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How Should Metropolitan Washington, DC, Finance Its Transportation Deficit?

Ian W.H. Parry

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Abstract

It is widely perceived that projected public spending on transportation infrastructure in the metropolitan Washington, DC, area for the next 20 years will not be enough to halt, let alone reverse, the trend of increasing traffic congestion. Consequently, there has been much debate about how additional sources of local revenues might be raised to finance more transportation spending.

This paper develops and implements an analytical framework for estimating the efficiency costs of raising \$500 million per annum in local revenue from five possible sources. These sources are increasing labor taxes, property taxes, gasoline taxes, transit fares, and implementing congestion taxes. Our model incorporates congestion and pollution externalities, and it allows for interactions between the different policies.

Under our central estimates, the efficiency cost of raising \$500 million in additional revenue from labor taxes is \$118 million; from transit fares is \$136 million; from property taxes is \$16 million; from gasoline taxes is \$66 million; and from congestion taxes is $-\$19$ million. The higher costs of the labor tax and transit fares reflect their negative impact on employment, and on pollution and congestion, respectively. A case could be made on efficiency grounds for using congestion fees and gasoline taxes to raise the revenue, though it should not be overstated. For example, much of the pollution externality is already internalized through pre-existing gasoline taxes, and the inelastic demand for peak-period driving and for gasoline limits the pollution and congestion benefits per dollar of revenue raised. Moreover, the relative advantage of these policies is sensitive to alternative scenarios for external damages. The property tax has a relatively low cost because it reduces pre-existing distortions created by the favorable tax treatment of housing.

Key Words: transportation; taxes; Washington, DC; welfare cost

JEL Classification Numbers: R48, H21, H23

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How Should Metropolitan Washington, DC, Finance Its Transportation Deficit?

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1. Introduction

Traffic congestion has become a major problem in the Washington, DC, metropolitan area (i.e., the District of Columbia, Northern Virginia, and suburban Maryland). According to the Texas Transportation Institute (1998), the Washington, DC, area has the second worst congestion in the nation after Los Angeles, and congestion causes 216 million person hours of delay each year. Daily backups have now spread to vast stretches of the Washington area highway system, particularly I-95, I-270, and the Capital Beltway, where only a few years ago traffic was relatively free flowing (Council of Governments 1999). The traffic problem is likely to become even more acute over the next 20 years, as vehicle miles traveled in the area are projected to grow by another 60% while under current plans, highway capacity will increase by only 20% (Department of Transportation 1996).

It is widely perceived that future spending on the Washington transportation system needs to be substantially higher than budgeted levels to prevent traffic gridlock becoming even worse. There are no funds available to expand the Metrorail system, for example, out to Tysons Corner and Dulles airport, or around the Beltway. Moreover, the costs of maintaining the existing Metrorail system (replacing rail cars, escalators, etc.) are projected to increase because much of the infrastructure is 30 years old. There is also a lack of funds for expanding the road network—such as adding a lane to the Beltway, building a bridge crossing to connect the Route 7/28 area of Northern Virginia with the Gaithersburg/Rockville area of Maryland, or building an intercounty connector from I-270 in Montgomery County to I-95 in Prince

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George's county.¹ Work has begun on replacing the Wilson Bridge across the Potomac River, but no funds have been set aside for any cost overruns. According to the Northern Virginia Transportation Coordinating Council (2000), transportation spending in Northern Virginia alone needs to be increased by \$14 billion over the planned level for the next 20 years to prevent congestion worsening.²

There has recently been much debate about how the Washington region might secure additional sources of transportation revenues.³ Delegate James Scott (D-Fairfax) recently sponsored a bill that would allow jurisdictions in Northern Virginia to hold a referendum on an increase in income taxation with additional revenues earmarked for transportation [Gov. Gilmore (R-VA) vetoed the bill, however]. Other options for raising revenue include increasing local gasoline, property, or sales taxes; raising transit fares; and implementing peak period congestion pricing on major highways.⁴

This paper is not about whether additional spending on transportation can be justified on economic grounds. Instead, we focus on the efficiency costs of raising an additional \$500 million annually from local revenue sources, the funding shortfall estimated by Cambridge Systematics (1998). This extra revenue would finance a spending increase on transportation of around 25%.⁵

The efficiency cost of raising this extra revenue equals the economic cost over and above the \$500 million transfer in spending power from the private sector to the government, and is caused by the

¹ See Board of Trade (1997a) for more discussion of proposed roadway projects. Road expansion projects tend to be controversial, however. For example, Gov. Glendening (Dem-MD) eventually blocked the much-debated intercounty connector.

² In fact, the current financial plan for the metropolitan Washington area borrows from projected surpluses during 2010-2020 to finance transportation deficits for 2000-2010. But these future surpluses hinge on the unrealistic assumption that no new investment projects will be started after 2010 (Price Waterhouse 1997). Moreover, the budget ignores the future cost of interest on the debt that will be incurred after 2000.

³ See, for example, editorials in the Washington Post on January 29, February 7, and March 11, 2000. Other regions have attempted to raise additional transportation revenues by increasing sales taxes and, to a lesser extent, property taxes (Cambridge Systematics 1998).

⁴ We do not analyze the efficiency effects of sales taxes because in our model they would be similar to those of the labor income tax.

⁵ Obviously the overall efficiency effect would depend on how the revenues were spent, for example, road versus transit. But our focus is purely on the financing costs.

impact of the policy on distortions created by externalities and by the tax system. At first glance it seems that there might be a strong case for raising the extra revenue from gasoline taxes or congestion fees because these policies reduce pollution and congestion externalities and hence appear to have large and negative economic costs. Conversely, we might expect significant efficiency costs from increasing labor taxes, because this policy reduces employment, and similarly for raising transit fares, because this policy indirectly adds to pollution and congestion from driving. This paper assesses whether these types of policy conclusions can in fact be drawn, and whether a strong case can be made for using one revenue source over the others, or for not using a particular revenue source.

The paper contributes to the literature in several ways. First, to our knowledge, it is the first attempt to analyze the efficiency costs of revenue-raising policies for the Washington, DC, area.⁶ Second, it expands the public finance literature on the excess burden of the tax system by analyzing a broader range of taxes. Most of this literature has focused on the excess burden of a single tax, usually the labor income tax (e.g., Ballard 1990, Ballard et al. 1985, Browning 1987, Feldstein 1999, Snow and Warren 1996, Stuart 1984). We also look at taxes on property, gasoline, mass transit, and congestion. In fact, there appears to be little empirical literature on the efficiency effects of these other taxes (we note some other studies below). Thus there is not much evidence on which to judge the economic case for raising additional revenue from these other taxes as opposed to labor income taxes.

Third, a key theme of our analysis is that the efficiency effects of a particular policy depend on how the policy interacts with the other policy distortions. For example, gasoline taxes, transit fares, property taxes, and congestion taxes tend to reduce the returns from work effort and hence reduce labor supply. Thus, they produce significant efficiency losses in the labor market, in the same way that higher labor taxes do. Partial equilibrium measures can therefore be highly misleading about the magnitude of, and even the sign of, the efficiency impact of tax increases.⁷

⁶ There are several useful, nontechnical discussions about the revenue potential of various local taxes (e.g., Board of Trade 1997b, Northern Virginia Transportation Coordinating Council 2000, Maryland Commission on Transportation Investment 1999). Our analysis builds on these studies by looking at the behavioral responses to higher taxes and the effects on economic efficiency.

⁷ Of course, it has long been recognized that the general equilibrium welfare effects of a tax can be very different from the partial equilibrium welfare effects when there are other tax distortions in the economy (e.g., Lipsey and Lancaster 1956, Harberger 1974), and some recent studies have emphasized the importance of indirect welfare effects in the labor market (see below). But the empirical magnitude of these interactions in the context of the policies we analyze has not really been spelled out before.

Fourth, the paper extends calculations of the efficiency costs of taxes to take into account the interactions of the taxes with external damages from pollution and congestion. It is worth noting that many previous studies of these externalities have not considered how they interact with the tax system, just as the public finance studies usually have abstracted from externalities. Thus, the paper indirectly contributes to the literature on externality assessment as well as to the literature on tax efficiency.

We use an analytical model to derive explicit formulas for the welfare effects, and revenue changes, from tax increases. Thus, the contribution of different underlying parameters to these effects is very transparent, and it is straightforward to infer how our results would change under alternative parameter assumptions. However, we provide only a rudimentary treatment of some policies, such as the property tax, and there is considerable uncertainty about some of the underlying parameters. Therefore, our paper should be viewed as laying out a preliminary framework for comparing the policies, which can be improved in the future through modeling refinements and through more econometric estimation of key parameters.

Under our central estimates, the efficiency cost of raising \$500 million from the labor tax is \$118 million; from transit fares is \$136 million; from property taxes is \$16 million; from gasoline taxes is \$66 million, and from the congestion tax is $-\$19$ million. As expected, costs are higher under the labor tax because this policy reduces employment, and under the transit fare because this policy indirectly increases pollution and congestion. But, for several reasons, the efficiency case for raising the additional revenues from gasoline and congestion taxes is not quite as overwhelming as we might have thought.

First, a large portion of the costs of pollution are already internalized through pre-existing gasoline taxes. Second, per dollar of revenue raised, the congestion and pollution benefits from gasoline taxes and congestion fees are limited, because the demand for both gasoline and for peak period travel is inelastic. Third, both these policies have adverse impacts on employment, and this narrows the cost differential between them and the labor tax. Fourth, the relative advantage of these policies is sensitive to the damages from pollution and congestion, which are uncertain—under a low-damage scenario raising additional revenues from the gasoline tax is more costly than raising the revenues from higher transit fares. Fifth, we only model an “ideal” congestion tax; in practice, congestion pricing would be less comprehensive than we assume and therefore less efficient. Sixth, other policies do have some efficiency advantages. For example, higher transit fares reduce a pre-existing, distortionary subsidy for transit travel, and higher property taxes counteract distortions from the favorable tax treatment of housing.

In short, gauging the efficiency effects of the revenue-raising policies is quite a complicated matter. Our results do suggest a preference for using congestion taxes, gasoline taxes, and property taxes, though this is subject to several qualifications.

The rest of the paper is organized as follows. The next section describes the model assumptions. Section 3 derives formulas for the welfare cost/gain from raising an extra dollar of revenue for each of the taxes. Section 4 presents estimates of these welfare effects. Section 5 compares the efficiency costs of raising \$500 million in revenues from the various taxes. Section 6 offers conclusions.

2. Model Assumptions

(i) *Utility.* Consider a one-period model of the metropolitan Washington, DC, economy where households have the following utility function:

$$(2.1) U = u(H, X, T, l) + \alpha(G^{PUB}) - \psi(P)$$

H is housing or real estate services, X is an aggregate of all other (nonhousing) consumption goods, T is sub-utility from travel, and l is leisure or nonmarket activities. $\alpha(\cdot)$ is utility from government spending on public goods, G^{PUB} , and $\psi(\cdot)$ is disutility from pollution, P . $u(\cdot)$ is quasi-concave, and $\alpha', \psi' > 0$.⁸

(ii) *Transport.* We disaggregate the annual amount of travel in the region into three components. R denotes the number of miles driven by car in the Washington area during peak periods (i.e., the morning and afternoon rush hours), OP is miles driven in the Washington area during off-peak periods, and M is miles traveled using the Metro system (either rail or bus), during peak or off-peak periods. For simplicity we do not model freight, as opposed to passenger, travel. Subutility from travel is given by:

$$(2.2) T = T(R, OP, M)$$

where $T(\cdot)$ is quasiconcave.

Driving at peak period causes traffic congestion, that is, the presence of an extra vehicle reduces the speed for other vehicles, thereby increasing the travel time of other drivers. Households do not take into account this external cost when deciding how much to drive at peak period. In contrast, there is no congestion externality from driving at off-peak period, or from using the Metro.⁹

⁸ For simplicity, we assume that pollution and public goods enter the utility function separably. This is a common assumption in the literature and rules out the possibility of certain feedback effects on labor supply. Evidence is lacking on whether these feedback effects are empirically significant or not. Our analysis does allow, implicitly, for feedback effects of traffic congestion on labor supply (see later).

⁹ Assuming that some of the congestion occurs at off-peak hours would not really affect our results, so long as we assumed that congestion fees were implemented at both peak and off-peak periods.

To travel a mile by a given mode requires ϕ_j units of time ($j = R, OP, M$), so that total travel time per household is $\phi_R R + \phi_{OP} OP + \phi_M M$. The total monetary cost to households from all driving is:

$$(2.3) \theta_R R + \theta_{OP} OP + (1 + t_G)G$$

θ_R and θ_{OP} are the nongasoline costs per mile from driving at peak and off-peak periods (vehicle wear and tear, parking costs, etc.). G denotes total gasoline consumption: $G = g_R R + g_{OP} OP$, where g_R and g_{OP} are gasoline consumption per mile at peak and off-peak periods (we normalize the supply price of gasoline to unity). t_G is the rate of gasoline tax. Later we model a congestion tax, but this is assumed to be zero in the initial equilibrium (essentially, there are no peak period fees in the Washington area at the moment). Driving time per mile at peak period, ϕ_R , though exogenous to the individual household, increases with the total amount of traffic, thus:

$$(2.4) \phi_R = \phi_R(R)$$

where $\phi'_R > 0$.

The Metro is publicly provided, and we assume that the (short-run) average cost of providing service is declining. One reason for this is that the load factor (i.e., passengers per train or bus) is likely to increase with travel demand, so that a doubling of travel demand can be met with less than a doubling of service frequency.¹⁰ For simplicity we denote the total production cost of rail service by $F + mT_R$, where F and m are parameters and m is the marginal supply cost. The passenger fare, or “tax,” per mile, is denoted by t_M .

(iii) *Production.* We assume that firms in the Washington region are competitive and employ labor to produce the two consumption goods, X and H , gasoline, and nongasoline inputs into road transport. We also assume that the supply curves for housing and gasoline are perfectly elastic, and we normalize the producer prices in these markets, the monetary cost per mile of road and Metro travel, and the gross wage, all to unity.¹¹

¹⁰ If we include travel time as part of the cost of producing travel services, average production costs could also be declining because a greater frequency of trains reduces passenger wait time at the platform. For more discussion about increasing returns in public transit, see for example Mohring (1972) and Viton (1992).

¹¹ The assumption of an infinitely elastic long-run supply of housing services is often assumed in the literature (e.g., King 1980).

(iv) *Government*. Although our focus is on local revenue increases, to measure the pre-existing policy distortions in various markets we need to consider the effect of both federal and state/District of Columbia policies. We denote the combined rate of tax on labor income imposed by these governments by t_L .

Real estate services are subject to a property tax denoted t_H . There is controversy over how distortionary the property tax is, but we postpone discussion of this for now. In addition, housing receives some favorable tax treatment through mortgage interest relief and exemption of imputed rent to owner-occupiers. We denote this tax subsidy, averaged across the real estate market, by \bar{s}_H . The consumer price of housing is therefore $1 - \bar{s}_H + t_H$.

Government revenue available for public goods spending, denoted REV , is:

$$(2.5) \quad REV = \sum_{j=L,H,G,M} t_j B_j - F - mM - \bar{s}_H H$$

where B_j is the base of tax j : $B_j = L, H, G$, and M when $t_j = t_L, t_H, t_G$, and t_M , respectively. That is, REV is equal to revenues from taxes on labor, housing, gasoline, and the Metro, minus outlays on the Metro and the tax-expenditure for housing. For the government budget to balance, $REV = G^{PUB}$.

(v) *Household Constraints and Optimization*. Households are subject to the following time constraint

$$(2.6) \quad \bar{L} = L + l + \phi_R R + \phi_{OP} OP + \phi_M M$$

where \bar{L} is the household time endowment. This equation says that the time endowment is allocated across labor supply, leisure time, and time on the three travel modes. In addition, the household budget constraint amounts to:

$$(2.7) \quad (1 - t_L)L = X + (1 - \bar{s}_H + t_H)H + \theta_R R + \theta_{OP} OP + t_G G + t_M M$$

The left-hand side here is net of tax labor income. The right hand side equals household expenditure on the aggregate consumption good, housing, and transport. Note that (2.6) and (2.7) imply that the opportunity cost of travel time is the net of tax wage. Empirical studies suggest it is a little below the net wage (see below); however, by choosing appropriate values for the ϕ s we can calibrate the model to be consistent with this evidence.

Finally, pollution is assumed to be proportional to the combustion of gasoline from road travel.¹² Thus:

$$(2.8) \quad P = G$$

(vi) *Diagrammatic Representation.* The pre-existing policy and externality distortions in the economy are summarized in Figure 1, where D , S , AC , and MSC denote demand, supply, average cost, and marginal social cost curves, respectively. The shaded triangles show the deadweight loss in each market caused by initial quantities (denoted by subscript 0) differing from the first-best optimal levels (denoted by superscript *).

In panel (a) the labor tax drives a wedge between the gross wage (equal to the value marginal product of labor) and the net wage (equal to the marginal opportunity cost of foregone leisure), hence labor supply is suboptimal.¹³ Panel (b) shows the “market” for peak road travel. The average cost curve reflects the sum of time and money costs per mile and is increasing in R due to the effect of more traffic on reducing travel speed. Households use the road up to the point where the benefit of one more trip (the height of D_R) equals the average cost. The marginal social cost exceeds the average cost because it includes the external cost imposed on other drives from more congestion.

In panel (c) D_G is the demand for gasoline (derived from the demand for peak and off-peak driving). The marginal social cost curve lies above the supply curve because gasoline causes external pollution damages. However, the price of gasoline is $1 + t_G$. As drawn in Figure 1, $1 + t_G < MSC_G$; hence gasoline consumption is excessive. However, in some of our scenarios the marginal pollution externality is less than the gasoline tax.

¹² 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, hence we can treat emissions as proportional to gasoline. Note that we ignore pollution from transit. The DC Metro is electric and pollution emissions are minimal, and emissions per passenger mile are much smaller for bus travel than for car travel.

¹³ The demand for labor curve is flat because of the assumption of constant returns and the assumption that labor is the only primary input. The upward sloping SL curve represents a situation in practice where a worker well to the left of L_0 has a low opportunity cost to being in the labor force (e.g., a young single worker who would be bored at home), while someone to the right of L_0 has a high opportunity cost to working (e.g., the partner of a working spouse who wants to stay home with the children).

Panel (d) shows the Metro market. Here, the marginal social cost of providing service lies below the average cost due to increasing returns. The gap between the marginal social and marginal private cost of Metro travel is $m - t_M$, shown as positive in the figure, implying an excessive amount of Metro travel. In other words, the subsidy overcompensates for increasing returns (see below). Finally, panel (e) shows the housing market. Here consumption is excessive because the consumer price of housing, net of the impact of taxes, is assumed to be below the supply price ($\bar{s}_H > t_H$).

3. Formulas for the Efficiency Effect of Raising \$1 in Additional Revenue

A. General Derivation

The marginal welfare cost (MWC) of a tax is the efficiency cost (or benefit) from raising one extra dollar of revenue. We use the definition of the MWC of a tax in Browning et al. (2000):

$$(3.1) MWC_j = \frac{\frac{de}{dt_j} - \frac{dREV^c}{dt_j}}{\frac{dREV^u}{dt_j}} \text{ for } j = L, H, G, \text{ and } M$$

' e ' denotes the household expenditure function (this is defined in Appendix A), $dREV/dt_j$ is marginal revenue from an increase in t_j , and superscript c and u denote compensated and uncompensated price effects. The denominator in (3.1) is the actual change in revenue that would result from an uncompensated tax increase. The numerator is the welfare loss (gain) from the pure substitution effect of the tax increase. It shows the compensation that must be paid to households to keep utility constant following an incremental increase in tax t_j , over and above the extra revenue raised when utility is constant. Therefore the MWC is the efficiency cost per dollar of additional revenue.¹⁴

Some manipulation gives (see Appendix A):

¹⁴ There is some confusion in the literature over the appropriate definition of the MWC. For example, in Ballard (1990) the MWC for government spending on public goods depends only on uncompensated price effects. However, we find the discussion in Browning et al. (2000) to be the most convincing on this issue.

$$(3.2) \quad MWC_j = \frac{- \left\{ t_L \frac{\partial L^c}{\partial t_j} - (\bar{s}_H - t_H) \frac{\partial H^c}{\partial t_j} - (MEC^P - t_G) \frac{\partial G^c}{\partial t_j} - MEC^R \frac{\partial R^c}{\partial t_j} - (m - t_M) \frac{\partial M^c}{\partial t_j} \right\}}{\frac{dREV}{dt_j}}$$

where $MEC^P = \psi'(P)/\lambda$ and $MEC^R = (1-t_L)R\phi'$ are the marginal external cost of pollution and congestion, respectively, expressed in monetary units and per capita terms.¹⁵

The numerator in (3.2) decomposes the welfare effect from an incremental increase in tax t_j into five components, corresponding to impacts in the five distorted markets in Figure 1. Each term equals a price wedge between marginal social benefit and marginal social cost, multiplied by a change in quantity (i.e., a slight increase or decrease in the area of a shaded triangle). For example, if labor supply is reduced in response to an increase in tax t_j ($\partial L^c / \partial t_j < 0$), this raises the MWC of tax t_j , because marginal social benefit exceeds marginal social cost in the labor market. Conversely, if gasoline demand falls ($\partial G^c / \partial t_j < 0$), this reduces the MWC of tax t_j , if the gasoline tax is below marginal external damages.

B. Specific MWC Formulas

(i) *Labor Tax.* For this case only, we simplify by ignoring the spillover welfare effects of higher labor taxes in other (nonlabor) markets of the economy. The main justification for this is that these markets are small relative to the labor market.¹⁶

We can obtain the following approximation for the MWC of the labor tax (see Appendix A):

$$(3.3) \quad MWC_L \approx \frac{\frac{t_L}{P_L} \varepsilon_{LL}^c}{1 - \frac{t_L}{P_L} \varepsilon_{LL}^u}$$

¹⁵ Note that the marginal external cost of congestion is the value of time $1-t_L$ multiplied by the increase in trip time per extra car, ϕ' , multiplied by the amount of per capita peak road traffic, R .

¹⁶ If we used a more general formula for the MWC of the labor tax, the terms corresponding to the spillover effects in other markets would be weighted by the size of the market relative to the labor market. These weights would be very small (see below).

where ε_{LL}^c and ε_{LL}^u denote the compensated and uncompensated labor supply elasticities, respectively, and $p_L = 1 - t_L$ is the net wage, or price of leisure. The numerator in (3.3), which reflects the welfare change per unit of the tax increase, depends on the compensated labor supply effect, because it reflects the pure substitution effect from the tax change. The denominator, which reflects the actual change in revenue from a tax increase, depends on the uncompensated labor supply effect (see Browning et al. 2000 for more discussion).

(ii) *Property tax.* We can obtain the following expression for the MWC of the property tax (see Appendix A):

(3.4) $MWC_H =$

$$\frac{\frac{\bar{s}_H - t_H}{p_H} \eta_{HH}^c - \pi_{LH} \frac{t_L}{p_H} \eta_{LH}^c + \pi_{GH} \frac{MEC^P - t_G}{p_H} \eta_{GH}^c + \pi_{RH} \frac{MEC^R}{p_H} \eta_{RH}^c + \pi_{MH} \frac{m - t_M}{p_H} \eta_{MH}^c}{1 + \frac{t_H - \bar{s}_H}{p_H} \eta_{HH}^u + \pi_{LH} \frac{t_L}{p_H} \eta_{LH}^u + \pi_{GH} \frac{t_G}{p_H} \eta_{GH}^u + \pi_{MH} \frac{t_M - m}{p_H} \eta_{MH}^u}$$

η_{iH} is the elasticity of the quantity in market i with respect to an increase in the consumer price of housing, π_{iH} is the size of market i relative to the size of the housing market (see Appendix A for definitions of η_{iH} and π_{iH}), and $p_H = 1 - \bar{s}_H + t_H$ is the consumer price of housing.

The first term in the numerator in (3.4) and second term in the denominator reflect the welfare effect and revenue change in the housing market. If we ignored all other terms, (3.4) would be similar to that in (3.3), where $\bar{s}_H - t_H$ is the net subsidy distortion in the housing market and η_{HH} is the own price elasticity of demand for housing. Note that, since $\eta_{HH} < 0$, the MWC would be *negative* in this case. The tax hike increases efficiency by reducing the net subsidy for housing. (Admittedly, this is a highly simplified treatment of the property tax—see Section 6).

The remaining terms in (3.4) reflect the spillover welfare and revenue effects in the other (nonhousing) markets. The relative importance of these cross-price effects depends on three factors: the size of the other market relative to the housing market (the π 's), the size of the price distortion in the other market relative to the consumer price of housing, and the cross-price elasticity.

The labor market effect can be expressed (see Appendix A):

$$(3.5) \frac{\pi_{LH} t_L \eta_{LH}}{p_H} = - \frac{t_L \mu_H \epsilon_{LL}}{p_L}$$

where μ_H reflects the degree of substitution between housing and leisure relative to the degree of substitution between goods in general and leisure. $\mu_H > 1$ implies that housing is a relatively strong leisure substitute and $0 < \mu_H < 1$ implies that housing is a relatively weak leisure substitute ($\mu_H < 0$ implies that housing is a leisure complement, but this case does not seem plausible). Labor supply falls because the increase in the price of housing drives up the general price level, thereby reducing the real household wage. This effect has been termed the “tax-interaction effect” and has been shown to be empirically important in several recent studies (see, e.g., Browning 1997, Goulder et al. 1997, and Parry and Oates 2000).¹⁷

Suppose that $\bar{s}_H = t_H$ (there is no distortion in the housing market), and we ignore effects in the gasoline, peak road, and Metro markets. Using (3.3)—(3.5) we see that the MWC of taxing housing would be less than the MWC from taxing labor if housing is a weak leisure substitute; the MWC of taxing housing is greater if housing is a relatively strong leisure substitute. These results are consistent with the Ramsey tax rule, which implies that weak (strong) leisure substitutes should be taxed (subsidized) relative to other goods.

(iii) *Gasoline tax.* The MWC of the gasoline tax can be expressed (see Appendix A):

$$(3.6) MWC_G =$$

$$\frac{\frac{MEC^P - t_G}{p_G} \eta_{GG}^c + \frac{t_L}{p_L} \mu_G \epsilon_{LL}^c + \pi_{HG} \frac{\bar{s}_H - t_H}{p_G} \eta_{HG}^c + \pi_{RG} \frac{MEC^R}{p_G} \eta_{RG}^c + \pi_{MG} \frac{m_M - t_M}{p_G} \eta_{MG}^c}{1 + \frac{t_G}{p_G} \eta_{GG}^u - \frac{t_L}{p_L} \mu_G \epsilon_{LL}^u + \pi_{HG} \frac{t_H - \bar{s}_H}{p_G} \eta_{HG}^u + \pi_{MG} \frac{t_M - m}{p_G} \eta_{MG}^u}$$

where η , μ and π are analogous to before and $p_G = 1 + t_G$ is the consumer price of gasoline. Note that, even if $t_G < MEC^P$ so that the pollution externality is not fully internalized, the MWC of the gasoline tax may still be positive depending on how it affects efficiency in the other markets.

¹⁷ Note that the labor market is a very large market and there is a large tax wedge of around 40% between the gross and net wage. Thus, it takes only a small reduction in labor supply to generate an efficiency loss that is significant relative to the efficiency change in the housing market.

(iv) *Transit tax.* The MWC of the transit tax can be expressed (see Appendix A):

(3.7)

$$MWC_M = \frac{\frac{m-t_M}{P_M} \eta_{MM}^c + \frac{t_L}{P_L} \mu_M \varepsilon_{LL}^c + \pi_{HM} \frac{\bar{s}_H - t_H}{P_M} \eta_{HM}^c + \pi_{GM} \frac{MEC^P - t_G}{P_M} \eta_{GM}^c + \pi_{RM} \frac{MEC^R}{P_M} \eta_{RM}^c}{1 + \frac{t_M - m}{P_M} \eta_{MM}^u - \frac{t_L}{P_L} \mu_M \varepsilon_{LL}^u + \pi_{HM} \frac{t_H - \bar{s}_H}{P_M} \eta_{HM}^u + \frac{\pi_{GM} t_G}{P_M} \eta_{GM}^u}$$

where $p_M = t_M$ is the transit fare and the η s are elasticities defined with respect to the transit fare.

From (3.7) we see that increasing the Metro fare t_M increases efficiency in the Metro market if the fare is below the marginal supply cost ($t_M < m$, $\eta_{MM} < 0$). But even if $t_M < m$, the marginal welfare cost of the transit tax can still be positive because of adverse spillover effects in other markets. For example, higher transit fares will increase the demand for driving, and hence increase pollution and congestion.

(v) *Congestion tax.* Finally, the MWC of the congestion tax is (see Appendix A):

(3.8) $MWC_R =$

$$\frac{\frac{MEC^R - t_R}{P_R} \eta_{RR}^c + \frac{t_L}{P_L} \mu_R \varepsilon_{LL}^c + \pi_{HR} \frac{\bar{s}_H - t_H}{P_R} \eta_{HR}^c + \pi_{GR} \frac{MEC^P - t_G}{P_R} \eta_{GR}^c + \pi_{MR} \frac{m - t_M}{P_R} \eta_{MR}^c}{1 + \frac{t_R}{P_R} \eta_{RR}^u - \frac{t_L}{P_L} \mu_R \varepsilon_{LL}^u + \pi_{HR} \frac{t_H - \bar{s}_H}{P_R} \eta_{HR}^u + \frac{\pi_{GR} t_G}{P_R} \eta_{GR}^u + \pi_{MR} \frac{t_M - m}{P_R} \eta_{MR}^u}$$

$p_R = 1 + t_R$ is the monetary cost of peak period driving. Note that this formula gives a lower bound estimate for the MWC in the sense that we implicitly assume that all congested roads are subject to congestion pricing. In practice, congestion pricing is unlikely to be this comprehensive, and consequently will be less efficient (e.g., Small and Yan 1999).

4. Calculations of the MWCs

Appendix B provides a detailed discussion of the parameter values used in the calculations, and the values are summarized in Tables 1a and b. Where data permits, we use parameter estimates for the metropolitan region, but often we must resort to average estimates for the whole U.S. economy. There is a lot of uncertainty over some parameters; hence our results should be treated with caution. But we indicate results over very broad parameter ranges, and we use Monte Carlo simulations to give some idea of the likelihood that the MWC of one policy exceeds that of another, given our parameter ranges.

Our calculations are for the impact on national economic welfare from local tax changes in the Washington region, because it seems appropriate to us to include the spillover welfare effects for other regions. For example, in response to higher local labor taxes we assume there is an efficiency loss from people leaving the labor force, but not from people switching to jobs outside the Washington region.¹⁸

(i) *Labor tax.* Table 2 shows calculations of the MWC of labor taxation using equation (3.3). The labor market tax distortion reflects the combined effect of payroll taxes, federal and local income taxes, and sales and excise taxes. Under our central values ($t_L=0.37$, $\varepsilon_{LL}^u=0.2$, $\varepsilon_{LL}^c=0.35$), the MWC is 0.23 (i.e., 23 cents of deadweight loss per dollar of additional revenue raised). Using our low and high values for these parameters implies that the MWC varies between 0.11 and 0.42.¹⁹

(ii) *Property tax.* The first column in Table 3 shows the MWC of the property tax according to equation (3.4), and using our central parameter values (see Table 1 and Appendix B). The central estimate for the MWC is 0.03. The first column also decomposes the efficiency changes in each of the five markets to the MWC.²⁰ The second and third columns show the efficiency changes in each market when we choose all relevant parameter values from their assumed ranges to make these terms as small and as large as possible. We note the following points.

First, there is a welfare gain in the housing market from raising the property tax; it is 9 cents per dollar in the central case and varies between 4 and 16 cents over our parameter ranges. According to our calculations, the subsidy from mortgage interest tax relief and the exemption of imputed income to owner-occupiers outweigh the property tax, leaving a net subsidy for housing of 7%—15% (Appendix B). Higher property taxes increase efficiency in the housing market by reducing this subsidy. The uncertainty

18 In addition, our estimates of the denominator in the MWC formulas reflect changes in revenues for all governments: in effect this means that we attach an efficiency loss/gain when local tax changes reduce/increase revenues for the federal government or other regional governments (the next section discusses changes in revenues for the District of Columbia only).

19 These values are a bit smaller than those reported in some other studies (e.g., Browning 1987). As discussed in Appendix B this is because we think it is appropriate to use a somewhat lower value for the labor tax rate.

Our analysis abstracts from some considerations that can raise the MWC of labor income taxes. See Browning (1994) on the implications of nontax distortions in the labor market, and Feldstein (1999) on the exemption of fringe benefits and other spending from income taxes.

20 That is, the figure for housing is the first term in the numerator in (3.4) divided by the (whole) denominator; the figure for labor is the second term in the numerator over the denominator, and so on.

over the net subsidy arises because it is not clear how distortionary the property tax is—the tax is not fully distortionary if people who pay higher property taxes are partially compensated by better local public services.

Second, raising a dollar of revenue from higher property taxes produces a welfare loss in the labor market, 17 cents in the central case, which is nearly as large as the welfare loss from raising a dollar of revenue from higher labor taxes, 23 cents. Moreover, in this central case we assume the degree of substitution between housing and leisure is a bit weaker than that between other goods and leisure. The reduction in labor supply occurs because, as discussed above, higher goods prices reduce the real household wage. Under different assumptions about labor tax rates, labor supply elasticities, and the relative degree of substitution between housing and leisure, the welfare loss in the labor market effect varies between 6 and 41 cents (Table 3, second row).

Third, the induced welfare impacts in the gasoline, peak period road, and Metro markets are typically unimportant. This is mainly because these markets are small relative to the housing market [for example, π_{MH} and π_{GH} in Equation (3.4) are 0.04 and 0.11, respectively].

In short, despite the adverse effect on labor supply, the MWC of the property tax is typically significantly below that of the labor tax in our model because the property tax works to reduce the net subsidy distortion for housing.

(iii) *Gasoline tax.* Our central value for the MWC of the gasoline tax is 0.07 (Table 4). At first glance, we might have expected the MWC of the gasoline tax to be strongly negative, because it reduces pollution and congestion. There are several reasons this is not the case.

First, pollution damages are assumed to be 60 cents per gallon in our central case. This estimate incorporates estimated damages to human health, visibility, and future global climate (Appendix B). However, the welfare gain from reduced gasoline depends on the pollution damages *net* of the gasoline tax, and the gasoline tax is around 40 cents per gallon. Thus, in our central case two-thirds of the damages from pollution are already internalized by the pre-existing gasoline tax. Second, the demand for gasoline is inelastic (η_{GG} is -0.35 in the central case). This limits the pollution benefits *per dollar of extra revenue*. Thus, in our central case the efficiency gain in the gasoline market is a fairly modest 7 cents per dollar (first column first row of Table 4). Under our most favorable parameter assumptions (pollution damages of 80 cents per gallon and $\eta_{GG} = -0.5$), the efficiency gain in the gasoline market is 19 cents.

Third, higher gasoline taxes do reduce congestion, but the proportionate reduction in miles traveled during the peak period is much smaller than the proportionate reduction in gasoline consumption. This is because some of the reduction in gasoline reflects reduced driving at off-peak periods, and some

of it reflects people purchasing more fuel-efficient cars in the long run. The induced welfare gain in the peak period road market lies between 5 and 12 cents, which is significant but not especially large (fourth row of Table 4).

Fourth, the gasoline tax has an adverse effect on labor supply by increasing the price of consumer goods and thereby reducing the real household wage. This causes an efficiency loss of between 6 and 41 cents under different assumptions about the labor tax, labor supply elasticities, and the relative degree of substitution between gasoline and leisure. In our central case, this effect is large enough to more than offset the efficiency gains from reducing pollution and congestion.²¹

Finally, the increase in gasoline taxation causes a modest welfare loss of between 2 and 14 cents in the Metro market because it increases the demand for Metro travel, thereby exacerbating the efficiency loss of the pre-existing fare subsidy (see below).²²

(iv) *Transit Tax.* Our central estimate for the MWC of the transit tax is 15 cents (Table 5), which is only 8 cents larger than the central estimate for the gasoline tax. At first glance this may seem a surprisingly small difference, because higher Metro fares indirectly increase pollution and congestion, and adversely affect the labor supply. Again, there are some subtle factors at work.

First, there is a large wedge between the marginal cost of providing transit service and the marginal benefit to households, or the transit fare. The fare is only 53% of average operating costs for the District of Columbia Metro system. Making some allowance for economies of scale still leaves a large net subsidy of 32% in our central case. Therefore, increasing the transit fare produces an efficiency gain of 14 cents in the transit market, even though the demand for transit is inelastic. This efficiency gain varies between 8 and 21 cents under alternative assumptions about the transit demand elasticity and the extent of economies of scale (Table 5, first row).

21 Another study that estimates the MWC of gasoline taxation for the United States, taking into account interactions with the tax system, is Bovenberg and Goulder (1997). In their numerical model, the MWC is (plus) 59 cents per dollar, which is way above our central estimate. A couple of factors explain some of the discrepancy. First, their estimate excludes pollution and congestion benefits. Without these benefits our central value for the MWC would be (plus) 37 cents. Second, they assume that gasoline is an average, rather than a relatively weak, substitute for leisure. Making this adjustment as well increases our central value to 44 cents.

22 We may have overstated the MWC of the gasoline tax in the sense that, for simplicity, our model abstracts from traffic accidents. However, a large portion of the costs of traffic accidents may be internal; for example, drivers will take into account the risk of fatalities to themselves (see Small and Gómez-Ibáñez 1999 for more discussion).

Second, the welfare losses from increased pollution and congestion are significant, but not huge (8 and 11 cents, respectively, in our central case). The efficiency loss from the increase in gasoline demand is mitigated to some extent by the pre-existing gasoline tax. In addition, the increase in demand for peak-period driving is not that large because some of the reduced transit travel reflects an overall reduction in the demand for travel, and some is reflected in more off-peak driving.²³

(v) *Congestion Tax*. The central value for the MWC of the congestion tax is minus 5 cents in our central case (Table 6). Based on a comparison of central values, the congestion tax is the only example where higher taxes produce a net gain rather than a net loss in economic efficiency.

Still, the MWC of the congestion tax is perhaps not as strongly negative as we might have expected. In our central case we assume the (marginal) congestion cost is 20 cents per mile, for peak period driving in the Washington area. This is five times our assumed pollution costs per mile and is substantially higher than in studies for other, less congested regions (see, e.g., Daniel and Bekka 2000 for the Delaware region). But again, because the demand for peak period driving is inelastic ($\eta_{RR} = -0.3$ in our central case), the efficiency gains from reducing congestion per dollar of extra revenue are limited to 15 cents in our central case (Table 6, first row). The efficiency gain varies from 7 to 26 cents under different scenarios for congestion costs and the peak period demand elasticity.

Moreover, the pollution benefits from congestion taxes are very small. Much of the pollution tax is internalized by the existing gasoline tax, and the gasoline market is fairly small relative to the market for peak period driving ($\pi_{GR} = 0.33$), and some of the reduced gasoline consumption on congested roads is offset by increased driving on other (uncongested) roads.²⁴ Finally, the congestion tax reduces the return to work effort; for example, it raises the costs of commuting to work, and the efficiency cost of the reduction in labor supply offsets two-thirds of the benefits from reduced congestion in our central case.²⁵

23 A recent study by Winston and Shirley (1998) finds very substantial efficiency gains from reducing transit fares. However, their analysis is not confined to Washington, DC, and for their purposes the costs of added congestion are a lot smaller. In addition, their analysis does not take into account the adverse impact on labor supply, which significantly raises the cost of higher transit fares in our analysis.

24 See Parry and Bento (2000a) for more discussion of these issues.

25 See Parry and Bento (2000b) for a detailed discussion of how congestion taxes affect labor supply. The calculations above make some allowance for reduced congestion itself having a positive feedback on labor supply. That is, the increase in monetary costs of driving to work is partially offset by a reduction in time costs of commuting (see Appendix B).

(vi) *Monte Carlo Simulations*. Clearly we should not put too much faith in our central estimates for the MWCs, because there is a lot of uncertainty over some of the underlying parameter values. We now turn to some Monte Carlo simulations to infer “confidence intervals” for the MWCs and to assess the likelihood of one MWC exceeding that of another, given our chosen parameter ranges. To do this we adopt triangular distributions for each of the uncertain parameters in Tables 1a and b, centered on the midpoint of the parameter ranges. We assume a 70% probability that a parameter value lies within the specified range, a 15% probability the parameter value is above our range, and a 15% probability it is below our range.²⁶ For a given randomly selected set of parameter values from their respective distributions, we then calculate the MWC for all the taxes using the formulas in Section 3. This procedure is repeated 10,000 times.²⁷

The first column in Table 7 shows the mean values of the MWCs over the 10,000 runs. These correspond very closely to the central values for the MWCs in Tables 2–6. The second column shows the 80% confidence intervals for the MWCs, that is, 8,000 of the 10,000 randomly generated values for the MWCs lie within these ranges. The 80% confidence intervals are as follows: 16 to 33 cents for the MWC of the labor tax; –6 to +10 cents for the property tax; –4 to +15 cents for the gasoline tax; 4 to 30 cents for the transit tax; and –12 to 1 cents for the congestion tax.

Because the confidence intervals are overlapping, in Table 8 we indicate the likelihood of the MWC of one tax exceeding that of another. In particular, we compare the MWC of each tax relative to that of the labor tax. In the first column we see that, for any randomly generated set of parameter values, the MWC of the property tax, gasoline tax, and congestion tax are always less than that of the labor tax. The MWC of the transit tax is less than that of the labor tax in 77% of the simulations. The second column indicates that the MWC of the property tax is less than 50% of the MWC of the labor tax with 98% probability, and with 88%, 31%, and 100% probabilities for the gasoline, transit, and congestion taxes, respectively. The final column shows that the MWC is negative, with 38% probability for the property tax, 22% for the gasoline tax, 4% for the transit tax, and 85% for the congestion tax.

²⁶ For example, for these simulations the minimum value of the labor tax is given by $0.34 - (0.4 - 0.34)0.15/0.7$ and the maximum value is given by $0.4 + (0.4 - 0.34)0.15/0.7$.

²⁷ We used the ANALYTICA software for these simulations.

5. Costs of Raising \$500 Million of Additional Revenue

In this section, we first estimate the increase in the various taxes that would be required to raise up to \$500 million of additional *local* revenue. We then compare the efficiency costs of raising this revenue from the different taxes.

A. Tax Increases Required to Raise \$500 Million

(i) *General Formula for the Revenues from Non-Incremental Tax Increases.* To consider nonmarginal tax changes, we make the assumption that all elasticities are constant. Using a second order Taylor series approximation, the change in quantity i following an increase in tax t_j is (superscripts 0 and 1 denote values before and after the tax change, and quantity changes are uncompensated):²⁸

$$(5.1) \Delta B_i \approx \frac{dB_i}{dp_j} \Delta t_j + \frac{d^2 B_i}{dp_j^2} \frac{(\Delta t_j)^2}{2} = \eta_{ij}^u B_i^0 \frac{\Delta t_j}{p_j^0} \left\{ 1 - \frac{\Delta t_j}{2p_j^0} \right\}$$

Using (2.5), the change in government revenue from an increase in tax t_j is:

$$(5.2) \quad \Delta REV = \Delta t_j B_j^0 - t_j^1 \Delta B_j + \sum_{i \neq j, R} t_i \Delta B_i - m \Delta B_M - \bar{s}_H \Delta B_H$$

The first term on the right in this expression is the extra revenue if there were no change in the base of tax t_i . The second term is the revenue loss due to the erosion of the base of tax t_j . The summation term reflects changes in tax revenues in other markets due to cross-price effects. The final two terms reflect changes in the costs of providing the Metro, and the tax-subsidy for housing, due to induced changes in demand in these markets. Using (5.1) and (5.2) we are able to estimate the extra revenue raised from tax increases.²⁹

To estimate revenue changes at the regional rather than the national level, we need to change a few of the parameter values assumed in Table 1a. For example, the loss of local revenue due to a given

²⁸ Note that

$$\frac{dB_i}{dp_j} = \eta_{ij} \frac{B_i^0}{p_j^0}; \quad \frac{d^2 B_i}{dp_j^2} = -\eta_{ij} \frac{B_i^0}{(p_j^0)^2}$$

²⁹ Note that we focus on the net change in revenue from all sources rather than just the change in revenue from tax t_j .

reduction in labor supply depends on the local tax rates only, rather than the combined effect of federal and regional taxes. Appendix D briefly describes the modified parameter assumptions we used to estimate local revenue changes.

(ii) *Empirical Relation Between Revenues and Tax Rates.* Using (5.1) and (5.2), figure 2 shows the relation between additional revenues (vertical axes) and higher tax rates (horizontal axes), for each of the five taxes. To illustrate the impact of behavioral effects, in each panel the dashed curve corresponds to when behavioral effects are ignored, that is, when we ignore the last four terms on the right in (5.2). The upper and lower solid curves in each panel show upper bound and lower bound estimates for the additional revenues from tax increases, that is, when we vary all parameter values within their assumed ranges to make the revenue gains as large and as small as possible.

Panel (a) shows revenues from increasing the local labor income tax. The upper and lower solid curves correspond to when the uncompensated regional labor supply elasticity is either 0.2 or 0.8. From these two curves, we see that the regional labor income tax would have to be increased from an average of 4% to 4.5%–4.6% to generate additional revenues of \$500 million. The gaps between the three curves in this panel are not very large because the erosion of the local tax base due to the reduction in labor supply is relatively small. This reflects the low rate of regional tax—income and sales taxes amount to only about 7% of total labor income.

Panel (b) shows that the local gasoline tax would have to be increased from an average of 20 cents per gallon up to 44–48 cents per gallon to generate \$500 million in extra revenue. Again the regional government bears only a portion (about half) of the total revenue loss from the reduction in gasoline demand. We estimate that the transit fare would have to increase from 53% of transit operating costs up to 118%–127% of costs to raise an extra \$500 million [Panel (c)]. Note that behavioral responses actually increase rather than reduce net local revenues in this case (i.e., the solid curves lie above the dashed curve). This is because reducing service in response to higher transit fares cuts the overall operating losses of the Metro system. Panel (d) indicates that a peak period congestion tax of 3.5–3.8 cents per mile would yield local revenues of \$500 million.³⁰ Finally, Panel (e) shows that \$500 million

³⁰ Obviously, if congestion pricing were less than fully comprehensive, the per-mile charges would have to be higher.

could be raised by increasing the property tax from an average rate of 1.30% on the value of housing up to 1.325%–1.330%.³¹

The relatively small discrepancies between the solid curves in each of the five panels in Figure 2 show that we can predict, without too much uncertainty, the tax increases required to generate the necessary revenues. Finally, note that our analysis does not consider the political feasibility of the tax increases. Most likely, it would be politically impossible to raise all of the \$500 million in revenue exclusively from local increases in gasoline taxes, transit fares, or congestion fees, because the required tax changes for these policies are quite drastic.

B. Efficiency Costs of Raising \$500 million

Figure 3 shows the MWC curves for each tax as the tax is increased from its initial level up to the level required to raise \$500 million in additional revenue. Panel (a) corresponds to our central parameter assumptions, and the intercepts of the MWC curves equal the central values for the MWCs from Tables 2–6.³² Here we see that the MWC curves for the labor tax, property tax, and congestion tax are just about flat, meaning that the efficiency costs of raising \$500 million in additional revenue is approximately equal to \$500 million times the MWCs estimated in Section 4.

In contrast, the MWC curves for the gasoline tax and transit fare have a strong upward slope. This reflects the relatively narrow bases of these taxes (reflected in low values for their π s), meaning that a proportionately large tax increase is required to generate a given amount of extra revenue. Thus, multiplying \$500 million by the MWCs for these taxes from Section 4 will significantly understate the total efficiency costs of raising this revenue. Under our central parameter values, the efficiency cost of raising \$500 million in extra revenue from labor taxes is \$118 million; from transit fares is \$136 million;

³¹ Other studies reach broadly similar conclusions about the increases in local income, property, and gasoline taxes necessary to raise \$500 million (e.g., Board of Trade 1997b). We are not aware of previous assessments of the revenue potential from congestion taxes and higher transit fares for the Washington region.

³² To obtain these curves we calculate the tax increases, Δt_j , necessary to obtain an additional \$250 million and \$500 million in revenues, as indicated by Figure 2, using our central parameter values. To calculate the MWC at these revenue amounts we simply use $t_j + \Delta t_j$ rather than t_j in the formulas in the section 3, keeping all the other parameters at their central values.

from property taxes is \$16 million; from gasoline taxes is \$66 million; and from the congestion tax is -\$19 million.

But it is important to acknowledge that the relative efficiency performance of the tax policies is very sensitive to different scenarios for external damages. In Panel (b) of Figure 3 we consider a high-damage scenario (pollution damages 80 cents per gallon, congestion damages 26 cents per mile). In this case the transit tax is the worst policy, causing efficiency losses of \$225 million, whereas the congestion tax and gasoline tax produce efficiency gains of \$70 million and \$25 million, respectively, for \$500 million in additional revenue. Finally, in Panel (c) we consider a low external damage scenario (pollution damages of 40 cents per gallon and congestion costs of 14 cents per mile). In this scenario the gasoline tax has the highest efficiency costs of any policy; indeed it would be most efficient to raise the first \$200 million of extra revenues from higher transit fares.

6. Conclusion

This paper develops and implements an analytical framework for estimating the efficiency effects of raising “small” and “large” amounts of additional revenues from labor taxes, property taxes, gasoline taxes, transit fares, and congestion taxes. The analysis is applied in the context of raising more revenues for transportation infrastructure spending in the metropolitan Washington, DC, area, but it would be straightforward to apply the analysis to other regions. Congestion and pollution damages are probably lower for other regions (except Los Angeles) which, other things being equal, would reduce the attractiveness of higher local gasoline taxes and congestion fees, and increase the attractiveness of higher transit fares.

Our results suggest that the efficiency costs of raising revenues in the District of Columbia region would be lowest under congestion taxes, property taxes, and gasoline taxes, and higher under transit fares and labor taxes. But the efficiency differences between the policies are perhaps not as large as we might have expected because of several subtle considerations. For example, all the policies adversely affect labor supply, and this narrows the gap between their efficiency cost and that of the labor tax. The demands for gasoline and for peak period driving are both inelastic, and this limits the pollution and congestion benefits from gasoline taxes and congestion fees for a given amount of additional revenue. In addition, pre-existing gasoline taxes internalize much of the pollution externality from gasoline, and the overall costs of higher transit fares are lower because fares are currently well below marginal supply costs.

There are several reasons our results are preliminary and should be treated with caution. First, the relative welfare effects of the tax increases are sensitive to alternative values for the external damages from pollution and congestion, and these are difficult to pin down. Second, our congestion tax policy assumes that all routes with traffic congestion will be priced. In practice, if congestion pricing were implemented it would be far less comprehensive, and therefore less efficient.³³

Third, our treatment of the property tax is also highly simplified. In particular, we treat housing as a consumption good whereas in part it is also an investment good. This means that property taxes may exacerbate the efficiency costs of taxes on capital, and this effect is excluded from our analysis. In addition, the long-run supply curve for housing may not be perfectly elastic, as we have assumed.³⁴ Finally, our analysis assumes that policies would be coordinated across jurisdictions in the metropolitan Washington region. If tax increases were not coordinated, revenue raising would be more costly than assumed in our analysis.

³³ For more discussion of the problems of incomplete pricing of congestion within a road network; see, for example, Small and Yan (1999) and Parry and Bento (2000a).

³⁴ Our analysis excludes several other factors that affect the amount of distortion in the housing market but are difficult to quantify. These include possible external benefits if homeowners take better care of property than renters, possible external costs from development on natural habitat, and regulations such as building codes and zoning laws.

Table 1a. Summary of Parameter Values Assumed in Calculations

Parameter	Illustrated range of values
Size of markets relative to the labor market	
Housing, π_{HL}	0.19
Gasoline, π_{GL}	0.02
Metro, π_{ML}	0.007
Peak road, π_{RL}	0.06
Own price demand elasticity ^a	
Labor (uncompensated supply elasticity), ϵ_{LL}^u	0.1 to 0.3
Labor (compensated supply elasticity), ϵ_{LL}^c	0.2 to 0.5
Housing, η_{HH}	-0.4 to -1.0
Gasoline, η_{GG}	-0.2 to -0.5
Metro, η_{MM}	-0.2 to -0.4
Peak road, η_{RR}	-0.2 to -0.4
Relative degree of substitution with leisure ^b	
Housing, μ_H	0.6 to 1.0
Gasoline, μ_G	0.6 to 1.0
Metro, μ_M	0.6 to 1.0
Peak road, μ_R	0.4 to 0.6
Net tax/subsidy	
Labor tax, t_L	0.34 to 0.40
Housing subsidy net of property tax, $\bar{s}_H - t_H$	0.07 to 0.15
Gasoline tax, t_G	0.5 (40 cents per gallon)
Metro fare (relative to average operating cost), t_M	0.53
Gap between MC and fare for Metro, $m - t_M$	0.22 to 0.42

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Congestion tax (initial value), t_R	0
Marginal external damages Pollution from gasoline, MEC^P	0.5 to 1.0 (40 – 80 cents per gallon)
Congestion from peak-period driving, MEC^R	0.35 to 0.65 (14 – 26 cents per mile)

^a We use different values for the uncompensated and compensated labor supply elasticities, but the same values for the uncompensated and compensated demand elasticities (see Appendix B).

^b μ equals (is less than) one when the good is an average (relatively weak) substitute for leisure.

Table 1b. Cross-Price Elasticities

	Housing	Gasoline	Metro	Peak road
Housing	–	–0.05 to –0.5	–0.05 to –0.5	–0.05 to –0.5
Gasoline	–0.01 to –0.08	–	0.4 to 0.8	–0.04 to –0.08
Metro	0 to –0.01	0.05 to 0.1	–	0.005 to 0.03
Peak road	–0.02 to –0.08	–0.07 to –0.13	0.5 to 1.0	–

Table 2. Marginal Welfare Cost of Labor Tax

	Central	Lower bound	Upper bound
MWC_L	0.23	0.11	0.42

Table 3. Marginal Welfare Cost of Property Tax

	Central	Lower bound	Upper bound
MWC_H	0.03		
Decomposition			
Housing	–0.09	–0.16	–0.04
Labor	0.17	0.06	0.41
Gasoline	–0	–0.05	0
Road	–0.03	–0.10	–0.01
Metro	0	–0.02	0

Table 4. Marginal Welfare Cost of Gasoline Tax

	Central	Lower bound	Upper bound
MWC_G	0.07		
Numerator terms			
Gasoline	-0.07	-0.19	0
Labor	0.21	0.07	0.6
Housing	-0.04	-0.1	-0.01
Road	-0.08	-0.12	-0.05
Metro	0.06	0.02	0.14

Table 5. Marginal Welfare Cost of Transit Tax

	central	Lower bound	Upper bound
MWC_M	0.15		
Numerator terms			
Metro	-0.14	-0.21	-0.08
Labor	0.12	0.04	0.31
Housing	-0.02	-0.05	0
Road	0.11	0.03	0.20
Gasoline	0.08	0	0.17

Table 6. Marginal Welfare Cost of Congestion Tax

	Central	Lower bound	Upper bound
MWC_M	-0.05		
Numerator terms			
Road	-0.15	-0.26	-0.07
Labor	0.10	0.04	0.20
Housing	-0.02	-0.04	0
Gasoline	-0.01	-0.02	0
Metro	0.03	0.01	0.05

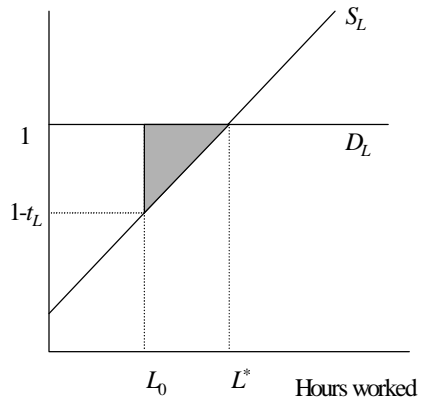
Table 7. Confidence Intervals for the Marginal Welfare Costs

Tax	Mean value of MWC	80% Confidence interval for MWC
Labor	0.24	0.16 to 0.33
Property	0.02	-0.06 to 0.10
Gasoline tax	0.05	-0.04 to 0.15
Transit tax	0.17	0.04 to 0.30
Congestion tax	-0.05	-0.12 to 0.01

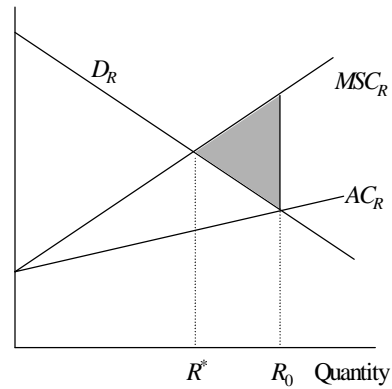
Table 8. Comparing the Marginal Welfare Cost of the Taxes

Tax	Probability that MWC of tax is less than		
	MWC of labor tax	50% of MWC of labor tax	0
Property tax	1	0.98	0.38
Gasoline tax	1	0.88	0.22
Transit tax	0.77	0.31	0.04
Congestion tax	1	1	0.85

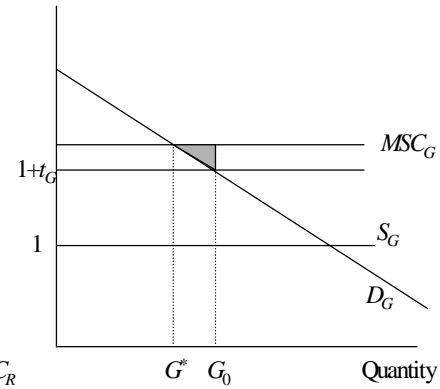
Figure 1



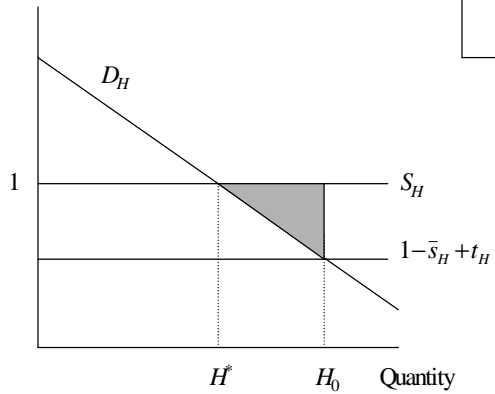
(a) Labor market



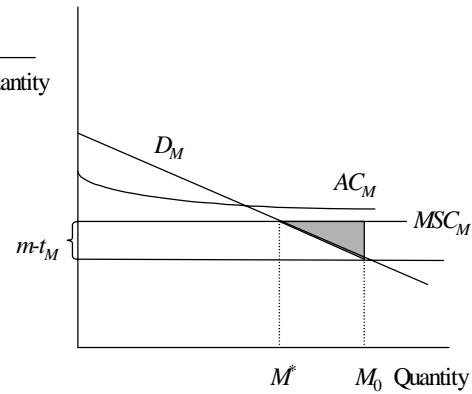
(b) Peak road travel market



(c) Gasoline market



(e) Housing market



(d) Metro market

Figure 2. Relationship Between Revenues and Tax Rates

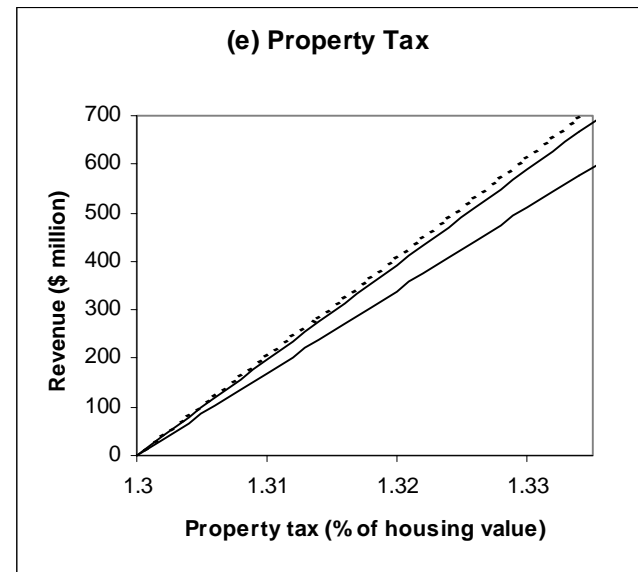
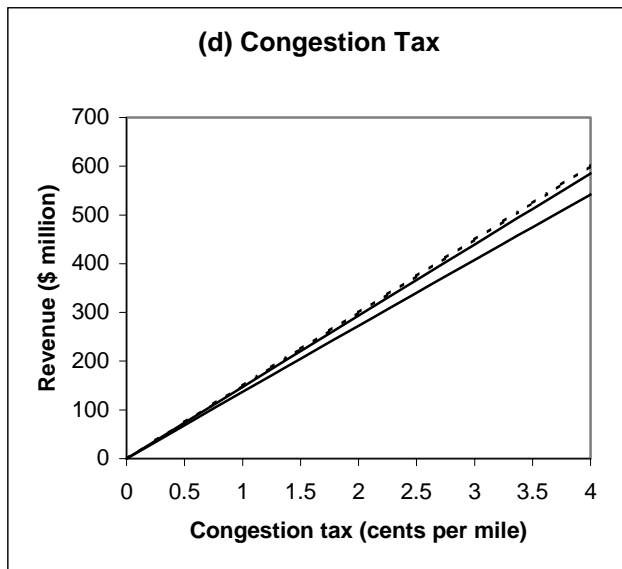
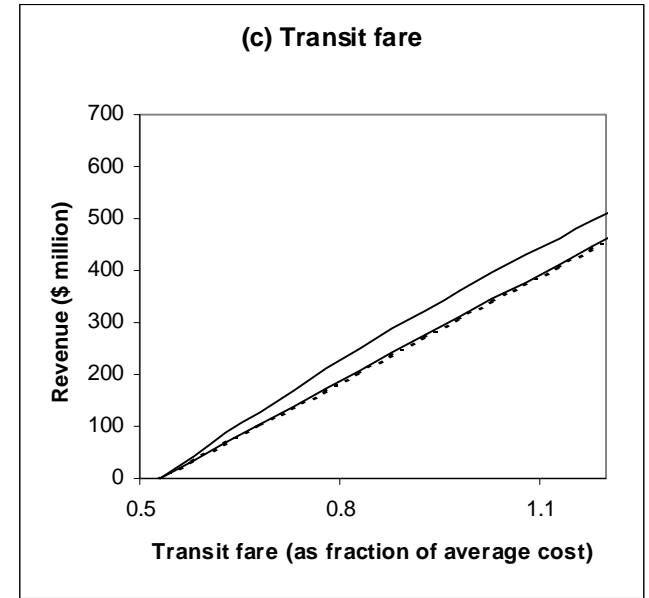
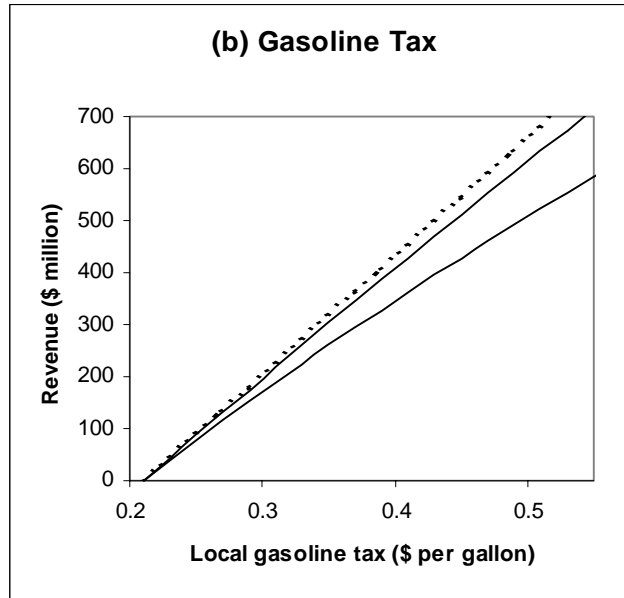
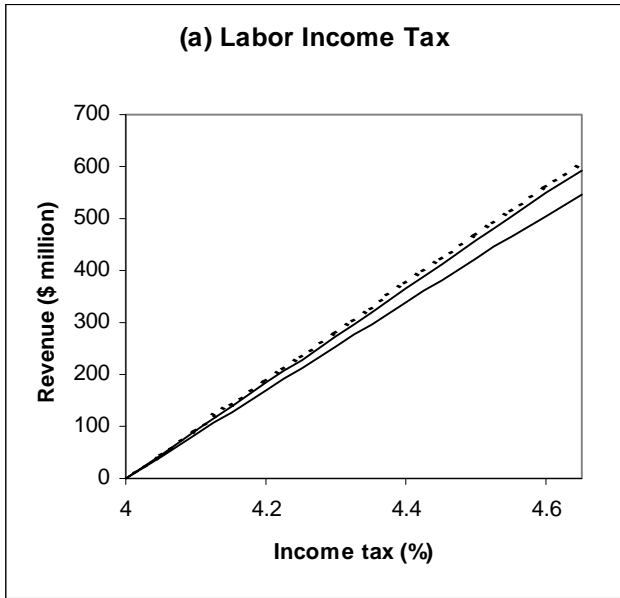
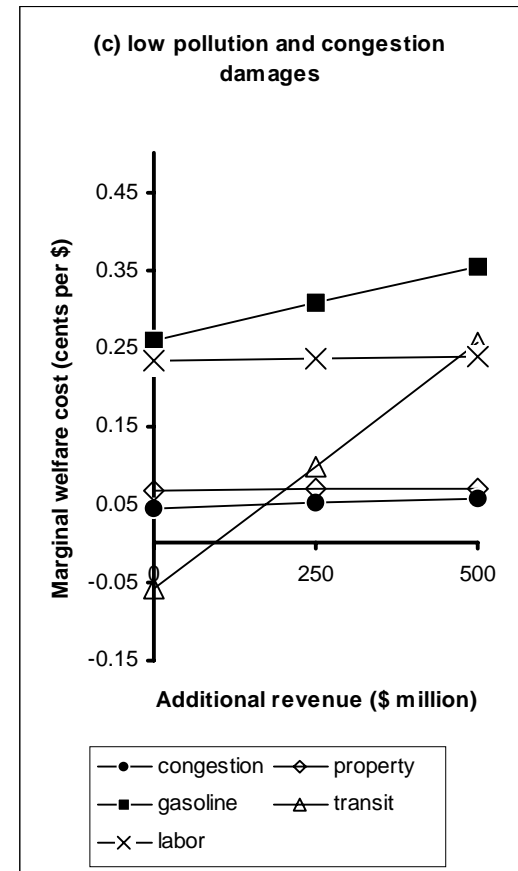
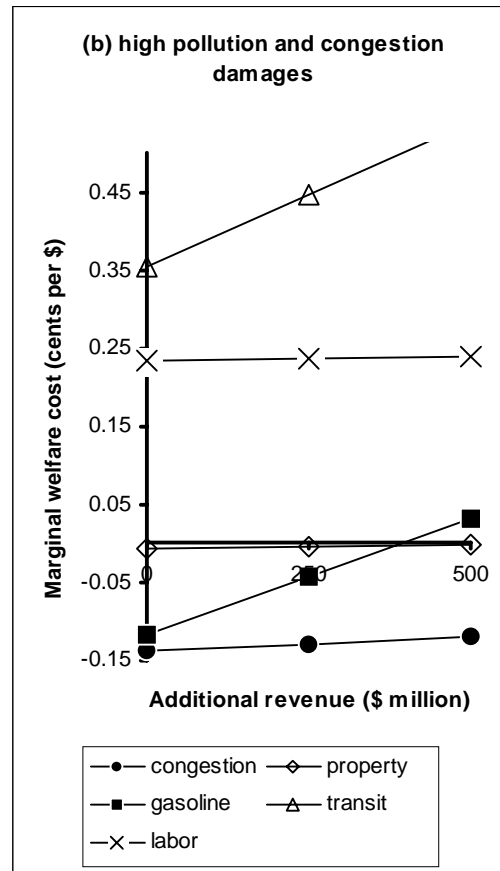
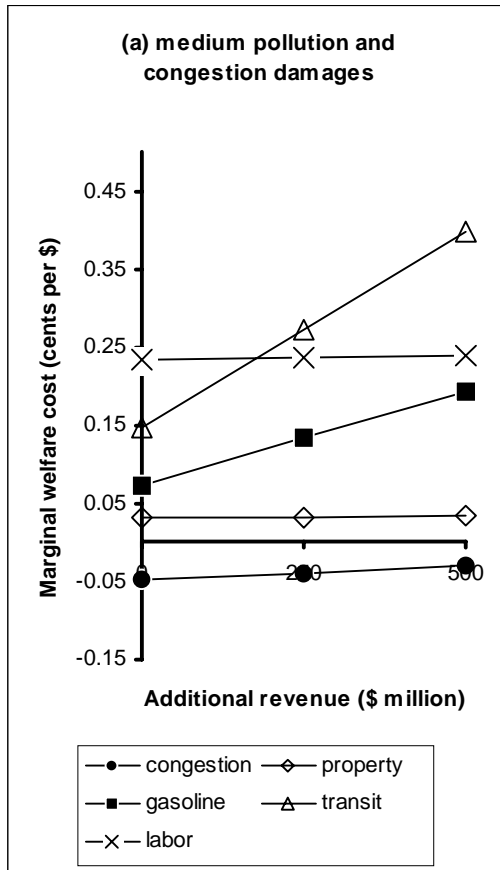


Figure 3. Marginal Welfare Costs from Raising an Extra \$500 million of Revenue



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Appendix A: Analytical Derivations

Combining (2.6) and (2.7) into a full income constraint, and using (2.11), the household utility maximization problem is:

$$(A1) V(t_L, t_H, t_G, t_M, \phi_R, G^{PUB}, P) = \text{Max } u\{H, X, T(R, OP, M), l\} + \alpha(G^{PUB}) - \psi(P) \\ + \lambda \left\{ (1-t_L)\bar{L} - (1-t_L)l - (1-t_L)[\phi_R R + \phi_{OP} OP + \phi_M M] \right. \\ \left. - X - (1-\bar{s}_H + t_H)H - \theta_R R - \theta_{OP} OP - t_G G - t_M M \right\}$$

where the Lagrange multiplier λ is the marginal utility of income and $V(\cdot)$ is indirect utility. The household chooses the quantity of consumption goods, travel, and non-market activity to maximize utility subject to the full income constraint. From the household's first order conditions we can obtain the uncompensated demand and labor supply functions:³⁵

$$(A2) B_j^u = B_j^u(t_L, t_H, t_G, t_M, \phi_R) ; j = H, R, M, L, G, X, OP$$

The dual of the household problem is:

$$(A3) e(t_L, t_H, t_G, t_M, \phi_R, G^{PUB}, P, V^*) = \text{Min } \left\{ (1-t_L)l + (1-t_L)[\phi_R R + \phi_{OP} OP + \phi_M M] \right. \\ \left. + X + (1-\bar{s}_H + t_H)H + \theta_R R + \theta_{OP} OP + t_G G + t_M M \right\} \\ + \lambda^{-1} \left\{ u[H, X, T(R, OP, M), l] + \alpha(G^{PUB}) - \psi(P) - V^* \right\}$$

where $e(\cdot)$ is the expenditure function and V^* is the maximized value of utility. This problem yields the compensated demand and labor supply functions:

$$(A4) B_j^c = B_j^c(t_L, t_H, t_G, t_M, \phi_R) ; j = H, R, M, L, G, X, OP$$

³⁵ Due to separability, these equations do not depend on G^{PUB} or P .

Differentiating (A3) gives:

$$(A5) \quad \frac{\partial e}{\partial t_j} = B_j; \quad \frac{\partial e}{\partial \phi_R} = (1-t_L)R; \quad \frac{\partial e}{\partial P} = \frac{\psi'(P)}{\lambda}$$

Using (2.4) and (2.8), note that:

$$(A6) \quad \frac{de}{dt_j} = \frac{\partial e}{\partial t_j} + \frac{\partial e}{\partial \phi_R} \phi' \frac{\partial R^c}{\partial t_j} + \frac{\partial e}{\partial P} \frac{\partial G^c}{\partial t_j}$$

Differentiating (3.5) for compensated and uncompensated tax changes gives:

$$(A7) \quad \frac{dREV^c}{dt_j} = B_j + \sum_i t_i \frac{\partial B^c}{\partial t_j} - m \frac{\partial M^c}{\partial t_j} - \bar{s}_H \frac{\partial H^c}{\partial t_j} \quad i = H, M, L, G$$

$$(A8) \quad \frac{dREV''}{dt_j} = B_j + \sum_i t_i \frac{\partial B''}{\partial t_j} - m \frac{\partial M''}{\partial t_j} - \bar{s}_H \frac{\partial H''}{\partial t_j}$$

Deriving (3.2). This is easily obtained by substituting (A5)–(A7) in (3.1).

Deriving (3.3). This can be obtained by setting $t_j = t_L$, using (3.2) and (A8), ignoring all terms in non-labor markets, and using:

$$(A9) \quad \varepsilon_{LL} = \frac{\partial L}{\partial(1-t_L)} \frac{1-t_L}{L}; \quad p_L = 1-t_L$$

Deriving (3.4). This can be obtained by setting $t_j = t_H$, using (3.2) and (A8), and using:

$$(A10) \quad p_H = 1 - \bar{s}_H + t_H; \quad \eta_{HH} = \frac{\partial H}{\partial t_H} \frac{p_H}{H}; \quad \eta_{LH} = \frac{\partial L}{\partial t_H} \frac{p_H}{L}; \quad \eta_{GH} = \frac{\partial G}{\partial t_H} \frac{p_H}{G}; \quad \eta_{RH} = \frac{\partial R}{\partial t_H} \frac{p_H}{R};$$

$$\eta_{MH} = \frac{\partial M}{\partial t_H} \frac{p_H}{M}; \quad \pi_{LH} = \frac{L}{H}; \quad \pi_{GH} = \frac{G}{H}; \quad \pi_{RH} = \frac{R}{H}; \quad \pi_{MH} = \frac{M}{H}$$

Deriving (3.6)–(3.8). These equations can be obtained by following the same procedure as for the property tax (see below also), and using $t_j = t_G$, t_M or t_R . The remaining notation is given by:

$$\eta_{ij} = \frac{\partial X_i}{\partial p_j} \frac{p_j}{X_i}; \mu_j = \frac{\eta_{jL}}{\sum_i \eta_{iL} \pi_{iL}}; \pi_{ij} = \frac{B_i}{B_j}$$

Deriving (3.5). Consider first a compensated price change. The compensated labor supply function can also expressed:

$$(A11) L = L(p_X, p_H, p_G, p_R, p_{OP}, p_M, p_L)$$

where the p 's are the money prices of final goods (including travel and leisure) purchased by the household. This function is homogeneous of degree zero in all prices. Thus, totally differentiating we can obtain:

$$(A12) \sum_j \frac{\partial L^c}{\partial p_j} = -\frac{\partial L^c}{\partial p_L}$$

Using the Slutsky symmetry property:

$$(A13) \sum_j \frac{\partial B_j^c}{\partial p_L} = -\frac{\partial L^c}{\partial p_L}$$

Further manipulation gives:

$$(A14) \sum_j \eta_{jL}^c \pi_{jL} = -\epsilon_{LL}^c$$

Using the definitions of π_{LH} and η_{LH}^c , and Slutsky symmetry, we can obtain:

$$(A15) \frac{\pi_{LH} \eta_{LH}^c}{p_H} = \frac{1}{H} \frac{\partial L^c}{\partial p_H} = \frac{1}{p_L} \eta_{HL}^c$$

From (A14) and (A15):

$$(A16) \frac{\pi_{LH} \eta_{LH}^c}{p_H} = -\frac{\mu_H^c}{p_L} \epsilon_{LL}^c; \mu_H^c = \frac{\eta_{HL}^c}{\sum_j \eta_{jL}^c \pi_{jL}}$$

From (A16), we can easily obtain (3.5). Note that the denominator of μ_H is a weighted average of the cross-price elasticities between all goods and leisure (the π 's sum to unity). Thus, housing is an average substitute for leisure when $\mu_H = 1$ and a weak substitute for leisure (relative to other goods) when $\mu_H < 1$.

Now consider an uncompensated price change. Subtracting $\eta_{LI} = (\partial L / \partial I) I / L$, the income elasticity of labor supply (I denotes income), from both sides of (A14) gives:

$$(A17) \sum_j \eta_{jL}^c \pi_{jL} - \eta_{LI} = -\varepsilon_{LL}^u$$

Analogous to (A15), and using the Slutsky equation:

$$(A18) \frac{\pi_{LH} \eta_{LH}^u}{p_H} = \frac{1}{H} \frac{\partial L^u}{\partial p_H} = \frac{\eta_{HL}^c - \eta_{LI}}{p_L}$$

From (A17) and (A18):

$$(A19) \frac{\pi_{LH} \eta_{LH}^u}{p_H} = -\frac{\mu_H^u}{p_L} \varepsilon_{LL}^u; \mu_H^u = \frac{\eta_{HL}^c - \eta_{LI}}{\sum_j \eta_{jL}^c \pi_{jL} - \eta_{LI}}$$

Again, μ_H^u measures the relative degree of substitution between housing and leisure. For simplicity, we make the approximation: $\mu_H^u \approx \mu_H^c = \mu_H$.

Appendix B. Parameter Values used to Calculate the MWCs

(i) *Labor Market Parameters.* Since we focus on national economic welfare, we are interested in the effects of local labor taxes on the work/leisure decision, but not on the decision of whether to work in the DC area as opposed to other regions. We are not aware of labor supply elasticity estimates (excluding migration effects) that are specific to the DC region, but there have been many estimates of male and female elasticities for the whole economy. 48% of the labor force in Maryland and Virginia is female and 52% in DC.³⁶ Using these weights, and the survey in Fuchs et al. 1998, we consider a range of 0.1 to 0.3 for the uncompensated labor supply elasticity, and 0.2 to 0.5 for the compensated elasticity, with central values of 0.2 and 0.35 respectively.

We use a central value of 37% for the labor tax, which reflects federal and local income taxes (14%), social security taxes (14%), and sales and excise taxes less gasoline taxes (9%), (see Appendix C). This is an average rate of tax, and differs from the statutory rates because of various deductions. The average rate of tax is relevant for the labor force participation decision, and this decision accounts for about two-thirds of the labor supply elasticity. The marginal rate of tax, which determines the hours worked decision, is higher. Therefore, by using an average tax rate we understate somewhat the distortionary effect of the tax.³⁷ But on the other hand the payroll tax may not be fully distortionary if workers expect some compensation in the form of a higher state pension (Feldstein and Samwick 1992). Given these considerations, we consider a range of 34%—40% for the labor tax.

Wages and salaries for 1995 in Northern Virginia, Suburban Maryland, and the District of Columbia were \$32.7 billion, \$25.6 billion and \$29.7 billion respectively (Bureau of Economic Analysis 2000). For our purposes the size of the labor market reflects total labor costs, including payroll taxes paid by employers (Appendix C). Thus we multiply these numbers by 1.07 to obtain gross labor earnings (L) for the DC region of \$93.7 billion. Labor earnings for the whole economy are \$3,357 billion (see Appendix C).

³⁶ Statistical Abstract of the United States 1998, Table 649.

³⁷ Other studies, for example Browning (1987), use estimates of the marginal tax rate rather than the average tax rate. Thus, they implicitly attribute all of the labor supply response to changes in hours worked and none to changes in the participation rate.

(ii) *Housing Parameters*. For our purposes “housing consumption” consists of services to owner-occupiers who receive mortgage interest tax relief, and all other real estate services (businesses, rented accommodation, and owner-occupiers with no tax relief). We estimate the respective shares (for the United States as a whole) for these two groups as follows.

Property tax payments were \$188 billion in 1994 and the tax expenditure against federal income taxes for property taxes was \$14 billion (*Statistical Abstract of the United States 1996*, Tables 472 and 518). The people receiving this exemption are roughly the same group that itemizes mortgage interest on their Federal income tax returns. The marginal federal income tax rate faced by the average household is about 25% (Feldstein 1999). Therefore the total property taxes paid by this group was about $\$14/0.25 = \56 billion, or about 30% of total property tax payments. We assume 30% of real estate belongs to people itemizing mortgage interest, and 70% for the rest.

We estimate the value of housing services to those receiving the mortgage interest deduction by dividing the estimated federal tax expenditure for mortgage interest, \$48.4 billion in 1994 (*Statistical Abstract* Table 518), by the marginal rate of federal income tax 25%, which yields \$193.6 billion. In other words, we assume that the mortgage interest rate proxies for housing services as a fraction of the price of housing. Dividing by 0.3 gives the total value of real estate services, \$645.3 billion. Dividing by labor earnings for the whole economy gives $\pi_{HL} = 0.19$.

According to Rosen (1985), Table 3.1, the subsidy from the tax exemption for imputed income to owner-occupiers is about 80% of the tax-subsidy from mortgage interest. Mortgage interest is also not subject to sales tax, or local income tax. Assuming a marginal federal income tax of 25%, a marginal local income tax of 6%, and sales tax of 4% gives a total subsidy of 55% ($=25 \times 1.8 + 6 + 4$) to households receiving mortgage tax relief. The remainder of real estate services is just exempt from the sales tax. The weighted average subsidy for the real estate market (\bar{s}_H) is therefore $.3 \times 55 + .7 \times 4 = 19\%$.

The effective property tax rate in DC is about 0.9% per dollar of the market value of housing, about 1.1% in Northern Virginia, and about 2.2% in suburban Maryland.³⁸ We assume an average rate for the region of 1.3% (this includes a minor adjustment for the deduction from income taxes). The mortgage

38 Figures from Office of Tax and Revenue (1998), www.dat.state.md.us/sdatweb/index.html.

interest rate—our proxy for the value of real estate services—was about 8% in the mid-1990s³⁹; thus the property tax is 16% of real estate services.

However, there is controversy in the literature over how distortionary the property tax is (Mieszkowski and Zodrow 1989, Oates 1994). The more traditional view is that it is a non-distortionary user fee for local public goods—people who live in jurisdictions with higher property taxes are compensated with better schools, parks, etc. Another view is that it is a tax on housing relative to other spending on consumption and investment and is fully distortionary. We illustrate cases where 25%, 50%, and 75% of the property tax is distortionary. This gives low, medium, and high values for the net subsidy wedge in the housing market, $\bar{s}_H - t_H$, of 0.07, 0.11 and 0.15.⁴⁰

From the Slutsky equation it is straightforward to show that the uncompensated and compensated demand elasticities for a commodity are likely to have similar values so long as the commodity is a small share of the household budget. For simplicity, we use the same value for the compensated and uncompensated demand elasticities for housing, gasoline, transit and peak-period driving. Based on the housing literature, we adopt values of -0.4 , -0.7 and -1.0 for the housing demand elasticities (η_{HH}^c and η_{HH}^u).⁴¹

If consumption and leisure were weakly separable in the utility function then μ_H would equal the expenditure elasticity for housing (Deaton 1981), which is probably larger than the magnitude of the price elasticity (e.g., second homes are a luxury good). But higher quality housing probably raises the value of non-market time relative to market time. We consider cases where $\mu_H = 0.6$, 0.8 and 1 (housing is a weak leisure substitute in the first two cases). This is somewhat ad hoc, but alternative values do not substantially change the overall results.

39 Statistical Abstract of the United States 1996, Table 787.

40 However to calculate revenue changes rather than efficiency changes in the housing market (i.e. the denominator in the MWC formulas), we use the nominal property tax rate, hence $\bar{s}_H - t_H = 0.03$.

41 See for example Hanushek and Quigley (1980), Mayo (1981), Rosen (1985), Harrington (1989) and Rapaport (1997). Note that—since the welfare effect is measured from a national rather than regional perspective—the relevant housing demand elasticity reflects the substitution from real estate services into other goods, and not the effect of people moving to houses elsewhere in response to regional tax changes.

(iii) *Gasoline Parameters.* The federal gasoline tax rate is 18 cents per gallon and the state gasoline taxes are 18 cents (Virginia), 20 cents (District of Columbia) and 24 cents (Maryland). We assume a total gasoline tax rate of 40 cents for the region, and a producer price of 80 cents, implying $t_G = 0.5$.⁴²

We adopt a range of -0.2 to -0.5 for the (long run) gasoline demand elasticity (see Dahl 1986, for a discussion of the empirical evidence), which reflects reduced demand for driving and increased demand for more fuel-efficient cars. To the extent that gasoline is effectively an input into general production—for example, it is needed for commuters to get to work or firms to transport products—we would expect it to be roughly an average substitute for leisure. But on balance gasoline is probably a relatively weak leisure substitute because a portion of it is used in leisure-related trips. We illustrate cases where μ_G is between 0.6 and 1.

Small and Kazimi (1995) estimated the external costs of (non-carbon) auto emissions from gasoline combustion amounted to about 60 cents per gallon (75% of the producer price), but there is a lot of uncertainty surrounding the damage estimates (Krupnick et al. 1997). Moreover the study focuses on Los Angeles, which is more polluted than the Washington region. Based on the climate change literature, we think that a plausible range for the future costs of climate change from carbon emissions is \$0—\$100 per ton of carbon, although Nordhaus (1994) usually uses a values less than \$20 per ton. Assuming one ton of carbon is produced by 335 gallons of gasoline, \$100 per ton translates into 30 cents per gallon. We illustrate cases where the total damages from carbon and non-carbon pollutants amount to 50%, 75%, and 100% of the producer price.

Assuming the average vehicle does 15 miles per gallon in the DC area, and a consumer gasoline price of \$1.20, gasoline costs are 8 cents per mile. Annual vehicle miles traveled in the Washington DC area is around 30 billion (Texas Transport Institute 1998), therefore total gasoline costs are \$2.4 billion. Dividing by regional labor earnings gives $\pi_{GL} = 0.02$.

(iv) *Metro Parameters.* For fiscal year 2000 the operating costs for Metrorail and Metrobus together were \$678 million, and passenger fare revenues were \$357 million, implying $t_M = 0.53$, or an average subsidy of 47% (Washington Metro Area Transit Authority, 2000). We are not aware of any

⁴² The above figures are from Department of Transportation (1998) and the Statistical Abstract of the United States 1998, Table 791. We assume a 10 cents mark up of the retail price for gasoline over the refiner price.

studies of the gap between short run average and marginal cost for public transit in the DC area, due to increasing returns. Ochelen et al. (1998) assume the gap is 10% of operating costs in their model of the Brussels transportation system. We illustrate cases where the gap is 5%, 15%, and 25% of operating costs. This implies that the gap between short run marginal cost and the transit fare, $m - t_M$, is 22%, 32%, or 42%.

From a survey of the literature, Small (1992) pp. 11 concludes that a reasonable value for the elasticity of transit trips with respect to the transit fare is around -0.3 , and we consider a range of -0.2 to -0.4 . By the same reasoning as for gasoline, we illustrate cases where μ_M is between 0.6 and 1. Dividing the costs of metro travel by labor earnings gives $\pi_{ML} = 0.007$.

(v) *Road Travel and Congestion*. According to Small (1992), pp. 84 non-gasoline costs of driving (vehicle wear and tear, parking fees, etc.) are about four times as large as gasoline costs. Since gasoline costs are 8 cents per mile, total money costs are 40 cents per mile. About half of the 30 billion annual vehicles miles in the Washington DC area occurs at peak period (Texas Transport Institute 1998). Thus, total money costs of peak-period driving is \$6 billion, implying $\pi_{RL} = 0.06$.

Annual congestion costs for the Washington DC region are about \$2.9 billion (Texas Transport Institute 1998). Assuming all these costs occur at peak period, this amounts to an average cost of about 20 cents per mile, or 50% of money costs. Congestion costs consist of \$2.6 billion in delay costs, equal to 216 million hours of delay, times the opportunity cost of time \$12, plus \$0.3 billion in additional fuel consumption.⁴³ This is an overestimate in the sense that it includes delay costs caused by vehicle accidents and breakdowns (though delay costs are greatly magnified in heavy traffic). On the other hand we are really interested in the marginal congestion cost per mile, which exceeds the average congestion cost. We consider scenarios when (marginal) congestion costs are 35%, 50%, and 65% of money costs (i.e. 14 to 26 cents per mile).⁴⁴

⁴³ Person hours of delay can be obtained by comparing the time it takes to drive a mile at existing travel speeds with the time it would take at free-flow speeds, and multiplying the difference by annual vehicle miles traveled.

\$12 is about half the average hourly wage rate in DC. See Small (1992) pp. 43-45 for more discussion of the opportunity cost of travel time.

⁴⁴ These congestion costs are high relative to those in some other studies (see e.g. Daniel and Bekka, 2000 on the Delaware region). But traffic congestion in Washington, DC, is particularly heavy.

Based on empirical literature (see e.g., Oum et al. 1992, Goodwin 1992) we illustrate cases where the elasticity of demand for peak period travel with respect to money costs η_{RR} is -0.2 , -0.3 , and -0.4 . Assuming that peak-period road travel is essentially by commuters it is effectively an input into general production, and it should be an average substitute for leisure. However, Parry and Bento (2000) show that peak travel is actually a relatively weak leisure substitute because the feedback effect of reduced congestion raises the wage net of commuting costs, and this offsets some of the adverse effect on labor supply from a congestion fee. Indeed if the (average) congestion cost function is as steeply sloped as the demand curve (which is certainly plausible under congested conditions) then it can be shown that the relative degree of substitution with leisure would be 0.5. We consider cases where $\mu_R = 0.4, 0.5$ and 0.6 .

(vi) *Other Cross-Price Elasticities.* In response to peak period congestion fees, people may drive at off-peak hours, switch to the metro, or reduce the number of trips by car-pooling or trip chaining. We assume that one third of reduced peak freeway trips are diverted onto public transport (this is roughly consistent with evidence in Pickrell 1989). This implies that $\pi_{MR}\eta_{MR} = -0.33\eta_{RR}$, or η_{MR} is roughly between 0.5 and 1. If there were no substitution into off-peak driving, $\eta_{GR} = 0.5\eta_{RR}$, since peak driving is 50% of all driving. We assume $\eta_{GR} = 0.33\eta_{RR}$, which implies that one third of the reduction in peak driving is due to increased driving at off-peak hours.

An incremental increase in the gasoline tax has the same impact on peak-road travel as an incremental increase in the total money cost of peak-road travel, times the share of gasoline costs in the money cost of driving (0.25). Therefore $\eta_{RG} = 0.25\eta_{RR}$, or η_{RG} lies between -0.04 and -0.08 . We assume that, following an increase in the gasoline tax, 33% of the reduction in gasoline is due to substitution in favor of transit travel (the rest is due to reduced overall demand for travel, or switching to more fuel efficient cars), thus $\pi_{MG}\eta_{MG} = -0.33\eta_{GG}$, or η_{MG} lies between 0.4 and 0.8.

In response to higher transit fares we assume that between 30% and 60% of the reduction in transit trips is reflected in more peak-period road travel. Therefore $\pi_{RM}\eta_{RM} = -0.3\eta_{MM}$ to $-0.6\eta_{MM}$, which implies that η_{RM} lies between 0.005 and 0.03.

The cross-price elasticities between the transport markets and housing are more difficult to gauge. To the extent that more housing spending reflects people moving further out from the District to larger suburban lots, or buying second homes, vehicle miles traveled will increase, while if spending is on raising the value of existing homes (e.g. by extensions) the demand for travel will be roughly unaffected.

We illustrate cases where the proportionate increase in travel is 10%, 30%, or 50% of the proportionate increase in housing spending. That is, $\eta_{GH} = \eta_{RH} = \eta_{MH} = 0.1\eta_{HH}$ to $0.5\eta_{HH}$.

We obtain the remaining cross-price elasticities from:

$$\eta_{ij} = \frac{\partial X_i}{\partial p_j} \frac{p_j}{X_i} = \frac{\partial X_j}{\partial p_i} \frac{p_j}{X_i} \frac{p_i}{p_i} \frac{X_j}{X_j} = \eta_{ji} \frac{p_j}{p_i} \frac{\pi_{jL}}{\pi_{iL}}$$

This relation is exact for compensated price changes and an approximation for uncompensated changes. Table 2b summarizes the implications of our assumptions for the range of values for the cross-price elasticities.

Finally, the remaining π s, reflecting the size of markets relative to other, non-labor markets, are easily obtained from the π_{iL} s. For example, the size of the gasoline market relative to the metro market is

$$\pi_{GM} = \pi_{GL} / \pi_{ML}, \text{ and so on.}$$

Appendix C: Estimation of the Labor Tax

To estimate the average rate of labor tax we follow (approximately) the procedure in Mendoza et al. (1994) using OECD (1997)'s *Revenue Statistics* (Table 65), and *National Accounts* (pp. 60), for the year 1994.⁴⁵ One difficulty is here is that income tax revenues are not decomposed into those from labor and capital income. However, it seems reasonable to assume that labor and capital income are taxed at about the same rate in the United States (e.g. Lucas 1990). Thus, we can calculate the average tax rate on all income as follows:

$$(C1) t_l = \frac{1100}{OSPUE + PEI + W}$$

where:

1100 is taxes on income, profits, and capital gains of individuals, \$672,522 million.

OSPUE is the operating surplus of private unincorporated enterprises, \$441,600 million.

⁴⁵ This gives the average labor tax for the whole economy rather than for the DC region. However the difference between the two is probably small.

PEI is agent property and entrepreneurial income, \$768,800 million.

W is wages and salaries, \$3,105,900 million.

This calculation gives $t_l = .156$.

The average rate of tax on labor income is given by:

$$(C2)t_L = \frac{t_l W + 2000 + 5000}{W + 2200}$$

where:

2000 is total social security contributions, \$479,970 million.

5000 is taxes on goods and services, less revenues from gasoline taxes, \$293,832 million.

2200 is employers' contributions to social security, \$251,143 million.

The denominator in (B2) is gross wages paid by employers. Thus from this formula we obtain values of 14% for the income tax, 14% for social security contributions, and 9% for sales and excise taxes.

Appendix D: Parameter Values Used in Local Revenue Estimates

The reduction in labor supply that affects local revenue changes reflects both substitution into leisure and people moving to jobs outside the Washington DC area. Studies generally find that regional taxes have a significant effect on local employment levels, though taxes are less important than other factors (Mark et al. 2000, pp. 106-7). We consider cases where the uncompensated labor supply elasticity is between 0.2 and 0.8.⁴⁶

The appropriate labor tax to calculate local revenue losses due to reductions in labor supply is the local rate of income tax plus sales tax. Income tax rates are 6%–9.5% in DC, 2%–4.85% in Maryland and 2%–5.75% in Virginia, and sales tax rates are 5.75% in DC, 5% in Maryland and 3.5% in Virginia

⁴⁶ We might expect the sensitivity of employment and capital to regional tax rates to be roughly similar. Based on the empirical literature, Bartik (1991) pp. 37-43 suggests that the size of the elasticity of capital with respect to regional tax rates is around 0.1 to 0.6.

(Office of Tax and Revenue 1998). We assume the combined rate of income and sales tax for the region is 8%.

We assume that the tax expenditure for mortgage interest and homeowner imputed income is borne equally by federal and regional governments. This means that the nominal property tax, less tax subsidies born locally, is 6.5%. We use a local gasoline tax rate of 21 cents per gallon (see above). The values for all other parameters are unchanged from those in Tables 1a and b.