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the Built Environment**

# **Welfare Effects of Transport Policies**

An analysis of congestion pricing and infrastructure investments

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with a specialisation in Transport Systems  
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## **Abstract**

Interactions between the transport market and other distorted markets, such as the labor market, can have a large impact on the overall welfare effect of a road pricing policy or a congestion charge. Many road pricing studies therefore try to incorporate effects from other distorted markets in the analysis. A difficulty when assessing the welfare effect of a future transport policy is also that many factors and parameters needed for the analysis is uncertain.

This thesis contains three papers all studying different methodological approaches to analyzing the welfare effects of transport policies. The first two papers analyze the welfare effect of congestion pricing in distorted economies. The main contribution of the first paper is to analyze how the welfare effect of a congestion charge in a distorted economy depends on what assumptions we make regarding the tax system in the initial no-toll situation. A critical assumption in many cost-benefit analyses of congestion charges is that the whole population has a single value of time. The second paper studies the effect of a congestion charge in a population of commuters with a continuously distributed value of time. The main contribution of the paper, compared to previous literature, is that it studies the welfare effect and distributional impact of a congestion charge in a population with endogenous labor supply and heterogeneous value of time where mode-choice self-selection plays an important role.

The third paper studies the climate benefit of an investment in high speed rail by calculating the magnitude of annual traffic emission reduction required to compensate for the annualized embedded emissions from the construction of the line. To account for uncertainties in underlying assumptions, a Monte Carlo simulation framework is used in the analysis. The paper finds that to be able to balance the annualized emissions from the construction, traffic volumes of more than 10 million annual one-way trips are usually required, and most of the traffic diverted from other transport modes must come from aviation.



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## **List of papers:**

- (I) Westin, Jonas (2011) How to evaluate the welfare effects of congestion charges?
- (II) Westin, Jonas (2011) Welfare Effects of Congestion Pricing in a Population with Continuously Distributed Value of Time
- (III) Kågeson, Per and Westin, Jonas (2010) The climate effect of high speed rail – a sensitivity analysis





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# Welfare Effects of Transport Policies

*Tous les événements sont enchaînés dans le meilleur des mondes possible ...  
Cela est bien dit, répondit Candide, mais il faut cultiver notre jardin.  
- Voltaire, Candide, Chapitre XXX Conclusion.*

## 1 Introduction

Road congestion is a large problem in many urban areas where a high demand for road traffic during morning and afternoon peak hours may cause long delays. To deal with this problem, transport economists have for a long time argued for the use of congestion charges for reducing the congestion level and the associated delays.

In a standard textbook analysis of road pricing, Pigouvian taxes are used to internalize congestion and environmental externalities by equating the price of travel with its marginal social cost. If the economy has no other distortions and 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 there are distortions in other interconnected markets (Rouwendal and Verhoef 2006).

Since a transport market often can have large feedback externality effects in other distorted markets, the actual welfare effect of a transport policy may differ significantly from the effect predicted by a first-best analysis that ignores spillover effects in other distorted markets (Parry and Bento 2002). To evaluate the full effect on welfare of a road pricing policy, we therefore need to incorporate interactions between the transport market and other distorted markets in the analysis.

This thesis contains three papers, all studying different methodological approaches to analyzing welfare effects of transport policies. The first two papers analyze the welfare effect of congestion charges in distorted economies. The main contribution of paper I is to analyze how the welfare effect of a congestion charge in a distorted economy depends on what assumptions we make regarding the tax system in the initial no-toll situation, i.e. whether the policy is analyzed in a balanced (optimal) or an unbalanced (not optimal) initial tax system. In particular the revenue recycling argument related to road pricing is discussed. The paper also extends previous research by studying the welfare effect of both marginal and non-marginal toll policies.

A critical assumption in many of the previous cost-benefit analyses of congestion charges is that the whole population has a single value of time. Paper II studies the effect of a congestion charge in a population of commuters with a continuous wage distribution. The main contribution of the paper, compared to previous literature, is that it studies the welfare effect and distributional impact of a congestion charge in a population with endogenous labor supply and heterogeneous value of time where mode-choice self-selection plays an important role.

The third paper focuses on a completely different area, the climate benefit of investment in high speed rail and is written in collaboration with Per Kågeson. The paper studies the climate benefit of an investment in high speed rail by calculating the magnitude of annual traffic emission reduction required to compensate for the annualized embedded emissions from the construction of the line. To account for uncertainties in underlying assumptions, a Monte Carlo simulation framework is used in the analysis. The paper finds that, to be able to balance the annualized emissions from the construction, traffic volumes of more than 10 million annual one-way trips are usually required, and most of the traffic diverted from other modes must come from aviation.

## **2 Previous research on road pricing**

To analyze the welfare effect of transport policies in distorted economies, a research literature has emerged where interactions between the transport market and other distorted markets are studied (Calthrop et al. 2010; Fosgerau and Pilegaard 2008; Mayeres and Proost 1997; Parry and Bento 2001; Van Dender 2003). A general methodology in this literature is to incorporate effects in other distorted markets in the cost-benefit analysis by embedding a model of the transport market in a general equilibrium framework. This type of analysis is also often referred to as second-best in the sense that it incorporates market imperfections and other type of restrictions outside of the transport system in the analysis.

One market that has been given special attention in the road pricing literature is the labor market. Since the worst congestion is usually related to peak hour travel, this has raised apprehensions about how the labor market might be affected by a congestion charge targeted at reducing peak hour travel, which is often associated with work-related commuting.

The main argument is that since a congestion charge may raise the cost of commuting to work, it can decrease employment at the extensive margin in a similar way as an income tax. Parry and Bento (2001) even argue that the resulting losses in the labor market can exceed the Pigouvian welfare gain from internalizing the congestion externality in the transport market. However, if the collected revenues from the congestion charge are used to cut distortionary income taxes, they show that a double dividend can arise where welfare increases both in the transport market and in the labor market. The literature is hence related to the double-dividend literature and the idea that it sometimes is efficient to tax externalities higher than their partial equilibrium Pigouvian level, given that the revenues are used to cut distortionary taxes elsewhere in the economy (see Bovenberg 1999; Parry and Oates 2000; Ballard and Don Fullerton 1992; Schwartz and Repetto 2000; and Kim 2002).

A related argument, often found in the road pricing literature, is therefore that the welfare effect of a congestion charge or a road pricing policy critically depend on how the collected revenues are recycled back into the economy (see Parry and Bento 2001; Van Dender 2003; De Borger and Wuyts 2009; Fosgerau and Van Dender 2010). One reason for this is that the value of the collected revenues often is larger than the value (in monetary terms) of the time gains from the reduced congestion. During the Stockholm congestion charging trial in 2006, the value of the shorter travel times were for example estimated to be around two thirds of the collected toll revenues (Eliasson 2009).

Comparing different revenue recycling schemes; using the revenues to reduce distortionary labor taxes is in general preferred to returning them in a lump-sum transfer (Parry and Bento 2001; Verhoef and Ubbels 2002), unless equity considerations are explicitly included in the social welfare function as in Mayeres and Proost (2001). The argument is related to the weak double-dividend claim, stating that an environmental tax in general improves welfare more if the revenues are returned through cuts in other distortionary taxes instead of being returned in a lump-sum transfer (see Goulder 1995; and Bovenberg 1999).

Using a simple analytical model, Parry and Bento (2001) also argue that the efficiency gains are larger if the toll revenues are recycled through reduced labor taxes instead of being spend on increased public transport subsidies. An opposite result is however found in De Borger and Wuyts (2009) who argue that since a labor tax cut and an increased public transport subsidy have very different effects on congestion, it may be more efficient to recycle the revenues via a targeted public transport subsidy, rather than spending the revenues on a general reduction of distortionary labor taxes. Interactions between different transport modes also complicate the analysis. The economy of scale in the public transport system can for instance be important for the overall welfare from a policy that induces a modal-shift from car to public transport. A troublesome implication of the conflicting results in the literature is that the estimated welfare effects and the relative efficiency of different revenue recycling policies depend, not only on which markets that are included in the analysis, but also on how the interactions between different transport modes are modeled. However, as pointed out by Rouwendal and Verhoef (2006), since many of the needed relationships can be hard to measure, both the total welfare effect as well as the optimal toll levels can be difficult to assess empirically.

This has given rise to the question of how to evaluate the welfare effect of a road toll or a congestion charge in an economy with other distorted markets? The question has practical implications when it comes to how the welfare effects from a road pricing policy should be evaluated. From the road pricing literature three arguments can be identified:

1. Since a congestion charge may raise the cost of work-related commuting, it can reduce labor supply which, in interaction with pre-existing distortions in the labor market, can result in a welfare loss of the same magnitude as the welfare gains in the transport market.
2. The welfare effect of a road pricing policy therefore needs to be analyzed in a second-best setting where interactions with other distorted markets are included in the analysis; and
3. How the revenues are recycled back to the economy are crucial for the total welfare of a road pricing policy.

In the following sections these three arguments will be discussed. The argumentation is based on the first two papers in the thesis referred to as paper I and paper II.

### **3 The labor market effect of a congestion charge**

Determining what effect a congestion charge has on the labor market in a real situation is often difficult. In the evaluation of the Stockholm congestion charging trial, the labor market effects were discussed as a source of uncertainty but not included in the final cost-benefit calculations (see Eliasson 2009). While the accessibility to the labor market as a whole can be reduced (since the peak period traffic is reduced), accessibility can be improved for high-income earners and business related travelers who are willing to pay the charge. There are also long term and dynamic effects related to both the matching in the labor market and the housing and location market.

#### ***3.1 The labor market response at the extensive margin***

A standard assumption in the transport literature on labor supply and commuting is that a congestion charge decreases labor supply at the extensive margin (Calthrop et al. 2010; Mayeres and Proost 1997, Mayeres and Proost 2001; Van Dender 2003; Parry and Bento 2001). The result is generally based on the assumption that the commuters only can choose labor supply at the extensive margin (participation in the labor force modeled as the number of workdays), whereas labor supply at the intensive margin (work hours per day or work intensity) is assumed to be fixed. The assumption creates a strict complementarity between labor supply and the number of commuting trips. This means that, conditional on a chosen transport mode, a commuter can only reduce his or her transport cost by reducing labor supply.

A change in labor supply at the extensive margin can be interpreted in multiple ways; as an effect on the actual number of work days, as a change in the labor force participation rate or as a location effect. In the models used in paper I and II, we study work-related commuting between two fixed geographical locations, that is, individuals who live in a suburb and commutes to work in a central business district (CBD). Labor supply in this setting can therefore be interpreted as the share of the population who choose to work in the CBD, compared to those who choose to work in the local area (or choose to exit the labor force altogether). A policy that increases (reduces) labor supply, would therefore correspond to the situation where more (less) people choose to work in the CBD and less (more) choose to work where they live or quit the labor market.

In many of the models in the road pricing literature, the road space during peak hour is assumed to only be used for work-related commuting, thus ignoring the impact from other type of trips such as leisure trips and freight transports. The motivation behind this assumption is often that work trips constitute the main part of the traffic during the morning and afternoon peaks when congestion is most severe. However, even a small share of non-work-related car trips can have a large impact on the marginal travel time.

A policy that reduces the amount of non-work-related traffic during rush hour can therefore have a positive impact on labor supply. Differentiating the congestion charge between trip purposes is one policy that can reduce congestion without having the same negative impact on work-related commuting (see Van Dender 2003). But even a uniform congestion charge can increase the number of work trips (and hence labor supply) if the value of the time gains from the reduced number of leisure trips is large enough to outweigh the increased monetary cost of commuting. This can both

happen if the initial share of non-work-related travel is large, or if the leisure trips are more cost-sensitive than the work trips and the congested speed-flow curve is steep.

### ***3.2 The labor market response at the intensive margin***

The assumption that labor supply only is chosen at the extensive margin is however a critical assumption when analyzing the effect of a congestion charge, 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 Gutiérrez-i-Puigarnau and van Ommeren (2010). The assumption is often motivated with results from the empirical labor market literature, where the labor supply response at the extensive margin (labor force participation) in general is seen as more important than the response at the intensive margin (hours of work) (Kleven and Kreiner 2006).

Many empirical studies indicate that the labor supply elasticity is larger along the extensive than the intensive margin, i.e. the employees are more willing to adopt their participation than hours worked (Kimmel and Kniesner 1998). There might also be constraints and regulations in the labor market that limit the individuals’ possibilities to choose their work hours. Another study by Gutiérrez-i-Puigarnau and van Ommeren (2010) use socio-economic panel data for Germany to 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 small positive effect of distance on weakly labor supply. This implies that the positive effect on daily hours, at least for Germany, is stronger than the negative effect on the number of work days. Their analysis does however not include effects on the labor force participation.

Once at work, a congestion charge makes it more attractive to work longer hours by example go from a part-time job to a full-time job or work overtime. Since a congestion charge can have a positive effect on labor supply at the intensive margin, it is nevertheless important to not beforehand disregard the effect on both the extensive and the intensive margin when estimating the total effect on labor supply from a congestion charge. Especially in a flexible labor market, where the commuters are allowed to choose the number of work hours without restrictions (such as small business owners and self-employed), the commuters can compensate for the increased commuting cost by working longer hours each work day, making the overall effect on total labor supply, at least in theory, ambiguous.

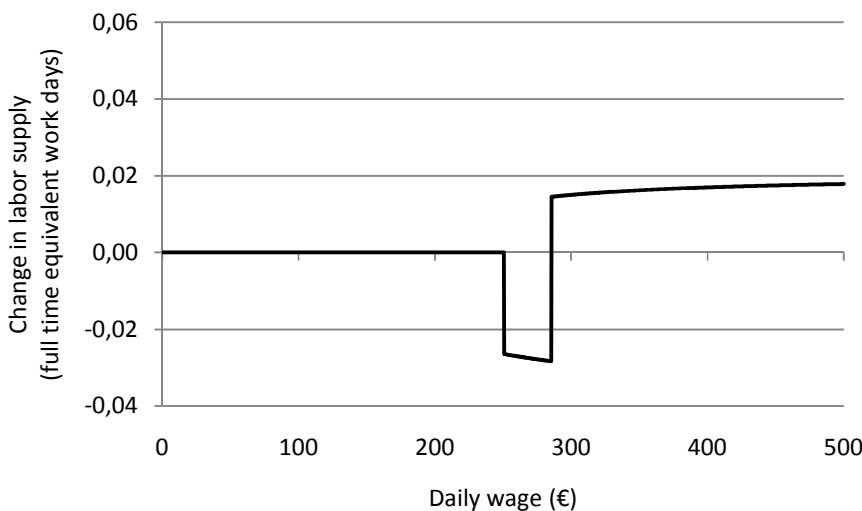
### ***3.3 The labor market response in a heterogeneous population***

A critical assumption in a large part of the road pricing literature where the welfare effect of a road pricing policy is analyzed in a second-best setting, is that all commuters have the same value of time. This is a problematic assumption when it comes to congestion charges, 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 welfare effect of a congestion charge in a heterogeneous population is examined in paper II. In the paper, a population with continuously distributed value of time, commutes between home and work in a static economy. Each commuter is assumed to choose labor supply and mode of transportation based on his or her daily wage. The commuters can choose between two transport

modes to get to work, a fast but expensive mode subject to congestion (car) and a slow but cheap mode with no congestion (public transport). Given a fixed wage distribution, paper II shows that there exists a unique modal-split wage level, such that all commuters with a higher wage only choose car and all commuters with a lower wage only choose public transport.

Since a congestion charge increases the cost of commuting by car, the modal-split wage is shifted upwards causing more people to commute by public transport instead of car. The effect on total labor supply therefore depends on both the effect from the modal-shift and the effect on labor supply for the remaining car commuters. The effect is illustrated in Figure 1 where change in labor supply as a function of wage before and after the introduction of a congestion charge is shown. To isolate the direct effect from the congestion charge we assume that the revenues are not recycled back to the commuters.



**Figure 1: Change in labor supply as a function of daily wage for a congestion charge in a population with continuous wage distribution where the revenues are recycled elsewhere in the economy. The congestion charge has a negative effect on labor supply for the car commuters who switch from car to public transport, but has a positive effect for the commuters that continue to commute by car.**

The increased monetary cost of car commuting shifts the modal-split wage upwards, reducing the number of car commuters. For the commuters that changes travel mode, the congestion charge has a negative effect on labor supply. For the remaining car commuters, the positive effect on labor supply from the reduced congestion more than offset the negative effect from the increased monetary cost of commuting. The congestion charge therefore has a positive effect on labor supply for the commuters that continue to commute by car.

By introducing user heterogeneity into the analysis we see that the distributional impact of a congestion charge is important for explaining the full effect on labor supply. Increasing the monetary cost of car commuting will make some people to work less while others will work more. The effect on total labor supply is hence ambiguous. When the revenues are used elsewhere in the economy, aggregate labor supply in this example is positive.

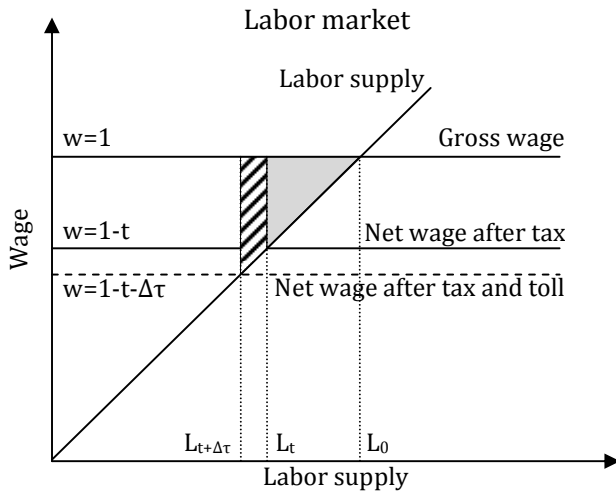


The difference between this and previous models is that this model explicitly takes into account that people have different value of time and therefore model how their choice of travel mode is affected by their daily wages. The mode-choice self-selection mechanism reduces the negative impact on labor supply from a congestion charge since it makes the commuters with the lowest willingness to pay for car transport switch transport mode so that the remaining car commuters, with a higher willingness to pay, can work more.

#### 4 Analyzing transport policies in distorted economies

When analyzing a transport policy in a distorted economy, spillover effects from the transport market into other distorted markets can have a large effect on the actual welfare effect of the policy. In an undistorted labor market, the welfare effect from a marginal decrease in labor supply would be negligible. With pre-existing distortions, the labor supply effect becomes more important. This can be illustrated in a simple example.

Consider a situation where a working population commutes between home and work using a congested road. To reduce congestion, a congestion charge is introduced. If the congestion charge increases the cost of commuting, it can decrease the net wage in a similar way as an income tax, depending on what alternatives the commuters have to get to work. Given that the labor market already is distorted by an income tax, the increased cost will be added to the existing distortion, creating an additional deadweight loss in the labor market. The effect is illustrated in Figure 2.



**Figure 2: The welfare effect in the labor market from a congestion charge that increases the cost of work-related commuting in a labor market with a pre-existing distortionary income tax.**

We assume that labor supply is directly proportional to the net wage after taxes and transportation, i.e.  $L(w) = w$ . To simplify the calculations, we normalize the gross wage to one. The income tax  $t$  gives rise to a pre-existing loss in the labor market equal to  $\frac{t^2}{2}$ . We further assume that the congestion charge increases the cost of work-related commuting with  $\Delta\tau$ . From the figure we see that the congestion charge increases the pre-existing deadweight loss from the income tax, reducing the net wage from  $1 - t$  to  $1 - t - \Delta\tau$  and labor supply from  $L_t = 1 - t$  to  $L_{t+\Delta\tau} = 1 - t -$

$\Delta t$ . The resulting welfare loss is given by the dashed area and is equal to  $t\Delta\tau + \frac{\Delta\tau^2}{2}$ . Without the pre-existing distortion, the loss from the congestion charge in the labor market would only have been  $\frac{\Delta\tau^2}{2}$ . This shows that interactions between the transport market and other distorted markets can have a significant impact on the total welfare effect of a road pricing policy which in turn can also have an effect on the optimal toll levels.

Parry and Bento (2001) argue that the resulting loss in the labor market from a congestion charge can be of the same magnitude as the welfare gain in the transport market from the reduced congestion externality. However, if the collected toll revenues are used to cut the distortionary income tax in the labor market, welfare increases both in the transport market and in the labor market. The argument in the literature is therefore that the way the revenues from a congestion charge is recycled is crucial for the overall welfare effects of the policy. Note however that while a marginal reduction of the income tax  $\Delta t$  reduces the pre-existing deadweight loss from the income tax, it has a negligible effect on the additional deadweight loss caused by the congestion charge.<sup>1</sup>

## 5 Revenue recycling and the welfare effects of road pricing revisited

### 5.1 *The critical choice of starting point for the analysis*

To assess the welfare effects of a road pricing policy, we need to specify a social welfare function, utility functions for the agents in the economy, production functions for the firms, and budgetary and behavioral constraints on the agents. A behavioral constraint can for example be that an agent treats an endogenous parameter as exogenous, such as the marginal impact on travel time from traveling on a congested road. In addition to this, we need to choose the available policy instruments and define restrictions for what the government can do. The restrictions can be motivated on different grounds; a political restriction can be that the government cannot use lump-sum taxes, and a technological restriction can be that the road toll cannot price discriminate between different travelers based on their trip purpose.

Analyzing the welfare effect of a new road pricing policy is in many situations equal to analyzing the effect of lifting a governmental constraint. That is, we study a situation where the government prior to the policy was restricted from using road tolls (by technical, political or other reasons). To make the analysis, we also need to specify values for the remaining policy instruments (taxes, tolls and transfers) in the initial no-toll situation. How these policy instruments are chosen is very important, especially when we want to compare the effect of different revenue recycling policies in a distorted economy.

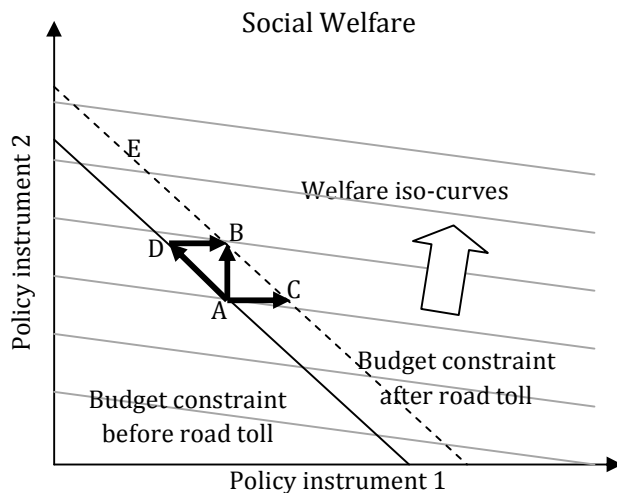
The reason for this is that when we model the economy, we also implicitly determine an optimal set of policy instruments for which social welfare is maximized given the restrictions on the government. We therefore need to make a distinction between initial situations where the policy

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<sup>1</sup> The reduction in the pre-existing deadweight loss is  $t\Delta t - \frac{\Delta t^2}{2}$  and the reduction in the additional loss from the congestion charge only is  $\Delta t\Delta\tau$ . If we look at marginal changes, all squared delta terms are negligible.

instruments are chosen in an optimal way to maximize social welfare, and initial situations where they are not optimally chosen. In a distorted economy, this is the same as asking whether the distorted markets are balanced or unbalanced. By balanced we mean that the marginal costs (and benefits) of all non-constrained policy instruments are equal and that the government cannot increase social welfare without violating any constraint. Observe that distortionary taxes still can be used in a balanced tax system, if they are motivated by welfare from public spending and the lack of lump-sum taxes.

If we instead study a model with an unbalanced tax system, such as the model in Parry and Bento (2001) where the initial income tax is above the optimal level, we can always increase welfare just by lowering the income tax, regardless if the road toll is used or not. The problem with this approach is that it makes it difficult to separate the welfare effect from the road pricing policy from the welfare effect from a general adjustment of the tax system. This can be feasible if we want to study the tax system as a whole, but becomes problematic if we want to isolate the welfare effect of a specific policy. The point is illustrated in Figure 3.



**Figure 3: The welfare effect of recycling the revenues from a congestion charge through policy instrument 2 (A to B) is equal to a combined policy where first a general adjustment of the tax system is made (A to D) and then the revenues are recycled using instrument 1 (D to B).**

In the figure we see social welfare as a function of two policy instruments. The grey lines show iso-curves for social welfare and we assume that welfare increases with both instruments. Before the road toll, the government's budget constraint is given by the solid black line. In the initial situation we are in point A. The tax instruments are unbalanced in this situation since the government can increase welfare just by making adjustment of the policy instruments along the existing budget line.

Assume now that the government wants to know the welfare effect of introducing a new road toll. Without loss of generality, we assume that the only effect of the road toll is to provide the government with additional revenues. The road toll hence shifts the budget constraint outwards to the dashed line. This allows the government to recycle the revenues by changing a combination of the two policy instruments. Since the tax system is unbalanced, recycling the revenues through policy instrument 2 (A to B) increases welfare more than if the revenues are recycled using policy

instrument 1 only (A to C). But going from A to B is identical to first making a budget-neutral adjustment of the tax system (by going from A to D) and then recycle the revenues from the road toll through policy instrument 1 (D to B).

Analyzing the welfare effect of a road toll in an unbalanced tax system is problematic since we compare two things at the same time; the welfare effect of the road toll and the welfare effect of an adjustment of the underlying tax system. Because why should we limit the analysis to only including policies where merely the toll revenues are used for adjusting the tax system, when we, without violating any constraints, can improve welfare even more by making an even larger adjustment part of the recycling policy, (A to E) for example.

An argument for analyzing a situation with an unbalanced tax system is that the real tax system we want to model is likely to be unbalanced. Introducing a road toll can also give the government an opportunity to make corrections in the tax system. However, there might still be a good idea to separate the welfare effect of the general tax adjustment from the welfare effect of the road toll, not least because it is difficult to measure (and agree upon) all the costs and benefits in the whole tax system and hence how close to an optimal tax system we actually are initially.

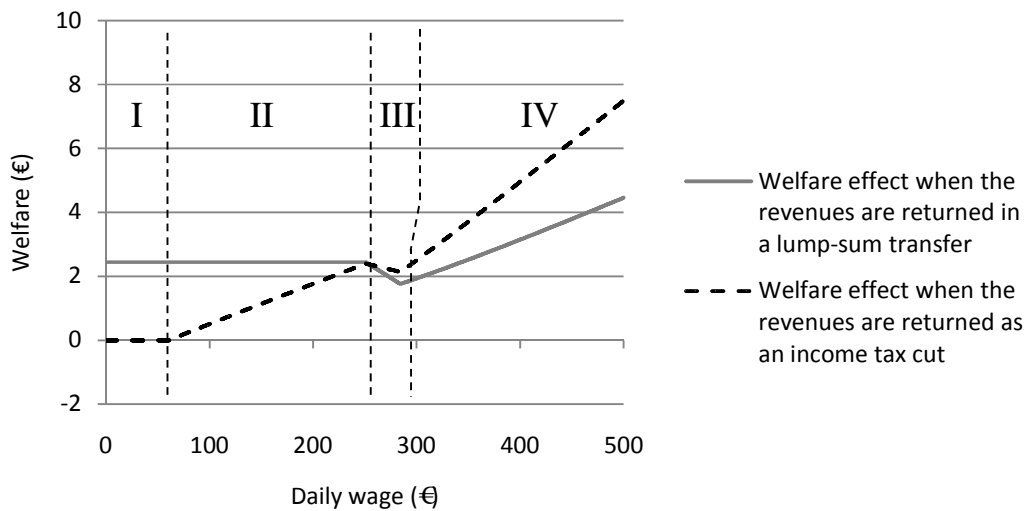
By studying the system “as if” it was balanced in the initial situation, we can isolate the welfare effect of the specific policy we are interested in. Observe that the welfare effect in the balanced approach still includes a valuation of the collected revenues.

The whole revenue recycling approach can also be criticized from a much broader systems analytical perspective since it disregards the effect a chosen recycling policy may have on subsequent policies and decisions. To determine the marginal welfare effect of a revenue recycling policy where we choose between recycling the revenues either on project A or on project B, we need to know whether the non-selected project will be implemented anyway or not. If both projects will be carried out regardless of what we choose, then it becomes problematic to say that one of the recycling policies improves welfare more than the other. Without this knowledge, it may be better to value the collected toll revenues more in terms of an “average” marginal cost of public funds, instead of the marginal cost (or benefit) of a particular policy instrument or project.

One illustration of this problem is the Stockholm congestion charges, where the collected toll revenues are earmarked for road investments (Eliasson et al. 2009). Because the road investments in Stockholm also are funded by other national taxes, there is a risk that the revenues from the congestion charge reduce the regular funding from the national government. It’s just swings and roundabouts. How we draw the boundary of the system that we analyze is therefore important for an analysis where we want to compare the relative efficiency of different revenue recycling policies.

## 5.2 The distributional impact of a congestion charge

Even if the choice of revenue recycling instrument has no or little effect on welfare in a balanced tax system, the distributional impact of the policy still depends on how the collected toll revenues are recycled. An illustration of this is shown in Figure 4 below. Using the model developed in paper II, the distributional impact of a congestion charge under two different revenue recycling policies is analyzed. Figure 4 shows welfare as a function of the daily wage in a population of commuters with a heterogeneous wage distribution. To clarify the discussion, the population is divided into four different groups (I,II,III,IV); group I consists of people with the lowest wage that do not commute; group II contains public transport commuters; group III consists of car commuters in the no-toll situation that switch to public transport because of the congestion charge; and group IV consists of the car commuters that remain to drive car to work after the congestion charge is introduced.



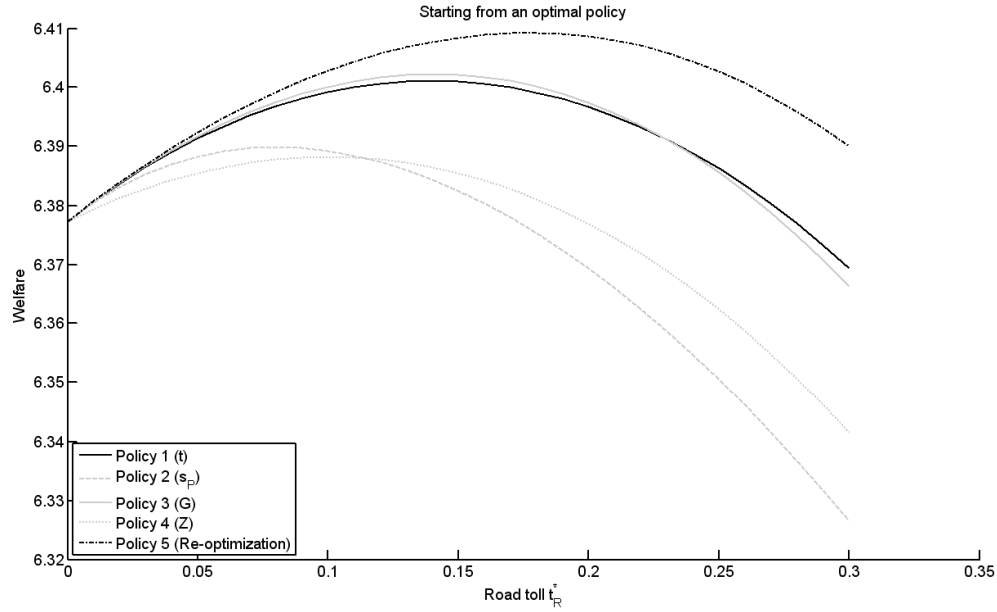
**Figure 4: Welfare as a function of daily wage for a congestion charge of 5€ under two different revenue recycling schemes, a lump-sum transfer and an income tax cut.**

As can be seen from the figure, the distributional impact of the congestion charge strongly depends on the chosen form of revenue recycling even though total welfare is the same for both policies. In the example, people on a low income (group I and II) benefit more from increased public spending (through a lump-sum transfer) compared to a labor tax cut, while people on a high income (group II and IV) have opposite preferences. We also see that although the commuters with the highest income pay most of the charges, they also gain most from the congestion charge since they have the highest value of time and hence benefit most from the policy regardless of how the revenues are recycled.

## 5.3 The difference between marginal and non-marginal policies

The results above are only valid for marginal road pricing policies. For non-marginal policies we also need to consider how the interactions between the congestion charge and the remaining system affects the optimal levels of the other policy instruments. An illustration of this is shown in

Figure 5 taken from paper I where the welfare effect of a congestion charge under five different recycling policies are analyzed as a function of the chosen toll level.



**Figure 5: Social welfare as a function of the toll level for a road toll under five different revenue recycling policies all starting from an optimal situation where all policy instruments (except for the road toll) are chosen to maximize welfare in the no-toll situation.**

For marginal toll levels, the road toll  $t_R^*$  has the same effect on welfare, regardless if the revenues are used to lower the income tax (policy 1), increase the public transport subsidy (policy 2), increase the consumption of the public good (policy 3), or if all policy instruments are re-balanced to maximize welfare for the given toll level (policy 5). Since the distortions in the initial situation is balanced, the marginal benefit of public funds (e.g. the income tax) is equal to both the marginal benefit of the public good and the marginal benefit of public transport subsidy. Recycling policy 4, where the revenues are returned in a lump-sum transfer, performs worse than the other policies because the lump-sum transfer is constrained to zero in the initial situation studied in paper I.

For non-marginal toll levels, welfare for the policies starts to deviate. When the toll increases, social welfare increases more if the revenues are recycled through a lower income tax or increased consumption of the public good, compared to when the revenues are spend on increasing the public transport subsidy. The reason for this is that part of the benefit of a public transport subsidy comes from its ability to reduce congestion. A congestion charge that reduces congestion therefore also reduces the need (and benefit) of a public transport subsidy.

## 6 Conclusions

How should we analyze the welfare effect of a transport policy in a distorted economy? Since a transport market often can have large feedback externality effects into other distorted markets, the total welfare effect of a road pricing policy, such as a congestion charge aimed at reducing peak hour traffic, depends on the welfare effects in other interconnected markets in addition to the welfare effect in the transport market.

One example, often referred to in the road pricing literature, is the labor market. Since a congestion charge can increase the overall cost of work-related commuting, it may have a negative effect on labor supply in a similar way as an income tax. Given that the labor market already is distorted by an income tax, the loss in the labor market from the increased commuting cost can even exceed the welfare gain from the reduced congestion externality in the transport market (Parry & Bento 2001). However, if the collected revenues from the congestion charge are used to cut distortionary income taxes, a double dividend can arise where welfare increases both in the transport market and in the labor market.

A general conclusion from the literature is therefore that the welfare effect of a road pricing policy in a distorted economy critically depends on the revenue use. This conclusion is however problematic, especially when studying marginal policies, because it does not separate the welfare effect from the road pricing policy from the effect of how the collected revenues are used. If we for example create a model where the taxes in the initial no-toll situation are too high compared to the benefits of public spending, we will find that it is more efficient to recycle the revenues from a marginal congestion charge through lower taxes rather than to increase public spending. This is however only an effect of the initial model assumption that the taxes initially were too high compared to public spending, and has nothing to do with the congestion charge or road toll per se.

Without a thorough analysis of what initial situation we are in, it might therefore make more sense to analyze the system “as if” the policy instruments in the initial no-toll situation are balanced. By balanced we mean that all non-constrained policy instruments (taxes, tolls and transfers) are chosen to maximize social welfare given the restrictions we place on the behavior of the government. This implies that the marginal costs and benefits of all non-constrained policy instruments in the system are equal. As a consequence, the welfare effect from a marginal congestion charge or road toll will be the same regardless of which non-constrained policy instrument the revenues are recycled on.

If the tax system is not balanced initially, introducing a road toll can give the government an opportunity to make corrections in the tax system. However, there might still be a good idea to separate the welfare effect of the general tax adjustment from the welfare effect of the road toll, not least because it is difficult to measure (and agree upon) all the costs and benefits in the whole tax system and hence whether we are at optimum or not initially.

To conclude, the type of general statements about how the revenues from a road toll should be spend to maximize welfare that can be found in the road pricing literature is problematic, since the relative efficiency of different recycling policies so strongly depend on the particular situation we

analyze and what assumptions we make regarding the efficiency of the initial policy instruments. The analysis is also sensitive to what markets and interactions we include in the analysis and whether we, for instance, include distributional considerations in the social welfare function or not.

We also examined the argument that a congestion charge reduces labor supply. Although difficult to assess in an empirical situation, the main argument is that since a congestion charge raises the overall cost of work-related commuting by car, it will have a similar effect on labor supply as an income tax raise. Hence if we believe that an increased income tax reduces labor supply, so will a congestion charge. However, upon closer examination the argument can be questioned. First, it is based on the assumption that labor supply is complementary to commuting which is not entirely true, since the commuters share the road space with leisure travelers and freight. The effect on total labor supply is complex and the commuters can adapt to a congestion charge in many ways, by changing travel mode, route, departure time, or location. Second, commuter heterogeneity is also important for the effect on labor supply since a congestion charge primary price out commuters with a low willingness to pay so that the remaining commuters with a higher willingness to pay can drive (and work) more. The effect on total labor supply is therefore ambiguous and depends on, among other things, the flexibility in the labor market, what alternative transport modes the commuters can choose between, the amount of non-work-related traffic and commuter heterogeneity.



## 7 Papers

### **7.1 *Paper I - How to evaluate the welfare effects of congestion charges?***

Westin, Jonas (2011)

Interactions between the transport market and other interconnected markets can have a large effect on the welfare of a road pricing policy or a congestion charge. An argument in the road pricing literature is therefore that the way the revenues from a road toll are recycled is crucial for the overall welfare of the policy.

Using a simple general equilibrium model we show that differences in the relative efficiency of different revenue recycling policies, especially for marginal toll policies, are more related to the initial model assumptions regarding the initial situation than being a direct feature of the road toll per se. For non-marginal toll policies, interactions between the road toll and the other policy instruments also need to be considered in the welfare analysis.

The contribution of the paper is to analyze how the welfare a congestion charge under different revenue recycling policies depends on whether the policy is analyzed in a balanced (optimal) or an unbalanced (not optimal) tax system. The paper also extends previous research by also studying the effect of non-marginal policies.

### **7.2 *Paper II - Welfare Effects of Congestion Pricing in a Population with Continuously Distributed Value of Time***

Westin, Jonas (2011)

Presented at the ERSA congress 19<sup>th</sup> – 23<sup>rd</sup> august 2010, Jönköping, Sweden.

Interactions between the transport market and other distorted markets, such as the labor market, can have a large impact on the overall welfare effect of a road pricing policy. Many road pricing studies therefore try to incorporate effects from other distorted markets in the analysis. A critical assumption in many of the previous 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 related to their value of time, given the existence of feasible transport alternatives. The purpose of the paper is to analyze the labor market effect from 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. Using a disaggregated demand model for the individuals' choice of travel mode, the paper studies the distributional impact of different revenue recycling policies, and analyzes how the mode choice self-selection mechanism affects the total welfare effect of a congestion charge. In a stylized numerical example, the effect of three different revenue recycling policies are analyzed; a lump-sum transfer, a labor tax cut, and a welfare maximizing readjustment policy.

Contrary to the general conclusion in many previous studies, the paper finds that when the revenues from the congestion charge are recycled back to the population, the overall effect welfare effect is positive, regardless if the revenues are returned in a lump-sum transfer or used to cut distortionary income taxes. For marginal toll levels, we also find that the total welfare effect of the congestion charge does not depend on the chosen form of revenue recycling. The distributional impact does however still depend on how the revenues are used.

The congestion charge increases labor supply for the remaining car commuters, but decreases labor supply for the individuals that change from car to public transport because of the congestion charge. The effect on total labor supply is hence ambiguous and depends on how the revenues are recycled. When the revenues are used elsewhere in the economy, aggregate labor supply is found to be positive. This indicates that the negative effect on labor supply from a congestion charge, found in many previous studies, might not generally hold.

### ***7.3 Paper III - The climate effect of high speed rail – a sensitivity analysis***

Kågeson, Per and Westin, Jonas (2010)

In this paper we use Monte Carlo simulation to identify the most important factors that shape the climate benefit of investments in high speed railway lines given uncertainty in future transport demand, technology and power production. We use these results to determine the magnitude of annual traffic emission reduction required to compensate for the embedded emissions from the construction of the line depreciated over the life of the infrastructure (without discounting).

We find that to be able to balance the annualized emissions from the construction, traffic volumes of more than 10 million annual one-way trips are usually required, and most of the traffic diverted from other modes must come from aviation. Projects involving extensive use of tunnels would require even more traffic to offset construction emissions. On the other hand, making optimal use of an existing parallel line after the completion of the high speed link may help balance the emissions from construction but depends on future demand for other types of rail traffic.

We conclude that in sparsely populated regions it may from a climate point of view be better to upgrade existing lines and to try to make people substitute air travel by modern telecommunications rather than investing large amounts of resources (and embedded emissions) in making us travel faster and more.

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