Section 5.

toll, see Table 6. The first is a base-case scenario. The second scenario is based on parameters for public transport that reflect the effects of extended services that are bundled to the road-pricing trial in Stockholm. Finally, a third scenario shows the effects in a city with an inferior standard of public transport. We only present the full results based on the assumption that the gross revenues of the road toll are redistributed as equal lump-sum transfers (while collection costs are ignored). However, we also calculate the results without redistribution of the revenues.

For the base case, the resulting modal split with and without the toll is shown in Table 7.

(Table 7 here)

By construction, the modal division without tolls matches the actual division. Imposition of the toll reduces the auto share by 30%.[25] As mentioned in Section 2.3, this is close to the 33% reduction estimated by a detailed traffic simulation model (Transek, 2004).[26] The corresponding increase of public transport is 15%.[27] As only 23% of the commuters pay the toll, the average toll payment over all individuals is SEK 9.

The impacts of tolls on travel times and welfare are reported in Table 8. Car travel-time is reduced by 15%, while discomfort of public transport increases by the equivalent of a 5%

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[24] Results for a toll rate at SEK 15, intended to represent an average rate, are available from the authors. These results are similar qualitatively to those presented here. The share of car users in the base case with the peak toll rate is 23.1%, while the lower rate results in 25.3%.

[25] The modal switch point increases from SEK 988.5 to SEK 1136 (average income is SEK 898.3). The switch point separating losers from winners without compensation is at SEK 2108.8.

[26] The daily reduction of car travel to and from the downtown area is estimated by Transek to be 23%. That estimate takes into account the time variation of the road tolls, which implies a lower average toll rate than the one we have considered. With our model and a toll rate at SEK 15, we obtain a 22% reduction of car travel.

increase in travel time. The average one-way commuting time increases by 5% from 39 to 41 minutes.

The last two columns of Table 8 report the average utility of users of the two modes after an equal lump-sum redistribution of revenues. The toll increases average utility of car users by 10.8%, and average utility of users of public transport by 8.7%. But total welfare increases by only 0.3% because of a reduction in the share of car users who have a considerably higher average utility. Indeed, since the average travel time of all commuters increases the welfare gain is due entirely to a more efficient distribution of travel time.[28]

(Table 8 here)

We now turn to a set of simulations that are intended to represent the effects of the road-pricing trial as it will be performed in Stockholm, i.e., as a second step following a huge program, funded by the central government, to increase the availability of public transport. The public transport investments are thus taken as exogenously financed. They are included to show how the government can increase the fraction of commuters who benefit from the reform. The goal is not to compare welfare in the two cases. (To do this it would be necessary to take into consideration the distortionary income taxes used to finance the investments.) Technically, we represent this by computing scenarios, with and without a toll, in which the congestion parameter, β_s, is set to zero. The average travel time of a one-way public transport

[27] A toll rate at SEK 15 results in an 11% increase of travel by public transport. Transek (2004) estimates with their detailed traffic model an increase of public transport of 7-8%, as the combined effect of the road toll and a major increase in Stockholm transit fares.

[28] As mentioned earlier, toll collection costs are not included in our model. Inclusion of these costs might well reverse the conclusion that tolls are socially efficient. However, our model does not take the peak/off-peak variation of the road tolls in Stockholm into account. As explained in Armelius (2005), the scope for peak/off-peak substitution of car travel is likely to substantially improve the net welfare gain of a road toll.

trip is set exogenously to 37.5 minutes. This value is obtained by assuming a 50% reduction of waiting times for a typical 44-minute trip that involves a transfer between two lines.[29]

The simulation results of these cases are presented in Table 9. The first pair of columns shows that the public-transport improvements reduce congestion for both modes. In fact, the effect on average one-way travel time of cars is equivalent to the effect of the road toll in the previous simulations, i.e. travel time is reduced to 25 minutes even before the toll is imposed.[30] Likewise, as shown by the next pair of columns, the modal split in the absence of a toll is equal to what was achieved by a toll in the previous simulations.[31]

The imposition of a toll further reduces the use of cars and road congestion. Average auto travel time falls by 15%, and average speed rises to close to the assumed free-flow speed of 50 km/hr. Also remarkable is that the auto share of trips falls to only ten percent. The average toll over all individuals is therefore only SEK 4. In contrast, the average utility for all individuals is SEK 21.5 higher than in the case without the improvement of public transport. Thus even if the public-transport enhancement program is substantially more expensive than the (gross) toll revenues, it may still increase total welfare.

(Table 9 here)

We also considered a counterfactual case representing the imposition of tolls under similar conditions as in Stockholm but with inferior public transport service, more like the typical

[29] The average waiting time at the first stop is assumed to be 8 minutes and the average time for an exchange 5 minutes.
[30] However, by assuming a fixed number of trips, our model may be exaggerating these positive “spill-over” effects on road congestion from improvements of public transport.
[31] This is a coincidence. Note that we have not accounted for the cost of improving the public-transport services.

situation of a large European city. This scenario is constructed by setting β_S = 0.36, i.e. the same as for the fast mode. Thus, we can think of a city where a large part of the public transport is provided by buses that use the same lanes as cars.[32] This value yields a ceteris paribus (i.e., for constant modal split) increase of average one-way travel time for public transport from the current 44 minutes to 53.5 minutes.

As is shown in Table 10, a roughly even modal split obtains in the absence of a road toll. Such a situation is close to what is typical of large cities in Western Europe (Kenworthy and Laube, 2001).

As a result of the significant deterioration of public transport, travel time by public transport is considerably longer. This induces substitution to the car, and consequently car drivers also suffer from more congestion.

Imposition of the road toll reduces the car share to 44%. Car travel time is reduced to 37 minutes. However, because more people choose public transport, travel time rises from 59 to 65 minutes one way: an increase of 11%! Thus, in this case tolling has a severe adverse side effect on the untolled (public transport) mode.

(Table 10 here)

As an illustration of the political repercussions of this dilemma, we show in Table 11 the proportions of net losers from road tolls in the three scenarios that have been considered.

[32] This interpretation is valid in our model when the numbers of users of the two modes are equal, as turns out to be the case without road tolls.

These proportions are calculated both with and without equal lump-sum redistribution of the toll revenues.

(Table 11 here)

In the case with revenue redistribution, improvement of public transport results in a modest reduction in the proportion of losers from 26 to 18%. The impact is much more dramatic in the absence of redistribution.[33] In this case, almost all commuters lose out without investment, while the fraction is reduced by more than ¾ to just 22% if the investment is made. In practice it is likely that some, but not all, of the revenue will be returned to commuters so that the actual welfare-distributional impacts are likely to be intermediate between the polar cases considered here.

6. Conclusions

The forthcoming road-pricing trial in Stockholm presents a political-economic puzzle. Why do political parties in Sweden and in Stockholm dare to advance a traffic policy reform that is so strongly resisted in most other major cities of the world, especially given that Stockholm is much less dependent on car travel for daily commuting? And why are these parties also so determined to further improve an already well-developed public-transport system?

The answers to these questions offered in this paper are based on the empirical observation that in Stockholm (and in other European cities) there seems to be a strong difference of public acceptance of road toll proposals between individuals who travel to work by car and

[33] The number of losers is smaller (97.5%) with worse public transport since it leads to high congestion on the fast mode, which in turn gives a greater decrease in time for the fast mode travellers as the toll is imposed. This leads to a lower $\tilde{y}$ (SEK 2071 compared to SEK 2109), which in turn

individuals who use other modes of transport. This indicates that voters are to a large extent e affected by considerations of their own interest. A majority of the commuters who will lose from the imposition of road tolls, even if gross revenues are fully redistributed as lump-sum transfers, are middle-income wage earners who currently commute by car.

The results of the numerical simulations in our study indicate how the proportion of commuters who will lose is affected by the level of public-transport services that are supplied in a city. At a “typical European city” standard, we estimate that the share of commuters who would not be fully compensated amounts to close to 30%. With the enhanced standard, paid by the national government, that will be achieved in Stockholm a short time before the road-pricing trial begins, this proportion is down to 18%.

These differences get more pronounced if there are no monetary transfers to the commuters. If revenues are not redistributed, there will be hardly any winners at all. With a superior public transport-system, a large majority of the commuters will be compensated even in the absence of any other transfers. The simple, but potentially important, insight provided by our computations is that in a case like Stockholm (and possibly London) where most commuters already travel by public transport, it can be politically wise to take any measures that are needed to keep up the quality of public-transport services during a road-pricing reform. This seems indeed to be the objective of the significant improvements of public transport, in particular bus services, that will be available in Stockholm from the end of August 2005, i.e., five months before the road-pricing trial starts.

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leads to more winners among the fast mode travellers. In both cases the only winners are those richer than $\tilde{y}$.

Our result highlights only one aspect of the politico-economic relationships that may influence the outcome of the road-pricing referendum. Another potentially important aspect is the non-perfect overlap between the constituency taking part in the referendum and the population of commuters that are affected by the road toll. For instance, residents within the city of Stockholm that do not need to cross the zone on a daily basis may favour tolls as a means of taxing residents living in surrounding municipalities (see Proost and Sen, 2005). Also, ideological attitudes towards restrictions of the right to use roads for free, against imposition of more taxes (or conversely, for charges as a means for avoiding more public expenditure driven by an ever-increasing demand for road space), etc. are likely to be important determinants of the outcome of the referendum in Stockholm.

Taking a broader view, our results suggest an explanation for striking differences in taxation of car use, such as gasoline taxes, between Europe and the rest of the world, in particular the United States. These tax differences obviously have a major role in explaining the considerably lower proportion of car usage for travel to work in the western European cities. Taxes on car usage restrict the demand for car travel, and sometimes are used as a cross-subsidy funding source for investments in public transport facilities. The superior quality of public transport services in Europe are another important factor. However, our analysis points to the possibility of a reverse causal direction as well. Public acceptance of political decisions to raise taxes on the use of cars are more likely in countries, or cities, where the majority use other modes for their daily travel.

In a political system where the ultimate decisions depend on the preferences of the median voter, one can expect taxes to be progressive, because the median income is lower than the average income.[34] In cities where everybody uses cars, road tolls in themselves (i.e., without redistribution of revenues) are regressive, and are therefore not likely to be accepted under such conditions. However, this is so only within the group of car users. In cities where a large proportion of the population uses other means of transport than the car, road pricing can instead be a means of taxing the relatively rich.

This implies that the development of the modal split of commuters in a city may be subject to self-enforcing vicious or virtuous circles, because the modal distribution itself influences the political support for measures that are intended to restrict the use of cars. Another cause of dynamic reinforcement effects are the network-externality features of public transport, i.e., consumption complementarity among all consumers of public-transport services (i.e., the so called Mohring effect).

The existence of such interactions has potentially important implications for urban transport policies, in particular in developing countries in which the majority still is walking, biking or going by bus to work. The development of the modal split may be strongly path dependent, i.e., efforts at an early stage to reduce car usage, such as road tolls, are not just short-term remedies but may have persistent effects.

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[34] However, the median-voter outcome is valid only in very simple representations of political decision-making. As summarised by Persson and Tabellini (2002, p. 52), “politics is much more than just vote counting”.

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Table 1. Modal split (main travel mode) of household travel in Stockholm crossing the toll zone, before the toll is implemented (autumn 2004). Shares of total travel distance, number of trips, and average trip time.

Mode	Distance	Number of trips	Average time (min./trip)
Walk	1%	2%	40
Bike	2%	4%	29
Car	36%	33%	30
Public transport	58%	59%	44
Other	3%	3%	33
All	100%	100%	39

Source: Own computations based on Trivector (2005).

Table 2
One-way charges, at different times in weekdays

6.30-6.59	7.00-7.29	7.30-8.29	8.30-8.59	9.00-15.29	15.30-15.59	16.00-17.29	17.30-17.59	18.00-18.29
10 SEK	15 SEK	20 SEK	15 SEK	10 SEK	15 SEK	20 SEK	15 SEK	10 SEK

Table 3
Estimated effects of charges on traffic (vkm/hr) on weekdays

	Morning rush-hour	Mid-day
Car crossing toll line	-33%	-20%
Car inner city	-20%	-8%

Source: Transek (2004).

Table 4
Estimated effects on number of trips (v/hr), peak-hour on weekdays

	Car	Public transport	Walk or bike
To inner city	-23%	+6 to 7%	n.a.
Metropolitan area	-3%	+2 to 3%	+3%

Source: Transek (2004).

Table 5.
Initial parameters of the congestion functions

Parameter	Slow mode	Fast mode
α_j	0.15625	0.085
β_j	0.06086	0.36

Table 6.
Overview of the simulation scenarios

Status of public transport	No toll	Toll (SEK 20), No revenue re-distribution	Toll (SEK 20), Lump-sum revenue re-distribution
Base case (current Stockholm)	Tables 7 and 8	Table 11	Tables 7, 8 and 11
Extended services	Table 9	Table 11	Tables 9 and 11
Inferior services	Table 10	Table 11	Tables 10 and 11

Table 7.
Simulation results for the modal split. Percentages of travellers choosing car and public transport.

Category	No road toll	With road toll
Car	33%	23%
Public transport	67%	77%

Table 8.
Effect of a road toll on travel time and average welfare.- keeping public transport capacity constant? Percent of commuters that gain from the toll (without revenue recycling)

Group	One-way travel time [minutes]		Average utility [SEK/day]	
	No toll	Toll	No toll	Toll
Car	30	25	1156	1281
Public transport	44	46	511	556
All	39	41	721	723

Table 9.
Effects of a road toll after a major enhancement of public transport

Group	One-way travel time [minutes]		Modal split [percent]		Average utility [SEK/day]	
	No toll	Toll	No toll	Toll	No toll	Toll
Car	25	21	23	10	1318	1622
Public transport	37.5	37.5	77	90	573	647
All	35	36	100	100	743	745

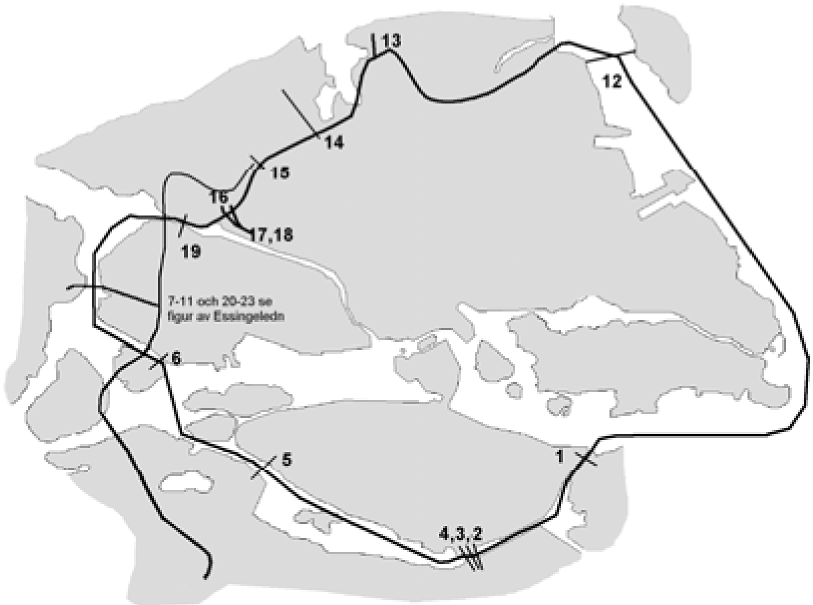
Table 10.
Effects of a road toll with inferior public transport

Group	One-way travel time [minutes]		Modal split [percent]		Average utility per individual [SEK/day]	
	No toll	Toll	No toll	Toll	No toll	Toll
Car	42	37	50	44	939	985
Public transport	59	65	50	56	409	433
All			100	100	670	673

Table 11.
Proportion of losers (commuters with a negative net welfare change) with and without revenue redistribution in the three public-transport scenarios.

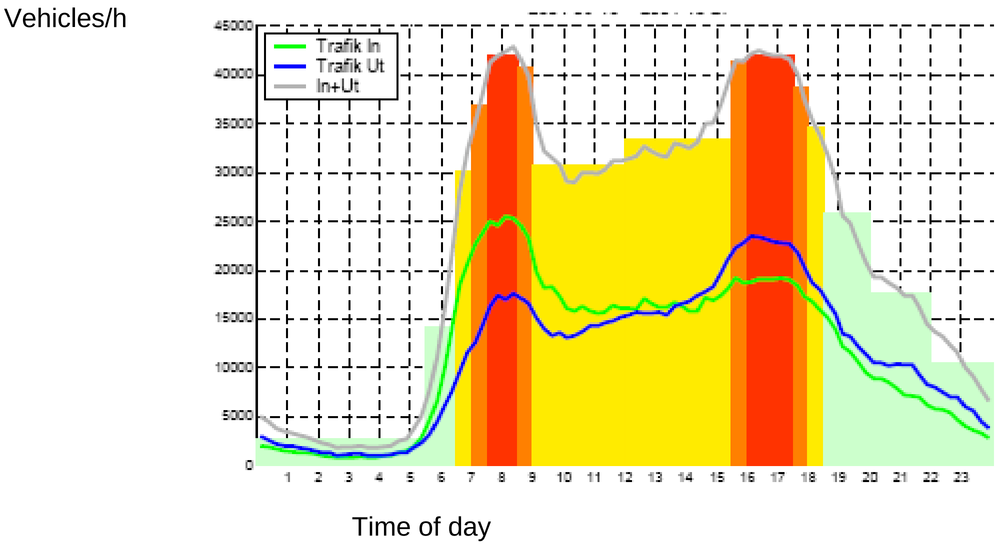
	With revenue redistribution	No revenue redistribution
Road toll	26.5%	97.7%
Road toll and better public transport	17.7%	22.1%
Road toll and worse public transport	29.4%	97.5%

Figure 1
The road-toll cordon area and the location of toll stations 1 – 6 and 12 - 19. Toll stations 7-11 and 20-23 are along the north-south connection Essingeleden.



Source: USK (2005).

Figure 2
Traffic flow (inbound, outbound and total, respectively) over the cordon line in weekdays (average number of vehicles per hour in weekdays from September 15 to October 27, 2004).



Source: USK (2005).