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Labor Market Effects of Road Pricing in a Population with Continuously Distributed Value of Time

Paper for ERSA special session on road pricing, 19-23 August, 2010

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Abstract

Interactions between the transport market and other distorted markets, such as the labor market, often have large impact on the overall welfare effect of a road pricing policy. Many road pricing studies try to incorporate effects from other distorted markets in the analysis. A general conclusion in many of these studies is that the way the revenues are recycled is crucial for the total welfare of the policy.

A critical assumption in many of the previous cost-benefit analyses of congestion charges is however that there only exists a single value of time. This is somewhat surprising since one of the main features of a congestion charge is that it sorts people according to their value of time, given the existence of feasible transport alternatives. The purpose of the paper is to analyze the labor market effects of a congestion charge when commuters have continuously distributed value of time.

In the paper a simple traffic model is embedded within a general equilibrium framework where a large number of heterogeneous individuals choose labor supply and mode of transportation. A modal-choice approach is used to model how the value of time for different individuals affects their choice of travel mode to analyze the effect of self-selection on labor supply, total welfare and the distributional impact of the different revenue recycling policies,

Using a stylized numerical model of the Stockholm congestion charging trial we find that; when the revenues are recycled back to the population, the overall welfare impact is found to be positive, regardless if the revenues are returned in a lump-sum transfer, as a public transport subsidy or used to cut income taxes. The congestion charge also reduces the need (and benefit) of subsidizing public transport. Regardless of how the revenues are recycled a majority of the commuters benefit from the congestion charge, the individuals that changes from car to public transport does however loose on the policy. The congestion charge increases labor supply for remaining car commuters, but decreases labor supply for the individuals that changes from car to public transport due to the congestion charge.

Keywords: congestion charges, welfare effects, distributional impacts, modal-choice, general equilibrium

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Introduction

In a standard textbook analysis of congestion charges, Pigouvian taxes are used to adjust the price of car travel to set the price to its marginal social cost by incorporating the congestion externality and reducing the associated delays. When all prices in the economy are equal to their marginal costs, this pricing rule ensures a welfare improving Pareto efficient solution. This result does however not necessarily hold if other interconnected markets in the economy are distorted (Rouwendal and Verhoef, 2006). Previous research on road pricing has studied how interactions between the transport market and other distorted markets, such as the labor market, can crucially affect the overall welfare impact of a congestion charge. Since a congestion charge raises the cost of commuting to work, it can decrease employment at the extensive margin in a similar way as an income tax. It has even been shown that, without any form of revenue recycling, the resulting welfare loss from the decreased employment can exceed the Pigouvian welfare gain from internalizing the congestion externality (Parry and Bento, 2001).

A critical assumption in many of the previous cost-benefit analyses of congestion charges is that there only exists a single value of time. This is somewhat surprising since one of the main features of a congestion charge is that it sorts people according to their value of time, given the existence of feasible transport alternatives.

This paper intends to challenge this simplification by analyzing how previous results hold if we, instead of using a representative individual, consider a population with a continuous wage distribution and a continuously distributed value of time. The paper will study the welfare effect and the distributional impact of a congestion charge in a commuting population with endogenous labor supply and heterogeneous value of time where the revenues are recycled back to the population.

In the paper a simple traffic model is embedded within a general equilibrium framework where a large number of individuals with heterogeneous value of time choose labor supply at the extensive margin and mode of transportation. In contrast to previous models, a modal-choice approach is used to model how the value of time for different individuals affects their choice of travel mode. The disaggregated travel demand model makes it possible to analyze how mode choice self-selection affects the costs and benefits of a congestion charge under three different revenue recycling schemes. Special attention will also be given to the distributional impacts of the analyzed policies. In this paper the analysis is restricted to work

related commuting on a single link, but the model framework could just as well be applied to a multi regional spatial CGE model. The model used in the paper is created with the Stockholm congestion charging trial in mind, but the framework can be applied to any city with a well developed public transport service.

The paper begins with a theoretical background presenting different approaches for studying road pricing and congestion charges in a distorted economy. The background serves as foundation for the analytical framework presented in the subsequent section. In this section we define the analytical model and examine some of its analytical properties. Then a numerical example where a computable general equilibrium model, calibrated with data from the Stockholm congestion charging trial, is used to analyze the welfare effect and the distributional impact of three different revenue-recycling schemes under the assumption that the value of time in the working population is continuously distributed. The paper ends with some concluding remarks.

Background

Research on road pricing

In a standard textbook analysis on road pricing, often only the effects in the transport market are included in the analysis. This can be a feasible simplification if the connection between the transport market and the other markets in the economy is weak or if the other inter-connected markets are undistorted. Since a transport market often can have large feedback externality effects in other distorted markets, such as the labor market, the conditions for this simplification might not hold in practice. The actual welfare effects of a transport policy can therefore be quite different from those predicted by a first-best analysis that ignores the spillover effects in other distorted markets, as pointed out by Parry and Bento (2002).

In response to this problem, a research literature has emerged where the interaction between road pricing and pre-existing distortions in other interconnected markets are studied. Mayeres and Proost (1997) adopt theoretical results from the optimal tax literature to road pricing, allowing them to study optimal tax structures and revenue neutral tax reforms in a tax system with congestion type of externalities. A recurrent policy recommendation in the literature is that the collected revenues should be used to reduce distortive labor taxes rather than being used to subsidize public transport or being returned in a lump-sum transfer, see e.g. Mayeres and Proost (2001), Parry and Bento (2001) and Ubbels and Verhoef (2002).

An opposite result is found in De Borger and Wuyts (2009) who study how employer-paid parking affects the relative efficiency of different recycling instruments in a model with a budget-neutral tax increase on car commuting. Since a labor tax cut and a public transport subsidy have very different effects on congestion (and parking costs), recycling the revenues via a public transport subsidy may be more efficient than to use the revenues to reduce taxes on labor. A troublesome implication of this result is that the estimated welfare effect and the relative efficiency of a revenue recycling policy depend on which markets that is included in the analysis, and whether the policy instruments set are at the welfare optimizing levels in the initial situation or not.

Among other Parry and Small (2009) argue that even substantial levels of public transport subsidies can be efficient, even when they are financed with distortionary income taxes. The interactions between road pricing and public transport are also discussed in Small (2004). Assuming that the public transit subsidy is at its optimal level before the charges, the question we need to answer is how the introduction of the congestion charge affects this level.

Several studies have also tried to incorporate these ideas into a traditional cost-benefit analysis framework for transport projects, adapted to allow for external distortions and market imperfections, see e.g. Calthrop et al. (2008), Pilegaard and Fosgerau (2008) and Zhu et al. (2009). An overview of the road pricing literature can be found in Fosgerau and Van Dender (2010).

Revenue recycling in a general equilibrium framework

To analyze the problems mentioned above, many researchers have applied a general equilibrium perspective on transport pricing in order to incorporate different types of second-best effects from other distorted markets. This has led to an extensive literature where transport models are embedded within a general equilibrium framework. The general equilibrium approach to road pricing is also related to the double-dividend debate, the idea that it sometimes is optimal to tax negative externalities higher than the partial equilibrium Pigouvian level, if the revenues are used to cut distortionary taxes elsewhere in the economy, see e.g. Goodstein (2003) and Parry and Oates (2000). A general conclusion in many of these models is that the way the revenues are recycled is crucial for the total welfare (Dender, 2003). The revenue recycling question is often formulated as follows; how should the revenues from a congestion charge be recycled to increase total welfare most; and how do the optimal taxation levels change when a congestion charge is introduced?

Parry and Bento (2001) use a simple general equilibrium model to study how the welfare effects from a road toll on work related commuting depend on the form of revenue recycling. In their model, a single representative household makes decisions about labor-leisure and transportation mode. The authors assume that labor supply is endogenous and strictly complementary to commuting. To get to work, the household can either use a congested road or a non-congested public transport system. Only work related trips are considered in the model. The household tries to maximize its utility choosing between consumption and leisure. The household also gets utility from commuting, which means that it will prefer a mix of travel modes.

Since a congestion tax raises the overall cost of commuting to work, it affects the net wage similar to an income tax and will therefore decrease employment at the extensive margin. If the revenues are returned in the form of a lump-sum, the authors find that the welfare loss in the labor market can exceed the Pigouvian welfare gain from internalizing the congestion externality. Comparing this with two other recycling schemes, subsidized public transport and lowered labor taxes, they find the latter the most preferable. For both these revenue recycling schemes, the net welfare effect is found to be positive.

This basic model has been extended in many different directions. Dender (2003) studies optimal tax structures in the case pricing can or cannot be differentiated between trip purposes. Dender reaches similar results as Parry and Bento but also stress the importance of differentiating between labor and leisure trips.

An important assumption in many of the models on commuting and congestion charges is that labor supply is chosen as the number of workdays in a given period. This is a critical assumption since it implies that, “conditional on the choice of transport mode … workers may only reduce their commuting cost by reducing their total labor supply” as pointed out by Gutierrez-i Puigarnau and Van Ommeren (2009). If the workers are allowed to choose their daily number of work hours, they can compensate for the increased commuting cost by working longer hours each work day, leading to an ambiguous effect on total labor supply. In an empirical study using socio-economic panel data for Germany, Gutierrez-i Puigarnau and Van Ommeren (2009) study the effect of commuting cost on labor supply patterns. Using an exogenous change in commuting distance as a proxy for a change in transport cost, they find a weakly positive effect of distance on total labor supply. Their study does however not include effects on the labor force participation. This result stands in contrast to the standard assumptions in the transport literature, that the response on the extensive margin

(participation/number of work days) is more important than the response on the intensive margin (hours of work), see Kleven & Kreiner (2006). A larger analysis of possible labor market responses to a congestion charge can be found in Westin (2010).

The labor supply effect at the extensive margin can also be interpreted as a location effect. A decrease in labor supply in a model of work related commuting between a suburb and the city centre can be interpreted as the commuters choose to work at another location than in the city centre. Effects on location and land use from a transport policy are for example modeled in Eliasson and Mattsson (2001), Venables (2007), and Anas and Kim (1996). Sundberg (2009) investigate region effects of different transport related infrastructure polices; and the effect on regional unemployment of the EU Transport Policies is studied in Korzhenevych and Bröcker (2009).

Equity effects and the distributional impact of a congestion charge

The distributional impact of a congestion charge is a topic that has gained much attention. In many partial-equilibrium studies of congestion pricing, where only the direct effects in the transport market are included in the analysis, the distributional impact is often found to be regressive. De Palma and Lindsey (2004) find that congestion pricing may have a progressive impact on welfare if the general-equilibrium effects are accounted for in a comprehensive policy framework where transport pricing is integrated in the general fiscal policy.

The importance of including distributional considerations when analyzing congestion charges is also demonstrated by Mayeres and Proost (2001) who study revenue neutral marginal policy reforms in an economy with heterogeneous individuals. One finding in their study is that the ranking of the policy instruments in terms of their marginal welfare cost depends on the degree of inequality aversion. Mayeres and Proost (2002) also show that the efficiency, equity and acceptability of a reform crucially depend on how the revenues are used. Their main conclusion is that equity and acceptability cannot be discussed only at the level of the transport market, instead a wider analysis is needed that includes the use of the revenues and its effects. One reason for this is that the value of the collected charges is much larger than the net benefits. Using the revenues to reduce public transport fares will clearly have a different distributional impact than a labor tax cut or a lump-sum replacement, as is illustrated in Eliasson and Mattson (2006) and Berg (2007).

Several empirical studies of congestion charges have also empirically analyzed welfare and equity effects of a real congestion charging system; see for instance Transek (2006) for a

review of the equity effects of the Stockholm Trial. Karlström and Franklin (2009) estimate the welfare effects of the Stockholm Trial for different demographic groups including both the toll's direct effect and effect in the form behavioral adjustments as a result of the toll. Disregarding the effect of revenue recycling they find a small and regressive effect of the toll even though the magnitude of the overall effect is not significant.

The modal-choice approach to road pricing

Another modeling approach that has been used to study road pricing is mode choice models, see e.g. Arnott and Yan (2000), Glazer and Niskanen (2000), Small and Yan (2001) and Hultkrantz and Liu (2009). The modal-choice approach is suited for transport systems with a well developed public transport system that can serve as a substitute to commuting by car.

Armelius and Hultkrantz (2006) use a modal-choice model in an ex-ante study of the Stockholm congestion trial to estimate the welfare effects of road tolls. In the model a working population with an exogenous wage distribution commutes to work crossing a road toll. To get to work individuals can choose between two transport modes, a fast and expensive mode (car) and a slow and cheap mode (public transport). Compared to the models in the previous section, labor supply is constant so the individuals can only choose their transport mode to maximize their utility. Given a fixed income distribution Armelius (2004) shows that there exists a unique break point income level such that people with a higher income choose car and those with a lower income level choose public transport. She also derives an analytical expression for the break point.

The approach also makes it possible to study the political acceptance, equity effects and the distributional impact of a congestion charge. In the study Armelius (2004) finds that a road toll affects the middle class the most negative, while the winners are found both among people with a high and a low income depending on how the revenues are recycled.

A critical assumption in the model is that mode choice is strongly correlated with the value of time. The model does neither account for effects in the interconnected labor market as labor supply is treated as exogenous.

An advantage of the modal-choice approach, compared to general equilibrium models using representative individuals, is that it models mode choice decisions at a disaggregated level in a way that captures traveler heterogeneity and simplifies the analyses of the distributional impacts of a road toll. It also makes it possible to model individuals' choice of travel mode explicitly as a function of their value of time.

A difficulty with the approach is that it is difficult to find a good measure of the aggregated social welfare of congestion pricing when people in the population have different value of time. Mayet and Hansen (2000) show that the optimal toll level depends on how the aggregated social welfare is calculated. When aggregating the utility of individuals with different value of time, different outcomes is reached depending on if all individuals are assumed to have equal marginal utility of income or equal marginal utility of time. In the paper we have chosen to measure welfare as an equivalent variation of a lump-sum transfer. In response to the aggregation problem, we will also compare the equivalent variation to a strictly utilitarian welfare measure of the total utility in the population.

Analytical model

The model used in this paper extends the general equilibrium framework in Parry and Bento (2001) with a modal-choice model following Armelius and Hultkrantz (2006). The model has also many similarities to the mixed discrete-continuous utility maximization model in Anas and Liu (2007).

A simple traffic model is embedded within a general equilibrium model where labor supply is endogenous and strictly complementary to commuting. In the model a population of heterogeneous individuals commutes between home and work in a static economy. The individuals differ only in their exogenous daily wage w.[1] Assuming that the population is large, we can treat them as a continuum with density function $f(w)$ for $0 \leq w \leq \infty$. To simplify the calculations we normalize the size of the population to one, i.e. $\int_0^\infty f(\varepsilon)d\varepsilon = 1$.

The utility of an individual is given by:

$$U = u(C, N) \qquad (1)$$

where the utility function $u(.)$ is quasi-concave and continuous, C is consumption of a composite commodity with price normalized to one and N is leisure measured as the total free time in the period.

[1] The wage distribution can also be seen as a distribution of productivity. Assuming that each individual has an exogenous productivity p and work at a competitive firm with production function, $y = pL$, where L is the number of work days chosen by the individual. The individual's daily wage w will hence be equal to his or her productivity p.

Each individual chooses the number of work days L and mode of transportation to maximize his or her utility subject to constraints in time and budget. The daily work hours are fixed and normalized to one. We also assume that the individuals can choose the number of work days without restriction, i.e. the job opportunities are unlimited.

Following Parry and Bento (2001) and Dender (2003) we assume that the number of work trips is strictly complementary to labor supply. To commute to work, the individuals can choose to drive on a congested road R subject to congestion or using the public transport system P. A commuting trip (back-and-forth) with car requires π_R units of time and costs c_R, and a daily commuting trip with public transport costs c_P and takes π_P units of time.

The utility maximization problem for an individual with daily wage w can be formulated as:

$$\begin{gathered} \max_{\mathrm{R,P}} U = u(C, N) \\ s.t. \quad C = [(1-t)w - c_R - \tau]R + [(1-t)w - c_P + s]P + G \\ \bar{L} = N + (1+\pi_R)R + (1+\pi_P)P \\ R, P \geq 0 \end{gathered} \tag{2}$$

where R and P are the number of work days the individual commutes by car and public transport respectively, t is the proportional labor tax rate, τ is the congestion charge for commuting trip by car, s is the public transport subsidy for one way trip, G is the governmental lump-sum transfer and $\bar{L}$ is the time endowment. All these variables are assumed to be non-negative. We assume that the lump-sum is equally distributed in the population. The individual's total labor supply is hence given by $L = R + P$. Finally we assume that the individuals take the travel time and governmental lump-sum transfer as exogenous when choosing their travel mode and optimal amount of labor.

In the model assume that the individuals do not have any special preferences for any of the transport modes. Instead each individual is assumed to choose the transport mode that gives him or her, the highest ratio between consumption and leisure. An individual with a daily wage w will earn $r_R(w) = \big((1-t)w - c_R - \tau\big)/(1+\pi_R)$ consumption units for every day of leisure if he or she commutes by car, and $r_P(w) = \big((1-t)w - c_P + s\big)/(1+\pi_P)$ if commuting by public transport. Since the ratios are linear functions of the daily wage w with different slopes there exists a unique wage level $\hat{w}$ where the individual is indifferent between the travel modes, i.e. $r_R(\hat{w}) = r_P(\hat{w})$. The wage level $\hat{w}$ can be expressed analytically as:

$$\hat{w} = \frac{(c_R+\tau)(1+\pi_P) - (c_P - s)(1+\pi_R)}{(1-t)(\pi_P - \pi_R)} \tag{3}$$

If we assume that the travel time for the car commuting π_R always is lower than the travel time for public transport π_P, and that the cost for car $(c_R + \tau)$ is higher than the cost for public transport $(c_P - s)$ we can show that there exists a modal-split point in the population that will split the population into two groups.[2] This modal-split point is equal to the wage level $\hat{w}$ where the individual is indifferent between the travel modes. All individuals with a daily gross wage level w' below this point, i.e. $w' < \hat{w}$, will commute by public transport and those with a higher wage will commute by car.

From equation (3) we can also calculate how the commuters respond to a congestion charge. Since a congestion charge makes it more expensive to commute by car, the effect will be the same as if the car cost c_R is increased. This will shift the modal-split point to a higher daily wage level, decreasing the share of car commuters in the population. A policy that reduces the car travel time π_R has an opposite effect, shifting the modal-split point downward making the commuting by car more attractive and increasing the car share.

Labor supply discontinuity

From the first-order conditions for utility maximization can we calculate the optimal level of consumption C_m^* and N_m^* leisure as a function of the daily wage w, conditional on a chosen travel mode m. Inserting these into the time and budget constraints we can calculate the conditional labor supply function[3] $L_m^*(w)$ as a function of the daily wage w and travel mode m as:

$$L_m^*(w) = \frac{\bar{L} - N^*}{1 + \pi_m} = \frac{C^* - G}{(1-t)w - c_m} \qquad (4)$$

Assuming that leisure is a normal good, this function is an increasing function of the daily wage. If the underlying preferences are strictly convex then the demand for consumption and leisure are continuous functions of the daily wage. This implies that the conditional labor supply function $L_m^*(w)$ is a continuous function of the wage w for a fixed travel mode m. Observe that the conditional labor supply function for car $L_R^*(w)$ in general are not equal to

[2] I.e. $\pi_P > \pi_R > 0$, $c_R + \tau > c_P - s$ and $1 > t > 0$. For anyone to choose public transport we also need to assume that $(c_P - s)/(1 - \pi_P) < (c_R + \tau)/(1 - \pi_R)$.

[3] The conditional labor supply function $L_m^*(w)$ is a function of the daily wage and a chosen travel mode, while the optimal labor supply function $L^*(w)$ only is a function of the daily wage.

the conditional labor supply function for public transport $L_P^*(w)$ since the travel times π_m and costs c_m for car and public transport differ.

The optimal labor supply function $L^*(w)$ is a function of the daily wage and the optimal choice of travel mode. As seen in previous section does the modal-choice only depend on whether the individual's wage w is lower or higher than the modal-split wage $\hat{w}$. The optimal labor supply function can be calculated as a function of the exogenous parameters:

$$L^*(w) = L(w, \pi_R, \pi_P, c_R, c_P, t, \tau, G) \tag{5}$$

Since an individual with wage $\hat{w}$ is indifferent between the travel modes, both travel modes must give the same utility. This implies that the optimal level of consumption and leisure at the split point wage $\hat{w}$ are the same for both travel modes.[4] The optimal level of labor supply will however depend on the chosen travel mode since the travel time π_m and cost c_m for car and public transport differ. This creates a discontinuity in the labor supply curve $L^*(w)$ at the modal-split point $\hat{w}$ where the individual is indifferent between the travel modes. The size of the discontinuity at the modal-split point is:

$$\Delta L^*(\hat{w}) = L_R^*(\hat{w}) - L_P^*(\hat{w}) = \frac{\bar{L}-\hat{N}^*}{1+\pi_R} - \frac{\bar{L}-\hat{N}^*}{1+\pi_P} = \frac{(\pi_P-\pi_R)(\bar{L}-N^*)}{(1+\pi_R)(1+\pi_P)} = \frac{(c_R-c_P)(C^*-G)}{((1-t)w-c_R)((1-t)w-c_P)} \tag{6}$$

The intuition behind the discontinuity in the labor supply curve is that an individual at the modal-split point can use the time saved by choosing car instead of public transport to work more in order to fully compensate for the higher transportation cost.

Congestion and governmental budget restriction

Since road usage is subject to congestion, we let the car travel time π_R be a function of the number of car trips. Since we have assumed that labor supply is strictly complementary to commuting, every working day require one commuting trip. The travel time with car is thus a function of the aggregated labor supply of all individuals that commutes by car, i.e.

$$\pi_R = VDF\left(\int_{\hat{w}}^{\infty} L_R^*(\varepsilon) f(\varepsilon) d\varepsilon\right) \tag{7}$$

[4] I.e. $C_R^*(\hat{w}) = C_P^*(\hat{w})$ and $N_R^*(\hat{w}) = N_P^*(\hat{w})$.

where $\widehat{w}$ is the modal-split point, $L_R^*(\varepsilon)$ is labor supply as a function of the daily wage for car commuters, $f(\varepsilon)$ is the chosen wage density function and $VDF(.)$ is a volume delay function. The volume delay function is an increasing function giving the average travel time as a function of the total number of car trips on the road.

The governmental budget restriction can be calculated as follows:

$$G = g(Z_t + Z_\tau - Z_{PT}) \tag{8}$$

$$Z_t = t\int_0^\infty \varepsilon L^*(\varepsilon) f(\varepsilon) d\varepsilon \tag{9}$$

$$Z_\tau = \tau\int_{\widehat{w}}^\infty L_R^*(\varepsilon) f(\varepsilon) d\varepsilon \tag{10}$$

$$Z_{PT} = pt\left(s\int_0^{\widehat{w}} L_P^*(\varepsilon) f(\varepsilon) d\varepsilon\right) \tag{11}$$

where G is the normalized governmental lump-sum transfer to each individual, $g(.)$ is a governmental production function,[5] Z_t is the labor tax revenues, Z_τ is the toll revenues, Z_{PT} is the cost of the public transport subsidy, t is the labor tax rate, τ is the congestion charge for a return trip, s is the public transport subsidy and $pt(.)$ is a production function used to capture some of the costs associated with organizing the subsidy. The lump-sum transfer G is defined to be distributed equally in the population.

The reason for including a governmental production function and not just assuming that the government only redistributes the collected taxes is that we want to allow for adjustments of the marginal benefit of public funds in the initial situation without a congestion charge. By adjusting the marginal costs and benefits in the initial situation we can isolate the welfare effects of the congestion charge from general welfare effects of adjusting the remaining policy instruments (G, t and s) in the initial situation without ever including a congestion charge. This issue is further discussed in the calibration section.

[5] The governmental production function can be interpreted as if the government uses the collected taxes to buy a composite commodity from the competitive firms from which it produces a governmental commodity which is a perfect substitute to the commodity itself.

Welfare, aggregated labor supply and total production

From the utility maximization problem we can calculate the indirect utility function for an individual with daily wage w as a function of the exogenous parameters.

$$V_w = V(w, \pi_R, \pi_P, c_R, c_P, s, t, \tau, G) \quad (12)$$

Using the indirect utility function we can measure the equivalent variation of a policy as the lump-sum payment EV that makes the individual indifferent between the situation before and after the policy has been implemented. We define the equivalent variation $EV(w)$ for an individual with wage w to be:

$$V\left(w, \pi_R^0, \pi_P^0, c_R^0, c_P^0, s^0, t^0, \tau^0, G^0 + EV(w)\right) = V(w, \pi_R^1, \pi_P^1, c_R^1, c_P^1, s^1, t^1, \tau^1, G^1) \quad (13)$$

The total welfare change of a policy can then be calculated as the lump-sum payment needed to make everyone in the population indifferent between the before and after situation, that is:

$$EV = \int_0^\infty EV(\varepsilon) f(\varepsilon) d\varepsilon \quad (14)$$

A problem with using equivalent variation to measure welfare is that the result depends on at which base prices we make the comparison. We will therefore combine this money metric welfare measure with a strictly utilitarian measure of the total welfare in the population, i.e.

$$U = \int_0^\infty U(\varepsilon) f(\varepsilon) d\varepsilon \quad (15)$$

In addition to these two welfare measures, we calculate the aggregated labor supply in the population.

$$L = \int_0^\infty L^*(\varepsilon) f(\varepsilon) d\varepsilon \quad (16)$$

Since the population is normalized to one this number is the same as the mean number of workdays in the population.

The total production is the value of the populations aggregated work. Since we have assumed that every individual's daily gross income w is equal to his or her productivity, total production can be calculated as:

$$P = \int_0^\infty \varepsilon L^*(\varepsilon) f(\varepsilon) d\varepsilon \quad (17)$$

Policy scenarios

In the numerical example we will analyze and compare three revenue recycling scenarios against a base case scenario without a congestion charge. In the scenarios the revenues are

used to increase the lump-sum transfer G; cut the income tax t; and increase the public transport subsidies s respectively. The scenarios correspond to the revenue recycling schemes analyzed in Parry and Bento (2001). In the analysis the effects on social welfare, aggregated labor supply, total production as well as the distributional impacts of the different recycling schemes will be considered. To analyze and compare the effects of the different scenarios we solve the general equilibrium model numerically. In addition to the scenarios above we also study the situation where all three policy instruments (s, t, G) are optimally adjusted to maximize social welfare conditional on a chosen congestion charge τ.

Base case scenario

In the base case scenario the congestion charge for the car mode is set to zero, i.e. $\tau = 0$. We assume that all tax revenues from the labor tax are returned in a lump-sum transfer back to the population and that the transfer is equally distributed among all individuals. The scenario is calibrated such that the marginal welfare of all three governmental policy instruments (s^0, t^0, G^0) are equal. This means that the government cannot increase social welfare by adjusting any of the three policy instruments without exceeding the governmental budget constraint (8).

Lump-sum scenario

In this scenario the toll revenues are used to increase the lump-sum transfer back to the population from the reference level G^0 to G^Gwhile keeping the income tax and the public transport subsidy at their reference level, i.e. (s^0, t^0, G^G). The increase is not given directly by the collected revenues; instead the new transfer is calculated from the governmental budget constraint (8). This is because that if the congestion charge has a negative impact on labor supply, this will also lower the revenues from the income tax.

Labor tax cut scenario

In this scenario the revenues are returned in the form of a labor tax cut, i.e. (s^0, t^T, G^0). The labor tax in this scenario t^T depends on how much of the aggregated labor tax revenues that can be compensated by the revenues from the congestion charge while holding the lump-sum transfer and the public transport subsidy constant at the reference level without exceeding the governmental budget constraint.

Public transport subsidy scenario

In the public transport scenario the revenues are used to increase the subsidy on public transport s^S. The lump-sum transfer and the income tax are held constant at the reference level, i.e. (s^S, t^0, G^0).

Optimal adjustment scenario

In the optimal scenario all three policy instruments are adjusted to maximize social welfare conditional on a given congestion charge τ, i.e. (s^τ, t^τ, G^τ).

Numerical example

The model in the numerical example is calibrated using stylized data from the Stockholm congestion charging trial. Numerical values for the parameters have been collected from Eliasson (2008), Eliasson (2009), Eliasson et al. (2009), Hultkrantz and Liu (2009) and Trivector (2006). The model is only calibrated to measure the relative differences of the policies. This simplifies the calibration procedure since this allows us to use a normalized population instead of calibrating the model to the actual number of commuters in Stockholm. The downside of this simplification is that this does not give us any absolute measure of welfare implications of the different recycling schemes. The calibration procedure largely follows the procedure in Hultkrantz and Liu (2009). The model has been implemented in Matlab and can be obtained upon request from the author.

Experiences from the Stockholm congestion charging trial

In the first half of 2006 the Stockholm congestion charging trial was performed. The congestion charge was implemented as a single-cordon toll encircling the inner city of Stockholm. In addition to the charges, the trial was supplemented by extended public transport services. The primary objective of the charges was to reduce congestion, increase accessibility and improve the environment. The purpose of the trial was to "test whether the efficiency of the traffic system could be enhanced by congestion charges" (City of Stockholm, 2006b). The cost for crossing the cordon was set to between 10 and 20 SEK depending on the time of day.

The trial created a reduction in traffic crossing the charge cordon with 22% compared to the year before. The reduction in traffic also had a significant effect on travel times. The queue times on the approach roads to and from the inner city decreased by one third during the

morning peak period and were halved in the afternoon rush. Results from travel surveys in connection to the trial indicate that around half of the reduction in car trips corresponded to work or school related commuting. Almost all of these car commuters changed to public transport, highlighting the importance of public transport substitution for maintaining the overall level of work commuting, Eliasson et al. (2009). More information regarding the effects of the trial can be found in City of Stockholm (2006a), Eliasson (2008), Eliasson (2009) and Kottenhoff and Brundell Freij (2009).

Choosing the base case scenario

To compare the impact of the chosen policies, we need to specify a base case scenario from which to make the comparisons. The choice of base case scenario is important since it has a large effect on the relative performance of the different revenue recycling policies. If we create a model where for example the marginal benefit of the public spending (such as a lump-sum transfer) is lower than the marginal cost of public funds (some of which originates from distortionary taxes on labor) in the initial situation with no congestion charge; then it is clear that any revenues from a congestion charge should be spend on decreasing distortionary taxes, rather than to increase public spending. This has however more to do with the initial model assumption than being a feature of the congestion charge. If the marginal costs and benefits are not equal in the initial situation, we cannot separate the welfare effect of the congestion charge from the welfare effect of a general adjustment of the governmental policy instruments. We therefore need to choose a base case scenario where the marginal costs are equal to the marginal benefits of the different policy instruments (except for the congestion charge).

This implies that the government chooses income tax, public transport subsidy and lump-sum transfer to maximize social welfare in the model. Assuming that the government has a strict budget constraint we can frame the problem as choosing an optimal income tax t_0 and public transport subsidy s_0 to maximize social welfare, i.e. (s_0, t_0, G_0), where the lump-sum G_0 is given by the governmental budget constraint.

Since we want to study a situation that resembles reality this means that we need to create a model where the optimal income tax is separated from zero. This is also the reason for why we have included a production function for the governmental lump-sum transfer, in contrast to many previous models studying revenue recycling where the government just redistributes the collected taxes.

This approach allows us also to study how the optimal point (s', t', G') changes when we introduce a congestion charge. From the deviation we can then calculate the direct welfare effect from a revenue recycling policy. This direct effect can then be combined with the effect on welfare from a general adjustment of the policy instruments in the cases where we believe that the policy instruments' in the initial situation differ from their welfare maximizing levels.

Calibration

To calibrate the model numerically we need to specify the daily income distribution, set parameter values to the income tax, travel costs and travel times, and specify functional forms for the volume delay function and the utility function. We assume, following Hultkrantz and Liu (2009), that the daily gross income distribution follows a lognormal distribution and that the average monthly wage is 27 700 SEK and the median monthly wage is 22 400 SEK divided by an average labor supply in the population of 22 full time equivalent work days per month.[6] The distribution is shown in Figure 1.

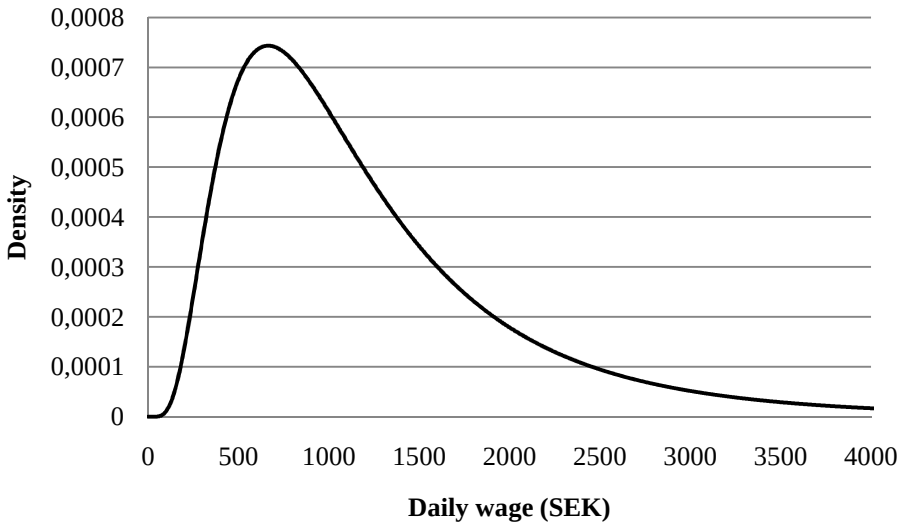

Figure 1: Daily wage distribution

We also need to specify the functions for volume delay and utility. To simplify the calculations we define that the individuals have Cobb-Douglas type of utility functions:

$$u(C, N) = C^{\alpha} N^{(1-\alpha)} \qquad (18)$$

[6] The lognormal distribution $y \sim lognormal(\mu, \sigma^2)$ has the statistical properties, mean $\bar{y} = e^{\mu + \frac{\sigma^2}{2}}$ and median $\tilde{y} = e^{\mu}$.

where the parameters α is assumed to be equal for all individuals and calibrated to set the average number of full time equivalent work days in the population close to 22 days per month in the base case scenario.

For volume delay function we use the Bureau of Public Roads function from 1964 which is a widely used volume delay function, Spiess (1990). The function is given by:

$$\pi_R = \pi_0 \left[1 + 0.15 \left(\frac{\int_{\hat{e}}^{\infty} L_C(\varepsilon) f(\varepsilon) d\varepsilon}{K} \right)^4 \right] \qquad (19)$$

where π_0 is the free-flow travel time and the constant K is the road capacity. These are calibrated to capture standard travel times for the Stockholm traffic. If the free-flow speed is 50 km/h the resulting commuting time for car without congestion will be 43 min/day. The public transport cost before subsidy is set to 66 SEK/day and the travel cost for car is assumed to be 118 SEK/day. The public transport time is 120 min/day for the same travel length. The calibrated parameters are summarized in Table 1.

The base case scenario is chosen so that the governmental policy instruments (s^0, t^0, G^0) maximizes social welfare without a congestion charge. The base case scenario is chosen such that the car share is around one third of the total number of commuting trips. To set the optimal income tax above zero we need to adjust the governmental production function to increase the marginal benefit of the lump-sum transfer. To simplify the analyze we assume that the governmental production function has constant return to scale, i.e. $g(z) = w_g\, z$. We also increase the cost of subsidizing public transport with the same factor, i.e. $Z_{PT} = w_s\, s \int_0^{\widehat{w}} L_P^*(\varepsilon) f(\varepsilon) d\varepsilon$.

Since social welfare in the model is measured as an equivalent variation, the measure depends on what initial situation we measure the equivalence from. To find the set of policy instruments that maximizes social welfare we search for an initial situation where the equivalent variation has a local maximum.

Table 1: Summary of model parameters

Parameter	Value
Daily income distribution, mean[7] μ	6.9256
Daily income distribution variance σ^2	0.4250
Car cost c_R	118 SEK/day
Public transport cost before subsidy c_P	66 SEK/day
Utility parameter α	0.45
Public transport travel time π_P	0.250 units of time (120 min/day)
Car free-flow travel time π_0	0.0895 units of time (43 min/day)
Car road capacity constant K	7.49 trips/day
Time endowment $\bar{L}$	90 units of time (30 days)
Governmental production function parameter w_g	1.3
Public transport subsidy cost parameter w_s	1.3
Subsidy in base case scenario s^0	63.60 SEK/return trip
Income tax in base case scenario t^0	30.45%
Lump-sum transfer in base case scenario G^0	

Simulation results

Modal-split point and the effect of a congestion charge

We first analyze the base case scenario without a congestion charge. Figure 2 illustrates labor supply as a function of the daily wage w. Labor supply is measured in full time equivalent work days.

Figure 2 shows labor supply as a function of the daily wage w for the base case scenario with no toll. The black curve shows actual labor supply $L^*(w)$ for the optimal choice of travel mode. The two grey curves correspond to the conditional labor supply functions for public transport $L_P^*(w)$ and car $L_R^*(w)$. Since each individual will choose the travel mode that maximizes his or her utility, this splits the population into two distinct groups depending on the choice of travel mode. We also see that individuals with a high income will work more if they commute by car than by public transport. This creates a discontinuity in the labor supply curve at the modal-split point where the individual is indifferent between commuting by car or public transport.

[7] Mean and variance of the associated normal distribution.

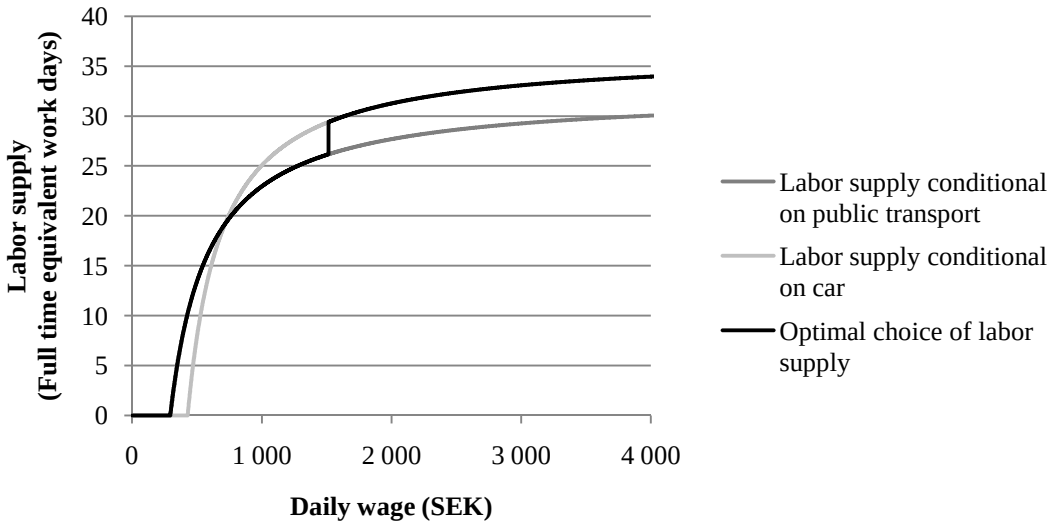

Figure 2: Labor supply as a function of the daily wage for the base case scenario

Next we study the effect on imposing a congestion charge by comparing the base case scenario with the public transport subsidy scenario where the toll revenues are used to increase the public transport subsidy. Figure 3 presents labor supply as a function of income for the base case and the public transport subsidy scenario. The congestion charge makes it more expensive to commute by car, shifting the modal-split point to a higher daily income level and increasing the number of people that uses the public transport system. The toll will also have a negative direct effect on labor supply for the remaining car commuters since it decreases the net wage similar to an income tax increase. The increased subsidy strengthen the modal-shift, making the public transport alternative even more attractive. All these effects will reduce the number of car trips which will decrease congestion and lower the travel time for car π_R. The reduction is however to counterbalanced by the shorter travel time which will shift the modal-split point downwards and stimulate labor supply among the remaining car commuters. This opposite effect will therefore to some degree compensate for the increase in car cost, making the total decrease in the number of car trips lower than would otherwise be the case.

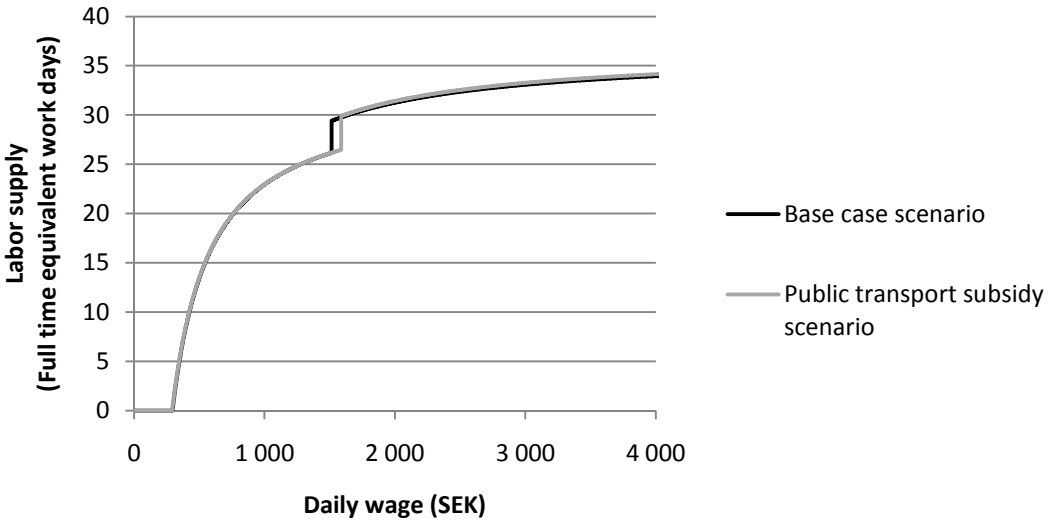

Figure 3: Labor supply as a function of the daily gross income for the base case scenario and for the public transport subsidy scenario

The welfare effect of a congestion charge

The results from the numerical simulation for all policy scenarios are summarized in Table 2. The table shows figures of welfare, aggregated labor supply, total production, modal-split point and car travel time for the analyzed scenarios. The table also contains values for the lump-sum transfer, income tax and public transport subsidy for all scenarios. The scenarios are evaluated for a daily congestion charge of 10 SEK (i.e. the total cost of one return trip).

Table 2: Scenario summary for the policy scenarios evaluated for a congestion charge of 10 SEK

	Base case scenario	**Lump-sum transfer (G)**	**Labor tax cut (T)**	**Public transport subsidy (S)**
Welfare EV	0 SEK	18.36 SEK	19.01 SEK	13.47 SEK
Utilitarian welfare U	1017.66	1018.00	1017.86	1017.88
Aggregated labor supply L	22.17 days	22.11 days	22.15 days	22.16 days
Total production P	33 781 SEK	33 746 SEK	33 786 SEK	33 790 SEK
Modal-split point $\widehat{w}$	1 515 SEK	1 580 SEK	1 579 SEK	1 589 SEK
Car travel time π_R	54.0 min	51.3 min	51.4 min	51.0 min
Congestion charge τ	0 SEK	10 SEK	10 SEK	10 SEK
Lump-sum G	11 909 SEK	11 942 SEK	11 942 SEK	11 942 SEK
Income tax t	30.45%	30.45%	30.34%	30.45%
Public transport subsidy s	63.60 SEK	63.60 SEK	63.60 SEK	65.07 SEK

From the table we see that the congestion charge produces positive welfare, regardless of how the revenues are recycled back into the economy. The welfare gain from the lump-sum transfer recycling scenario is almost as large as when the revenues are used for cutting the labor tax. This stands in contrast to the results in Parry and Bento (2001) where the lump-sum recycling scheme had a negative effect on total welfare due to increased losses in the labor market. The reason behind the difference is that we in this model, compared to the model by Parry and Bento, have chosen an initial starting point where the marginal welfares of all three policy instruments are equal. By choosing an initial situation where the marginal benefit of public funds (e.g. the governmental transfer) is lower than the marginal cost of public funds (e.g. the income tax), we can always increase welfare by reducing the income tax at the expense of a reduction of the governmental transfers. It is then also evident that any additional revenues, such as those collected from a congestion charge, is better spend on reducing the income tax than on increasing the already oversized public funds. However, this has more to do with the choice of base scenario than with the congestion charge per se.

The relatively poor welfare gain from the increased subsidy is in contrast, a direct effect of congestion charge. Since a part of the welfare gain from the public transport subsidy is connected with its ability to reduce congestion, a congestion charge that reduces congestion therefore reduces the need (and potential benefit) of the subsidy. Welfare is in the analysis measured as an equivalent variation between the evaluated scenarios and the base case. All three revenue recycling scenarios also increase welfare in a strictly utilitarian sense.

Table 2 also shows the car travel times for the chosen scenarios. Although car travel time, and hence congestion, is reduced regardless of how the toll revenues are used, subsidizing public transport is clearly the most effective policy for reducing congestion. The reason for this is that the subsidy works in the same direction as the congestion charge, thus reducing the number of car trips even further than the toll alone. An income tax cut will on the other hand have the opposite effect because the increased net income both stimulates car commuters to work and travel more; and makes more people switch to the car mode. From the table we also see that the congestion charge has a negative effect on aggregated labor supply in all three scenarios. The total effect is however small and not robust for changes in key parameter values for both the public transport subsidy and the labor tax cut.

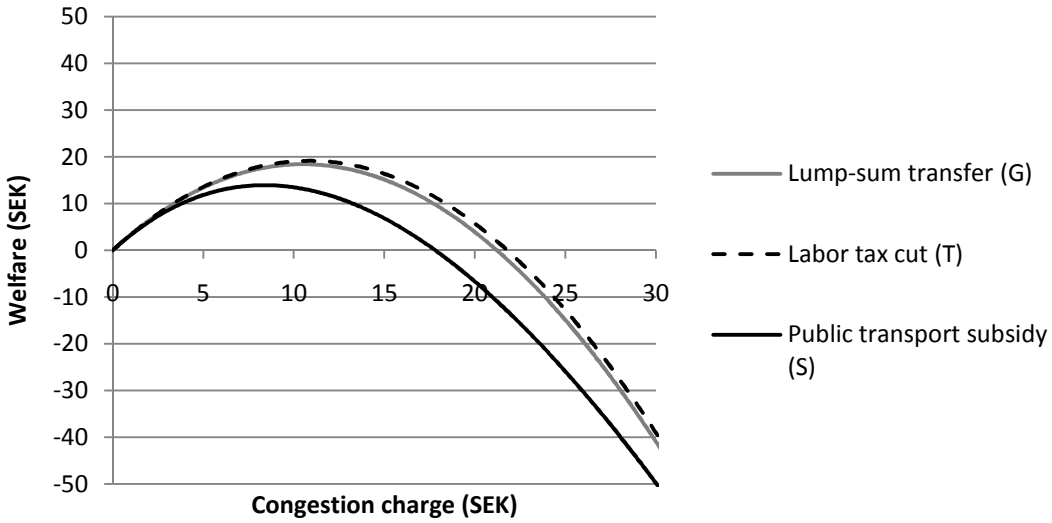

Figure 4: Welfare measured as an equivalent variation from the base case scenario as a function of the congestion charge

Figure 4 shows welfare as a function of the congestion charge for the evaluated policy scenarios. We see that the congestion charge initially increases welfare regardless of how the revenues are recycled. Setting the congestion charge too high will on the other hand reduce welfare.

The distributional impact of a congestion charge

The model can also be used for analyzing the distributional impact of a congestion charge. Figure 5 shows welfare as a function of the daily wage in the population. The gains and losses from the congestion charge are distributed unevenly across individuals in the population regardless of how the revenues are recycled. This means that none of the analyzed recycling policies are Pareto improving for all individuals in the population. We can also see that car commuters with the highest income gain the most from a congestion charge. The losers can be found among those switching from car to public transport and in the group of remaining car drivers with lowest value of time. The toll also has a positive effect on the existing public transport users which is logical since they are not directly affected by the congestion charge.

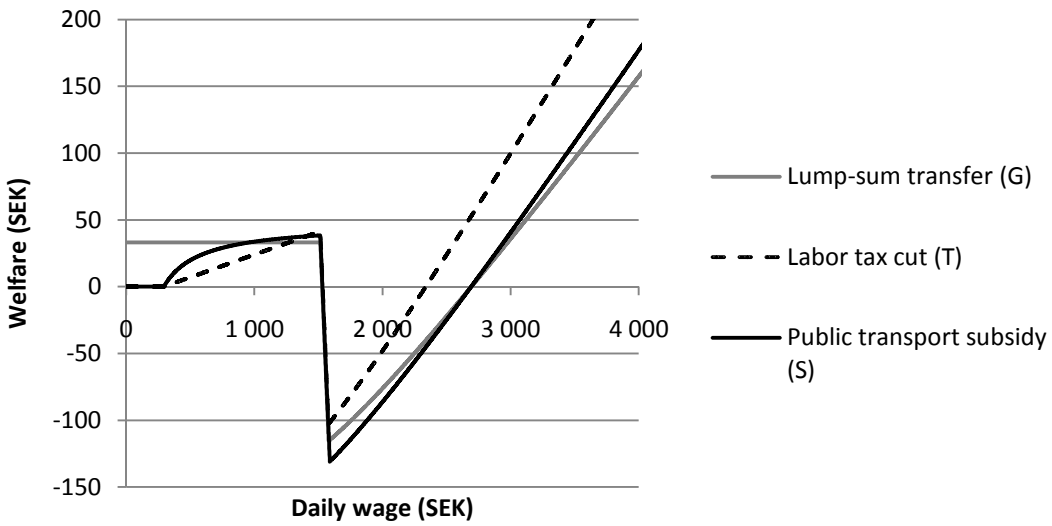

Figure 5: Welfare as a function of daily wage measured as an equivalent variation from the base case scenario and a congestion charge of 10 SEK

Comparing the different revenue recycling scenarios we see that, while a labor tax cut benefits individuals with the highest income the most, the lump-sum transfer and public transport subsidy favors the segments of the population with low to middle incomes. We can also see that individuals with a daily wage above 2680 SEK prefers the subsidy to the increased transfer since they find the lower travel time more than the increased transfer.

From the figure we also see that all recycling policies are favored by some group of individuals depending on their daily wage. As shown in the figure, individuals with low income gain more from increased lump-sum transfers and subsidies while individuals with high income gain most from a labor tax cut. The results is by no means surprising but still important to remember when evaluating the welfare effect of a transport policy, especially if one is interested in distributional consequences and political acceptance of the analyzed policy. Depending on how we aggregate welfare we will also come to different conclusions about which policy that improve total welfare most.

The scenarios also have different distributional impact on the supply of labor in the population. In Figure 6 the difference in labor supply compared to the base case scenario is shown for the analyzed policy scenarios. While all schemes increase labor supply for individuals on high-income, the effect varies more among low-income earners. While both a public transport subsidy and a labor tax cut stimulate labor supply in the low-income group, the effect from the subsidy is much stronger. The reason for this is that the subsidy works as a targeted labor tax cut for the part of the population with the lowest income who uses public transport. Since it only targets a part of the population, it has a larger effect on the daily net

income (income after taxes and commuting costs) than if the same amount of revenues were spent on a labor tax cut for the entire population.

Figure 6: Differences in labor supply as a function of daily wage compared to the base case scenario for a congestion charge of 10 SEK

Figure 6 also indicates that the public transport subsidy increases labor supply more than a labor tax cut even for individuals with the highest daily income. This can seem counterintuitive since they have no direct benefit from subsidies on the other mode. The public transport subsidy does however cause more people to switch to public transport to benefit from the subsidy which have an indirect effect on labor supply for the remaining car commuters through reduced congestion. The intuition behind this is that the marginal price of increasing labor supply among high-income earners with a lower labor tax is higher than the marginal price of increasing labor supply with lower travel times by convincing more people to switch to public transport by a subsidy.

The total effect on labor supply, shown in Table 2, is negative in all the evaluated scenarios even though the share of the population who increases their labor supply is very large in both the labor tax cut scenario and the increased public transport subsidy scenario, see Table 3. The reason for this is that the relatively small positive effect on labor supply for the majority of the commuters cannot compensate for the large negative labor supply effect on the part of the population that changes from car to public transport because of the congestion charge.

Acceptability of a congestion charging policy

The model can also be used to analyze how the political acceptance for a congestion charge depends on how the revenues are recycled. One measure of political acceptance is to look at

the share of net winners and net losers from a given policy compared to the base case scenario. In Table 3 we see that the lump-sum transfer, the labor tax cut and the public transport subsidy scenarios all have a large share of net winners, around 80%. This indicates that the political acceptance for a congestion charging policy could be rather high when the revenues are recycled back to the population.

Table 3: Comparison of the evaluated scenarios relative to the base case scenario with a congestion charge of 10 SEK

	Lump-sum transfer (G)	**Labor tax cut (T)**	**Public transport subsidy (S)**
Share of population with negative utility ($\Delta U<0$)	19.8%	16.4%	19.8%
Share of population with positive utility ($\Delta U>0$)	80.2%	80.8%	77.5%
Share of population with decreased labor supply ($\Delta L<0$)	72.2%	2.1%	2.4%
Share of population with increased labor supply ($\Delta L>0$)	25.0%	95.1%	94.8%

The effect on an optimal adjustment of the policy instruments

Last we investigate the effect when all policy instruments are adjusted to maximize social welfare conditional on a given congestion charge τ, i.e. (s^τ, t^τ, G^τ). This makes it possible, both to study the importance of the constrained adjustment in the previous three scenarios compared to an optimal recycling scheme; and to study how the optimal levels of public transport subsidy, income tax and governmental lump-sum transfer is affected by a congestion charge.

Figure 7 shows the optimal choice of policy instruments as a function of the congestion charge. To summarize the optimal values for all three instruments in the same figure they are shown as a percentage of the values in the base case scenario, i.e. $(s^\tau/s^0, t^\tau/t^0, G^\tau/G^0)$.

The congestion charge decreases the optimal labor tax, lump-sum transfer and public transport subsidy. The effect is strongest for the public transport subsidy which decreases to zero as the congestion charge increases. This is a direct result of the substitutability between a public transport subsidy and a congestion charge for reducing congestion. The optimal choice of lump-sum transfer and income tax are also somewhat lower with a congestion charge than in the base case scenario. This indicates that the potential welfare gain from a congestion charge can be much larger if all policy instruments are readjusted for the chosen congestion charge than by just recycling the collected revenues through a single policy instruments. Especially

for the recycling policies where the revenues are spend on increasing the public transport subsidy or returned in a lump-sum transfer this is important, since the congestion charge decreases the optimal levels of all the policy instruments.

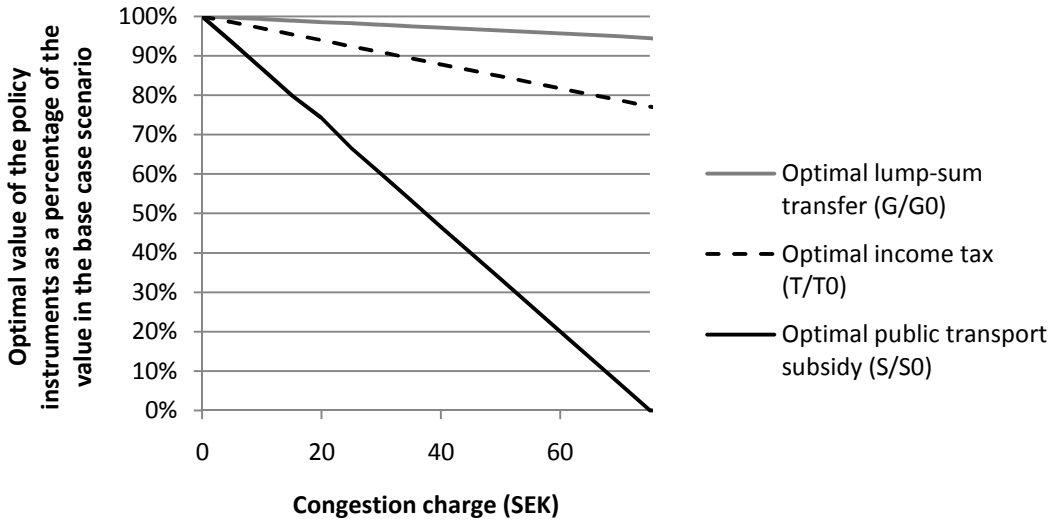

Figure 7: Optimal policy instruments as a function of the congestion charge

In the numerical example we can for instance nearly double total welfare of a congestion charge of 10 SEK by readjusting all policy instruments optimally compared to only recycling the revenues through a labor tax cut.[8] The acceptability of the optimal readjustment policy is however much lower since the increase in total welfare comes at the expense of a larger share of net losers of the policy. The optimal readjustment policy also decreases utilitarian welfare compared to the base case scenario. This illustrates how important the choice of welfare measure is for measuring welfare in a heterogeneous population and also highlights the fact that the chosen welfare measure does not include any distributional considerations.[9] This is also the reason why we treat the optimal readjustment policy separately.

[8] For a congestion charge of 10 SEK the a maximal welfare level of 34.26 SEK can be obtained by setting the income tax to 29.56%, the public transport subsidy to 55.10 SEK and the lump-sum transfer to 11 840 SEK.

[9] A strictly utilitarian welfare measure will have a similar shape as in Figure 5 but put less weight on the welfare of the highest income group compared to the money-metric equivalent variation welfare measure.

Robustness analysis

In the numerical example, the congestion charge was found to produce positive welfare for all analyzed revenue recycling schemes, at least if the congestion charge was not too large. This result is robust to changes in the model parameters as long as the level of congestion in the base case scenario is not too low. Increasing the road capacity decreases the congestion externality which reduces potential welfare gain from a congestion charge. Reducing the cost for subsidizing public transport has a similar effect, making it less expensive to reduce congestion with a subsidy compared to a congestion charge. Depending on how cost-effective the subsidy is, it can even be optimal with a negative congestion charge; turning the congestion charge into a subsidy that reduces the cost of car commuting in order to stimulate labor supply.

When comparing the three recycling policies we saw that the welfare gain from recycling the revenues from a congestion charge through an increased lump-sum transfer EV_G was nearly as large as when the collected revenues were used to cut the labor tax EV_T. Recycling the revenues through an increased public transport subsidy EV_S had on the other hand a much smaller effect on total welfare. To analyze the robustness of these results; we vary key parameters; recalibrate the policy instruments in the base case scenario; and then study the welfare effect of the three different revenue recycling policies for a small congestion charge.

Reducing the road capacity increases the welfare of the congestion charge since the congestion is more severe in the before toll situation. The high level of congestion in the base scenario also makes the labor tax cut recycling policy less effective compared to both the public transport subsidy and the lump-sum transfer policies. The reason is that the labor tax cut has a positive effect on the number of car trips and hence counteracts the congestion charge. By changing the parameter values of the model we can make the lump-sum transfer policy to increase welfare more than the labor tax cut. This means that the relative performance[10] of the three different revenue recycling policies is not robust to changes in the underlying assumptions about key parameter values.

The effect on total labor supply was in the initial analysis found to be negative for all three recycling policies. Nor is this effect robust to changes in the initial model assumptions.

[10] I.e. EV_G/EV_T, EV_s/EV_t etc.

Increasing the congestion in the base case scenario causes the congestion charge to have a positive effect on aggregated labor supply for both the labor tax cut and the public transport subsidy recycling policies. When the revenues are used to increase the lump-sum transfer, labor supply is still negative, even for high initial congestion levels. This is because an increased lump-sum transfer neither stimulates low income earners to work more, nor creates any additional stimulating effect on the remaining car commuters.

In the preceding analysis we have assumed that the governmental policy instruments (s^0, t^0, G^0) in the base case scenario are chosen to maximize social welfare. This means that the marginal utility of all instruments in the initial situation are equal. This assumption might not hold in reality and we will therefore discuss the effect on the welfare analysis of relaxing this assumption.

First we look at the situation where the public transport subsidy is below its optimal level in the base case scenario. This means that we can increase welfare by increasing the subsidy at the expense of the other two policy instruments (decreased lump-sum transfer and increased labor tax). If we in this situation impose a moderate congestion charge, will the direct welfare effect of the congestion charge be overshadowed by the general distortion in the system, resulting in a situation where recycling the revenues through an increased public transport subsidy improves welfare more than any other recycling policy.

If we on the other hand choose an initial situation where the marginal benefit of the lump-sum transfer is lower than the corresponding marginal cost of the labor tax; we get a model where recycling the revenues through an increased lump-sum transfer even can reduce welfare.

Concluding remarks

In the paper we have analyzed the welfare effects of a congestion charge in a population with a continuously distributed value of time. Using a disaggregated demand model for the individuals' choice of travel mode, we have both studied the distributional impact of different revenue recycling policies and analyzed how the mode choice self-selection mechanism affects the welfare effect of a congestion charge. In a numerical example, calibrated to resemble the Stockholm congestion charging system, we have analyzed the effect of three different revenue recycling polices; a lump-sum transfer; a public transport subsidy; and a labor tax cut.

From the analysis we saw that a congestion charge;

- can have a positive impact on welfare, regardless if the revenues are returned in a lump-sum transfer, as a public transport subsidy or used to cut income taxes.
- reduces the need (and benefit) of subsidizing public transport;
- affects the individuals that changes from car to public transport due to the toll more negative compared to those who do not change mode of transport;
- has an ambiguous effect on total labor supply.

First we saw that all revenue recycling policies had a positive effect on the total welfare. This stands in contrast to earlier studies where the efficiency loss in the labor market was found to exceed the welfare gains from internalizing the congestion externalities in the transport market. Two main reasons behind this result are; first, in the analysis we only considered the direct effect of the congestion charge since we have assumed that the policy instruments (save the congestion charge) was optimally chosen in the no-toll scenario; second, we studied a population with continuously distributed value of time. The analysis hence stresses the importance of recognizing that people have different value of time and that this can have a substantial effect on the welfare analysis. This is because the congestion charge primary price out people with a low willingness to pay so that people with a higher willingness to pay can drive more. Disregarding equity considerations, the congestion charge leads to a more efficient use of the available road space.

The analysis also revealed interplay between the public transport subsidy and the congestion charge. A congestion charge that reduces congestion also reduces the need (and potential welfare gain) of a public transport subsidy, since a part of the benefit from a public transport subsidy comes from its ability to reduce the congestion externality by attracting commuters to

switch from car to public transport. Recycling the revenues from a congestion charge via an increased public transport subsidy will therefore lead to a situation with an over-subsidized public transport system, given that the subsidy was set at its optimal level in the initial situation. The welfare gain from recycling the collected toll revenues through an increased public transport subsidy was therefore found to be smaller than both the lump-sum and the labor tax cut recycling policy. The welfare gain from the lump-sum policy was also found to be more or less equal to the labor tax cut policy. One reason for this is that the labor tax cut increases the demand for car travel and therefore counteracts the congestion charge.

From the robustness analysis we also saw that the congestion charge can have a positive effect on total labor supply; both if the revenues are recycled through a labor tax cut and through an increased public transport subsidy. A precondition for this is that the initial congestion level must be high enough. We also saw that the public transport policy had a stronger positive effect on labor supply among car commuters than the labor tax cut, even though this group did not benefit from the subsidy directly.

A critique of the model is that the modal choice approach used in this paper tends to overestimate the correlation between an individual's daily gross income and his or her mode choice. Without this strong correlation, some of the results, especially the effect the subsidy had on attracting car commuters to switch to public transport would be smaller. Nevertheless, user heterogeneity and self sorting cannot be ignored completely and, as has been shown in this paper, can have a substantial effect on both the general welfare effects and the distributional impact of a congestion charge.

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