

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. The resulting welfare loss in the labor market can easily exceed the Pigouvian welfare gain from internalizing the congestion externality. However, if congestion tax revenues are used to reduce labor taxes, the net impact on labor supply is positive, and this can raise the overall welfare gain from the congestion tax by around 100 percent. Nonetheless the optimal congestion tax still equals the Pigouvian tax.

Keywords: Externalities; congestion; tax distortions; welfare effects

JEL classification R41; H21; H23

I. Introduction

Recent decades have witnessed a dramatic increase in the amount of road traffic and associated delays due to congestion. In the United States, 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. Clearly, it is important to understand the economic impacts of proposed measures and the optimal amount of traffic restraint.

*We are grateful to Alan Krupnick, Inge Mayeres, Billy Pizer, Stef Proost, Tom Rutherford, Zmarak Shazali, Mike Toman, two referees and, in particular, Ken Small, for helpful comments and suggestions. We also thank seminar participants at the University of Warwick, the World Bank, Resources for the Future and the European AERE conference in Oslo.

¹*Statistical Abstract of the United States* (1997, Table 1015).

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 transit fares, and high occupancy vehicle lanes.² Moreover, the development of electronic collection devices has made road charges that vary with traffic flows during the day easier to implement.³

The theory of optimal congestion taxes, and how much to invest in additional road capacity, was developed by Walters (1961), Vickrey (1963), Mohring and Harwitz (1962), Strotz (1965), Kraus, Mohring, and Pinfeld (1976), and others. The basic framework has been extended to capture some second-best considerations that arise from other externalities and pre-existing policies within the transport system. For example, Newbery (1988) discusses accident externalities; Liu and McDonald (1998) and Verhoef, Nijkamp, and Rietveld (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.⁴

This paper is also about congestion taxes in a second-best setting but, unlike the above papers, our focus is not on other distortions within the transport system. Instead, our paper contributes to the literature by exploring interactions with pre-existing distortions in the economy-wide labor market 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 welfare losses that are sizeable relative to the partial equilibrium costs of regulation. On the other hand, there is an offsetting

²These 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 optimal substitution away from the congested road onto alternative transport options. See Parry (2000) for more discussion.

³Electronic time-of-day pricing schemes have been implemented in Singapore, and Norway's cities of Oslo, Trondheim, and Bergen. They have been slower to catch on in the United States, but electronic single lane tolls now exist on Route 91 in southern California, I-15 in San Diego, and I-10 in Houston. For more information about current and planned road pricing schemes, see the *Toll Roads Newsletter*.

⁴For surveys of the literature on road pricing, see e.g. Morrison (1986) and Hau (1992). Recent empirical studies of congestion pricing include Mohring and Anderson (1994) and Calthrop and Proost (1998).

effect if regulations raise government revenues (as pollution taxes and auctioned pollution permits do) and this revenue is used to reduce distortionary taxes.⁵

In this paper we embed a simple model of work-related traffic congestion into a general equilibrium model 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 transportation projects (this has been the practice in Norway). Alternatively, revenues can be used to improve economic efficiency by reducing the rates of other distortionary taxes in the economy.⁶ We examine cases where congestion tax revenues are used to reduce distortionary taxes and to provide subsidies for transit fares. We also examine the standard textbook assumption that revenues are returned to households in lump-sum transfers and hence do not affect economic efficiency. To our knowledge, this is the first extensive comparison of such 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 addressing the congestion externality. The increase in labor supply arises because the combination of reduced congestion and reduced labor taxes more than compensates workers (as a group) for the congestion fee, implying an increase in the returns to work, net of taxes and commuting costs. The welfare gain in the labor market raises the overall

⁵See e.g. Goulder, Parry, Williams and Burtrow (1999) and Parry, Williams, and Goulder (1999). It has long been recognized in public finance that regulatory policies interact with the tax system and this causes their general equilibrium welfare impacts to differ from their partial equilibrium effects. The contribution of the more recent literature is to demonstrate the potentially substantial empirical magnitude of this welfare difference; see Parry and Oates (2000) for a non-technical discussion.

⁶Indeed, Harrington, Krupnick, and Alberini (2000) find a discernible reduction in public opposition to congestion fees if people expect to get back some of the revenues in the form of other tax reductions.

⁷Repetto, Dower, Jenkins, and Geoghegan (1992) estimate that the welfare gains from recycling revenues in tax cuts can be substantial relative to the partial equilibrium welfare gain from imposing a set of congestion taxes in the United States. This study makes a valid point about the importance of revenue recycling. However, since it does not use a general equilibrium model, it does not capture important interactions between congestion taxes and pre-existing taxes in the labor market discussed below. 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, by separating out the different components of the welfare change, and by illustrating welfare impacts across a wide range of parameter values.

welfare gain from the congestion tax by roughly 100 percent under a wide range of parameter values—although the optimal tax is still equal to the Pigouvian level. Thus, the policy produces a double dividend: it reduces the congestion externality and it reduces the efficiency costs of pre-existing tax distortions.

As discussed below, this result differs from that in a number of recent studies of revenue-neutral environmental taxes. These studies find that a pollution tax typically reduces labor supply, even when the revenues are used to cut labor taxes, and hence there is no double dividend. In our 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. Even though people have to pay a fee to drive to work, their commute time is shorter, and at the margin fewer people are discouraged from quitting the labor force. Taking into account this feedback effect, the net impact of the congestion tax on labor supply is positive, after revenue recycling. To our knowledge, this is the first paper to give a convincing example of where shifting taxes off labor and onto externalities can give rise to a substantial double dividend, due to the presence of positive feedback effects on labor supply.

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. This causes a relatively large welfare loss in the labor market because there is a large tax wedge between the gross and net wage. Indeed, the welfare loss in the labor market usually more than offsets the entire welfare gain from internalizing the congestion externality. This result is robust to a wide range of transport and labor market parameters.

When congestion tax revenues are used to subsidize transit fares rather than cut labor taxes, the net impact on labor supply can be positive, but is smaller. Moreover, 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.

In sum, the presence of pre-existing tax distortions, and the form of revenue recycling, crucially affect the magnitude of the welfare effect of congestion taxes. In fact, in many of our scenarios the form of revenue recycling determines whether the policy produces a substantial welfare gain, or whether it actually *reduces* social welfare.⁸ These results have very fundamental implications for the way economists evaluate congestion taxes.

⁸In this connection, regulations that force local governments to earmark congestion tax revenues for transportation projects could significantly limit welfare gains, while requirements forcing governments to use revenues to cut other taxes could significantly enhance welfare.

Any cost/benefit analysis that does not take into account the indirect effects in the labor market may give seriously misleading results about not only the magnitude, but possibly even the direction, of the overall welfare effect of congestion taxes.

Some important caveats are in order. First, our objective is to illustrate the size of the welfare effect in the labor market, relative to the partial equilibrium welfare effect of congestion taxes. For this purpose we abstract from a number of complications. For example, the effects of pre-existing gasoline taxes are ignored—as discussed below, these effects would be important to incorporate in a more comprehensive analysis of congestion taxes. We assume that the transportation infrastructure and the geographical location of firms and households are fixed. The possibility of congestion on competing routes, pollution and accident externalities, suboptimal transit pricing, and so on, are also ignored. We also abstract from distributional considerations, and how new revenue sources might be used in practice, given the pressures for additional spending and tax relief from competing interest groups. Nonetheless, the key mechanisms we highlight would be at work in more general models—our analysis should be viewed as a component that might be usefully inserted into more comprehensive models of congestion taxes.

Second, we focus only on work-related congestion. Congestion taxes on leisure-related traffic would not reduce labor supply prior to revenue recycling, though the welfare gain from using revenues to cut distortionary taxes rather than finance lump-sum transfers would be the same as below. Third, revenues may be used for other purposes, for example public goods or reducing local sales or property taxes. We comment on how this might affect our results.

The rest of the paper is organized as follows. We begin in Section II 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 III and IV 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 V concludes and discusses limitations to the analysis.

II. Analytical Model

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:

$$U = u(C, N) + T(R, P), \quad (1)$$

where $u(\cdot)$ and $T(\cdot)$ 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 public transit (i.e., metro). Although the purpose of transport activity in this model is for people to get to work, we allow for some utility $T(\cdot)$ from travelling. This enables us to incorporate imperfect substitutability between transportation modes.⁹

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:

$$L = R + P. \quad (2)$$

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:

$$\bar{L} = N + L + \pi R + \phi P, \quad (3)$$

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

We assume the following relationship:

$$\pi = \pi(R), \quad (4)$$

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

⁹ T may represent the utility from listening to the radio in the car and from reading on the train. More generally T may be negative if commuting causes stress and boredom. The separability in (1) implies that the transportation mode decision does not affect the amount of work effort. We regard this as a reasonable simplification.

deciding 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. In this section we assume that transportation only requires household time and not other inputs such as gasoline, road and rail maintenance, etc. This is unrealistic, but does not really affect our key results (see below).

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. 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:

$$tL + \tau R = G. \tag{5}$$

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

The household budget constraint is:

$$C + \tau R = (1 - t)L + G. \tag{6}$$

The LHS of this equation is spending per period on the consumption good and the congestion tax. The RHS 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 (1) subject to the budget constraint (6), the time constraint (3), equation (2), and taking π as exogenous. The first-order conditions yield (assuming $R, P > 0$):

$$1 - t = (1 + \pi) \frac{u_N}{u_C} - \frac{T_R}{u_C} + \tau \tag{7a}$$

$$1 - t = (1 + \phi) \frac{u_N}{u_C} - \frac{T_P}{u_C}. \tag{7b}$$

These expressions 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:

$$\pi \frac{u_N}{u_C} - \frac{T_R}{u_C} + \tau = \phi \frac{u_N}{u_C} - \frac{T_P}{u_C}. \quad (8)$$

That is, in equilibrium the cost of an additional trip by road and transit are equal.

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

$$R = R(\tau, t, G, \pi) \quad P = P(\tau, t, G, \pi) \quad L = L(\tau, t, G, \pi). \quad (9)$$

The Welfare Effects of Congestion Taxes

Revenues Used to Cut the Labor Tax. The welfare effect of an incremental increase in the congestion tax with revenues used to reduce the labor tax can be expressed (see the Appendix):

$$\left\{ \pi' R \frac{u_N}{u_C} - \tau \right\} \left\{ -\frac{dR}{d\tau} \right\} + t \frac{dL}{d\tau}. \quad (10)$$

$\pi' R u_N / u_C$ 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 into account when deciding whether to use the 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 (10) is the change in labor supply multiplied by the tax wedge between the gross and net wage. The gross wage reflects the value marginal product of labor; 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 is to increase or decrease labor supply.

From differentiating (9) when G is constant, the change in labor supply can be separated into three effects:

$$\frac{dL}{d\tau} = \frac{\bar{\partial L}}{\partial \tau} + \left\{ \frac{\partial L}{\partial t} \frac{dt}{d\tau} \right\}^+ + \left\{ \frac{\partial L}{\partial \pi} \pi' \frac{dR}{d\tau} \right\}^+, \tag{11}$$

where (from differentiating (5) and using (9)):

$$\frac{dt}{d\tau} = - \frac{R + \tau \frac{dR}{d\tau} + t \frac{dL}{d\tau}}{L} < 0. \tag{12}$$

The first effect in (11) is the negative impact on labor supply from an incremental increase in the congestion tax. This increases the cost of commuting to work by road and 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.¹⁰ 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.

Manipulating (11) and (12) yields:¹¹

$$\frac{dL}{d\tau} = \frac{- \left\{ \frac{\partial L}{\partial t} \frac{dR}{d\tau} \frac{\tau}{L} \right\}^+ + \left\{ \frac{\partial L}{\partial \pi} \pi' \frac{dR}{d\tau} \right\}^+}{1 + \frac{t}{L} \frac{\partial L}{\partial t}}. \tag{13}$$

The denominator in this expression is positive so long as an incremental increase in the labor tax raises rather than decreases labor tax revenues (this is satisfied for the parameter values used below). The first term in the numerator reflects the net impact of the first two effects in equation (11) and it reduces labor supply, except when $\tau = 0$.¹² However, the second term in

¹⁰In theory $\partial L/\partial t$ could be positive if the income effect outweighs the substitution effect. We ignore this possibility because the evidence suggests the economy-wide uncompensated labor supply elasticity is positive (see below). We also ignore the possibility that $dt/d\tau$ 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 traffic reductions.

¹¹Note that $\partial L/\partial \tau = (\partial L/\partial t)R/L$. That is, a unit increase in the price of commuting has the same effect on labor supply as a unit reduction in the household wage, multiplied by the size of commuting costs to labor supply.

¹²Following an incremental increase in τ , household surplus in the road-use market falls by R . However, the government only obtains $R + \tau dR/d\tau < R$ in additional revenue. Recycling the revenues back to households (by reducing the labor tax) does not fully compensate them; hence the net impact is to reduce labor supply.

the numerator, which reflects the effect of reduced commute time on labor supply, is positive even when $\tau = 0$. Thus *the net impact of a revenue-neutral congestion tax is to increase labor supply*, at least for modest levels of taxation.

This result differs from, but is still consistent with, 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 pre-existing labor taxes; see e.g. Goulder *et al.* (1999). 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 (11). Second, the “revenue-recycling effect” is the gain from using additional pollution tax revenues to reduce the labor tax. This is analogous to $(\partial L/\partial t)(dt/d\tau)$ in (11). However, *since these studies typically assume utility is separable in environmental quality there is no feedback effect on labor supply analogous to the third term in (11), hence the net impact of the pollution tax is (usually) to reduce labor supply.*¹³

Setting (10) equal to zero, substituting from (13), and noting that $\partial L/\partial \pi = (\partial L/\partial \tau)u_C/u_N = (\partial L/\partial t)(R/L)(u_C/u_N)$, we obtain the optimal congestion tax:

$$\tau^* = \pi'Ru_N/u_C.$$

This is just the Pigouvian tax, equal to the marginal congestion cost. Thus, the marginal impact on labor supply is positive up to a point where the congestion externality is fully internalized ($dL(\tau^*)/d\tau = 0$).¹⁴

¹³Indeed, if the road was not congested so that $\pi' = 0$ in equation (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 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, a congestion tax is still part of the optimal tax system, even if the direct time saving benefits from reducing congestion are ignored. Mayeres and Proost (1997) provide some discussion of congestion taxes as part of an optimal tax system.

¹⁴In a long-run setting, revenues may be used to finance additional road construction. In this case the welfare gain from the revenues is the net social benefit from the capacity expansion. If there were diminishing returns to expanding road capacity, then the Pigouvian congestion tax would raise more revenue than required to finance the optimal amount of capacity expansion, leaving some scope for cutting labor taxes and an additional source of welfare gain; see Mohring and Harwitz (1962).

Revenues Finance Lump-sum Transfers. Now suppose that additional revenues finance lump-sum transfers—the standard textbook assumption.¹⁵ Using (9) the change in labor supply is given by:

$$\frac{dL}{d\tau} = \frac{\partial L}{\partial \tau} + \left\{ \frac{\partial L}{\partial G} \frac{dG}{d\tau} \right\} + \left\{ \frac{\partial L}{\partial \pi} \pi' \frac{dR}{d\tau} \right\}. \quad (14)$$

The first and third terms in this equation are analogous to those in the previous case, equation (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.

Revenues Used to Subsidize Public Transit Fares. Reducing congestion using a combination of congestion fees and transit fare subsidies is less efficient than relying on congestion fees alone when there are two or more travel modes (see below). Here we discuss the impact of this policy on labor supply.

When congestion tax revenues finance a transit subsidy, denoted s , we need to add sP to the right side of the government and household budget constraints, (5) and (6). Thus s appears as an argument of the functions in (9) and, since t and G are now constant, the change in labor supply is:

$$\frac{dL}{d\tau} = \frac{\partial L}{\partial \tau} + \left\{ \frac{\partial L}{\partial s} \frac{ds}{d\tau} \right\} + \left\{ \frac{\partial L}{\partial \pi} \pi' \frac{dR}{d\tau} \right\}. \quad (15)$$

Transit 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 increase in labor supply, and hence welfare gain in the labor market, is smaller when revenues are used to subsidize transit, instead of directly cutting the labor tax.

¹⁵Roughly speaking, this may represent a case when new revenues finance additional transfer payments (such as pensions), or public spending that is a close substitute for private spending (possible examples include health care, education, food stamps). Looking at this case helps us to decompose the welfare gains from using new revenues to cut distortionary taxes, as opposed to not using the revenues to improve economic efficiency.

III. Numerical Model of Work-related Congestion

In order to quantify the welfare discrepancies between alternative congestion taxes, we turn to a model with several extensions, solved numerically.¹⁶ 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 transit subsidies. Second, we assume that the production of transportation services requires real resource inputs (representing fuels, wear and tear on trains and cars, etc.). To obtain empirical results we need to specify functional forms. This section describes the structure and calibration of the model.

*Model Structure*¹⁷

The production function for market goods is given by:

$$X = \min\{L, T\}, \quad (16)$$

where T is the total number of trips. Thus there are fixed proportions between labor supply L and the total number of trips; in other words each day of work requires a commuting trip. We define:

$$T = \{(\alpha_R R)^{(\sigma_T-1)/\sigma_T} + (\alpha_P P)^{(\sigma_T-1)/\sigma_T} + (\alpha_F F)^{(\sigma_T-1)/\sigma_T}\}^{\sigma_T/(\sigma_T-1)}, \quad (17)$$

where F is the number of trips on a non-congested road per household.¹⁸ σ_T is a substitution elasticity parameter and the α 's are share parameters (and similarly for other equations below). There is imperfect substitution between trips, governed by σ_T . This formulation is equivalent to, though computationally simpler than, allowing for utility from travel as in (1). The household has the following constant elasticity of substitution (CES) form for utility:

$$U = \{(\alpha_C C)^{(\sigma_U-1)/\sigma_U} + (\alpha_N N)^{(\sigma_U-1)/\sigma_U}\}^{\sigma_U/(\sigma_U-1)}, \quad (18)$$

where σ_U is the elasticity of substitution between leisure and consumption.

¹⁶We are grateful to Tom Rutherford for help in developing a program in GAMS with MPSGE.

¹⁷Unless otherwise stated, variables are as defined in Section II.

¹⁸This 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. To keep our results transparent, we abstract from congestion on this road.

We define the following transportation “production” functions:

$$P = \min \left\{ \frac{N^P}{\phi_P}, \frac{X^P}{\theta_P} \right\} \tag{19a}$$

$$F = \min \left\{ \frac{N^F}{\phi_F}, \frac{X^F}{\theta_F} \right\} \tag{19b}$$

$$R = \min \left\{ \frac{D}{\phi_R}, \frac{X^R}{\theta_R} \right\};$$

$$D = \{(\alpha_{DR}N^R)^{(\sigma_D-1)/\sigma_D} + (\alpha_{DA}RA)^{(\sigma_D-1)/\sigma_D}\}^{\sigma_D/(\sigma_D-1)}. \tag{19c}$$

N^i is the total amount of time spent per household traveling 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 (19a) and (19b) 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 (19c) 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 “road availability”, RA . Thus, the smaller is road availability, the greater the amount of time required to make a trip.¹⁹

Road availability is determined as follows:

$$RA = \pi_1 - \pi_2 R, \tag{20}$$

where $\pi_1, \pi_2 > 0$ are parameters. Equations (19c) and (20) produce a relationship between travel speed ($1/N^R$) and traffic flow (R).²⁰ The parameter values we choose imply that this relation is approximately linear over the relevant range of traffic reductions.²¹

Goods market equilibrium requires:

$$X = C + X^R + X^P + X^F. \tag{21}$$

¹⁹In practice, gasoline consumption increases as congestion raises travel times. However, incorporating this effect would have essentially the same impact as increasing the time delay costs associated with a given level of traffic.

²⁰Introducing the composite D is a slightly roundabout way of generating the speed/flow relation, but was necessary for computational reasons.

²¹We experimented with non-linear speed/flow functions, but this had little effect (since the linear function provides a reasonable approximation to a non-linear function when traffic is reduced by a relatively modest amount).

This equation says that the output of goods equals household consumption, plus goods that are required for transportation. The household time constraint is:

$$\bar{L} = L + N + N^R + N^P + N^F. \quad (22)$$

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

$$C + X^R + X^P + X^F + \tau R - sP = (1 - t)L + G. \quad (23)$$

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:

$$G = tL + \tau R - sP, \quad (24)$$

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.

Calibration

We choose the consumption/leisure elasticity 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 ($\sigma_U = 1.52$).²² Alternative values are considered in the sensitivity analysis. We assume a labor

²²These values are based on a recent opinion survey among labor economists; see Fuchs, Krueger, and Poterba (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, and they reflect the effect of wages on (a) the participation decision, (b) the total number of days worked in a year, and (c) the average hours worked per day.

These are the "correct" values for estimating the impact of labor tax cuts on labor supply. However, they overstate the impact of changes in commuting costs on labor supply, which only depends on (a) and (b). The degree of overstatement is probably fairly small, because the participation decision accounts for about two-thirds of the labor supply response, while the other third is due to the combined effect of (b) and (c). On the other hand, another factor may work in the opposite direction. Lower transport costs may induce people to travel further distances to look for higher paying, more productive jobs, therefore increasing effective labor supply; see Rouwendal (1999). These observations strengthen the case for sensitivity analysis with respect to labor supply elasticities.

tax rate of 38 percent; other studies use similar values, e.g. Lucas (1990).²³ Thus the value of commuting and leisure time at the margin is 62 percent of the gross wage. Roughly speaking, this seems a reasonable starting assumption; cf. Small (1992, pp. 43–44). But estimates differ widely and we discuss alternative assumptions later.²⁴ 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 that the uncompensated (general equilibrium) demand elasticity for trips with respect to monetary costs (expressed as a positive number) is initially 0.4 for each mode ($\sigma_T = 0.8$), which is roughly consistent with the literature.²⁵ σ_D and π_2 are chosen to imply that a 1 percent reduction in traffic flow would raise car speed by 0.9 percent. 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 flow in a first-best setting without distortionary taxes would be about 10 percent.²⁶ 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 ($\sum X^i = 0.4\sum N^i$), which is roughly consistent with the literature; see e.g. Small (1992, pp. 76–77).

²³We 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; see Browning (1987). 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.

²⁴Estimates of the value of travel time vary from a low of about 20 percent of the gross wage in a recent study by Calfee and Winston (1998) to a high of about 100 percent.

²⁵As a rough rule of thumb, a 1 percent increase in the cost of using a road reduces traffic flow by 0.33 percent, at a specific point in time; see Small (1992, p. 11). We use a somewhat higher value to allow for intertemporal substitution, that is using the congested road at off-peak hours.

²⁶This is roughly consistent with optimal traffic reductions estimated in some other studies; see e.g. Repetto *et al.* (1992, Table 12, top panel).

In practice, the government raises a substantial amount of revenue from other transport taxes, including taxes on motor fuels and motor vehicles. In the U.S., revenues from these sources amounted to \$52 billion and \$13 billion, respectively, in 1994; see *Statistical Abstract of the United States* (1997, Table 478). Our analysis does not incorporate the effects of pre-existing gasoline taxes. Clearly, in a more comprehensive analysis of congestion taxes it would be important to capture induced welfare effects in the gasoline market, taking account of both gasoline taxes and pollution externalities; see e.g. Mayeres (1998). The point of our analysis is to demonstrate the relative importance of induced welfare effects in the labor market, and these effects are independent of the level of gasoline taxes (given the relative costs of congestion).

IV. Simulation Results

In this section we present results under our benchmark parameters, explore the sensitivity of these results to alternative parameter values and discuss travel associated with leisure activities.

Benchmark Results

Marginal Welfare Effects. In Figure 1(a) the horizontal axis shows percentage reductions in traffic flow on the congested road. 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} is the marginal welfare effect of a congestion tax in a (hypothetical) first-best setting without labor taxes. The height of this curve reflects the marginal externality cost of road use minus the tax rate, and corresponds to the “Pigouvian” welfare effect $\pi Ru_C/u_N - \tau$ in equation (10). The marginal welfare impact is positive up to the point where the tax reduces congestion by 10 percent.

The other three curves in Figure 1 show the marginal welfare effects of congestion taxes with pre-existing taxes on labor. MW^{TAX} denotes the case when 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 at the margin. The gap between MW^{TAX} and MW^{PIG} is declining. This is due to declining marginal revenues, as less traffic reduces the base of the congestion tax, and hence induces a smaller welfare gain from recycling additional revenues in tax cuts. The optimal traffic reduction is the same as in the first-best case, which is consistent with the result in Section II that the optimal (second-best) tax equals the Pigouvian tax.

MW^{LST} is the marginal welfare impact of a congestion tax with revenues returned as lump-sum transfers. This curve lies well below MW^{PIG} since the

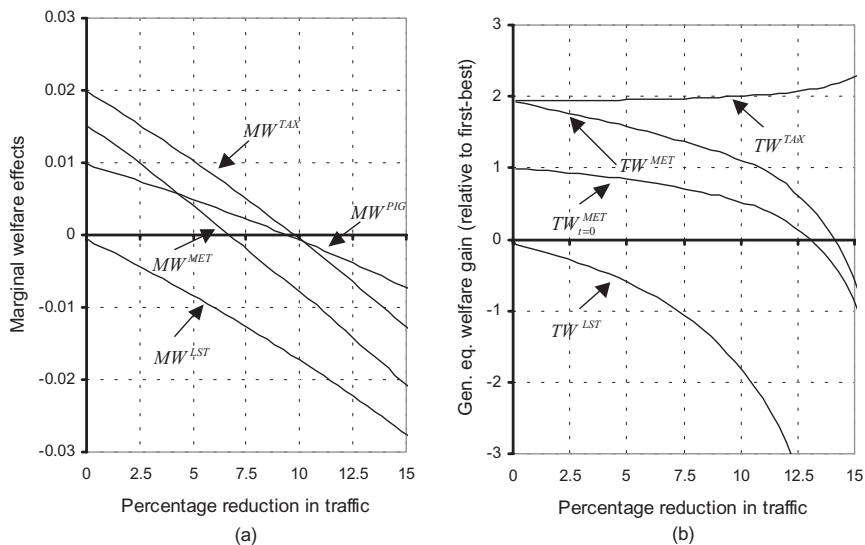


Fig. 1. (a) Marginal welfare effects; (b) Total welfare effects

policy reduces labor supply, producing a welfare loss in the labor market. Clearly, this dramatically limits the ability of this policy to enhance overall welfare. Indeed the intercept of MW^{LST} is (slightly) below the horizontal axis, implying that *any* level of congestion tax will reduce welfare (this result does not always apply in our later simulations).

Finally, MW^{MET} is the marginal welfare gain when revenues subsidize metro fares. This policy is less efficient than when revenues finance tax cuts 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 transit subsidy rather than the congestion tax reduces congestion, there will not be optimal substitution between the congested and non-congested roads. Second, though this policy can increase labor supply, the increase is less than if revenues finance tax cuts.²⁷

Total Welfare Effects. In Figure 1(b) we compare the total welfare effects of congestion taxes. On the vertical axis we have the general equilibrium

²⁷Up to the point where MW^{MET} and MW^{PIG} intersect, the welfare gain from incremental increases in labor supply exceeds the incremental welfare loss from the suboptimal allocation among transport modes.

welfare gain of policies, expressed relative to the Pigouvian welfare gain, i.e. the welfare gain from a congestion tax in the model without labor taxes.

TW^{TAX} shows the relative welfare gain when revenues finance cuts in the labor tax. This curve is roughly constant at 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 with revenues returned lump sum, is always below the horizontal axis. In fact, *reducing traffic by the optimal Pigouvian amount (10 percent) would produce an overall welfare loss equal to almost double the Pigouvian welfare gain.*

At the Pigouvian amount of traffic reduction, the gap between TW^{TAX} and TW^{LST} is almost 4, implying that the welfare gains from using revenues to cut distortionary taxes rather than finance transfer payments is almost four times the Pigouvian welfare gains. Thus in these benchmark simulations, *there is drastically more at stake in terms of economic welfare in what the government does with congestion tax revenues, than the entire welfare gains from internalizing the congestion externality.*²⁸

The curves $TW_{t=0}^{MET}$ and TW^{MET} decompose the two sources of welfare loss when revenues finance transit subsidies instead of tax cuts. $TW_{t=0}^{MET}$ is the welfare gain 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 optimal 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 flow. Finally TW^{MET} is the welfare gain from the congestion tax/metro subsidy with the pre-existing labor tax. This curve lies above $TW_{t=0}^{MET}$, since the policy increases labor supply, therefore producing a welfare gain when the labor market is distorted. Comparing TW^{MET} with TW^{TAX} at the Pigouvian traffic reduction, using revenues for transit subsidies instead of tax cuts reduces the welfare gain from the congestion tax by about 90 percent of the Pigouvian welfare gain. Of this, about 50 percent is due to

²⁸We can do a quick calculation to check this result. If we approximate by assuming linear demand and marginal social cost curves, the Pigouvian welfare gain is 0.5 times the traffic reduction times the Pigouvian congestion tax, i.e., $0.5(R_0 - R_1)\tau$. The welfare gain from using revenues for tax cuts equals the marginal excess burden of taxation (0.24) times revenue (τR_1). Expressing the latter effect over the former gives $0.48(1 - r)/r$, where $r = (R_0 - R_1)/R_0$. When $r = 0.1$, the welfare gain from recycling revenues in labor tax cuts would be 4.3 times the Pigouvian welfare gain.

Our results seem consistent with Mayeres (1998). Using a computable general equilibrium model for Belgium, she estimated the cost of financing additional public spending by raising congestion taxes, labor taxes, and lump-sum taxes. She infers that there would be a substantial welfare 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 these results with ours.

the suboptimal allocation of commuting among transport modes, and the remaining 40 percent is due to the smaller welfare gain in the labor market.

In practice, local governments may use new revenues for other purposes, e.g. to finance public goods, or cut property and sales taxes. Some indication of how this would affect our results may be inferred from Figure 1(b). In our model the welfare gain from recycling revenues in labor tax cuts rather than lump-sum transfers is 24 cents per dollar. Suppose that revenues were used to finance a public good or other tax cut that generated a 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 1(b). If social benefits were 36 cents per dollar, the gap between TW^{TAX} and TW^{LST} would increase by 50 percent, implying that the congestion tax would generate an overall welfare gain equal to about four times the Pigouvian welfare gain.

Sensitivity of Results to Key Parameter Values

Demand Elasticity for Road Use. In Figure 2 we vary the transport mode substitution elasticity σ_T between 0.2 and 1.4 (the transport demand elasticity varies between 0.1 and 0.7). When $\sigma_T = 0.2$ the first-best optimal traffic reduction (where $MW^{PIG} = 0$ in Figure 1(a)) is 2.7 percent and when $\sigma_T = 1.4$ it is 15.9 percent. 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 compare the area under the marginal welfare curves above the horizontal axis in Figure 1(a) to the area under MW^{PIG} .

As the demand elasticity increases, the Pigouvian welfare gain increases and this shifts up all the curves in Figure 1(a). Thus it is more likely that MW^{LST} 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 that implied by a partial equilibrium analysis. The relative welfare potential of the other policies (indicated by the MAX^{TAX} , MAX^{MET} , and $MAX_{t=0}^{MET}$ curves) is only modestly sensitive to the transport demand elasticity.

Speed Elasticity. In the first set of rows in Table 1, we vary the speed elasticity with respect to traffic flow between 0.6 and 1.2, which implies that the Pigouvian traffic reduction varies between 6.7 and 11.9 percent. This has the effect of shifting all the marginal welfare curves in Figure 1(a) either down towards the origin when the speed elasticity is reduced, or out away from the origin when it is increased. The maximum welfare gain, relative to

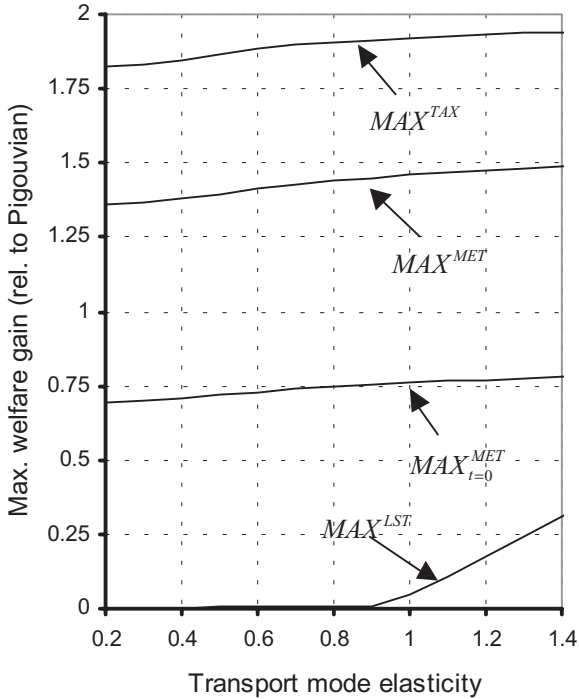


Fig. 2. Road demand elasticity

the Pigouvian welfare gain, is only moderately affected when congestion tax revenues finance tax cuts or transit subsidies (see the right-hand set of columns). When revenues finance lump-sum transfers, the maximum welfare gain becomes positive under the higher speed elasticity, but it is still only 10 percent of the Pigouvian welfare gain.

Transit Share and Pre-existing Subsidies. In Figure 3 we vary the initial share of commuting by metro between 5 and 50 percent (the shares of traffic on the congested and non-congested roads are scaled up and down proportionately). The vertical axis again shows the maximum welfare gain 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 to the metro share. In contrast, the maximum welfare gain under the congestion tax/metro subsidy falls from 170 to 35 percent of the Pigouvian gain as the metro share falls from 50 to 5 percent (see the MAX^{MET} curve). The smaller the transit share, the more the optimal reduction in congestion involves substitution onto the non-congested road

Table 1. *Sensitivity of results with respect to key parameters*

Parameter values	Optimal reduction in traffic (%)				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	0.10	1.35
2. Labor sup. elast. ^a							
low	9.4	10.0	3.4	7.3	1.78	0.15	1.30
high	9.6	8.9	0.0	6.6	2.14	0.0	1.47
3. Labor tax rates							
33%	9.6	9.4	1.1	7.3	1.68	0.01	1.28
43%	9.6	9.3	0.0	7.0	2.22	0.0	1.65
4. Value of time							
31% of wage	5.9	5.7	0.0	4.1	1.86	0.0	1.42
93% of wage	11.9	11.6	2.5	8.3	1.91	0.08	1.47

^aThe uncompensated labor supply elasticity varies between 0.05 and 0.35 and the compensated between 0.25 and 0.45.

rather than transit. Since transit subsidies cannot induce the optimal substitution between the congested and non-congested road, this policy is relatively more inefficient the smaller the transit share. Metro subsidies are also less efficient than labor tax cuts at stimulating labor supply, the smaller the share of transit in work trips.

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 just raises the pre-existing labor tax from 38 to 39 percent). In practice, however, public transportation systems are typically priced at well below marginal cost. Incorporating pre-existing transit subsidies in our analysis further reduces the welfare loss from recycling congestion tax revenues in (additional) 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.

Labor Market Parameters. In the second set of rows in Table 1 we vary the uncompensated labor supply elasticity between 0.05 and 0.35 and the compensated labor supply elasticity between 0.25 and 0.45. The more (less) responsive is labor supply to changes in wages (net of taxes and commuting

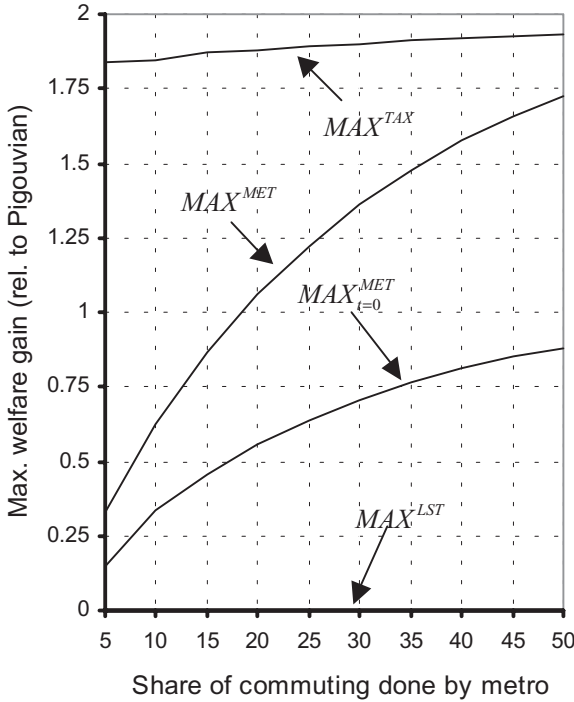


Fig. 3. Size of the metro

costs), the larger (smaller) are the welfare impacts in the labor market relative to the Pigouvian welfare effect of congestion taxes. We see that a lower (higher) labor supply elasticity has a modest effect on lowering (raising) the relative welfare potential of the congestion tax when revenues finance labor tax cuts. Similarly, under our low labor supply elasticity scenario, the welfare potential when revenues are returned lump sum is greater, but it is still only 15 percent of the Pigouvian welfare gain.

In the third set of rows in Table 1 we vary the labor tax rate between 33 and 43 percent. This has a noticeable effect—for example, the maximum welfare gain when revenues finance 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 with lump-sum replacement is still only trivially positive.

Value of Time. In our benchmark simulations we assumed that the value of time was 62 percent of the gross wage, and that time costs per trip were the same as money costs. In the fourth set of rows in Table 4 we re-calibrate the

model to imply that travel time costs are between 31 and 93 percent of the gross wage.²⁹ This has the effect of reducing or increasing the costs of congestion and, as with changing the speed elasticity, the marginal welfare curves in Figure 1(a) either shift in towards, or out away from, the origin. Again, under the high value of time, when the Pigouvian traffic reduction rises to 11.9 percent, the maximum welfare gain under the congestion tax with lump-sum replacement becomes positive, but is still only 8 percent of the Pigouvian welfare gain.

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 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 transit subsidies, but the relative welfare impact of this policy is highly sensitive to the transit share in travel trips.

Leisure-related Travel

Peak-period congestion is often associated with people going to and from work.³⁰ However, leisure-related trips (e.g. shopping, going to the gym, picking up children, etc.) also add to congestion. In this case the congestion tax does not directly discourage labor supply, and avoids the welfare loss in the labor market prior to revenue recycling. Here 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 a welfare gain in the labor market that roughly corresponds to the gap between TW^{TAX} and TW^{LST} in Figure 1(b). That is, the Pigouvian congestion tax could induce a general equilibrium welfare gain of about five 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

²⁹We altered the value of travel time by varying the time cost per trip.

³⁰For example, according to surveys in the late 1980s, 70–98 percent of trips on I-405, SR-91, and I-110 in southern California between 6 and 10 a.m. were work related; see Giuliano (1994, Table 5).

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.

V. Conclusion

This paper examines how pre-existing tax distortions in the labor market change the welfare effect of congestion taxes, under alternative assumptions about the disposition of the revenues. A congestion tax on work-related traffic with revenues returned lump sum reduces labor supply in our analysis and the welfare loss in the labor market can easily offset the welfare gain 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 welfare gain in the labor market about doubles the overall welfare gains from the congestion tax—although the optimal tax is still equal to the Pigouvian level. Recycling the revenues in transit fare 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.

There are a number of limitations to our analysis that might be worth relaxing in future work. First, we take the capacity of the transport system as given. It would be useful to explore how tax distortions in labor and capital markets affect the optimal amount of investment in transportation infrastructure. In addition, our analysis does not capture long-run impacts on congestion due to changes in the location of households.

Second, we could allow for other “distortions” in the transport sector, such as accident and pollution externalities, congestion on competing routes, transport taxes, etc. For example, it would be useful to examine welfare effects when congestion tax revenues are used to reduce gasoline taxes or vehicle registration fees. This would require extending the model to capture non-work-related driving, pollution externalities associated with gasoline, and possibly vehicle purchase decisions.

Third, besides distorting the labor market, income taxes also distort the choice between tax-favored spending—e.g. homeowner mortgage interest, employer-provided medical insurance—and ordinary (non-tax-favored) consumption. This means that the welfare gains from using congestion tax revenues to cut income taxes could be significantly larger than above, due to the welfare gain from removing distortionary tax subsidies; see Feldstein (1999) and Parry and Bento (2000) for more discussion.

Fourth, we abstract from the distributional effects of congestion taxes. Clearly, people who drive during rush hour, and particularly those who have a long commute, bear the burden of a congestion tax, while all workers

including non-motorists would benefit from a cut in labor taxation. Hence there could be significant redistribution of income between these groups.³¹ Another important point is that we ignore the possibility that additional public spending financed by congestion taxes may produce social benefits by helping low-income groups, even though it may not improve economic efficiency *per se*.

Appendix: Analytical Derivations

Deriving Equation (10)

Using (1)–(4) and (6) we can define the household’s indirect utility function as follows:

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

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 (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 (12), and dividing by λ to convert to monetary units, we obtain (10).

³¹ Allowing for multiple households may also alter the efficiency effects of congestion taxes, if the labor supply elasticity for motorists differs from that for workers as a whole.

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 (5), with respect to τ and s , when we include sP on the RHS, we can obtain:

$$\frac{ds}{d\tau} = \left\{ \frac{R + \tau \frac{dR}{d\tau} + t \frac{dL}{d\tau} - s \frac{dP}{d\tau}}{P} \right\}. \quad (\text{A3})$$

We need to compare the middle terms on the RHSs of equations (11) and (15). Substitute (A3) and $\partial L/\partial s = -(\partial L/\partial t)P/L$ in (15). Substitute (12) and $\partial L/\partial \tau = (\partial L/\partial t)R/L$ in (11). Comparing, we find that the change in labor supply is smaller by the term

$$\frac{\partial L}{\partial t} \frac{dP}{d\tau} \frac{s}{L} > 0$$

when revenues finance the subsidy rather than the reduction in labor tax.

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First version submitted November 1999;
final version received November 2000.