

Estimating the Welfare Effect of Congestion Taxes: The Critical Importance of Other Distortions Within the Transport System

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Abstract

This paper uses analytical and numerical models to illustrate how the presence of other distortions within the transport system changes the overall welfare effect of a congestion tax. These other distortions include a transit fare subsidy, congestion on competing (unpriced) routes, accident externalities, gasoline taxes, and pollution externalities.

Each of these pre-existing distortions can substantially alter the welfare effect of a congestion tax that would be predicted by a first-best analysis. If congestion taxes encourage travel on other congested routes, they can produce sizeable indirect welfare losses. In addition, induced reductions in the demand for gasoline can lead to substantial welfare losses when, as appears to be the case for European countries, gasoline taxes significantly exceed marginal pollution damages. On the other hand, congestion taxes may produce significant welfare gains by offsetting accident externalities, though these gains are partially offset by increased accidents on competing roadways. To the extent that congestion taxes increase the demand for transit, they can induce significant welfare gains or losses, depending on whether transit fares are above or below marginal supply costs.

The importance of other distortions varies considerably across different transport systems and across different countries. Our generic analysis illustrates the proportionate change in the welfare effect of a congestion tax due to each of these distortions over a wide range of parameter scenarios.

Key Words: congestion tax, welfare effect, transit subsidy, gasoline tax, accidents, pollution

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1. Introduction

The failure of policies to halt the trend of rising traffic congestion in many urban areas has heightened interest in peak-period pricing schemes.¹ Economists have tended to favor peak-period congestion taxes over other short-run approaches to reducing congestion, such as mass transit fare subsidies and gasoline taxes, because this policy tackles the congestion externality directly and leads to an optimal redistribution of travel on alternative transport modes, and at off-peak hours.² In principle, the welfare analysis of first-best congestion pricing is straightforward. The optimal fee is simply equal to the externality cost an additional driver would impose on other drivers by slowing down average car speeds, and the welfare gain from this tax is the familiar Harberger triangle between the marginal social cost curve and the peak-period demand curve for road use.

But in practice we do not live in a first-best world. Economists have long warned us that the actual welfare effects of public policies can be quite different from those predicted by a first-best analysis that ignores the spillover effects of the policy in other distorted markets within the economic system (e.g., Lipsey and Lancaster 1956; Harberger 1974). Indeed in the context of congestion taxes, a recent paper by Parry and Bento (2000) underscores the potential importance

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¹ See, e.g., *The Economist*, December 6, 1997, pp.15—16.

² See, e.g., Downs (1992) for a descriptive discussion. Parry (2000) shows that these other policies typically forgo more than two thirds of the welfare gains from a first-best optimal congestion tax.

of spillover effects in the labor market, which is substantially distorted at the margin by the tax system. They find that a tax on commuter traffic can discourage labor force participation at the margin by reducing the household wage, net of taxes and commuting costs. The resulting welfare loss in the labor market may actually exceed the Pigouvian welfare gains from internalizing the congestion externality. But if the congestion tax revenues are used to cut labor income taxes, the net impact on labor supply is positive in their model, and the overall welfare gains are about twice as large as the Pigouvian welfare gains.³

This paper focuses on the implications of pre-existing policies and externalities within the transportation system rather than pre-existing distortions in the labor market.⁴ There are a variety of potentially important interactions within the transport system to consider. First, imposing a congestion fee on one road may induce a reallocation of traffic that exacerbates congestion externalities on other competing routes. For various reasons, an absence of policy intervention may prevent these other congestion externalities from being internalized. For instance, the other routes may be back roads through neighborhoods, and it might be prohibitively costly to install traffic monitors at every intersection.

Second, mass transit is typically subject to increasing returns, implying that the marginal cost of supply is below the average cost (see below), but at the same time operating costs are often heavily subsidized. Depending on which of these two factors dominates, the price of travelling by rail or bus could be above or below the (short-run) marginal social cost of service provision. In this setting, an expansion of transit services, in response to a shift in demand away from driving along congested roads, may produce significant welfare gains or losses in the public transportation market.

³ Usually, the net impact of shifting taxes off labor and onto “bads,” such as pollution, is to reduce labor supply (e.g. Bovenberg and de Mooij 1994; Parry and Oates 2000). The opposite result occurs in the above case because reducing the externality itself—congestion—has a positive feedback effect on labor force participation.

⁴ For the most part, the implications of these other distortions can be explored independently of the labor market distortion. The exception is that to the extent congestion taxes alter revenues elsewhere in the transport system, for example by reducing gasoline demand, a more general analysis would take into account the efficiency loss from reduced gasoline tax revenues.

Third, reducing traffic congestion also helps alleviate possible externalities associated with vehicle accidents. Again though, imposing congestion pricing on one road may lead to substitution effects that exacerbate accident externalities on competing routes.

Fourth, reducing traffic congestion produces indirect benefits by reducing tailpipe emissions of certain air pollutants. But this also exacerbates distortions created by gasoline taxes and increases pollution from competing roads.⁵

Fifteen years ago, Winston (1985 p. 80) noted that there was very little quantitative analysis on the extent to which other distortions in the transport system might affect the welfare impact of a new congestion tax; he suggested that this was a key area for future research. Since then a number of studies have shed some light on second-best congestion taxes in the presence of these distortions.⁶

For example, studies suggest that the external costs of accidents per vehicle mile might be fairly sizable relative to congestion costs, while the pollution damages might appear relatively small.⁷ But the welfare effect of a tax on a congested road when substitution effects compound accident externalities on other routes has not been extensively studied. Nor has the interaction between congestion taxes and gasoline taxes.

Several papers have looked at congestion taxes applied to a subset of lanes on a congested freeway (e.g., Route 91 in Orange County, California). The welfare potential of these policies tends to be limited because the substitution by drivers away from the priced lane

⁵ Vehicles also impose an externality by wearing out roadways; this externality has been carefully analyzed by Newbery (1988a). Road damage is caused mainly by heavy trucks. The analysis below does not consider trucks.

⁶ For our purposes a “second-best” policy refers to a pure congestion tax imposed in the presence of multiple pre-existing distortions. In some other studies a second-best policy refers to a blunt instrument that must be used in place of a pure congestion tax, such as a charge that does not vary with the time of day or does not cover all congested lanes on a freeway.

⁷ See, e.g., Newbery (1988b) on accidents and Small and Kazimi (1995) on pollution. For a general discussion of the social costs of transportation see, e.g., Delucchi (1997), Quinet (1997) and ECMT (1998).

compounds the welfare losses from congestion externalities remaining on unpriced lanes.⁸ But there has been little quantitative analysis of how the welfare impact of a congestion tax (applied to all freeway lanes) is affected by congestion on routes that are not a perfect substitute in demand for the priced freeway.⁹

This paper contributes to the literature in the following respects. First, we provide a unifying analysis that captures all the second-best interactions mentioned above; other studies usually focus on just one of the distortions. Thus, besides illustrating how each distortion in isolation affects the welfare gains from congestion taxes, we also illustrate the effect of all the interactions combined.¹⁰ Second, we include some distortions—notably sub-optimal transit pricing, congestion on competing routes, and gasoline taxes—that have not received much attention in previous second-best studies of congestion taxes. Third, instead of relying on a set of parameter values that are specific to a particular transport system, we provide a generic analysis that illustrates the proportionate change in the welfare effect of a congestion tax over wide ranges of parameter values. This provides rules of thumb for adjusting results from a first-best analysis of congestion taxes.¹¹

To give some flavor of the results, we find that the welfare losses from compounding congestion on competing roadways can be sizeable relative to the Pigouvian welfare gains from

⁸ See, e.g., Small and Yan (1999), Verhoef and Small (1999), Liu and McDonald (1998), Braid (1996) and Parry (2000).

⁹ However, a recent theoretical analysis by Verhoef (2000) examines optimal congestion taxes in the presence of unpriced links within a transport network.

¹⁰ This paper is not about how to optimally price a whole transport network *per se* (for some discussion of this see Ochelen et al., 1998). Instead we ask, given that other parts of the transport network are not optimally priced (and will not be optimally priced in the near future), to what extent can this strengthen or weaken the case for congestion taxes?

¹¹ Our paper complements some studies that use more detailed computational models to evaluate alternative transportation policies in the presence of multiple distortions, which have been applied mainly to Belgium (e.g., Ochelen et al. 1998). Our approach differs by considering more distortions (multiple congestion externalities), by illustrating results for a broad range of parameter values (rather than to a city-specific network), and in particular by decomposing the underlying importance of each individual distortion.

internalizing the congestion externality, although the substitution effect is dampened somewhat by the increasing cost of travel on these routes. The effect of congestion taxes on reducing accidents can significantly raise the overall welfare gain from the tax. However, the welfare gain is very sensitive to the portion of accident costs that are external (rather than private) and is dampened by the increase in accidents on competing roadways. Induced reductions in the demand for gasoline can lead to substantial welfare losses when, as appears to be the case for European countries, gasoline taxes greatly exceed marginal pollution damages. Spillover effects in the transit market are also potentially important, and are more likely to be positive when the fare subsidy is small and negative when it is large.

The next section of the paper describes the structure of our model. We also solve the model analytically for incremental increases in a congestion tax to provide a theoretical framework for interpreting subsequent results. Section 3 describes the model calibration. Section 4 presents simulation results showing the proportionate change in the welfare gain from a congestion tax due to other distortions under wide ranges of parameter values. In Section 5 we draw conclusions and discuss some limitations of the analysis.

2. Theoretical Framework

A. Model Assumptions

Consider a model in which a large number (H) of homogeneous agents make trips from the suburbs to the city center using four travel modes. First, they can drive along a freeway. Second, they can use an alternative “back roads” route, along neighborhood and city streets. Third, agents can use rail transit.¹² Each of these three options involves travel during peak periods. The final option is to drive at off-peak hours (along the freeway or back roads). The number of trips per agent in a given period (i.e., traffic volume or flow, assuming one occupant per vehicle) is denoted T_F (peak-period freeway trips); T_B (back roads trips); T_R (transit trips); and T_{OP} (off-peak trips).

¹² Introducing bus transit would be a little more complicated, since buses add to congestion caused by cars.

There is congestion on the freeway and back roads during rush hour but not at off-peak hours. When a road is congested the presence of an extra vehicle reduces the average speed, hence increasing trip times for all drivers. If a mode is not congested, an additional vehicle does not affect the average speed. Since drivers do not take into account their impact on affecting the travel time of other drivers, congestion creates the standard externality problem. We assume that a congestion tax can be implemented on the freeway at rush hour, but is administratively infeasible on the back roads.

The total time an agent spends traveling by mode j over the period, N_j , and the agent's total money expenditure travelling on mode j , v_j , are:

$$(2.1) N_j = \phi_j T_j; v_j = \theta_j T_j; j = F, R, B, OP$$

where ϕ_j and θ_j are time and money cost per trip.

Although all the ϕ 's and θ 's are exogenous to an individual agent, ϕ_F and ϕ_B vary with the peak-period freeway and back-roads traffic volumes as follows:

$$(2.2) \phi'_F = \phi'_F (HT_F) \quad \phi'_B = \phi'_B (HT_B)$$

where ϕ'_F and $\phi'_B > 0$. Thus, the greater the traffic volume the longer the trip time.

Money costs that agents pay per trip consist of fuel expenses g_j (the supply price of fuel is normalized to one), and non-fuel expenses (vehicle wear and tear, fares for transit, etc.), $\tilde{\theta}_j$. We assume that g_j is independent of travel speed and is zero for (electronic) rail transit. Money costs are affected by three government policies: a tax rate of τ_g on gasoline, a transit fare of rate f , and a tax of τ_F for using the freeway at peak period. Thus, the money costs per trip are given by:

$$(2.3) \quad \theta_F = \tau_F + (1 + \tau_g)g_F + \tilde{\theta}_F \quad \theta_R = f$$

$$\theta_{OP} = (1 + \tau_g)g_{OP} + \tilde{\theta}_{OP} \quad \theta_B = (1 + \tau_g)g_B + \tilde{\theta}_B$$

Agents have the following nested CES utility function:

$$(2.4) U = U(C, l, T, Z) = \left\{ C^{\frac{\sigma_U - 1}{\sigma_U}} + l^{\frac{\sigma_U - 1}{\sigma_U}} + T^{\frac{\sigma_U - 1}{\sigma_U}} \right\}^{\frac{\sigma_U}{\sigma_U - 1}} - \psi(Z) - \mu(A^p + A^e)$$

$$T = T(T_F, T_B, T_{OP}, T_R) = \left\{ (T_F)^{\frac{\sigma_T-1}{\sigma_T}} + (T_B)^{\frac{\sigma_T-1}{\sigma_T}} + (T_{OP})^{\frac{\sigma_T-1}{\sigma_T}} + (T_R)^{\frac{\sigma_T-1}{\sigma_T}} \right\}^{\frac{\sigma_T}{\sigma_T-1}}$$

where T is “travel services”, C is the consumption of market goods, and l is leisure. σ_U is the elasticity of substitution between these three “goods” and determines the elasticity of total travel demand. In turn, sub-utility from travel services depends on the number of trips made on each mode, where there is imperfect substitution between modes.¹³ The demand elasticity for freeway travel is primarily determined by the parameter σ_T .

$\psi(\cdot)$ in (2.4) is disutility from a given amount of pollution Z , where $\psi' > 0$. Pollution is determined by:

$$(2.5) Z = \beta H \{g_F T_F + g_B T_B + g_{OP} T_{OP}\}$$

where β is emissions per unit of gasoline (a constant) and the term in brackets is gasoline consumption from all travel modes per agent.¹⁴

$\mu(\cdot)$ is disutility from (expected) accident damages, which consists of private accident costs due to the agent’s own behavior, A^p , and external costs caused by other drivers, A^e (see below). These components are determined by:

$$(2.6) A^p = \sum_{j=F,B,OP,R} a_j^p T_j ; A^e = H \sum_{j=F,B,OP,R} a_j^e T_j$$

where the a ’s are accident cost coefficients for different modes.

Agents are subject to the following budget constraint:

¹³ In practice, infra-marginal people are not indifferent between travel modes, e.g., some people enjoy driving so that they can listen to the radio, while others prefer rail because they can read. In addition, people are not perfectly indifferent between working “normal” hours and shifting their workday to avoid peak-hour traffic.

¹⁴ In practice, tailpipe emissions per unit of gasoline (aside from carbon emissions) can be altered through various technology fixes. But in our analysis there is no change in the incentive to reduce emissions per unit of gasoline, so we can treat emissions as proportional to gasoline. We abstract from the possibility that the pollution damage per mile differs between drivers. In practice pollution per mile tends to increase with the age of the driver’s vehicle (e.g., Verhoef *et al.* 1995).

$$(2.7) C + v_F + v_R + v_B + v_{OP} = L + G$$

where L is labor supply and the wage rate is normalized to unity. G is an exogenous lump-sum transfer to each agent. The price of the consumption good and the wage rate are both normalized to unity. Equation (2.7) therefore equates expenditure on consumption and transportation with labor earnings and the transfer payment.

The agent's time constraint is:

$$(2.8) L + l + N_F + N_B + N_{OP} + N_R = \bar{L}$$

That is, the sum of labor, leisure, and travel time equals the agent's time endowment \bar{L} . More time spent traveling therefore reduces utility by reducing time for leisure and work.¹⁵

On the production side, competitive firms hire workers to produce market goods, where production is proportional to labor input. These goods are consumed directly by households, and are also used as intermediate goods in transportation. The metro is publicly provided, and we assume that the average cost of providing service is declining. One reason for this is that the load factor (i.e. passengers per train) is likely to increase with travel demand.¹⁶ For simplicity we denote production costs for rail service by $F + mT_R$, where F and m are constant and m is marginal supply cost.

Finally, the government budget constraint is:

$$(2.9) G + F + mT_R = \tau_F T_F + \tau_g \sum_{j=F,B,OP} g_j T_j + fT_R$$

That is, government spending on transfer payments and transit provision equals transport tax revenues plus transit fare revenues.

¹⁵ This formulation implies that the value of travel time equals the market wage, whereas the evidence suggests that it is well below the wage (see below). However, by choosing appropriate values for the ϕ_j 's, we can calibrate the model to be consistent with appropriate values for the share of time costs in total travel costs.

¹⁶ When we include travel time as part of production costs, average production costs could also be declining because a greater frequency of trains reduces passengers' wait time at the platform. For more discussion about increasing returns in rail transit, see, for example, Mohring (1972) and Viton (1992).

B. Decomposing the Welfare Effect of an Increase in the Congestion Tax

The (general equilibrium) welfare change caused by an incremental increase in the congestion tax (expressed in monetary units) consists of five components (see the Appendix for a derivation):

$$(2.10) \frac{1}{\lambda} \frac{dU}{d\tau_F} = \underbrace{(MEC_F - \tau_F) \left(-\frac{dT_F}{d\tau_F} \right)}_{dW^F} - \underbrace{(m-f) \frac{dT_R}{d\tau_F}}_{dW^S} - \underbrace{MEC_B \frac{dT_B}{d\tau_F}}_{dW^C} \\ - \underbrace{(MEC_g - \tau_g) \sum_{j=F,B,OP} g_j \frac{dT_j}{d\tau_F}}_{dW^G} - \underbrace{\sum_{j=F,B,OP,R} MEC_j^a \frac{dT_j}{d\tau_F}}_{dW^A}$$

where $MEC_F = HT_F \phi'_F U_l / \lambda$, $MEC_B = HT_B \phi'_B U_l / \lambda$, $MEC_g = \psi' \beta H / \lambda$, $MEC_j^a = \mu H a_j^e$ and the Lagrange multiplier λ is the marginal utility of income.

dW^F is the welfare gain from reduced congestion on the freeway. This equals the (general equilibrium) reduction in freeway trips multiplied by the gap between the marginal external cost (MEC_F) and the congestion tax. MEC_F is the utility loss, aggregated over all agents and all trips made at peak period, due to the impact of one more driver on adding to congestion and raising the average trip time by ϕ'_F . Increasing the congestion tax will increase this source of welfare gain up to the point where $\tau_F = MEC_F$. This is the ‘‘Pigouvian’’ congestion tax.

dW^S is the welfare change from the induced substitution into subsidized transit. It equals the increase in transit trips multiplied by the difference between marginal cost and the transit fare. If the fare is less (greater) than the marginal cost, the increase in demand produces a welfare loss (gain), since the marginal benefit to agents from using transit is less (greater) than the marginal social cost of service provision. dW^C is the welfare loss from compounding congestion on (unpriced) back roads. This is the product of the increase in back-roads trips and the marginal external cost of congestion on this route, MEC_B . dW^G is the welfare impact in the gasoline market. This equals the overall reduction in gasoline consumption (the summation term)

multiplied by the wedge between the marginal social cost and the marginal social benefit of gasoline, which is positive (negative) when the gasoline tax is less (greater) than the marginal external cost of pollution.¹⁷ Finally, dW^A is the welfare change from the overall impact on traffic accidents. This is the sum of the change in trips weighted by the external component of accident costs per trip.

3. Model Calibration

We now calibrate the above model, and solve numerically for non-marginal congestion taxes, to quantify the relative size of the various components of the welfare change under a wide range of plausible parameter values.¹⁸ We specify the following functional form for trip time as a function of traffic volume:

$$(3.1) \quad \phi_j = \phi_{j0} \left\{ 1 + 0.15 [T_j / CAP_j]^4 \right\} \quad j = F, B$$

where CAP_j is a measure of road capacity and ϕ_{j0} is the time required to travel along the road when there are no other cars. The inverse of this function gives the travel speed.¹⁹

(i) Transportation Parameters. We choose T_j / CAP_j to imply a “typical” congestion scenario where peak-period speed on the freeway is initially one half of the free-flow speed (the speed when there are no other cars), and a “severe” congestion scenario, when the travel speed is one third of

¹⁷ Thus, simply adding marginal external damages from pollution to the marginal external cost of congestion will overstate the welfare gain from a congestion tax in two respects. First, the welfare gain per unit reduction in gasoline is *net* of the gasoline tax. Second, the reduction in gasoline is *net* of any increase in gasoline consumption on competing routes.

¹⁸ We programmed the model in GAMS with MPSGE. Details of the computer programs are available at www.rff.org/~parry/Links/transp3.htm. It is prudent to check that the results from numerical models are consistent with “back-of-the-envelope” calculations from an analytical model. We provide a discussion of this consistency at the same web address.

¹⁹ This is the Bureau of Public Roads formula, which has been empirically validated in the literature (e.g., Small 1992, pp. 69-72). It implies that the average cost curve for peak-period freeway travel eventually has an infinite slope but does not bend backward (hence we ignore the case of “hyper-congestion” where the presence of additional drivers reduces speed by so much that the traffic flow actually falls). Our results are not greatly affected by using alternative specifications.

the free-flow speed.²⁰ In our benchmark scenario modal shares in total trips are .33 (peak-period freeway); .33 (transit); .17 (back roads) and .17 (off-peak). We consider a variety of alternative modal shares in cases where relative welfare effects are significantly affected.

We assume that money costs (running costs and vehicle depreciation) and time costs (including delays from congestion) per trip are the same across modes in the typical congestion scenario ($\phi_j = \theta_j$ for $j = F, R, B, OP$).²¹ These parameters are sensitive to different assumptions about the opportunity cost of travel time, gasoline tax rates, and so on, and we discuss the implications of other assumptions. We define the “full” cost of a trip as the sum of money and time costs.

σ_T is chosen to imply that the demand elasticity for peak-period freeway trips with respect to monetary costs is -0.35 (or the full price elasticity is -0.7).²² We discuss the implications of other values. σ_U is chosen to imply that about 15% of the reduction in peak-period freeway trips under a congestion tax is due to reduced overall demand for travel services and 85% is due to substitution between travel modes.²³

²⁰ In major urban areas about one third of vehicle travel takes place under congested conditions, in which speeds average half of the free-flow rate (Arnott and Small 1994, pp. 446).

²¹ For example, time and money costs (running cost and vehicle depreciation) are each about 25 cents per vehicle mile for a driving speed of 30 m.p.h. (Small 1992, pp. 75-85). We calculated the time and money shares for bus, commuter rail, light rail, and heavy rail for 1997 using operating costs per passenger mile and average travel speeds obtained from the American Public Transport Association (www.apta.com/stats/#A2) and assuming an opportunity cost of time equal to half the hourly wage in 1997 (inferred from *Statistical Abstract of the United States 1997*, Table 671). This yielded approximately equal time and money shares (gross of fare subsidies). In our severe congestion scenario, time costs account for two thirds of the total costs of peak-period freeway travel.

²² This is a typical value from the literature, although there has been a wide range of estimates (see Small 1992, ch. 2; Goodwin 1992).

²³ We assume that the value of travel services is 10% of the value of output and that leisure is 50% of labor supply (these values are not important for the results).

The above parameter values imply that the first-best optimal reduction in peak-period freeway traffic (i.e., when there are no distortions other than freeway congestion) is 7.5% and 11% in the typical and severe congestion scenarios respectively.

(ii) Transit Parameters. Our model represents a short-run situation in which the main capital stock of the transit system (the number of rail platforms, miles of track, etc.) is fixed: increasing trips implies increasing the frequency of service or increasing the load factor.

For the United States in 1997, passenger revenues covered 50% of the operating costs of commuter rail, 29% of the costs for light rail, and 66% of the costs for heavy rail (and 32% for bus).²⁴ Fare revenues cover about 20% to 70% of operating costs in most European countries, though on average the recovery rate is a little higher than in the United States (Pucher 1988, Table 3). Some cities in developing countries, including Calcutta, Mexico City, and Rio de Janeiro, appear to have similar recovery rates, but in Santiago, Manila, and Hong Kong, for example, fares exceed estimated operating costs, implying negative rates of subsidy (Allport and Thomson 1990). Below, we illustrate scenarios in which the fare subsidy (equal to $1 - (\text{passenger fares})/(\text{operating costs})$) varies from -20% to 100% of (money) costs.

However, what matters for efficiency is the gap between marginal (rather than average) costs and fares (equation (2.10)). This gap is smaller than the above rates of subsidy by: $(\text{average cost} - \text{marginal cost})/(\text{average cost})$. We illustrate cases in which the gap between average and marginal cost is 10% and 40% of average cost.²⁵

The share of travel by transit varies widely. In Boston and Washington, DC, the transit share (rail and bus) is about one seventh; in New York, Paris, and London it is about one third;

²⁴ From American Public Transportation Association (www.apta.com/stats/#A2).

²⁵ Cost functions for rail transit generally show declining average costs (e.g., Berechman 1993, pp. 127-128; Viton 1992). In theory, the gap between average and marginal cost could be anywhere between 0% and 100%. In the TRENEN model, which has been used to simulate transport policies in Belgium (e.g., Ochelen et al. 1998), the gap is 10%. Other studies suggest the gap could be significantly larger (Viton 1992).

and in Zurich and Prague, it exceeds one half (Pucher and Lefèvre 1996). We consider cases in which the transit share varies between .17 and .50.²⁶

(ii) Congestion on Back Roads. For this case what matters is the amount of displaced freeway traffic ending up on the back roads and the degree of pre-existing congestion on the back roads. We illustrate cases in which 0 to 45% of the traffic displaced from the congested freeway is diverted onto the back roads. We apply the congestion function in (3.1) to the back roads, and calibrate T_j / CAP_j to imply that the (absolute and relative) reduction in speed due to congestion is either the same or 50% of the reduction in speed caused by peak-period freeway congestion.

(iii) Accident Externalities. Two key issues here are the relative magnitude of accident damages and the portion of these damages that are an external (as opposed to private) cost. Based on the literature, a central estimate is that accident costs are about the same size as total time costs.²⁷ But because there is uncertainty over these estimates we consider cases in which they are 50% lower and 50% higher than time costs.²⁸

At first glance the social cost of accidents appears to exceed the (expected) private costs for a number of reasons, though on closer inspection some of these reasons are tenuous (e.g., Small and Gómez-Ibáñez 1999). First, the presence of an additional vehicle may increase the probability that other drivers will collide. However, people drive more carefully in heavy traffic, and accidents are less deadly at slower speeds. In fact, some studies find that average accident

²⁶ Note that the transit share in travel to work, which is where transit mainly competes with congested roads, is larger than the transit share in total travel in urban areas. The latter includes suburb-to-suburb trips that do not compete with peak-period freeway trips to and from work.

²⁷ See, for example, Small and Gómez-Ibáñez (1999) pp. 196-5 and Small (1992), pp. 75-85. The major component of damage estimates is people's willingness to pay to avoid the risk of fatal and non-fatal injuries; other components include property damage and delays from traffic hold ups.

²⁸ ECMT (1998), Table 46, found that average accident costs for 17 European countries were only about one third of the estimates reported in Small and Gómez-Ibáñez (1999) (assuming \$1 = .85 ECU). This is mainly because the study assumed a more conservative value for a statistical life (pp. 179).

costs may actually fall with traffic volume (e.g., Fridstrøm and Ingebrigsten 1991). Second, insurance premiums appear to be a fixed rather than variable cost. That is, when someone makes an additional trip they do not pay more insurance even though they add to the risk that an accident may occur. However, premiums often depend on experience, prior accident record, and distance traveled for daily commuting. Indeed Small and Gómez-Ibáñez (1999) suggest that, in the absence of contrary evidence, the best starting assumption is that insurance costs are perceived as private variable costs by road users. Third however, insurance companies may not pay the full social costs of accidents. For example, they do not compensate other drivers for the time delays caused by accidents, and some of the costs of treating injuries may be picked up by the government (especially in countries with a socialized health service). In short, it is difficult to pin down the split between private and external costs; we consider cases in which the external cost of accidents is between 10% and 50% of the social costs.²⁹ We assume that accident costs per trip are the same across driving modes, but that there are no accident costs on transit.³⁰

(iv) Gasoline Tax and Pollution Damages. Table 1 displays gasoline tax rates expressed relative to producer prices—roughly 60 cents per gallon in December 1998—for various countries. These range from 4.88 for the United Kingdom to .73 for the United States. Tax rates in typical European countries are 300%-400% of producer prices, and between 100% and 250% of producer prices in typical Latin American countries.

In a careful study Small and Kazimi (1995) estimated the damages from volatile organic compounds, nitrogen and sulfur oxides, and particulate matter due to the combustion of gasoline in the Los Angeles metropolitan area. Their central estimate for the total damages was 3.3 cents per mile. Given the uncertainty over this estimate, and that pollution damages vary across urban and rural areas, and areas with strong and weak air circulation, we also consider cases of 1.7 and 5 cents per mile. Incorporating future climate change damages does not make a huge difference: plausible low, medium, and high damage estimates for carbon emissions might be \$5, \$30, and

²⁹ This yields external accident costs that are comparable to those in Ochelen et al. (1998).

³⁰ Estimated accident costs per passenger mile for rail are less than 10% of those for roads in ECMT (1998), pp. 183.

\$75 per ton (e.g., Nordhaus 1994), or .07, .45, and 1.1 cents per mile.³¹ Putting these numbers together, we obtain damages of roughly 60%, 120%, and 180% of the producer price of gasoline.³²

For Western European countries, pollution damage estimates per vehicle mile are somewhat lower than for the United States, because of higher fuel efficiency and the assumption that people's willingness to pay for reducing pollution is lower.³³ In developing countries, however, pollution damages could be larger because of greater population exposure and more polluting vehicles.

The last column in Table 1 shows gasoline taxes net of the above range for marginal pollution damages. In most cases the entries are positive, reflecting gasoline taxes in excess of marginal pollution damages. In these cases, to the extent that a congestion tax reduces the consumption of gasoline, this produces a welfare loss (in contrast it is often suggested that reducing gasoline consumption will produce a welfare gain). We illustrate cases where the net gasoline tax varies between -100% and 400% of the producer price.

Finally, our simulations assume that the producer price of gasoline (i.e. excluding taxes and pollution damages) is one eighth of money costs (inferred from Small 1992, pp. 75-85).

4. Simulation Results

We now take each distortion in isolation and explore how it changes the welfare effect of the Pigouvian congestion tax. The final subsection considers the net impact of all the distortions simultaneously.

A. Transit Subsidy

³¹ One ton of carbon is produced by 335 gallons of gasoline (Manne and Richels 1992).

³² This assumes an average of 20 miles per gallon for the auto fleet (Small 1992).

³³ According to ECMT (1998), Table 78, air pollution damages averaged across Europe amount to about 1.3 cents per mile.

On the horizontal axes in Figure 1 we vary the transit fare subsidy between – 20% and 100%. The vertical axes indicate the welfare loss (or gain) due to the change in demand for transit induced by the congestion tax, expressed as a proportion of the Pigouvian welfare gain (i.e., the welfare gain from imposing the Pigouvian tax when there are no other distortions present). Figure 1 illustrates several fairly basic but nonetheless important points.

In panel (a) the upper and lower curves correspond to the welfare impacts when the marginal costs of supplying transit are 90% and 60%, respectively, of the average costs (i.e., $m/(F/T_R + m) = .9$ or $.6$) for the typical congestion scenario and baseline assumptions about other parameters. When the transit subsidy exceeds the gap between average and marginal cost this means that the transit fare is below marginal cost ($f < m$) and the increase in transit travel produces a welfare loss. When the transit fare exceeds marginal cost ($f > m$), the transit subsidy could be positive or negative, depending on whether the fare is below or above average cost (i.e. whether f is below or above $F/T_R + m$). But the increase in transit travel now produces a welfare gain.

These welfare effects are potentially important. For example, when marginal cost is 90% of average cost and the transit fare subsidy is 50%, then the welfare loss in the transit market offsets 56% of the Pigouvian welfare gain from internalizing the congestion externality. On the other hand, when marginal cost is 60% of average cost and the transit subsidy is 20%, there is a welfare gain equal to 25% of the Pigouvian welfare gain.³⁴ The welfare curves cut the horizontal axis (i.e. the welfare effect is zero) if the subsidy exactly covers the gap between average and marginal cost since $f = m$ in this case. Note that the relative welfare change in the transit market is approximately proportional to the transit subsidy, net of the gap between average and marginal

³⁴ The intuition for these results is straightforward. The Pigouvian welfare gain is approximately a triangle with base equal to the reduction in freeway trips and height equal to the proportionate increase in the full cost of travel due to congestion, which is .33 in the typical congestion scenario. The welfare change in the transit market is a rectangle with base equal to the increase in transit use, and height equal to the money subsidy, net of the gap between average and marginal cost, and expressed as a fraction of the full price, which is half the net money subsidy. For example in our base case when the transit share is 33%, about 42% of reduced freeway traffic is diverted into transit. So if the money subsidy is 50% and the gap between average and marginal cost is 10%, the welfare loss rectangle expressed relative to the Pigouvian welfare gain triangle is approximately $((.5-.1) \times .5 \times .42)/(.5 \times .33) = .51$.

cost. For example, on the upper curve as we increase the net subsidy from 20% to 40% to 60% (i.e. the gross subsidy increases from 30% to 50% to 70%), the relative welfare loss increases from 27% to 56% to 87%.

Comparing panel (a) and (b) in Figure 1, we see that the relative welfare effect is also sensitive to the size of the congestion externality. In particular, as we move from the typical to the severe congestion scenario, the relative welfare change in the transit market roughly halves.³⁵ Panel (c) shows the effect of varying the transit share (assuming typical congestion and marginal cost equal to 90% of average cost).³⁶ The relative welfare change in the transit market is roughly proportional to the transit share: when the transit share is .5 (top curve), the relative welfare changes are about three times as large as when the transit share is .17 (bottom curve).

In sum, the relative welfare losses in the transit market are very sensitive to the amount of congestion, the level of pre-existing subsidy, the gap between marginal and average cost, and the transit share. Clearly, we cannot pin down a priori the proportionate reduction in the welfare gain due to the transit subsidy: it depends on the parameter values applicable to a particular application. Still, the potential welfare changes can be substantial (relative to the welfare gain from internalizing the congestion externality) and are therefore important to include in a comprehensive cost/benefit analysis of congestion taxes.³⁷

These points are further underscored in Table 2. Here we show that the second-best optimal congestion tax expressed as a fraction of the Pigouvian tax varies noticeably depending

³⁵ Here, doubling the size of the congestion externality roughly doubles the height of the Pigouvian welfare gain triangle. The base is also larger, because of a larger substitution effect in response to the Pigouvian tax, but this means the base of the welfare change rectangle in the transit market will also be proportionately larger. Thus, the size of the rectangle relative to the triangle will be roughly halved.

³⁶ Here we hold the share of trips on the congested freeway at .33 and scale up and down the share on back roads and off-peak freeway accordingly.

³⁷ In practice money costs differ significantly across different transit systems (e.g., Small, 1992, pp. 52-61). Suppose that the money share was .6, rather than .5. Then a 50% money subsidy is equivalent to a 30% subsidy for the full cost, or a 60% subsidy when the money share is .5. Thus we can easily infer from Figure 1 the implications of alternative money/time cost shares in transit.

on the extent of congestion, the transit share, and the transit subsidy (again defined net of the gap between average and marginal cost). For example, when the transit share is .33, the optimal congestion tax lies anywhere between 65% and 108% of the Pigouvian tax.

B. Congestion on Other Routes

Figure 2 shows the fraction of the Pigouvian welfare gain that is offset, by the costs of exacerbating congestion on back roads, when the back roads traffic share varies between 0 and .67. The solid and dashed curves correspond to the typical and severe congestion scenarios respectively, and for each case the upper and lower curves correspond to when the marginal externality cost on back roads is 100% and 50% respectively of the marginal external cost on the freeway. We note a couple of points.

First, the relative welfare losses from exacerbating congestion on competing routes are potentially significant. For example, when the marginal external cost of congestion is the same on back roads as on the freeway (top two curves) the welfare loss amounts to about 20%, 45%, or 80% of the Pigouvian welfare gain when the back roads traffic share is .17, .33, and .50, respectively (for both the typical and severe congestion cases).

Second, when the marginal external cost of back roads congestion is 50% rather than 100% of the marginal external cost of freeway congestion, the relative welfare loss falls substantially, but by somewhat less than half. This is because, when congestion is less to begin with, added congestion has less of an impact on dampening the overall substitution into back roads (i.e. the marginal cost of congestion is convex from (3.1)).

Again then, the presence of congestion on competing routes can significantly change the overall welfare effect of a Pigouvian congestion tax, even in cases when a minor fraction of the displaced traffic adds to congestion elsewhere. Put another way, these results underscore the potential importance of applying congestion taxes broadly across competing and congested routes within a network rather than in isolation.³⁸

³⁸ Note that when the portion of displaced freeway traffic going onto the back roads is “large” this may approximate the case in which the competing route is an unpriced lane on the same freeway, that is, when the congestion tax is a single lane toll. Other studies have shown that the welfare gains from single lane tolls are severely limited because

C. Accident Externalities

In Figure 3 the horizontal axis now shows the percent reduction in peak-period freeway travel, and the curves separate out the welfare implications of accident externalities under our central parameters (accident costs equal to time costs, external costs 30% of total accident costs, and normal congestion). The lower curve gives the marginal welfare effect from reducing peak-period freeway travel in the first-best case when freeway congestion is the only pre-existing distortion. The upper curve shows the marginal welfare impact when we incorporate accidents for peak-period freeway trips, but (unrealistically) ignore accidents on other travel modes. Here, the welfare gain from imposing the Pigouvian congestion tax allowing for accidents is 1.94 times the welfare gain with no accidents (i.e. the ratio of area $0cdb$ to area $0ab$ is 1.94).

When we incorporate accidents on other roadways, the marginal welfare gain is shown by the middle curve. Now, the welfare gain from the Pigouvian congestion tax, allowing for accidents, is 1.56 times that without accidents (area $0efb$ is equal to 1.56 times area $0ab$). In this case, 41% of the reduced peak-period freeway trips are diverted onto other roadways; hence the reduction in overall accident risk is reduced by 41%. The purpose of this graph is to emphasize the point that ignoring the effect on accidents elsewhere in the transport network can lead to a substantial overstatement of the welfare gain from a congestion tax.

Table 3 shows the additional welfare gain from reducing accident externalities, expressed relative to the Pigouvian welfare gain, i.e. area $0efb$ to area $0ab$ in Figure 3. Each cell shows the range of outcomes as we vary the fraction of external costs in total accident costs from 10% to 50%, given other parameter values.

The indirect welfare gains from reducing accidents can be sizeable, but are obviously sensitive to the portion of accident costs that are external. For example under our central case parameters the welfare gain varies between 19% and 110% as we vary external costs between

they exacerbate congestion on unpriced alternative lanes (e.g., Small and Yan 1999; Liu and McDonald 1998; Braid 1996; and Parry 2000).

One caveat here is that freeway pricing may push drivers with relatively low time costs onto other congested routes, thereby lowering the efficiency costs of added congestion elsewhere. In this respect our homogeneous-agent analysis may overstate these additional costs (e.g., Small and Yan 1999).

10% and 50% of total accident costs (column (b), row (b)). Not surprisingly, the welfare gain is also very sensitive to the relative magnitude of total accident costs. As we vary total accident costs from 50% to 150% of time costs, the welfare gain from reducing accidents roughly triples (comparing column (a) and (c)). The welfare gain from reducing accidents is moderately sensitive to the combined share of back roads and off-peak driving; increasing this share from .17 to .5 reduces the welfare gain by around 30% to 40% (comparing rows (a) and (c), or row (d) and (f)), because of increased accidents on other routes. In addition, the welfare gain from reducing accidents is relatively less important in the severe congestion scenario. Here, the relative welfare gains are about 40% lower because the Pigouvian welfare gain is larger.

In sum, the welfare gains from reducing accidents are potentially important to include in a comprehensive evaluation of congestion taxes, but they are difficult to pin down accurately because of uncertainty over parameters, such as the fraction of accident costs that are external.

D. Gasoline Taxes and Pollution

On the horizontal axes in Figure 4 we vary the gasoline tax, net of pollution damages, between -100% and 400% of the producer price of gasoline. The vertical axis indicates the welfare loss (gain) from the reduction in gasoline induced by the congestion tax, expressed relative to the Pigouvian welfare gain. Panels (a) and (b) correspond to the typical and severe congestion scenarios.

To the left of 0 on the horizontal axis there is a welfare gain from the induced reduction in gasoline consumption that reaches a maximum of 25% of the Pigouvian welfare gain (panel (a)) when marginal pollution damage net of the gasoline tax is 100% of the producer price (typical congestion, benchmark modal shares). But the welfare losses can be substantial when the gasoline tax exceeds marginal pollution damages; they amount to 79% of the Pigouvian welfare gain when the (net) gasoline tax is 400% of the producer price (depending on the modal share of back roads and off-peak travel).

These results are somewhat sensitive to the combined modal share of back roads and off-peak travel. As we vary this share between .17 and .50, the welfare loss curve rotates either upward or downward about the origin by about 20%. This share determines how much of the reduced demand for gasoline for peak-period freeway trips is offset by increased use of gasoline

on other modes. As in previous cases, the welfare loss (or gain) from changes in gasoline demand is relatively less important in the severe congestion scenario (panel (b)) where the Pigouvian welfare gain is relatively larger.

E. All Distortions Together

Finally, Table 4 shows the net welfare loss or gain from including all the distortions simultaneously, expressed relative to the Pigouvian welfare gain. The first row adopts “central” values for all parameters (see the table notes for details). The net impact of other distortions is to produce a welfare loss offset of 6% to 11% of the Pigouvian welfare gain, depending on modal shares. The other rows vary the transit subsidy, the percentage share of external costs in total accident costs, and gasoline tax net of marginal pollution damages, independently. But by adding up the welfare differences between these cases and the central case, we can (approximately) calculate the effects of changing more than one parameter at a time.

For example, consider an “extremely favorable” scenario for congestion taxes with a transit subsidy of -10% (defined net of the gap between average and marginal cost), 50% of accident costs external, and a gasoline tax net of marginal pollution damages of -100% . The net welfare change when modal shares are $.33$ (middle column) is: $.06 + (-.41-.06) + (-.40-.06) + (-.42-.06) = -1.35$. Thus there is an additional welfare gain from the tax equal to 135% of the Pigouvian welfare gain. On the other hand, a “highly unfavorable” scenario might involve a net transit subsidy of 60% , 10% of accident costs external, and a net gasoline tax of 300% . In this case the welfare loss is $.06 + (.59-.06) + (.51-.06) + (.59-.06) = 1.57$; i.e. a welfare loss amounting to 155% of the Pigouvian gain, meaning that the total effect of the congestion tax is to reduce welfare by 55% of the Pigouvian welfare gains calculated without other distortions.

5. Conclusion

This paper develops a unifying analysis to illustrate how the welfare impact of a congestion tax is affected by the presence of other distortions within the transport system. Congestion taxes exacerbate congestion on competing roadways and induce a welfare loss (gain) in the transit market when transit fares are less (greater) than marginal costs. They can produce indirect welfare gains by reducing accident externalities, though these gains are offset to some extent by increased accidents on competing roadways. Congestion taxes can also produce

welfare losses through their negative effect on gasoline demand, and these losses are greater the larger the excess of gasoline taxes over marginal pollution damages. This paper illustrates the proportionate change in the welfare effect of a congestion tax due to each of these distortions under a wide range of scenarios. For each distortion, these changes can be substantial under plausible parameter scenarios, and are therefore important to include in any comprehensive analysis of congestion taxes.

Some limitations deserve mention. We do not provide a fully comprehensive analysis of second-best congestion taxes. There are other sources of distortion that might be important to consider but are beyond the scope of the current study. For example, we do not model the interactions between congestion taxes and parking subsidies, vehicle taxes, or vehicle technology standards. As noted in the Introduction, pre-existing distortions created by the tax system also have important implications for the welfare effects of congestion taxes.

Furthermore, we use a static framework in which the carrying capacity of transport modes is fixed. In the long run, permanent shifts in the demand for travel between modes caused by congestion taxes will lead to changes in the pattern of investment in transportation infrastructure. To the extent that there are distortions between the marginal social benefit and the marginal social cost of investment in different transport modes, these changes may give rise to significant welfare effects.

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Appendix: Deriving equation (2.9)

The representative agent maximizes utility (2.4), subject to the budget constraint (2.7), time constraint (2.8), and accident constraint (2.6). The agent's maximization problem is:

(A1)

$$\begin{aligned}
V(\tau_F, G, \phi_F, \phi_B, Z, A^e) = & \text{Max } U(C, l, T(\cdot)) - \psi(Z) - \mu(a_F T_F + a_B T_B + a_{OP} T_{OP} + a_R T_R + A^e) \\
& + \lambda \{ L + G - C - T_F [\tau_F + (1 + \tau_g) g_F + \tilde{\theta}_F] - f T_R \\
& \quad - T_B [(1 + \tau_g) g_B + \tilde{\theta}_B] - T_{OP} [(1 + \tau_g) g_{OP} + \tilde{\theta}_{OP}] \} \\
& + \gamma \{ \bar{L} - L - l - \phi_F T_F - \phi_B T_B - \phi_{OP} T_{OP} - \phi_R T_R \}
\end{aligned}$$

where λ and γ are the marginal utility of money and time respectively. $V(\cdot)$ is indirect utility which is a function of six parameters that are exogenous to agents: τ_F , G , ϕ_F , ϕ_B , Z , and A^e . These are the parameters that are altered when the government increases the congestion tax (in a revenue-neutral fashion); all other parameters in the model are fixed. From differentiating, we can obtain:

$$(A2) \quad \frac{\partial V}{\partial \tau_F} = -\lambda T_F; \quad \frac{\partial V}{\partial G} = \lambda; \quad \frac{\partial V}{\partial \phi_F} = -\gamma T_F; \quad \frac{\partial V}{\partial \phi_B} = -\gamma T_B; \quad \frac{\partial V}{\partial Z} = -\psi'; \quad \frac{\partial V}{\partial A^e} = -\mu'$$

To obtain the welfare effect, expressed in monetary units, from an incremental increase in the congestion tax, we totally differentiate the indirect utility function:

$$(A3) \quad \frac{1}{\lambda} \frac{dV}{d\tau_F} = \frac{1}{\lambda} \left\{ \frac{\partial V}{\partial \tau_F} + \frac{\partial V}{\partial G} \frac{dG}{d\tau_F} + \frac{\partial V}{\partial \phi_F} \frac{d\phi_F}{d\tau_F} + \frac{\partial V}{\partial \phi_B} \frac{d\phi_B}{d\tau_F} + \frac{\partial V}{\partial Z} \frac{dZ}{d\tau_F} + \frac{\partial V}{\partial A^e} \frac{dA^e}{d\tau_F} \right\}$$

Substituting from (A2) gives:

$$(A4) \quad \frac{1}{\lambda} \frac{dV}{d\tau_F} = -T_F + \frac{dG}{d\tau_F} - \frac{\gamma}{\lambda} T_F \frac{d\phi_F}{d\tau_F} - \frac{\gamma}{\lambda} T_B \frac{d\phi_B}{d\tau_F} - \psi' \frac{dZ}{d\tau_F} - \mu' \frac{dA^e}{d\tau_F}$$

Using (2.2):

$$(A5) \frac{d\phi_F}{d\tau_F} = H\phi'_F \frac{dT_F}{d\tau_F}; \frac{d\phi_B}{d\tau_F} = H\phi'_B \frac{dT_B}{d\tau_F}$$

Using (2.5) and (2.6):

$$(A6) \frac{dZ}{d\tau_F} = \beta H \left\{ g_F \frac{dT_F}{d\tau_F} + g_B \frac{dT_B}{d\tau_B} + g_{OP} \frac{dT_{OP}}{d\tau_{OP}} \right\};$$

$$\frac{dA^e}{d\tau_F} = H \left\{ a_F \frac{dT_F}{d\tau_F} + a_B \frac{dT_B}{d\tau_B} + a_{OP} \frac{dT_{OP}}{d\tau_{OP}} + a_R \frac{dT_R}{d\tau_R} \right\}$$

From totally differentiating the government budget constraint (2.7), we can obtain:

$$(A7) \frac{dG}{d\tau_F} = \left\{ T_F + \tau_F \frac{dT_F}{d\tau_F} + \tau_s \left(g_F \frac{dT_F}{d\tau_F} + g_B \frac{dT_B}{d\tau_B} + g_{OP} \frac{dT_{OP}}{d\tau_{OP}} \right) - (m - f) \frac{dT_R}{d\tau_R} \right\}$$

Substituting (A5)-(A7) into (A4), and noting that $\gamma = U_l$ yields the expression in (2.10).

Table 1. Gasoline Tax Rates for Selected Countries

(December 1998)

Country	Gasoline tax relative to producer price ^a	Gasoline tax net of pollution damages relative to producer price
United Kingdom	4.88	3.08 – 4.28
France	4.77	2.97 – 4.17
Germany	3.14	1.34 – 2.54
Italy	3.05	1.25 – 2.45
Belgium	3.36	1.56 – 2.76
United States	.73	-1.07 – 0.13
Canada	1.27	-0.53 – 0.67
Australia	1.98	0.18 – 1.28
New Zealand	1.07	-0.73 – 0.47
Brazil	2.29	0.49 – 1.69
Argentina	1.76	-0.04 – 1.16
Mexico	1.10	-0.70 – 0.50

^a Calculated by: (gas tax as a fraction of end user price)/(1 – gas tax as a fraction of end user price).

Source: *Energy Détente*, volume XX, February 26, 1999.

Table 2. Optimal Congestion Tax with Transit Subsidy

(as a fraction of Pigouvian tax)

Transit share	Net fare subsidy ^a					
	Typical congestion			Severe congestion		
	-.10	.20	.50	-.10	.20	.50
.17	1.07	.92	.83	1.01	.95	.91
.33	1.08	.82	.65	1.02	.92	.77
.5	1.09	.76	.40	1.03	.86	.62

^a Defined net of the gap between average and marginal cost.

Table 3. Relative Welfare Gain from Accidents

	Modal share on back roads and off-peak combined	Accident costs relative to time costs (external costs = 10-50%)		
		.5	1	1.5
		(a)	(b)	(c)
Typical congestion	.17	(a) .12 – .64	.25 – 1.3	.38 – 2.1
	.33	(b) .10 – .50	.19 – 1.1	.30 – 1.7
	.5	(c) .07 – .39	.15 – .83	.23 – 1.4
Severe congestion	.17	(d) .07 – .36	.14 – .76	.21 – 1.1
	.33	(e) .05 – .29	.11 – .60	.17 – .97
	.5	(f) .04 – .22	.08 – .47	.13 – .76

Table 4. The Net Welfare Impact from All Distortions

	Modal shares		
Transit	.17	.33	.50
back roads and off-peak	.50	.33	.17
Benchmark parameters ^a	.06	.06	.11
Net transit subsidy ^b			
-10%	-.20	-.41	-.57
60%	.32	.59	.81
Accident external costs			
10%	.40	.51	.46
50%	-.28	-.40	-.42
Net gasoline tax			
-100%	-.32	-.42	-.51
+300%	.48	.59	.81

^a Assumes typical congestion scenario, 25% net transit subsidy, 30% of accident costs are external and total accident costs equal time costs, gasoline tax net of marginal pollution damages equal 100% of the gasoline producer price, and congestion costs on back roads are 50% of those on peak-period freeway.

^b Transit subsidy is net of the gap between marginal and average cost.

Figure 1. Welfare Effects Due to a Pre-existing Transit Subsidy

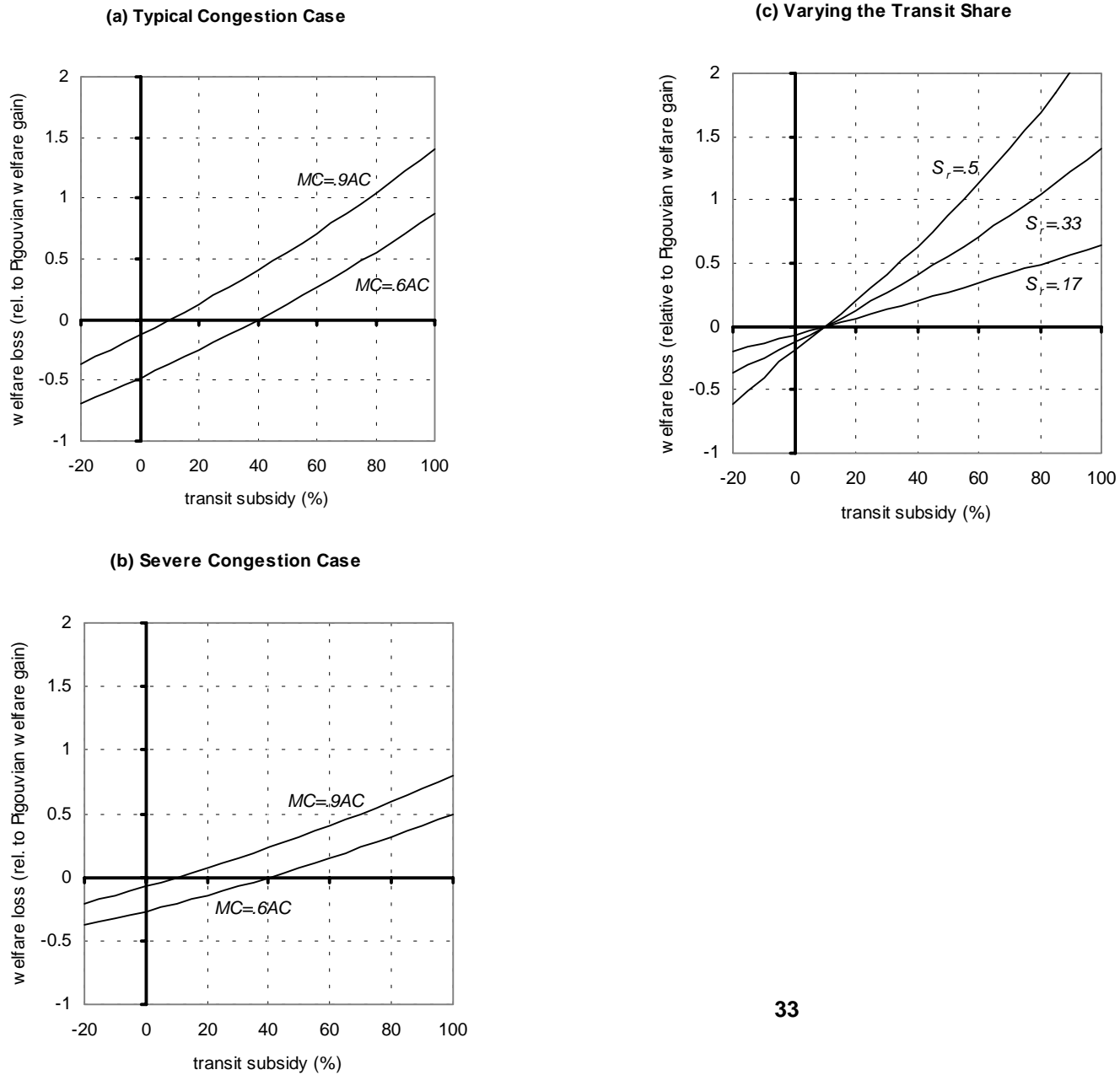


Figure 2. Welfare Losses Due to Congestion on Back Roads

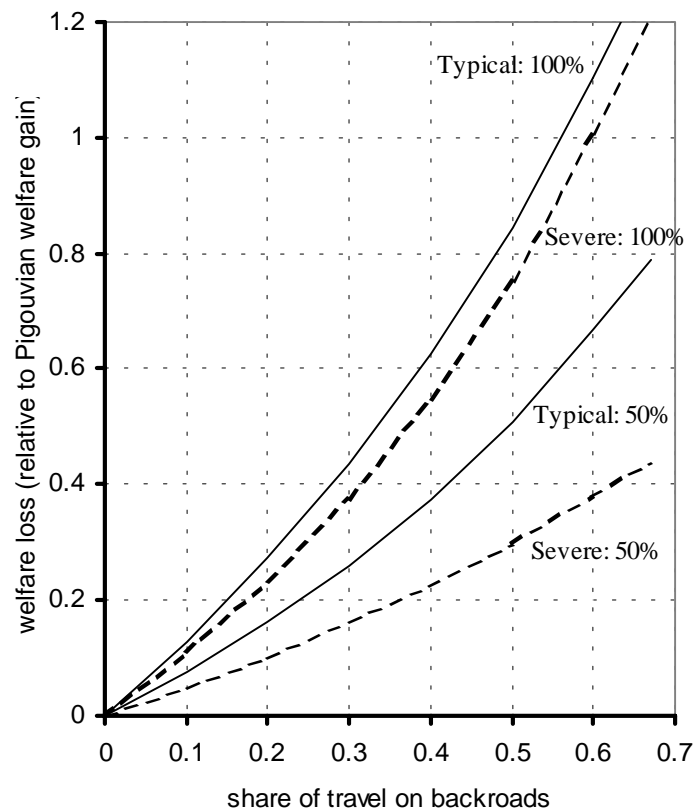


Figure 3. Marginal Welfare Gain from Accidents

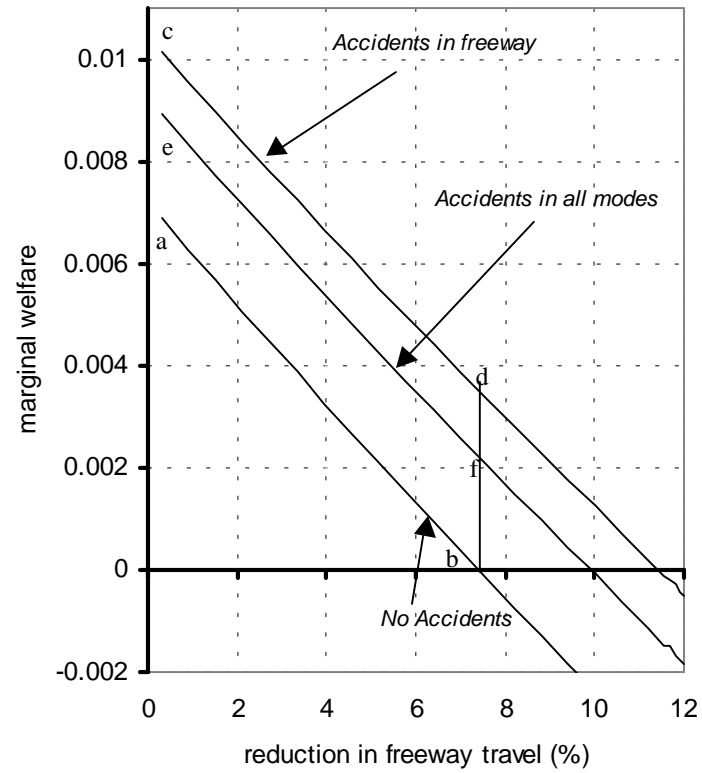


Figure 4. Welfare Effects Due to Gasoline Tax and Pollution

