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Revenue Recycling and the Welfare Effects of Road Pricing

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Revenue Recycling and the Welfare Effects of Road Pricing

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Abstract

This paper explores the interactions between taxes on work-related traffic congestion and pre-existing distortionary taxes in the labor market. A congestion tax raises the overall costs of commuting to work and discourages labor force participation at the margin, when revenues are returned in lump-sum transfers. We find that the resulting efficiency loss in the labor market can be larger than the Pigouvian efficiency gains from internalizing the congestion externality. In contrast, if congestion tax revenues are used to reduce labor taxes the net impact on labor supply is positive, and the efficiency gain in the labor market can raise the overall welfare gains of the congestion tax by as much as 100 percent. Recycling congestion tax revenues in public transit subsidies produces a positive, but smaller, impact on labor supply.

In short, our results indicate that the presence of pre-existing tax distortions, and the form of revenue recycling, can crucially affect the magnitude, and possibly even the sign, of the welfare effect of road-pricing schemes. The efficiency gains from recycling congestion tax revenues in other tax reductions can amount to several times the Pigouvian welfare gains from congestion reduction.

Key Words: externalities, congestion taxes, pre-existing tax distortions, general equilibrium welfare effects

JEL Classification Numbers: R41, H21, H23

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Revenue Recycling and the Welfare Effects of Road Pricing

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1. INTRODUCTION

Recent decades have witnessed a dramatic increase in the volume of road traffic and associated delays due to congestion throughout the world. In the United States total vehicle miles traveled increased by 82 percent between 1969 and 1990.[1] Traffic congestion imposes substantial costs on society. Schrank and Lomax (1996) estimated that the costs of travel delays and additional fuel consumption due to congestion amounted to $51 billion for the United States in 1993. The problems of traffic congestion are likely to worsen in the future with growing populations, real income, and labor force participation rates. Thus, there is mounting pressure for policies to reduce, or at least curb the growth of, traffic congestion.[2] Clearly, it is important to understand the economic impacts of proposed measures, and optimal amount of traffic restraint.

One approach to traffic restraint, often advocated by economists, is to require drivers to pay more for road use during peak periods. This policy represents a more direct, and hence more efficient, way to reduce congestion externalities than other measures, such as parking fees, gasoline taxes, subsidies for public transport, and high occupancy vehicle lanes.[3] Moreover, the development of electronic collection devices has made road charges that vary with traffic volumes over the course of the day easier to implement, and has reduced fears about the government collecting information on peoples' driving habits.[4]

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1 From *Statistical Abstract of the United States* 1997, table 1015.

2 See e.g. *The Economist*, Dec 6, 1997 pp. 15-16. The traditional response to roadway congestion has been to build more roads, but despite considerable investment--expenditure on highway construction and maintenance was $67 billion in 1994--this policy has failed to prevent major roads becoming more and more crowded. Additional road capacity does not penalize drivers for adding to congestion and creates more demand for road use in the long run (see Downs, 1992, for a lucid discussion).

3 These other policies do not optimally raise the cost of using congested roads relative to alternative non-congested roads, or using the road during off-peak periods. Hence they do not induce the most efficient substitution away from the congested road onto alternative transport options.

4 At various points within a road system deductions can be made electronically from a pre-paid credit card installed in vehicles. The tag plate of the car is recorded only if there is insufficient credit on the card. Previously, electronic schemes effectively followed each car through the road system and sent monthly bills to car owners. Electronic time of day pricing schemes have been implemented in Singapore, Norway's cities of Oslo, Trondheim, and Bergen, and will come into effect in Amsterdam, Rotterdam, Utrecht, and The Hague in

The theory of optimal congestion taxes, and how much to invest in additional road capacity, was developed by Walters (1961), Vickrey (1963, 1968), Mohring (1965, 1970), Strotz (1965), Kraus *et al*. (1976), and others. The basic framework has been extended to capture a variety of second-best considerations that arise from other externalities and pre-existing policies within the transport system. For example, Newbery (1988a, 1988b) discusses accident and road damage externalities; Liu and McDonald (1998), Braid (1996), and Verhoef *et al*. (1996) examine congestion taxes when congestion on competing routes goes unpriced; Glaister and Lewis (1978) examine the interaction between public transit subsidies and traffic congestion; and Small and Kazimi (1995) study the pollution costs of vehicle travel.[5]

This paper contributes to the literature on second-best congestion taxes by exploring interactions with pre-existing distortions outside the transportation sector, that are caused by the tax system. It builds on a growing body of analysis, mainly in environmental economics, that has shown that the welfare effects of new regulations can critically depend on how these policies interact with pre-existing tax distortions in the labor market. When new regulations drive up firm production costs and product prices they reduce the real household wage. This (slightly) reduces the overall quantity of labor supply. Given the large wedge between gross and net-of-tax wages, this reduction in labor supply can lead to efficiency losses that can be sizeable relative to the partial equilibrium costs of the regulation. On the other hand, there is an offsetting effect if regulations raise government revenues (as pollution taxes and auctioned pollution permits do) and this revenue is used to reduce distortionary taxes.[6]

In this paper we embed a simple "textbook" model of traffic congestion into a series of general equilibrium models to illustrate how the existence of tax distortions in the labor market crucially affects the overall welfare impacts of congestion taxes. A key issue that obviously crops up with congestion fees is what to do with the revenues that are raised. Often these revenues are earmarked for public transportation projects (this has been the practice in Norway). Alternatively, revenues can be used to improve economic efficiency by reducing

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Holland in 2001. Electronic pricing has been slower to catch on in the United States, but a notable example is Route 91linking Riverside to Orange County in Southern California. For more information about current and planned road pricing schemes see the *Toll Roads Newsletter*.

[5] For surveys of the literature on road pricing see for example Morrison (1986), Hau (1992), and Winston (1985). Newbery (1990) provides an overview of the relative importance of these second-best factors in determining optimal road charges. Some recent empirical studies of the welfare gains from congestion pricing include Cameron (1994), Mohring and Anderson (1994) and Calthrop and Proost (1998).

[6] For more discussion see e.g. Goulder *et al*. (1997) and Parry *et al*. (1999). In a different context, Browning (1997) estimated that the welfare costs of monopoly pricing in the United States are around ten times larger when the impact of reduced production on exacerbating tax distortions in the labor market is taken into account. It has long been recognized in the public finance literature that regulatory policies interact with the tax system and this causes the general equilibrium welfare impact of these policies to differ from the partial equilibrium effect (e.g. Harberger, 1974). The contribution of the more recent literature is to demonstrate the potentially substantial empirical magnitude of this welfare difference. For a review of the literature, and its policy implications, see for example Parry and Oates (1998).

the rates of other distortionary taxes in the economy. Indeed, Harrington *et al*. (1998) find a discernable reduction in public opposition to congestion fees if people expect to get back some of the revenues in the form of other tax reductions. We examine cases where congestion tax revenues are used to reduce distortionary taxes and to provide subsidies for public transit fares. We also examine the standard textbook assumption that revenues are returned to households in lump-sum transfers and hence do not directly affect economic efficiency. To our knowledge, ours is the first extensive comparison of these congestion policies in a second-best setting with distortionary taxes.[7]

We find that, if the revenues from a tax on work-related traffic congestion are used to reduce distortionary labor taxes, this tax shift typically reduces the deadweight costs of the tax system by encouraging labor force participation at the margin, in addition to offsetting the externality distortion from congestion. The increase in labor supply arises because the combination of reduced congestion and reduced labor taxes more than compensates commuters (as a group) for the congestion fee, implying that the returns to work--net of taxes and commuting costs--increase.[8] The efficiency gains in the labor market can raise the overall efficiency gains from the congestion tax by as much as 100 percent under a wide range of assumptions about parameter values.

In sharp contrast, if congestion tax revenues are used to finance government transfer payments instead of cutting labor taxes, the net impact of the congestion tax is to reduce household wages net of taxes and commuting costs and discourage labor supply. In most of our simulations the resulting efficiency cost in the labor market more than offsets the entire welfare gains from internalizing the congestion externality! When congestion tax revenues are used to finance public transit subsidies rather than labor tax cuts, the net impact on labor supply can be positive, but is smaller. In addition, this policy fails to optimally allocate commuters among alternative transport modes. We find that these sources of inefficiency can become relatively "large" at more substantial amounts of traffic reduction.

To sum up, the presence of pre-existing tax distortions, and the form of revenue recycling, can crucially affect the magnitude of the welfare effect of road-pricing schemes.

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[7] In an earlier study Repetto *et al*. (1992) estimate that the welfare gains from recycling revenues in other tax cuts can be substantial relative to the partial equilibrium welfare gain from imposing a set of Pigouvian taxes on congested roads in the United States. This study makes a valid point about the importance of revenue recycling. However, since the study does not utilize a general equilibrium model it does not capture important interactions between congestion taxes and pre-existing taxes in the labor market. Mayeres and Proost (1997) analyze congestion taxes as part of an optimal tax system, and Mayeres (1998) reports some simulation results on congestion taxes from a computable general equilibrium model of the Belgian economy. Our paper builds on these earlier studies by considering more alternatives for revenue recycling and illustrating the welfare impacts of policies across a wide range of values for key parameter values.

[8] As discussed below, this result differs from that in a number of other recent studies of environmental taxes. These studies find that the introduction of a pollution tax typically reduces labor supply, even when the revenues are used to cut distortionary labor taxes. In the present paper reducing the externality--congestion costs--induces a feedback effect that partially mitigates the adverse impact of the congestion tax on labor supply, prior to revenue recycling. As a result of this feedback effect, the overall impact on labor supply can be positive when revenues finance cuts in labor taxes.

In fact in many of our scenarios the form of revenue recycling determines whether the policy produces a very substantial welfare gain, or whether the net impact is actually to *reduce* social welfare. In this connection, regulations that restrict how local governments could use revenues from congestion taxes--such as those in Britain stipulating that such revenue sources must be used for public transport--may significantly limit the potential efficiency gains from this policy.

Some important caveats are in order. First, our objective is to illustrate the magnitude of the spillover effect from congestion taxes in the labor market, relative to the efficiency gain from internalizing the congestion externality. For this purpose we abstract from a number of practical complications that affect transportation systems. For example, we use a static analysis in which road capacity and the geographical location of firms and households are fixed. We ignore the complications posed by multiple congestion externalities, pollution and accident externalities, and pre-existing transport policies such as gasoline taxes, vehicle fees, and inefficient pricing of public transportation. We also abstract from distributional considerations, and sidestep the important public choice issue of how new revenue sources might actually be used in practice, given the pressures for additional spending and tax relief from competing interest groups. Nonetheless, we believe that the key mechanisms highlighted in our analysis would be at work in more general models. Our analysis should be viewed as component that might be usefully inserted into more comprehensive models of congestion taxes.[9]

Second, our analysis focuses only on weekday rush hour traffic congestion. As we discuss, there are notable examples of congestion caused by leisure activities (e.g. people going to the beach). In these cases congestion taxes would not reduce labor supply prior to revenue recycling, though the (absolute) welfare gain from using the revenues to cut distortionary taxes rather than finance lump-sum transfers would be the same as in our analysis. Third, in practice congestion tax revenues may be used for a variety of purposes other than assumed in our analysis, such as providing more public goods or reducing local sales or property taxes. Below we comment on how our results might be affected by alternative assumptions about revenue recycling.

The rest of the paper is organized as follows. We begin in section 2 with an analytical model that decomposes the general equilibrium welfare effects of alternative taxes on work-related traffic congestion, in the presence of distortionary labor taxes. Sections 3 and 4 describe and present simulation results on the welfare impacts of congestion taxes, using a more detailed version of the analytical model that is solved numerically. Section 5 concludes and discusses limitations to the analysis.

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[9] Put another way, the general equilibrium welfare effects of congestion taxes can be decomposed into the welfare gain from reducing the congestion externality, the welfare effect in the labor market, and additional welfare effects due to interactions with pre-existing policies and other externalities within the transport system. Our focus is purely on the labor market effects, and we believe that the size of these effects would not be greatly affected by introducing pre-existing transit subsidies, gasoline taxes, pollution externalities, etc. into the analysis.

2. ANALYTICAL MODEL

A. Model Assumptions

We model a static economy where households make both a labor/leisure decision and a transportation mode decision for rush-hour travel. The utility of the representative household is given by:

$$U = u(C, N) + T(R, P) \tag{2.1}$$

where $u(.)$ and $T(.)$ are quasi-concave and continuous. C denotes aggregate consumption of market goods and N is leisure, or time spent at home in non-market activities. R and P denote the number of days in a period that the household commutes to work using a congested road (such as an urban expressway) and using non-congested rail transit, or metro. Although the purpose of transport activity in this model is for people to get to work, we allow for some utility $T(.)$ from travelling. This enables us to incorporate imperfect substitutability between transportation modes.[10]

The household time endowment is denoted $\bar{L}$, which we interpret as the product of the number of hours per day and the number of days in a given period. Households choose how many days to work (L), but they are not free to choose the hours of work per day. We normalize units such that a day at work involves one unit of time. Labor supply (or total days worked) is therefore:

$$L = R + P \tag{2.2}$$

Each time the household commutes by road it loses π units of time, and each time the household commutes by metro it loses ϕ units of time. The household time constraint is:

$$\bar{L} = N + L + \pi R + \phi P \tag{2.3}$$

that is, the time endowment equals the sum of leisure, labor supply, and travel time.[11]

We assume the following relationship:

$$\pi = \pi(R) \tag{2.4}$$

where $\pi' > 0$. The average number of households using the road per day depends on the number of trips of the representative household over the period. As road use increases, the amount of congestion increases, and this reduces average speeds hence raising commute time, π. The number of people using the road is large, therefore π is effectively exogenous to an individual household. This introduces the familiar externality problem: when deciding

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[10] T may represent the utility from listening to the radio in the car and from reading a book on the train. Or more generally T may be negative if commuting causes a lot of stress and boredom. The separability in (2.1) implies that the transportation mode decision does not affect the amount of work effort. We regard this as a reasonable simplification.

[11] We are assuming that leisure on work and non-work days are perfect substitutes. This is not an important restriction for our purposes.

whether to use the road households do not take account of their impact on raising the commuting costs of all other road users.

In contrast, we assume that the time involved in commuting by public transit is not affected by the total number of commuters, that is, ϕ is a constant. For now we keep things simple by assuming that transportation only requires household time and not real resource inputs such as gasoline, maintaining roads, trains, and so on. Obviously this is unrealistic, but it turns out not to affect the key results in our numerical analysis.

To keep our analysis focussed on labor market effects we abstract from a host of other factors that can complicate the welfare effects of congestion taxes. These include possible congestion on the metro, gasoline taxes, parking subsidies, vehicle registration fees, and other externalities from driving such as pollution, wear and tear on roads, and car accidents. Moreover, public transport subsidies are pervasive in practice as a second-best response to driving externalities, perhaps when road pricing is politically difficult. In principle our analysis could be extended to allow for these factors, and hence provide a more comprehensive analysis of congestion-reducing policies (we briefly return to the issue of pre-existing transit subsidies in Section 4B).

Firms are competitive and employ labor to produce the consumption good. We assume the marginal product of labor is constant, hence firm profits are zero. Labor productivity is not affected by the mode of transport that is used to get to work. The marginal product of labor is normalized to imply a price of unity for the consumption good, and we normalize the gross wage to unity.

The government levies a proportional tax of t on labor earnings and provides a lump-sum transfer of G to households.[12] It also levies a congestion (or road) tax of τ which is paid each time a household uses the road. For the moment, we assume that congestion tax revenues are used either to reduce the labor tax or to increase the transfer payment. In these cases the government budget constraint is:

$$tL + \tau R = G \tag{2.5}$$

That is, revenues from the labor and congestion taxes equals government spending.

The household budget constraint is:

$$C + \tau R = (1-t)L + G \tag{2.6}$$

The left-hand side of this equation is spending per period on the consumption good and the congestion tax. The right-hand side is net-of-tax labor income plus the government transfer. Households choose leisure (N), consumption (C), labor supply (L), and the number of days travelling to work by road (R) and metro (P), to maximize utility (2.1) subject to the budget constraint (2.6), the time constraint (2.3), equation (2.2), and taking π as exogenous. From the household's first order conditions we can obtain:

[12] Roughly speaking, G may represent transfer payments (such as pensions), or public spending that is a close substitute for private spending (possible examples include health care, education, food stamps).

$$1-t=(1+\pi)\frac{u_N}{u_C}-\frac{T_R}{u_C}+\tau \tag{2.7a}$$

$$1-t=(1+\phi)\frac{u_N}{u_C}-\frac{T_P}{u_C} \tag{2.7b}$$

These equations equate the private benefit from an extra day's work--the net wage--with the private cost. The cost is the value of leisure time forgone by working and commuting an extra day by either mode of transport, minus the marginal utility from commuting (both these terms are expressed in consumption units), plus the congestion tax in the case of the road. From these equations we obtain:

$$\pi\frac{u_N}{u_C}-\frac{T_R}{u_C}+\tau=\phi\frac{u_N}{u_C}-\frac{T_P}{u_C} \tag{2.8}$$

That is, in equilibrium the cost of commuting an additional day by road equals the cost of commuting an additional day by public transit.

From the household's first order conditions and constraints we can also obtain the demand for road-use and public transit, and labor supply, as functions of parameters that are exogenous to households:

$$R=R(\tau,t,G,\pi) \qquad P=P(\tau,t,G,\pi) \qquad L=L(\tau,t,G,\pi) \tag{2.9}$$

B. The Welfare Effects of Road Taxes

We now analyze the welfare impacts of (marginally) increasing the congestion tax under different scenarios about how the revenues are recycled.

(i) Revenue-neutral congestion tax

Suppose there is an incremental increase in the congestion tax τ and the government budget constraint is maintained by adjusting the rate of labor tax. The welfare effect of this policy change can be expressed (see the Appendix):

$$\left\{\pi'R\frac{u_N}{u_C}-\tau\right\}\left\{-\frac{dR}{d\tau}\right\}+t\frac{dL}{d\tau} \tag{2.10}$$

$\pi'R u_N/u_C$ is the marginal external cost of road use. It equals the utility loss (in consumption units) per road user due to the increase in commuting time from an additional driver, multiplied by the number of road users. Households do not take this term in to account when deciding whether to go to work by road. An incremental increase in the congestion tax produces a welfare gain equal to the difference between the marginal external cost and the congestion tax, multiplied by the induced reduction in road use. The second term in (2.10) is the change in labor supply multiplied by the labor tax, or the wedge between the gross and

net-of-tax household wage. The gross wage reflects the value marginal product of labor and the net wage equals the opportunity cost to households of an extra day's work, that is, the opportunity cost of the time spent at work plus the costs of commuting. Whether there is a welfare gain or loss in the labor market depends on whether the general equilibrium impact of the policy change is to increase or decrease labor supply.[13]

From differentiating (2.9) when G is constant, the change in labor supply can be separated into three effects:

$$\frac{dL}{d\tau} = \frac{\partial L}{\partial \tau}^{-} + \left\{\frac{\partial L}{\partial t}^{+}\frac{dt}{d\tau}\right\} + \left\{\frac{\partial L}{\partial p}^{+}\frac{dR}{d\tau}\right\} \tag{2.11}$$

where (from differentiating (2.5) and using (2.9)):

$$\frac{dt}{d\tau} = -\frac{R + \tau\,\frac{dR}{d\tau} + t\frac{dL}{d\tau}}{L} < 0 \tag{2.12}$$

The first effect in (2.11) is the negative impact on labor supply from an incremental increase in the congestion tax. The congestion tax increases the cost of commuting to work by road and therefore reduces the overall return to work effort relative to leisure. The second effect is the positive impact on labor supply that results from the reduction in labor tax enabled by the additional congestion tax revenues, assuming $\partial L/\partial t$ and $dt/d\tau$ are negative.[14] The third effect is another positive impact on labor supply. This arises from the impact of the policy change on reducing congestion, and hence the time costs of commuting to work by road.

Substituting (2.12) in (2.11), and noting that $\partial L/\partial \tau = (\partial L/\partial t)R/L$, gives, after some manipulation:

$$\frac{dL}{d\tau} = \frac{-\left\{\frac{\partial L}{\partial t}^{+}\frac{dR}{d\tau}\frac{\tau}{L}\right\} + \left\{\frac{\partial L}{\partial p}^{+}\frac{dR}{d\tau}\right\}}{1 + \frac{t}{L}\frac{\partial L}{\partial t}} \tag{2.13}$$

The denominator in this expression is positive so long as an incremental increase in the labor tax increases rather than decreases labor tax revenues (this condition is satisfied for the parameter values we use below). The first term in the numerator reflects the net impact of

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[13] Note that changes in the demand for the metro do not (directly) produce welfare effects. This is because there is no wedge between marginal social benefit and marginal social cost in the metro market.

[14] In theory $\partial L/\partial t$ could be positive if the income effect (which increases labor supply because leisure is a normal good) outweighs the substitution effect (which reduces labor supply). We ignore this possibility because empirical evidence suggests the uncompensated labor supply curve for the whole economy is upward sloping (see below). In addition we ignore the possibility that $\partial t/\partial \tau$ is positive, which occurs beyond the peak of the congestion tax Laffer curve. This is reasonable because optimal congestion taxes do not lead to really drastic reductions in the number of road users.

first two effects in equation (2.11) and it reduces labor supply, except when $t=0$. Following an incremental increase in t household surplus in the road-use market falls by R. However, the government only obtains $R+t\,dR/dt < R$ in additional revenue. Recycling the revenues back to households (by reducing the labor tax) does not fully compensate them for the increase in congestion tax hence the net impact is to reduce labor supply. However the second term in the numerator--which reflects the effect of reduced time costs on encouraging labor supply--is positive even when $t=0$. Thus the overall impact of a revenue-neutral congestion tax is to increase labor supply, at least for modest levels of taxation. As a result the policy can produce a welfare gain in the labor market in addition to a welfare gain from reducing the congestion externality. Our numerical simulations demonstrate the crucial empirical importance of the labor market gain.

These qualitative results are different from, but still consistent with, a number of recent studies of pollution taxes. These studies show that (under certain simplifying assumptions) a revenue-neutral tax on pollution reduces labor supply and hence *increases* the costs of the tax system.[15] Two effects underlie this result. First the "tax-interaction effect" is the negative impact on labor supply brought about by the effect of pollution taxes on driving up product prices and hence reducing the real household wage. This is analogous to $\partial L/\partial t$ in (2.11). Second, the "revenue-recycling effect" is the gain from using additional pollution tax revenues to reduce the labor tax. This is analogous to $(\partial L/\partial t)(dt/dt)$ in (2.11). However, since these studies typically assume utility is separable in environmental quality there is no feedback effect on labor supply from reducing pollution externalities that is analogous to the third term in (2.11), and the net impact of the tax-interaction and revenue-recycling effects is (usually) to reduce labor supply. Thus, the feedback term in (2.11) is crucial in explaining why the welfare effect in the labor market is positive in our analysis and negative in studies of pollution taxes. Indeed if the road was not congested so that $p'=0$ in equation (2.13), a revenue-neutral road tax would reduce labor supply in our analysis.

Our results are also related to those from the optimal tax literature. When labor is the only primary input in an economy a labor tax (or equivalently a uniform consumption tax) is typically more efficient at raising government revenues than narrow-based taxes on individual consumption goods. This is because there are greater substitution possibilities for avoiding the narrow-based tax. The key exception to this, however, is goods that are relatively complementary with leisure. Similarly, it is easier for workers in our model to avoid a road tax than a labor tax, since they can change transport mode in addition to reducing labor supply. *However* since there is complementarity between the taxed "commodity" (congestion) and leisure (i.e. complementarity between reducing congestion and increasing

[15] See for example Bovenberg and Goulder (1998) for a survey of the literature on how pollution taxes interact with the tax system. This is often referred to as the "double dividend" literature as it explores whether or not shifting taxes off labor and capital and onto environmental "bads" can produce two benefits by improving the environment and reducing the costs of the tax system.

labor supply) a congestion tax is still part of the optimal tax system--even if the direct time saving benefits from reducing congestion are ignored.

Setting (2.10) equal to zero, substituting from (2.13), and noting that $\partial L/\partial \tau = (\partial L/\partial t)u_C/u_N = (\partial L/\partial t)(R/L)(u_C/u_N)$, we obtain the optimal congestion tax:

$$t^* = \tau' R u_N/u_C$$

This is just the Pigouvian tax, equal to the marginal congestion cost. Thus, the marginal impact on labor supply is positive up to point where the congestion externality is fully internalized.[16]

(ii) Congestion tax with lump-sum replacement

Now suppose that additional government revenues are returned to households in lump-sum transfers--the standard textbook assumption. Using (2.9) the general equilibrium change in labor supply in this case is:

$$\frac{dL}{dt} = \frac{\partial L}{\partial t}^{-} + \left\{\frac{\partial L}{\partial G}^{-}\frac{dG}{dt}\right\} + \left\{\frac{\partial L}{\partial \tau}^{+}\tau', \frac{dR}{dt}\right\} \qquad (2.14)$$

The first and third terms in this equation are analogous to those in the previous case, equation (2.11). However the second term, which reflects the effect of increased transfers, is a negative impact on labor supply (since leisure is a normal good, $\partial L/\partial G<0$)). Thus (not surprisingly) the overall welfare impact in the labor market is worse when revenues from congestion fees finance transfers rather than labor tax reductions--labor supply always falls under this policy in our simulations.

(iii) Revenues used to subsidize public transit fares[17]

It is well known that reducing congestion by a given amount using a combination of congestion fees and metro subsidies is less efficient than relying on congestion fees alone, when there are three or more transport modes (see e.g. Downs, 1992). Our numerical model captures this source of inefficiency and we postpone discussion of it to Section 4. For now we note an important additional source of inefficiency from this policy, compared with the revenue-neutral congestion fee, which has not previously received attention.

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[16] See Williams (1998) for more discussion of optimal second-best taxes on externalities with feedback effects (mainly in the context of health effects). Mayeres and Proost (1997) provide some discussion of congestion taxes as part of an optimal tax system.

[17] We do not consider a policy of directly subsidizing the metro, financed by raising labor taxes. Our focus is purely on how the welfare effects of congestion taxes crucially depend on the disposition of the revenues raised. Also, since our analysis is short run, we do not consider what happens when subsidies finance additional metro capacity, as opposed to reducing the private cost of using existing capacity.

When congestion tax revenues finance a public transit subsidy, denoted *s*, we need to add *sP* to the right-hand side of the government budget constraint (2.5) and to the right-hand side of the household budget constraint (2.6). Thus *s* appears as an argument of the functions in (2.9) and, since *t* and *G* are now constant, the general equilibrium change in labor supply is:

$$\frac{dL}{d\tau} = \underset{-}{\frac{\partial L}{\partial \tau}} + \left\{\underset{+}{\frac{\partial L}{\partial s}}\frac{ds}{d\tau}\right\} + \left\{\underset{+}{\frac{\partial L}{\partial p}}p'\frac{dR}{d\tau}\right\} \qquad (2.15)$$

Metro subsidies increase labor supply ($\partial L/\partial s > 0$), since they reduce the costs of commuting to work. However, as proven in the Appendix, the potential increase in labor supply, and hence efficiency gain in the labor market, is smaller when revenues are used to reduce the costs of using the metro, as opposed to directly cutting the rate of labor tax.

3. NUMERICAL MODEL OF WORK-RELATED CONGESTION

In order to explore, quantitatively, the welfare discrepancies between alternative congestion taxes we now turn to an extended version of the previous model, which we solve numerically. This section describes the structure and calibration of this model.[18]

A. Model Structure

The structure of the numerical model differs from the previous analytical model in several respects. First, we incorporate a third mode of transport, a non-congested road. This enables us to model more carefully the inefficiency associated with using revenues for public transit subsidies rather than for cuts in distortionary taxes. Second we assume, more realistically, that the production of transportation services requires real resource inputs (representing fuels, wear and tear on trains and cars, etc.) in addition to household time. Finally, in order to obtain empirical results we need to make specific assumptions about functional forms. Unless stated otherwise, variables are as defined in Section 2.

The household has the following constant elasticity of substitution (CES) form for utility:

$$U = \left\{(\alpha_C C)^{\frac{\sigma_U-1}{\sigma_U}} + (\alpha_N N)^{\frac{\sigma_U-1}{\sigma_U}}\right\}^{\frac{\sigma_U}{\sigma_U-1}} + \left\{(\alpha_R R)^{\frac{\sigma_T-1}{\sigma_T}} + (\alpha_P P)^{\frac{\sigma_T-1}{\sigma_T}} + (\alpha_F F)^{\frac{\sigma_T-1}{\sigma_T}}\right\}^{\frac{\sigma_T}{\sigma_T-1}} \qquad (3.1)$$

where *F* is the number of times each household uses a non-congested road.[19] The σ's and α's are parameters (and similarly for all other equations below). σ_U and σ_T are the elasticities of

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[18] We are grateful to Tom Rutherford for help in developing the programs for our numerical models. The programs are in GAMS with MPSGE.

[19] This could represent the same road as the congested road, but at off-peak hours, or an alternative road that is not congested during peak commuting hours. It could also represent walking or cycling to work. In practice of course, there could be enough traffic on the alternative road such that additional cars slow down average travel speeds. To keep our results transparent, we ignore the possibility of multiple congestion externalities.

substitution between leisure and consumption, and between transportation modes respectively, and the α's are share parameters.

We define the following transportation "production" functions:

$$P = \text{Min}\left\{\frac{N^P}{\phi_P}, \frac{X^P}{\theta_P}\right\} \tag{3.2a}$$

$$F = \text{Min}\left\{\frac{N^F}{\phi_F}, \frac{X^F}{\theta_F}\right\} \tag{3.2b}$$

$$R = \text{Min}\left\{\frac{D}{\phi_R}, \frac{X^R}{\theta_R}\right\}; \qquad D = \left\{(\alpha_{DR} N^R)^{\frac{\sigma_D - 1}{\sigma_D}} + (\alpha_{DA} S)^{\frac{\sigma_D - 1}{\sigma_D}}\right\}^{\frac{\sigma_D}{\sigma_D - 1}} \tag{3.2c}$$

N^i is the total amount of time spent per household travelling by transport mode i ($i = P, F, R$) in a given period and X^i is total expenditures on purchased inputs (gasoline, car maintenance, train fares, etc.) for each transport mode. The Leontief functions in equations (3.2a) and (3.2b) imply that one trip by transport mode i requires a fixed amount of time equal to ϕ_i and a fixed amount of expenditure equal to θ_i. In equation (3.2c) each road trip requires a fixed amount of expenditure θ_R and a fixed amount of a composite D, consisting of driving time N^R and speed, S. Thus, the slower the speed the greater the amount of time required to make a trip.[20]

Traffic speed is determined as follows:

$$S = \rho_1 - \rho_2 R \tag{3.3}$$

where $\rho_1, \rho_2 > 0$ are parameters. That is, speed declines linearly as traffic density (R) increases, which is a typical approximation for the speed/density relationship over the relevant range (Morrison, 1986).

The production of market output X is determined as follows:

$$X = \text{Min}\{\alpha_{XL} L, \alpha_{XT}(R + P + F)\} \tag{3.4}$$

This expression implies that transportation modes are perfect substitutes in production, that is, worker productivity is unaffected by which transport mode is used to get to work. In addition there is fixed proportions between labor supply L and the total number of trips $R+P+F$, in other words each day of work requires a commuting trip. Goods market equilibrium requires:

$$X = C + X^R + X^P + X^F \tag{3.5}$$

This equation says that the output of goods equals household consumption, plus goods that are required for transportation.

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[20] In practice gasoline consumption increases as congestion raises travel times. However incorporating this effect into our model would have essentially the same impact as increasing the time delay costs associated with a given level of traffic density.

The household time constraint is:

$$\bar{L} = L + N + N^R + N^P + N^F \tag{3.6}$$

That is, the time endowment is equal to the sum of labor supply, leisure, and total commuting time. The household budget constraint is:

$$C + X^R + X^P + X^F + \tau R - sP = (1-t)L + G \tag{3.7}$$

That is, the household spends on consumption, transportation goods, pays a tax of τ to use the congested road, and (if applicable) receives a subsidy of s for using the metro. Households choose consumption, leisure, and how much to travel on each transport mode, to maximize utility subject to the transport production functions, and the time and budget constraints.

Finally, the government budget constraint is given by:

$$G = tL + \tau R - sP \tag{3.8}$$

where $s > 0$ only in the case where revenues finance a public transit subsidy. To start with, we assume that the metro is provided privately rather than publicly.

B. Calibration

We now discuss the parameter values used in our benchmark simulations. The calibration procedure itself is somewhat technical. Details are provided in a handout, available from the authors upon request.

The consumption/leisure elasticity σ_U is a key parameter that determines the responsiveness of labor supply to changes in household wages net of commuting costs. We choose σ_U, along with the leisure to labor supply ratio, to imply values of 0.2 and 0.35 for the uncompensated and compensated labor supply elasticity respectively ($\sigma_U = 1.52$).[21] Alternative values are considered in the sensitivity analysis. We assume a labor tax rate of 38 percent (other studies use similar values, e.g. Lucas, 1990).[22] Thus the value of commuting

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[21] These values are based on a recent survey of opinion among labor economists (see Fuchs *et al*., 1998, Table 2). They are economy-wide estimates, assuming weights of 0.6 and 0.4 for the male and female labor supply elasticities respectively. The numbers overstate the sensitivity of total days worked to the extent that workers change average hours per day in response to changes in net wages, as opposed to changing their participation decision or total days worked in a year. However, based on our understanding of the literature, the degree of overstatement is likely to be small.

[22] We arrived at this figure as follows. The average rate of labor tax, which is relevant for the labor force participation decision, is (approximately) equal to the sum of revenues from personal income, payroll, and sales and excise taxes, expressed relative to gross labor earnings, and is about 35 percent. The marginal rate of tax (averaged across individuals) is about 43 percent (Browning, 1987), and this is relevant for decisions about overtime days. Assuming the participation decision and the overtime decision account for about two thirds and one third respectively of the total labor supply response to changes in wages gives a weighted average tax rate of 38 percent.

We abstract from non-tax sources of distortion in the labor market since--at least for the United States--these are probably of minor importance relative to the tax wedge. For more discussion of these issues see e.g. Browning (1994), Abrego and Whalley (1998).

and leisure time at the margin is 62 percent of the gross wage, which is roughly consistent with the literature (Small, 1992, pp. 43-44).[23] These assumptions imply that (ignoring congestion effects) the efficiency loss in the labor market from financing an additional dollar of government transfer payments by raising the labor tax is 24 cents, which is roughly consistent with other models (see e.g. Snow and Warren, 1996).

To start with, we choose the transportation mode elasticity σ_T to imply the size of the uncompensated (general equilibrium) demand elasticity for trips with respect to monetary costs is initially 0.4 for each mode ($\sigma_T = 0.8$). This is roughly consistent with the literature,[24] although obviously this elasticity depends on, for example, the number and proximity of alternative transport modes to congested roads in different urban areas. The parameters in the speed/density equation (3.3) are chosen to imply that a one percent reduction in road users would raise average car speed by 0.9 percent in the initial equilibrium. σ_D is set at unity. For simplicity, we assume (prior to congestion policies) that the total number of transport trips is divided equally among each transport mode ($R = P = F$). These assumptions imply that the optimal reduction in traffic density in a first-best setting without distortionary taxes would be about 10 percent.[25] We explore in some detail what happens under alternative values for these transportation parameters.

The remainder of our parameter assumptions have little effect on the relative welfare effects of policies (though the absolute levels are sensitive to them). These assumptions are that the money costs are the same on each mode ($\theta_i = \theta \; \forall \; i$) and that the total amount of time spent commuting is one seventh of total time at work in the initial equilibrium ($\sum N^i = L/7$). In addition, total money expenditures on transport are set equal to 40 percent of the total (gross of tax) time costs of transport ($\sum X^i = .4 \sum N^i$), which is roughly consistent with the literature (see e.g. Small, 1992, pp.76-77).

4. SIMULATION RESULTS

In this section we begin by presenting the results under our benchmark parameter values. We then explore the sensitivity of the results to alternative parameter values. Finally, we discuss travel associated with leisure as opposed to work activities.

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[23] In fact there have been a large number of studies that attempt to estimate the value of time lost in commuting. If the value of time lost in commuting was greater (less) than 62 percent of the gross wage, this would increase (decrease) the magnitude of the efficiency gains from internalizing the congestion externality relative to the efficiency impacts in the labor market.

[24] As a rough rule of thumb a one percent increase in the cost of using a road reduces traffic density by 0.33 percent, at a specific point in time (Small, 1992, pp. 11). We use a somewhat higher value to allow for intertemporal substitution, that is using the congested road at off-peak hours.

[25] This is roughly consistent with optimal traffic reductions estimated in some other studies. See for example Repetto *et al*. (1992), Table 12, top panel.

A. Benchmark Results

(i) Marginal welfare effects

In Figure 1a the horizontal axis shows percentage reductions in traffic density on the congested road (i.e. reductions in the number of trips) below the level without congestion taxes. The vertical axis shows the marginal welfare effect of alternative congestion taxes (expressed as a percentage of the initial money costs of travel on the congested road).

MW^{PIG} indicates the marginal welfare effect of a congestion tax in a (hypothetical) first-best setting without distortionary labor taxes.[26] The height of this curve reflects the marginal externality cost of road use minus the tax rate, and corresponds to the "Pigouvian" welfare effect $p'Ru_C/u_N - t$ in equation (2.10). The marginal welfare impact is positive up to the point when the tax reduces congestion by about 10 percent.

The other three curves in Figure 1 show the marginal welfare impacts of congestion taxes in the (realistic) second-best setting with pre-existing taxes on labor. MW^{TAX} denotes the case when congestion tax revenues are used to cut the labor tax. This curve initially lies above MW^{PIG}, when the net impact of this policy is to increase labor supply and produce an efficiency gain in the labor market. The gap between MW^{TAX} and MW^{PIG} is declining. This is due to declining marginal revenues from the increasing the congestion tax, and hence a smaller efficiency gain from recycling marginal revenues in labor tax cuts, as reduced road traffic reduces the base of the congestion tax. The optimal amount of traffic reduction is about equal to that in the first-best case, which is consistent with our prediction in Section 2 that the optimal tax equals the Pigouvian tax.

MW^{LST} is the marginal welfare impact of a congestion tax with revenues recycled in lump-sum transfers. This curve lies well below MW^{PIG} since the net impact of the policy is to reduce labor supply, producing an efficiency loss in the labor market. Clearly, this efficiency loss dramatically limits the ability of this policy to enhance overall welfare. In fact in this benchmark case the intercept of MW^{LST} is (slightly) below the horizontal axis, implying that *any* level of congestion tax is welfare-reducing (this is not a general result--the intercept is positive in some of our later simulations).

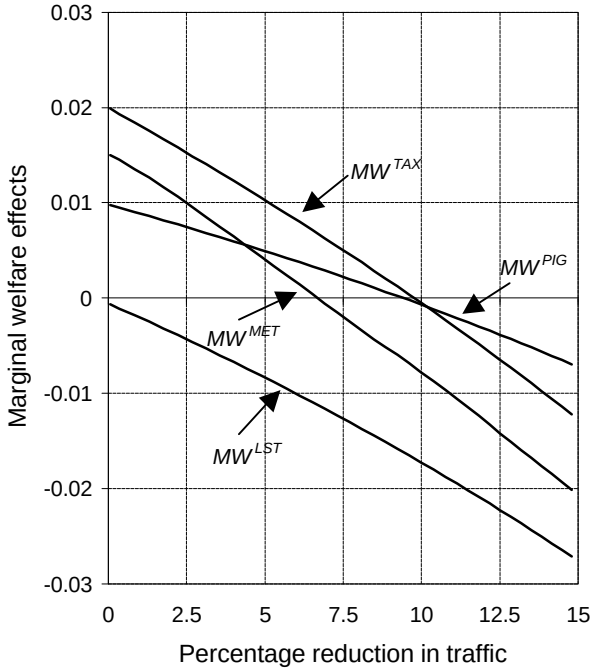
Finally, MW^{MET} is the marginal welfare gain from the congestion tax with revenues used to subsidize public transit fares. This policy is less efficient than the revenue-neutral congestion tax for two reasons. First, to reduce congestion efficiently requires shifting commuters away from the congested road and onto the non-congested road as well as the metro. However, to the extent that the public transit subsidy rather than the congestion tax reduces congestion, there will not be the efficient substitution between the congested and non-congested roads. Second, though this policy initially stimulates labor supply, the increase is less than if revenues are used to reduce the labor tax. Up to the point where MW^{MET} and

[26] For this case we set the labor tax equal to zero and adjust the distribution parameters in the model to keep all initial quantities (labor supply, road use, consumption, etc.) the same as in our benchmark model with pre-existing taxes. Congestion tax revenues are returned lump sum to households.

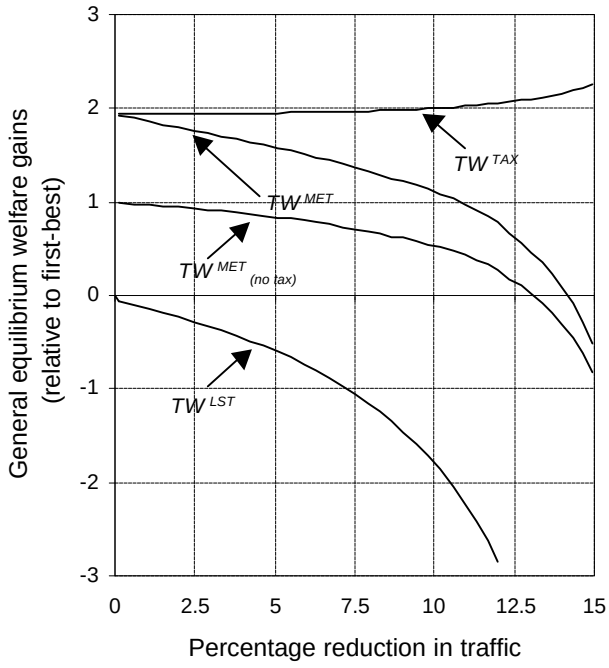
MW^{PIG} intersect, the efficiency gain from incremental increases in labor supply exceeds the incremental efficiency loss from the sub-optimal allocation among transport modes.

Figure 1

(a) Marginal welfare effects



(b) Total welfare effects



(ii) Total welfare effects

In Figure 1b we compare the total (as opposed to marginal) welfare impacts of policies. On the vertical axis we have the overall (general equilibrium) welfare gains under alternative congestion taxes, expressed relative to the Pigouvian welfare gain (i.e. the welfare gain from a congestion tax in the first-best version of model).

The top curve TW^{TAX} shows the relative welfare gain from the congestion tax when revenues finance cuts in the distortionary labor tax. This curve is roughly constant at about 2 implying that the induced welfare gains in the labor market are about equal to the Pigouvian welfare gain. In striking contrast TW^{LST}, the relative welfare impact under the congestion tax with lump-sum replacement, is always below the horizontal axis. In fact, reducing traffic by the optimal Pigouvian amount (10 percent) would result in a net efficiency loss equal to almost double the Pigouvian welfare gain!

The gap between TW^{TAX} and TW^{LST} reflects the efficiency gain from using congestion tax revenues to cut distortionary taxes (rather than returning them lump sum). At the Pigouvian

amount of traffic reduction the gap between these curves is almost 4, implying that the efficiency gains from using revenues to cut distortionary taxes rather than finance transfer payments is almost four times the Pigouvian welfare gains. In other words, in these benchmark simulations there is drastically more at stake in terms of economic efficiency in what the government does with congestion tax revenues, than the entire efficiency gains from internalizing the congestion externality.[27]

The curves TW^{MET}*(no tax)* and TW^{MET} decompose the two sources of inefficiency when revenues finance public transit subsidies (as opposed to cuts in labor taxes). TW^{MET}*(no tax)* is the relative welfare gain from this congestion tax in the hypothetical case with no pre-existing labor taxes. The difference between this curve and unity reflects the welfare loss due to the inability of this policy to induce the efficient allocation of commuting across all transport modes. This source of inefficiency is initially small, but amounts to about 50 percent of the Pigouvian welfare gain at a 10 percent reduction in traffic density. Finally TW^{MET} is the welfare gain from the congestion tax/metro subsidy when we incorporate the pre-existing labor tax. This curve lies above TW^{MET}*(no tax)*, since the net impact of the policy is to increase labor supply therefore producing an efficiency gain when the labor market is distorted. Comparing TW^{MET} with TW^{TAX}, using congestion tax revenues for public transit subsidies rather than labor tax cuts reduces the welfare gain from congestion taxes by about 90 percent of the Pigouvian welfare gain. Of this about 50 percent is due to the less efficient allocation of commuting among transport modes, and the remaining 40 percent is due to the smaller efficiency gain in the labor market.

We make one further point. In practice local governments may use congestion tax revenues for other purposes than assumed in our model, in particular to finance the provision of public goods, or cuts in property taxes and sales taxes. Some indication of how this would affect our results may be inferred from Figure 1b. In our model the efficiency gain from recycling revenues in labor tax cuts rather than lump-sum transfers is 24 cents per dollar. Suppose, for example, that revenues were used to finance a public good or other tax cut that generated net social benefit of 12 cents per dollar. For this case the total welfare curve would lie halfway between TW^{TAX} and TW^{LST} in Figure 1b. If net social benefits were 36 cents per

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[27] We can do some "back-of-the-envelope" calculations to check this estimate. If we approximate by assuming linear demand and marginal social cost curves, the Pigouvian welfare gain is the well-known Harberger triangle, equal to one half times the reduction in road use times the Pigouvian congestion tax, i.e. $(R_0 - R_1)\mathrm{t}/2$. The welfare gain from using congestion tax revenues to cut the labor tax equals the marginal excess burden of taxation (0.24) times congestion tax revenues ($\mathrm{t}R_1$). Expressing the latter effect over the former gives $0.48(1\text{-}r)/r$ where $r = (R_0\text{-}R_1)/R_0$. When r=0.1, this second-order approximation implies that the efficiency gain from recycling revenues in labor tax cuts would be 4.3 times the Pigouvian welfare gain.

Our results appear to be consistent with a recent study by Mayeres (1998). Using a computable general equilibrium model of the Belgian economy, she estimated the costs of financing additional government spending by raising congestion taxes, labor taxes, and lump-sum taxes. Using these results she infers that there would be a substantial efficiency gain from using congestion tax revenues to reduce distortionary taxes rather than provide lump-sum transfers. However, due to rather different model structures and assumptions about labor supply elasticities, it is difficult to directly compare our results with Mayeres's.

dollar recycled the gap between TW^{TAX} and TW^{LST} would increase by 50 percent, implying that the congestion tax would generate a general equilibrium welfare gain equal to about four times the Pigouvian welfare gain.

B. Sensitivity of Results to Key Parameter Values

We now consider alternative values for parameters, focussing only on those parameters that significantly affect relative welfare impacts.

(i) Demand elasticity for road use

We begin our sensitivity analysis by varying the transport mode substitution elasticity σ_T between 0.2 and 1.4, as shown along the horizontal axis in Figure 2 (this varies the transport demand elasticity between 0.1 and 0.7). This implies different optimal amounts of traffic reduction: in the first-best case the optimal traffic reduction (i.e. where $MW^{PIG} = 0$ in Figure 1a) is 2.7 percent when $\sigma_T = 0.2$ and 15.9 percent when $\sigma_T = 1.4$. Clearly, the easier it is for commuters to substitute between transport modes the less costly it is to reduce congestion. The vertical axis of Figure 2 shows the maximum welfare gain under alternative second-best congestion taxes, expressed relative to the Pigouvian welfare gain. That is, we are comparing the area under the marginal welfare curves above the horizontal axis in Figure 1a to the area under MW^{PIG}, for different values of σ_T.

As the demand elasticity increases the Pigouvian welfare gain increases and this has the effect of shifting up all the marginal welfare curves in Figure 1a. Thus it becomes more likely that the MW^{LST} curve will have a positive intercept. The maximum welfare potential of the congestion tax with lump-sum replacement rises from 0 after $\sigma_T = 0.9$ to about 30 percent of the Pigouvian welfare gain when $\sigma_T = 1.4$ (see the MAX^{LST} curve). Thus, even when the demand for road use is very elastic the welfare potential of this policy is still well below the amount that would be implied by a partial equilibrium analysis. The relative welfare potential of the other policies (indicated by the MAX^{TAX}, MAX^{MET}, and $MAX^{MET\ (no\ tax)}$ curves) are only modestly sensitive to the demand elasticity for road use.

(ii) Speed elasticity

In the first set of rows in Table 1, we re-calibrate parameters in equation (3.3) such that the (size of) the speed elasticity with respect to traffic density varies between 0.6 and 1.2.[28] This implies the optimal Pigouvian traffic reduction is either 6.7 or 11.9 percent. When the speed elasticity is larger, reducing traffic density has more impact on raising speeds; hence the Pigouvian welfare gains from congestion taxes are increased. The right-hand set of columns in Table 1 shows the maximum welfare gains under policies expressed relative to the Pigouvian welfare gains. As the speed elasticity increases, the size of the

[28] When the speed elasticity rises above unity the relationship between speed and traffic volume (where volume equals speed times density) becomes backward bending. This situation is often referred to as "hyper-congestion" in the literature.

Figure 2. Varying the demand elasticity for road use

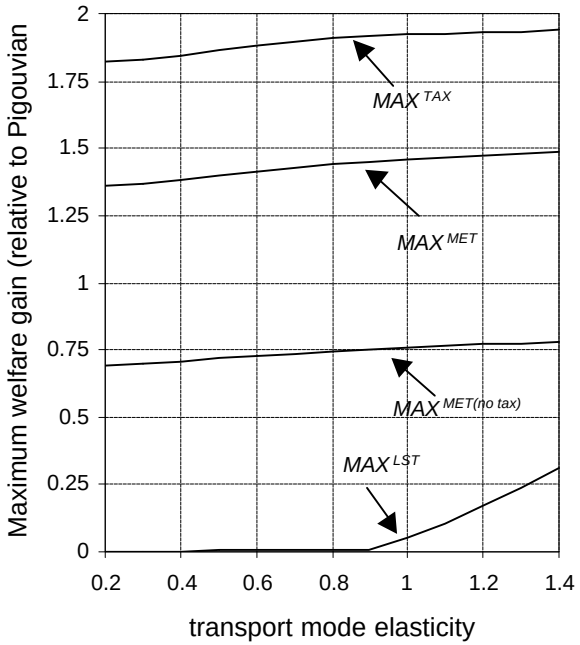
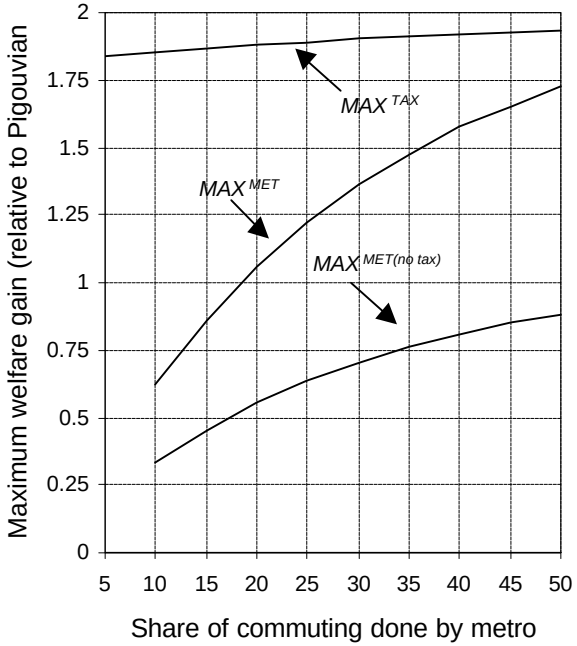


Figure 3. Varying the share of metro traffic



Pigouvian welfare gain increases relative to the welfare impact in the labor market, but this only has a modest impact on the relative welfare potential of the different policies.[29]

Table 1. Sensitivity of Results with Respect to Key Parameters

Parameter values	Optimal reduction in traffic density (%)				Maximum Welfare gain (relative to Pigouvian welfare gain)		
	Pigouvian	TAX	LST	METRO	TAX	LST	METRO
Benchmark	9.6	10.0	0.0	6.9	1.90	0.0	1.44
1. Speed elasticity							
0.6	6.7	6.8	0.0	5.5	2.20	0.0	1.60
1.2	11.9	11.4	2.9	9.1	1.78	.10	1.35
2. Labor sup. elast.[a]							
low	9.3	10.1	5.0	7.4	1.94	.30	1.48
high	9.4	9.3	0	7.8	1.82	0.0	1.38
3. Labor tax rates							
33%	9.6	9.4	1.1	7.3	1.68	.01	1.28
43%	9.6	9.3	0	7.0	2.22	0.0	1.65

[a] The uncompensated and compensated labor supply elasticities are 0.05 and 0.20 respectively in the low value case, and .30 and 0.50 respectively in the high value case.

(iii) Public transit share and pre-existing subsidies

Along the horizontal axis in Figure 3 we vary the initial share of commuting that is done by metro between 5 and 50 percent (we scale the shares of traffic on the congested and non-congested roads up and down proportionately). The vertical axis again shows the maximum welfare gain under alternative policies expressed relative to the Pigouvian welfare gain. The relative welfare impacts of the revenue-neutral congestion tax, and the tax with lump-sum replacement, are not especially sensitive the relative size of the metro. In contrast, the maximum welfare gain under the congestion tax/metro subsidy falls from 170 to 35 percent of the Pigouvian gain as the share of commuters using the metro falls from 50 to 5 percent (see the MAX^{MET} curve). The smaller the size of the metro the more the optimal reduction in congestion will involve substitution onto the non-congested road rather than more travel by public transit. Since public transit subsides cannot induce the efficient degree of substitution between the congested and non-congested road, this policy is relatively more inefficient the smaller the size of the metro. In addition, public transit subsidies are less

[29] We experimented with a non-linear speed/density function. However, this had little effect on our empirical results since the linear function provides a reasonable approximation to a non-linear function when traffic is reduced by a relatively modest amount (around 10 percent or so). In addition, our results are not very sensitive to alternative values for s_D.

efficient than labor tax cuts at stimulating labor supply the less the average household commutes to work by public transit.

Assuming the metro is publicly provided rather than privately provided has essentially no effect on our results, if the metro continues to be priced at marginal cost (this change essentially just raises the pre-existing labor tax from 38 to 39 percent). However in practice public transportation systems are typically priced at well below marginal cost (see e.g. Dodgson and Topham, 1987). Bringing in pre-existing public transit subsidies into our analysis further reduces the efficiency loss from recycling congestion tax revenues in (additional) public transit subsidies rather than labor tax reductions. For example, when we introduce a pre-existing public transit subsidy of 50 percent, the maximum welfare potential of the congestion tax with revenues recycled in (additional) metro subsidies falls from 140 percent to just 40 percent of the Pigouvian welfare gains.

(iv) Labor market parameters

In the second set of rows in Table 1 we vary the consumption/leisure elasticity to be consistent with plausible ranges for labor supply elasticities.[30] The more (less) responsive is labor supply to changes in wages (net of taxes and commuting costs) the larger (smaller) are the welfare impacts in the labor market relative to the Pigouvian welfare effect of congestion taxes. Our results show a modest amount of sensitivity to these elasticities. But even under conservative assumptions the welfare effect in the labor market is still important; for example, assuming low values for labor supply elasticities, it still reduces the welfare potential of the congestion tax with lump-sum replacement by 70 percent relative to the Pigouvian welfare gain.[31]

In the final set of rows in Table 1 we vary the labor tax rate between 33 and 43 percent (we consider this to be a plausible range). This has a noticeable effect on our results--for example the maximum welfare gain when congestion tax revenues finance labor tax cuts varies between 168 and 222 percent of the Pigouvian welfare gain. Even when the labor tax rate is 33 percent however, the maximum welfare potential of the congestion tax with lump-sum replacement is only trivially positive. Note that the optimal traffic reduction under the revenue-neutral congestion tax is not really affected by labor supply elasticities and labor tax rates. This is because the incremental change in labor supply, and hence incremental welfare effect, becomes zero at the point when the congestion externality is fully internalized, regardless of labor market parameters.

In short, these simulations demonstrate that two key results from our model are robust to a wide range of values for transportation and labor market parameters. These results are: a

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[30] The uncompensated labor supply elasticity varies between 0.05 and 0.30 and the compensated elasticity varies between 0.20 and 0.50.

[31] Note that a higher (lower) labor supply elasticity strengthens (weakens) both the Pigouvian welfare effect and the labor market effect. Thus, the ratio of these two effects is only moderately affected by changing labor supply elasticities.

tax shift off labor and onto work-related traffic congestion causes an overall welfare gain of roughly double the Pigouvian gain from internalizing the externality; in contrast, a congestion tax with lump-sum replacement may easily reduce overall welfare, despite the gains from reducing congestion. An intermediate case is when congestion tax revenues finance public transit subsidies, but the relative welfare impact of this policy is highly sensitive to the importance of the metro relative to other transport modes.

C. Leisure-Related Travel

Most traffic congestion is associated with people going to and from work. However there are some notable examples of congestion at weekends caused by people going to the beach, shopping malls, sports events, visiting relatives during holiday periods, and so on. In response to congestion taxes associated with these activities people may respond by re-scheduling these trips to other less busy times, or by substituting into other leisure activities (e.g. spending more Saturdays gardening at home rather than going to the beach). Possibly, people might also end up working more days, but this effect is probably minimal. At any rate, the crucial point is that the congestion tax does not directly discourage labor supply, and thereby avoids the efficiency loss in the labor market prior to revenue recycling.

Thus, in these cases a congestion tax with lump-sum replacement would induce a general equilibrium welfare gain approximately equal to the Pigouvian welfare gain from internalizing the externality. If instead revenues were used to reduce labor taxes the general equilibrium welfare gain would equal the Pigouvian welfare gain, plus an efficiency gain in the labor market that roughly corresponds to the gap between TW^{TAX} and TW^{LST} in Figure 1(b). That is, the optimal (revenue-neutral) Pigouvian congestion tax could induce an overall efficiency gain of about 5 times the Pigouvian welfare gain.

More generally, some fraction of drivers on a congested road could be commuting to work while the other drivers are involved in leisure pursuits. It is straightforward to infer the effects of a congestion tax in our analysis by taking the appropriate weighted-average of results for the work-related and leisure-related cases. For example, suppose two thirds of the drivers in the rush hour are commuting to work while the remaining third are involved in leisure activities. Then the net welfare loss from a tax with lump-sum replacement that reduces traffic by 10 percent in Figure 1(a) would fall from about 200 percent of the Pigouvian welfare effect to about 100 percent.

5. CONCLUSION

This paper uses analytical and numerical models to examine how pre-existing tax distortions in the labor market affect the welfare impacts of road-pricing schemes, under alternative assumptions about how the revenues raised are recycled. For taxes imposed on work-related traffic congestion, the net impact of a congestion tax with revenues returned lump sum to households is to reduce labor supply in our analysis. In fact under plausible parameters the resulting efficiency loss in the labor market can more than offset the efficiency

gains from internalizing the congestion externality. In contrast, the net impact of congestion taxes is to stimulate labor supply if revenues are used to reduce labor taxes. The resulting efficiency improvement in the labor market about doubles the overall welfare gains from the congestion tax. Recycling the revenues in public transit subsidies rather than tax cuts is less efficient, and the relative welfare discrepancy between these two policies is larger the greater the amount of traffic reduction. Taxes on traffic congestion associated with leisure (as opposed to work) activities avoid the adverse impact on labor supply, prior to revenue recycling. Indeed when revenues are used to reduce labor taxes in our simulations the overall efficiency gains can be several times the Pigouvian welfare gains.

The models presented above could be usefully extended in a number of different directions. First, we assume a static analysis where the existing capacity of the transport system is taken as given. It would be useful to explore how pre-existing tax distortions in labor and capital markets might affect the optimal amount of investment in transportation infrastructure over the long run. In addition, our analysis does not capture the potentially important long run efficiency impacts of congestion taxes brought about by induced changes in the location decision of households and firms (see e.g. Arnott, 1999, for recent discussion of these issues).

Second, we assume the congestion externality is the only source of pre-existing distortion within the transportation sector. In practice there might be a variety of other sources of economic distortion that importantly influence the overall welfare impacts of a congestion tax. For example, distortions due to pollution externalities, accident and road damage externalities, congestion externalities on alternative roads, or deviations from marginal cost pricing in public transportation systems. Furthermore, there are other markets outside the transportation sector that contain pre-existing distortions besides the labor market. For example, due to provisions in the tax system, certain markets, such as those for owner-occupied housing and medical insurance, are heavily subsidized. This means that the efficiency gains from recycling revenues in labor tax reductions can include not only those in the labor market, but also the efficiency gains from reducing distortionary subsidies for tax-favored spending. Results from other studies (Feldstein, 1999; Parry and Bento, 1998) suggest that we may have significantly underestimated the welfare gains from revenue-neutral congestion taxes.

Third, our focus is purely on the efficiency impacts of alternative congestion taxes. Clearly, the manner in which congestion tax revenues might be recycled would have important distributional consequences that affect the political feasibility of alternative policy approaches. Nonetheless, if for political or other reasons, congestion tax revenues are used for purposes other than to cut distortionary taxes, this can be at a huge sacrifice in terms of economic efficiency, and could even change the sign of the overall efficiency impact from positive to negative.[32]

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[32] See Becker and Mulligan (1997) for some analysis of how governments may spend new revenue sources, given pressures from competing interest groups.

Fourth, there are a variety of other policies that might be used, and are being used, to reduce congestion in place of road pricing, such as parking fees, high occupancy vehicle lanes, direct subsidies for public transport, and so on. It would be useful to explore how pre-existing tax distortions affect the efficiency properties of these other policy options. Finally, it might be useful in future analyses to allow for a more disaggregated treatment of the labor market. Our quantitative results are likely to change somewhat if the labor supply elasticity of the group that benefits from the labor tax cut differs from the group of (actual and potential) users of the transportation network.

APPENDIX: ANALYTICAL DERIVATIONS

Deriving Equation (2.10)

Using (2.1)-(2.4) and (2.6) we can define the household's indirect utility function as follows:

$$V(\tau, t, G, \pi) = \underset{\{C,N,R,P\}}{Max} \; u(C,N) + T(R,P) + \lambda\{G + (1-t)L - C - \tau R\} + \gamma\{\bar{L} - (1+\pi)R - (1+\phi)P - N\}$$

where λ and γ are the marginal utility of income and time respectively. The indirect utility function is expressed as a function of parameters that are exogenous to the household. Differentiating with respect to these parameters, gives:

$$\frac{\partial V}{\partial \tau} = -\lambda R \tag{A1a}$$

$$\frac{\partial V}{\partial t} = -\lambda L \tag{A1b}$$

$$\frac{\partial V}{\partial G} = \lambda \tag{A1c}$$

$$\frac{\partial V}{\partial \pi} = -\gamma R \tag{A1d}$$

To obtain the welfare impact of an increase in τ, when revenues are used to reduce the labor tax, we differentiate the indirect utility function, taking into account how the policy change affects congestion costs through equation (2.4). This gives

$$\frac{dV}{d\tau} = \frac{\partial V}{\partial \tau} + \frac{\partial V}{\partial t}\frac{dt}{d\tau} + \frac{\partial V}{\partial \pi}\pi' \frac{dR}{d\tau} \tag{A2}$$

Substituting from (A1) and (2.12), and dividing by λ to convert to monetary units we obtain (2.10).

Proof that the increase in labor supply is smaller when revenues finance the metro subsidy instead of the labor tax reduction:

From totally differentiating the government budget constraint (2.5), with respect to τ and *s*, when we include *sP* on the right hand side, we can obtain:

$$\frac{ds}{dt} = \frac{\left\{R + t\,\frac{dR}{dt} + t\frac{dL}{dt} - s\frac{dP}{dt}\right\}}{P} \tag{A3}$$

We need to compare the middle terms on the right-hand sides of equations (2.11) and (2.15). Substitute (A3) and $\partial L/\partial s = -(\partial L/\partial t)P/L$ in (2.15). Substitute (2.12) and $\partial L/\partial t = (\partial L/\partial t)R/L$ in (2.11). Comparing, we find that the change in labor supply is smaller by the term $\frac{\partial L}{\partial t}\frac{dP}{dt}\frac{s}{L} > 0$ when revenues finance the subsidy rather than the reduction in labor tax.

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