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Transport taxes with multiple trip purposes

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Abstract

I consider an urban transport system in which passenger cars and buses are used for commuting trips and for leisure trips, where both transport modes contribute to congestion, and where commuting is a strict complement to taxable labour supply. The optimal tax structure for raising a given amount of government revenue is discussed for the cases where differentiation of the transport tax between trip purposes is and is not possible. Using a stylised dataset for Belgian urban environments, the optimal tax structure is computed. When differentiation of transport taxes between trip purposes is possible, a shift to the taxation of relative complements to leisure is observed. When differentiation is not possible, reforming transport taxes generates substantial welfare gains only when the labour tax can be simultaneously reduced.

Keywords

Transport, externalities, congestion taxes, general equilibrium welfare effects

JEL Classification

R41, H21, H23

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1. *Introduction*

Recently there is an increased interest in the theoretical and applied analysis of the welfare effects of congestion pricing in the presence of pre-existing tax and pricing distortions (Mayeres and Proost, 1997 and 2001; Munk, 1999; Parry and Bento, 1999 and 2000; Calthrop et al., 2000; Parry, 2000; Bento and Silva, 2001). These and other studies apply the insights of the optimal taxation literature and of the more recent double dividend debate to the transport sector, taking account of the fact that congestion is a ‘feedback externality’, meaning that it has effects on the consumption of taxed commodities. Typically, the results are that optimal second-best congestion charges will deviate from marginal external congestion costs, because of the interaction with existing distortionary taxes and because of the positive government revenue requirement. Furthermore, the welfare potential of second-best congestion charges is seen to critically depend on revenue use. In particular, it is preferable to reduce labour taxes rather than to redistribute the revenues in a lump sum way (e.g. Parry and Bento, 1999), unless the social welfare function exhibits a moderate or large degree of inequality aversion (Mayeres and Proost, 1997).

Given that a large share of trips during congested hours are commuting trips, and that commuting is complementary to labour supply, the interaction between congestion taxes and labour taxes can be expected to be important. In this paper, we investigate this interaction, taking account of the fact that non-commuting trips use the road simultaneously with commuters. Although the bulk of the congestion pricing literature makes no explicit assumptions on the practical implementation of congestion charges, it is often assumed that the charging system as such creates no congestion. This can be achieved through high-tech systems, e.g. on-road tolling points which deduct the charge from a smart card as a vehicle passes the tolling point. These systems are operational, and probably not prohibitively expensive (e.g. Small and Gomez-Ibanez, 1998). It is clear that such a system can not directly adapt the charge to the trip purpose, while such differentiation of transport taxes would in principle be desirable (e.g. Munk, 1999).

The purpose of this paper is to estimate the welfare cost of not differentiating charges between commuting trips and leisure related trips. Using a stylised dataset, it is suggested that (a) the welfare costs of uniform transport taxes depend on the level of the labour tax rate, and (b) that transport tax differentiation between leisure trips and commuting trips is strongly desirable when the labour tax rate is taken to be fixed at, e.g., the reference level. The policy implication is that high-tech charging systems should be complemented by other fiscal measures, e.g. income tax deductions of (part of) the congestion charges for commuting trips, when the labour tax rate is not flexible. When the administrative costs of tax deductibility are high (as suggested in Munk, 1999), flexibility of the labour tax is all the more important when considering transport tax reform.

The problem is studied in a simple general equilibrium model, which extends the analysis by Parry and Bento (1999). We model a transport system in which cars and buses simultaneously use a congestible single-link network in order to produce leisure trips and commuting trips, during peak hours. There is a strict complementarity between the number of commuting trips and the supply of fixed length labour days, in that each labour day requires a morning and an evening peak trip. Government can raise taxes on labour and on transport in order to finance a given transfer. In this

context, we analyse the welfare effects of various types of tax reform.¹ Since a single representative consumer approach is adopted, distributional issues are neglected. This implies that lump sum redistribution of transport tax revenues can safely be neglected, as using the revenues to cut the labour tax –or possibly other transport taxes- will yield higher welfare gains. Munk (1999) illustrates that the benefits of tax differentiation towards leisure transport are higher when distributional concerns are taken into account, provided that the expenditure share of leisure trips is higher for high income households and that the degree of inequality aversion is sufficiently large.

The structure of the paper is as follows. Section 2 presents the theoretical analysis. The optimal tax structure is derived for the cases where government can or can not differentiate transport taxes between trip purposes. Section 3 discusses a numerical illustration based on stylised data for Belgium. Section 4 concludes.

2. Theoretical analysis

In order to gain some insight in the characteristics of the optimal tax structure, we proceed as follows. Section 2.1 presents the set-up of the model and the first order conditions for a consumer optimum. The optimal tax structure is derived in section 2.2, for the second-best situation in which government has no access to a lump sum transfer. A distinction is made between the situation where tax differentiation between trip purposes is and is not feasible (sections 2.2.1 and 2.2.2 respectively). For the case with differentiation, the components of the optimal taxes are explained, and the optimal leisure and commuting transport taxes are given for the case where there are no cross-effects between leisure and commuting transport. For the case of uniform transport taxes, we limit ourselves to a presentation of the system of first order conditions where we neglect cross-price elasticities. This is sufficient to indicate what the basic effects of the uniformity constraint are.

2.1 Model components and consumer optimum

We use a strongly stylised representation of the urban transport sector, describing preferences by a single representative consumer's utility function as in (1) and assuming that the transport network can be represented as a single congestible link between a single origin and destination. Only morning and evening peak transport are analysed. The representative consumer neglects her impact on the congestion externality.

$$\begin{aligned}
 u &= U(q_0, q_1, q_2, N) + T(q_3, q_4) \\
 \text{where } q_0 &= \text{composite commodity (untaxed numéraire)} \\
 q_1 &= \text{leisure related car trips} \\
 q_2 &= \text{leisure related bus trips} \\
 q_3 &= \text{commuting by car} \\
 q_4 &= \text{commuting by bus} \\
 N &= \text{leisure}
 \end{aligned} \tag{1}$$

¹ The extensions with respect to Parry and Bento, 1999, are: (a) explicit representation of leisure trips in the theoretical analysis, (b) assuming a shared congestible network for both transport modes. The methodology is different as well.

The subutility function T allows that the consumer is not indifferent between transport modes for commuting. The choice of commuting mode has no direct impact on other consumption, however. In particular, modal choices in leisure transport and in commuting are made independently, up to an income effect. A strict complementarity between labour supply L and commuting trips is imposed, such that $L = q_3 + q_4$. We assume that the same transport mode is used for the morning and evening commuting trip.

Resource costs (c), taxes (t), money prices (p) and time costs (a , z) are as follows.

$$\begin{aligned}
p_i &= c_c + t_i && \text{money price of a car trip } (i = 1, 3) \\
p_i &= t_i && \text{money price of a bus trip } (i = 2, 4) \\
a &= a(F) && \text{in vehicle time required for a trip, } F = \sum_{i=1}^4 q_i = \text{traffic flow} \\
a' &\equiv \frac{\partial a}{\partial F} > 0 \\
z_i &= \bar{z} && \text{average waiting time for a bus } (i = 2, 4)
\end{aligned} \tag{2}$$

This structure implies a number of assumptions and restrictions:

- Since all modes simultaneously use the same link and travel at the same speed, in-vehicle time (a) for a trip is equal for all modes and trip purposes.
- The resource cost of a car trip is equal across trip motives. Taxes are allowed to differ across motives. In section 2.2.2, we introduce the restriction that transport taxes can not be diversified according to trip motives. The resource costs of car and bus trips are taken to be constant per trip.
- The money price of bus trips is equal to the tax. This tax may or may not cover the resource costs c_p , which are covered out of tax revenues (centralised supply of bus transport).
- All transport modes contribute to congestion. The contribution may differ between modes, but not between trip motives. In the theoretical analysis, the differential impact of modes on congestion is neglected, for reasons of clarity. The applied model in section 3 takes account of the different congestion effects of cars and buses.
- In general, average waiting times at bus stops are a decreasing function of the supply of bus trips (economies of density). The supply of bus trips may increase when demand for bus trips increases. We abstract from economies of density here. Including them is a straightforward extension, as long as bus supply decisions are not endogenised. A more detailed (partial equilibrium) analysis of the role of economies of density in urban transport pricing is in Van Dender and Proost (2001).

Normalising the gross wage to one, taking the numéraire (q_0) as the untaxed good and normalising its producer price to one, the consumer's money and time budget constraints can be written as in (3). These normalisations imply the assumptions of a constant returns to scale production technology, where labour is the only input into production, operating in a perfectly competitive environment. The marginal product of labour, i.e. the gross wage, is constant and does not depend on the commuting mode. In equations (3), t_L is the tax on labour supply, S is a lump sum transfer and $\bar{L}$ is the time endowment.

$$\begin{aligned}
(1-t_L)L + S &= q_0 + \sum_{i=1}^4 p_i q_i \quad [\lambda] \\
\bar{L} &= N + L + \sum_{i=1}^4 (a_i + z_i) q_i \quad [\gamma]
\end{aligned} \tag{3}$$

where $a_i = a$, $i = 1, \dots, 4$ and $z_i = \bar{z}$, $i = 2, 4$ and $z_i = 0$, $i = 1, 3$

Using the multipliers in square brackets, the first order conditions for a consumer optimum are as follows.

$$\begin{aligned}
U_0 &\equiv \frac{\partial U}{\partial q_0} = \lambda \\
U_1 &\equiv \frac{\partial U}{\partial q_1} = \lambda p_1 + \gamma a \\
U_2 &\equiv \frac{\partial U}{\partial q_2} = \lambda p_2 + \gamma(a + z) \\
T_3 &\equiv \frac{\partial T}{\partial q_3} = -\lambda(1-t_L) + \lambda p_3 + \gamma(1+a) \\
T_4 &\equiv \frac{\partial T}{\partial q_4} = -\lambda(1-t_L) + \lambda p_4 + \gamma(1+a+z) \\
U_N &\equiv \frac{\partial U}{\partial N} = \gamma
\end{aligned} \tag{4}$$

The marginal value of time hence is endogenous, and given by $\frac{U_N}{U_0} = \frac{\gamma}{\lambda}$. It is not equal to the gross

or net wage, as can be seen, e.g. for car commuting. : $\frac{\gamma}{\lambda} = \frac{((1-t_L) - p_3) + \frac{T_3}{\lambda}}{(1+a)}$. As is common in

the transport literature (e.g. Jara-Diaz, 2000), the value of time equals the net wage corrected for the disutility of commuting travel.

As the non-time resource costs of transport are constant, the indirect utility function can be written as $V = V(t_L; t_i, i = 1, \dots, 4; a; z; S)$. Recalling that F denotes the aggregate traffic flow, $a'F$ gives the marginal external congestion costs in time units from an extra unit of traffic flow. A marginal car trip directly translates into an extra unit of flow. As bus occupancy rates are taken to be constant, an extra bus trip leads to proportionally less additional flow. The proportionality between the flow effect of a car and a bus trip is indicated by α_i , with $\alpha_1 = \alpha_3 = \alpha_{car} = 1$ and $(\alpha_2 = \alpha_4 = \alpha_{bus}) < 1$. Consequently, e.g.:

$$\frac{\partial V}{\partial t_j} = -\lambda q_j - \gamma \sum_{i=1}^4 \alpha_i a' F \frac{\partial q_i}{\partial t_j}, j = 1, \dots, 4.$$

2.2 Optimal transport taxes

The government's problem is to maximise consumer welfare (given by the indirect utility function), subject to a budget constraint. The budget constraint stipulates that the available tax instruments must

be used to finance a given transfer S and the costs of bus supply. Hence, all instruments have two functions: raising revenue and internalising externalities. Section 2.2.1 deals with the case in which all transport commodities can be taxed separately. In section 2.2.2, the taxes are constrained in the sense that they are uniform across trip purposes.

In the formulation of the social welfare programme, production efficiency is assumed. From Diamond and Mirrlees (1971), it is known that production efficiency is not necessarily optimal when not all final commodities can be taxed. Issues of production efficiency will be neglected in the present analysis.

2.2.1 Differentiation of transport taxes across trip purposes

Government uses transport taxes and labour taxes in order to maximise the representative consumers' indirect utility, subject to the tax revenue constraint. The Lagrangian in (4) produces the critical points. Use of the lump sum transfer is ruled out, so that we are in second-best.

$$\mathfrak{L} = V(t_L; t_i, i=1, \dots, 4; a; z; S) + \mu \left(\sum_{i=1}^4 t_i q_i + t_L L - \sum_{i=2,4} c_p q_i - S \right) \quad (5)$$

In this set-up, there are five instruments (four transport taxes and the labour tax), for five taxable commodities (four transport commodities and labour). However, the strict complementarity between labour and commuting trips ($L = q_3 + q_4$) implies that one instrument is redundant. In other words, there is an indeterminacy in the choice of the five instruments. We first discuss the first order conditions, and then look at optimal leisure transport taxes and commuting taxes when there are no cross-price effects between both.

First-order conditions

After some re-arranging, the system of first-order conditions can be written as in equations (4.6). We write them out in full in order to clarify the similarities and the differences. The expressions are in terms of the uncompensated price elasticities. The elasticities take account of the change in congestion levels caused by price changes. Note that due to the additive structure of the utility function, there is no substitution effect between labour and leisure trips by either transport mode. Price changes for one trip purpose only affect demand for the other purpose through the income effect and via congestion. The main characteristics of the optimal taxes are discussed in the next four points.

First, note that public transport taxes (6.2 and 6.4) reflect the marginal resource cost of the bus trip. This of course follows from the assumption that government supplies bus trips, and uses taxes to finance this supply. The bus taxes are effectively equal to the bus fares (see 2). As car users directly incur the resource costs of their trips, these resource costs do not appear in the expressions for the car taxes.

Second, all transport taxes (6.1 to 6.4) contain three similar components: the Ramsey component, the trip interaction component and the Pigouvian component (as indicated in expression 6.1). We briefly discuss these components.

The Ramsey component refers to the revenue raising function of the tax. It appears because of the assumed absence of a lump sum tax instrument (S is constant). It is decreasing in the own price elasticity of the taxed good, and increasing in the marginal cost of public funds (μ/λ). Therefore, the

Ramsey component is positive as long as the uncompensated own price elasticity of the taxed good is negative, and when the marginal cost of public funds is larger than one.

The Pigouvian component (last term in the transport tax equations) stipulates that the transport taxes are used to internalise the congestion externality caused by the taxed good. However, this component is decreasing in the marginal cost of public funds. Together with the Ramsey component, this indicates that the revenue raising function of the tax becomes relatively more important as the marginal cost of public funds increases, and less attention is given to the correction of the inefficiencies from the externality.

The trip interaction component consists of three subcomponents, each of which relates to the deviation between taxes and marginal external congestion costs (plus the marginal resource cost of a bus trip in the case of bus transport markets) on the other transport markets. It captures the interactions between taxes when there are pricing distortions on other transport markets (in the case of the labour tax: all transport markets). When these deviations are zero, the trip interaction components drop from the tax expression. However, as can be seen by considering the system of equations formed by the first order conditions, marginal social cost pricing in transport is not optimal. This directly implies that trip interaction components will matter in the optimal tax structure.

Third, note that for commuting transport (6.3 and 6.4) only the sum of the transport tax and the labour tax is determined by the first order condition. This is the consequence of the strict complementarity between commuting and labour supply, which causes one tax instrument to be redundant. The indeterminacy of the commuting and labour taxes is further discussed below.

Fourth, the expression for the labour tax contains no specific Pigouvian component. The Ramsey and the trip interaction components are similar to those of the transport taxes. The absence of the Pigouvian term suggests that labour supply as such generates no congestion. However, as commuting trips clearly do cause congestion and as the complementarity between commuting and labour supply is strict, it may as well be said that labour supply causes congestion. This again points to the indeterminacy of the tax configuration concerning labour and commuting.

In the next paragraphs, we discuss the solution to the system of first order conditions under the simplifying assumption that the cross price elasticities between commuting and leisure transport markets are zero. This allows to solve for the optimal leisure transport taxes from equations (6.1) and (6.2), and for the labour- and commuting-related taxes from equations (6.3) to (6.5). We first discuss the optimal taxes for leisure trips, and then turn to commuting and labour taxes.

$$\frac{t_1}{p_1} = \underbrace{\frac{1-\mu/\lambda}{\mu/\lambda} \frac{1}{\varepsilon_{11}}}_{\text{Ramsey}} - \underbrace{\frac{1}{p_1} \left[\frac{\varepsilon_{21}}{\varepsilon_{11}} \frac{q_2}{q_1} \left(t_2 - c_p - \frac{\gamma}{\mu} \alpha_2 a' F \right) + \frac{\varepsilon_{31}}{\varepsilon_{11}} \frac{q_3}{q_1} \left(t_3 + t_L - \frac{\gamma}{\mu} a' F \right) + \frac{\varepsilon_{41}}{\varepsilon_{11}} \frac{q_4}{q_1} \left(t_4 + t_L - c_p - \frac{\gamma}{\mu} \alpha_4 a' F \right) \right]}_{\text{Trip interaction : interaction with distortions on other transport markets}} + \underbrace{\frac{\gamma}{\mu} \frac{a' F}{p_1}}_{\text{Pigou}} \quad (6.1)$$

$$\frac{t_2}{p_2} = \frac{c_p}{p_2} + \frac{1-\mu/\lambda}{\mu/\lambda} \frac{1}{\varepsilon_{22}} - \frac{1}{p_2} \left[\frac{\varepsilon_{12}}{\varepsilon_{22}} \frac{q_1}{q_2} \left(t_1 - \frac{\gamma}{\mu} a' F \right) + \frac{\varepsilon_{32}}{\varepsilon_{22}} \frac{q_3}{q_2} \left(t_3 + t_L - \frac{\gamma}{\mu} a' F \right) + \frac{\varepsilon_{42}}{\varepsilon_{22}} \frac{q_4}{q_2} \left(t_4 + t_L - c_p - \alpha_4 \frac{\gamma}{\mu} a' F \right) \right] + \frac{\gamma}{\mu} \frac{\alpha_2 a' F}{p_2} \quad (6.2)$$

$$\frac{t_3 + t_L}{p_3} = \frac{1-\mu/\lambda}{\mu/\lambda} \frac{1}{\varepsilon_{33}} - \frac{1}{p_3} \left[\frac{\varepsilon_{13}}{\varepsilon_{33}} \frac{q_1}{q_3} \left(t_1 - \frac{\gamma}{\mu} a' F \right) + \frac{\varepsilon_{23}}{\varepsilon_{33}} \frac{q_2}{q_3} \left(t_2 - c_p - \frac{\gamma}{\mu} \alpha_2 a' F \right) + \frac{\varepsilon_{43}}{\varepsilon_{33}} \frac{q_4}{q_3} \left(t_4 + t_L - c_p - \frac{\gamma}{\mu} \alpha_4 a' F \right) \right] + \frac{\gamma}{\mu} \frac{a' F}{p_3} \quad (6.3)$$

$$\frac{t_4 + t_L}{p_4} = \frac{c_p}{p_4} + \frac{1-\mu/\lambda}{\mu/\lambda} \frac{1}{\varepsilon_{44}} - \frac{1}{p_4} \left[\frac{\varepsilon_{14}}{\varepsilon_{44}} \frac{q_1}{q_4} \left(t_1 - \frac{\gamma}{\mu} a' F \right) + \frac{\varepsilon_{24}}{\varepsilon_{44}} \frac{q_2}{q_4} \left(t_2 - c_p - \frac{\gamma}{\mu} \alpha_2 a' F \right) + \frac{\varepsilon_{34}}{\varepsilon_{44}} \frac{q_3}{q_4} \left(t_3 + t_L - \frac{\gamma}{\mu} a' F \right) \right] + \frac{\gamma}{\mu} \frac{\alpha_4 a' F}{p_4} \quad (6.4)$$

$$\frac{t_L}{p_L} = \frac{1-\mu/\lambda}{\mu/\lambda} \frac{1}{\varepsilon_{LL}} - \frac{1}{p_L} \left[\frac{\varepsilon_{1L}}{\varepsilon_{LL}} \frac{q_1}{L} \left(t_1 - \frac{\gamma}{\mu} a' F \right) + \frac{\varepsilon_{2L}}{\varepsilon_{LL}} \frac{q_2}{L} \left(t_2 - c_p - \frac{\gamma}{\mu} \alpha_2 a' F \right) + \frac{q_3}{L} \left(t_3 - \frac{\gamma}{\mu} a' F \right) + \frac{q_4}{L} \left(t_4 - c_p - \frac{\gamma}{\mu} \alpha_4 a' F \right) \right] \quad (6.5)$$

Optimal taxes for leisure trips

In case the uncompensated price elasticities between leisure and commuting markets are zero, the optimal leisure car tax, conditional on an optimal leisure bus tax, is implicitly defined by equation (7). The expression for the optimal leisure bus tax is analogous, except that it contains the resource cost of the bus trip (as in 6.2). It is omitted for reasons of brevity.

$$\frac{t_1}{p_1} = \left[\frac{\epsilon_{22}}{\epsilon_{11}\epsilon_{22} - \epsilon_{21}\epsilon_{12}} - \frac{p_2 q_2}{p_1 q_1} \frac{\epsilon_{21}}{\epsilon_{11}\epsilon_{22} - \epsilon_{21}\epsilon_{12}} \right] \left[\frac{1 - \mu/\lambda}{\mu/\lambda} \right] + \frac{\gamma}{\mu} \frac{a' F}{p_1} \quad (7)$$

Simultaneously setting optimal taxes for leisure trips by all modes implies that the modal taxes do no longer reflect the deviation between prices and marginal social costs in the substitute mode. The optimal tax expression hence only contains the Ramsey component and the Pigouvian component, while the congestion-related part of the modal interaction term drops out. The Pigouvian component is unchanged with respect to equation (6.1). However, the dependence of the car tax on the cross-price elasticities with respect to the substitute mode (leisure bus transport), remains. This is reflected in the modification, with respect to equation (6.1), of weight of the Ramsey term. The next paragraphs discuss the role of the cross-price effects between leisure car and bus trips.

When the cross-price elasticities are zero, the weight of the Ramsey term simplifies to $(1/\epsilon_{11})$, which is the same as in equation (6.1). With non-zero cross price effects, the weight consists of two components. Assuming that the uncompensated own price elasticities are negative, that the uncompensated cross-price elasticities are positive and that the own price effects are larger (in absolute terms) than the cross-price effects², it follows that the first component is negative and the second one positive. As the second component is subtracted from the first one, the weight is negative under our assumptions on the elasticities. The overall Ramsey term is therefore positive, given that the marginal cost of public funds is positive.

According to the first component of the weight, the Ramsey term is set such as to avoid excessive distortions in the taxed market and in substitute markets. The component is decreasing in the own price elasticity of leisure car trips and in the cross-price elasticities with respect to the leisure bus market. It is increasing in the own price elasticity of leisure bus trips. However, the second component of the weight amends the first one, in the sense that it increases the Ramsey element of the optimal tax on leisure car trips in as far as leisure bus trips are a substitute. This increase is larger, the better a substitute leisure bus trips are for leisure car trips. This effect is conditional on the assumption that leisure bus trips are taxed optimally. If this is the case, the tax base is not reduced strongly in case leisure car taxes primarily cause a substitution towards (optimally taxed) leisure bus trips.

² These assumptions are satisfied in the applied model of section 3.

Optimal taxes for commuting trips and for labour

Now consider the commuting transport taxes and the labour tax, while retaining the assumption of no cross-price effects between leisure transport and commuting transport markets. The first order conditions only define the sum of the labour tax and the commuting tax for each mode. The combination of the conditions for car and bus commuting determines the car and bus commuting taxes up to a difference with the labour tax. This is indicated by expression (8), which is the counterpart of (7) for the car commuting tax. The interpretation is the same as for (7), except that now only the sum of the car commuting tax and the labour tax is determined. The expression for the optimal ‘bus plus labour tax’ is fully analogous, except for the inclusion of the bus resource cost in the bus tax.

$$\frac{t_3 + t_L}{p_3} = \left[\frac{\varepsilon_{44}}{\varepsilon_{33}\varepsilon_{44} - \varepsilon_{43}\varepsilon_{34}} - \frac{p_4 q_4}{p_3 q_3} \frac{\varepsilon_{43}}{\varepsilon_{33}\varepsilon_{44} - \varepsilon_{43}\varepsilon_{34}} \right] \left[\frac{1 - \mu/\lambda}{\mu/\lambda} \right] + \frac{\gamma}{\mu} \frac{a' F}{p_3} \quad (8)$$

R_3

Substitution of the optimal commuting tax expressions in condition (6.5) for the labour tax (taking account of the simplification with respect to cross-price elasticities) establishes the following relationship between the Ramsey term weights of the commuting taxes. Let R_3 denote the Ramsey term weight of the car commuting tax (as indicated in (8)), and R_4 the Ramsey term weight of the bus commuting tax. We then have:

$$\varepsilon_{LL} = \frac{p_L L}{q_3 R_3 + q_4 R_4} = \frac{p_L (q_3 + q_4)}{q_3 R_3 + q_4 R_4} \quad (9)$$

Equation (9) indicates that the Ramsey terms weights of the commuting transport taxes are inversely related to the elasticity of labour supply. A higher elasticity of labour supply implies less revenue raising through commuting transport taxes. Hence, commuting is taxed less when the tax discourages labour supply more. Further, note that the weighted sum of the Ramsey weights has the same sign as the labour supply elasticity. As the latter here refers to the tax, it can expected to be negative. This implies that the overall Ramsey component of commuting transport taxes is positive. Note that this does not necessarily lead to commuting taxes above marginal external congestion costs, as the Pigouvian component is corrected downwards for the marginal cost of public funds.

2.2.2 Uniform transport taxes across trip purposes

In contrast to the previous section, transport taxes are now required to be uniform across trip purpose, so that $t_1 = t_3 = t_{car}$ and $t_2 = t_4 = t_{bus}$. The government problem becomes:

$$\mathfrak{S} = V(t_L; t_{car}; t_{bus}; a; z; S) + \mu \left(\sum_{i=1,3} t_{car} q_i + \sum_{i=2,4} t_{bus} q_i + t_L (q_3 + q_4) - \sum_{i=2,4} c_p q_i - S \right) \quad (10)$$

Since there are now three instruments for five commodities, the model describes an additional source of second-best, in terms of transport tax instruments. All taxes are uniquely defined. The optimal transport taxes now depend on the price sensitivity and the traffic flow shares of both leisure trips and

commuting trips. The general tax expressions for this model become rather intractable, so that we limit the discussion to the system of equations in (11), where cross-price effects between transport modes are neglected. This is sufficient to point out the main differences with the case of section 2.2.1.

$$\begin{aligned}
t_L &= \left(\frac{1 - \mu/\lambda}{\mu/\lambda} \right) \frac{p_L}{\varepsilon_{LL}} + \frac{q_3}{L} \left(t_{car} - \frac{\gamma}{\mu} a' F \right) + \frac{q_4}{L} \left(t_{bus} - c_p - \frac{\gamma}{\mu} \alpha_{bus} a' F \right) \\
t_{car} &= \left(\frac{1 - \mu/\lambda}{\mu/\lambda} \right) \frac{q_1 + q_3}{\frac{\partial q_1}{\partial t_{car}} + \frac{\partial q_3}{\partial t_{car}}} - t_L \frac{\frac{\partial q_3}{\partial t_L}}{\frac{\partial q_1}{\partial t_{car}} + \frac{\partial q_3}{\partial t_{car}}} + \frac{\gamma}{\mu} a' F \\
t_{bus} &= \left(\frac{1 - \mu/\lambda}{\mu/\lambda} \right) \frac{q_2 + q_4}{\frac{\partial q_2}{\partial t_{bus}} + \frac{\partial q_4}{\partial t_{bus}}} - t_L \frac{\frac{\partial q_4}{\partial t_L}}{\frac{\partial q_2}{\partial t_{bus}} + \frac{\partial q_4}{\partial t_{bus}}} + \frac{\gamma}{\mu} \alpha_{bus} a' F + c_p
\end{aligned} \tag{11}$$

The labour tax is seen to depend on the commuting transport taxes. The trip interaction terms are the same as in the case with differentiated transport taxes. However, as will be seen next, the transport taxes will be set differently because of the uniformity constraint.

The transport tax expressions contain a Ramsey term, which depends on the price sensitivities of the affected trip purposes. This is a first effect of the uniformity constraint. Whereas in the unconstrained case, the Ramsey term only depends on the price elasticity per mode and per purpose, the present Ramsey term refers to both affected trip purposes.

The second effect of the uniformity constraint shows up in the co-dependence of the transport taxes on the labour tax (cf. the second term in the transport tax expressions). In particular, transport taxes are revised downward in as far as a marginal labour tax change has effects on commuting (hence on labour supply), relative to the (negative) effect of a modal price on total modal demand. *Ceteris paribus*, the higher the sensitivity of commuting to the labour tax, the larger the downward revision of the commuting tax. To the reverse, a higher sensitivity of transport (for all purposes) to the transport tax, implies a lower downward revision of the transport tax.

Intuitively, this second effect indicates how, under the restriction of uniform taxes across trip purposes, transport taxes are set to strike a balance between two policy objectives:

- Allowing a lower effective tax on labour supply through lower commuting taxes, and
- Decreasing the amount of leisure trips through higher leisure transport taxes. The latter policy objective is not directly related to the marginal external congestion cost, as this is tackled by the third (Pigouvian) component of the transport tax expressions. The actual policy goal is to reduce leisure transport, so as to allow faster commuting travel (by either commuting mode).

Due to the uniformity constraint on the transport tax, both policy goals can only be served imperfectly, and the optimal uniform transport tax is between the optimally differentiated taxes for both trip purposes.

To repeat, the basic effects of the uniformity constraint in transport taxes are that (a) the Ramsey term refers to the price sensitivities of all affected trip purposes, and (b) the correction of the transport taxes for the labour tax is counteracted by the desire to have a high transport tax in order to decrease leisure trips. As will be illustrated in the empirical illustration in section 3, the effect of the uniformity constraint plays out differently under different assumptions on the flexibility of the labour tax.

Before turning to the numerical implementation of the model, we briefly compare the preceding analysis to that of Parry and Bento (1999). Their model contains no leisure transport, and public transport is assumed to take place on a separate non-congested network. Non-time resource costs of transport are neglected. There are only two policy instruments: the labour tax and the car commuting tax. Using an equal yield tax reform method, they find that the optimal car commuting tax is equal to the marginal external congestion cost (a pure Pigouvian tax).

The intuition for this result is that in their model, the Pigouvian tax guarantees an optimal modal split, since the relative modal prices will then reflect the marginal social costs. However, if the public transport tax were allowed to differ from zero, the taxes would be indeterminate as in our model of section 2.2.1. Note that our results indicate that setting the public transport tax equal to zero is not necessarily optimal, even when public transport generates no congestion, as the Ramsey component may cause the optimal tax to be non-zero. In the Parry and Bento (1999) model, the Ramsey component can be set to zero, as the separable structure of the utility function guarantees that the Ramsey components are equal for car and bus commuting (so that it can fully be taken into account in the labour tax). The absence of the public transport tax in Parry and Bento (1999) should therefore be interpreted as a constraint on the available set of instruments. Finally, the absence of leisure transport modes in Parry and Bento (1999) naturally implies that trip purpose interactions do not matter.

3. Numerical illustration

3.1 Structure and calibration

The numerical model is fully analogous to the theoretical model, except that the preference structure imposes separability restrictions and that all taxes are bounded below at zero. The model is programmed in GAMS (Brooke et al., 1996). Data used in this paper are meant to reflect realistic orders of magnitude for Belgian urbanised environments, but do not refer to any particular case. The representative consumer's preferences are modelled with nested CES functions, according to the structure depicted in figure 1.

Figure 1 CES implementation of the utility function

where:	U	utility from non-work related activities
	T	utility from commuting and working time
	q ₀	composite consumption commodity
	q ₁	leisure transport by car
	q ₂	leisure transport by bus
	q ₃	commuting transport by car
	q ₄	commuting transport by bus
	N	leisure time
	NT	CES index of leisure transport
	NI	CES index of leisure activities

The model is calibrated to a dataset representing current Belgian transport prices in urban contexts (Van Dender and Proost, 1998) using a congestion function and quantities which are derived from a network model for the city of Namur, Belgium (Cornélis and Van Dender, 2001).³ The congestion function is linear, with a free flow speed of 60 km/h. At the reference traffic flow of 2450 passenger car units (PCU) speed is 30 km/h. Since a one-way trip distance of 20 km is assumed, daily travel time for a round trip by car is ca. 1.3h. To this we add a fixed average waiting time of 7.5 minutes (half of a 15 minute headway) for a one-way bus trip. The value of time, as implied by the calibration, is 7.65 Euro/hour. This is 47 % of the gross wage and 78 % of the net wage. These values are closely in line with available estimates (Small, 1992).

The total number of potential network users is 5000 individuals, of whom 1800 supply 8 hours of labour per day.⁴ The length of the working day is fixed. The representative individual hence supplies 0.36 days, or 2.88 hours of labour per day. The gross wage is 16.25 Euro/hour. With a labour tax of 40 %, the net daily labour income per representative individual is 28.1 Euro.

³ Calibrating this model requires the simultaneous solution of the system of first order conditions for the consumer. This is in contrast to models with fixed marginal values of time, where a (separable and parameterised) bottom-up calibration procedure is applicable. The simpler parameterised calibration procedure is not suitable here, as the multipliers of the money and time budget constraints for the consumer are not observed. These multipliers determine, a.o., the marginal value of time.

⁴ The population size as such is of little importance. It is scaled in order to accord with available road capacity. The labour force participation rate is taken to be 36%.

The modal split for commuting transport is two thirds car trips and one third bus trips. For leisure trips the car is used for 75 % of all trips. Commuting trips stand for 53 % of the total number of trips. These proportions are roughly consistent with the Belgian Mobility Survey (Pollet, 2000) and with more detailed data for Brussels (IRIS, 1993), if it is assumed that the bus mode is easily accessible in our example. The reference traffic flow of 2450 PCU is obtained by assuming that the average occupancy rate and PCU equivalent of a car is 1, while the average occupancy rate of a bus is 40 and the PCU equivalent of a bus is 2. The reference taxes for bus trips are sufficient to cover marginal external congestion costs⁵, while this is not the case for car trips. The ratio of taxes over marginal external congestion costs is 0.62 for car trips and 1.53 for bus trips.

In a CES function, the combination of elasticities of substitution with prices and quantities determines price elasticities. The values of the elasticities of substitution used for the central case, and the resulting compensated price elasticities for the reference equilibrium, are in table 1. The sensitivity of the results to these parameters is discussed in section 3.3.

The compensated elasticity of labour supply is 0.19. This is in line with the central estimates (0.15) in Hansson and Stuart (1985) and Ballard et al. (1985). It is below the values of 0.35 and 1.09, used by Parry and Bento (1999) and Mayeres (1999) respectively. The elasticity of labour supply is a key parameter in the model. It is mainly determined by the elasticity of substitution between q_0 and NL . We refer to section 3.3 for some insight into the dependence of model results on this parameter.

The own price elasticity of demand for commuting trips is determined by the labour supply elasticity. It is lower for commuting trips than for leisure trips. In addition, we choose parameters in the central scenario such that the cross-price elasticities between transport modes is larger for commuting trips than for leisure trips. The underlying assumption is that the availability of public transport modes is larger for commuting trips than for leisure trips, because of differences in the spatial distribution of origins and destinations. The model results are not very sensitive to these parameters however (section 3.3).

⁵ At least within the assumption that the marginal external congestion cost for each passenger's bus trip is found by equally distributing the marginal external cost of the vehicle over all occupants.

Table 1 Elasticities of substitution and main compensated price elasticities, central scenario

Elasticities of substitution		
Composite commodity – leisure index	$q_0 - NI$	0.7
Leisure transport – other leisure	$NT - N$	1.1
Leisure car trips – leisure bus trips	$q_1 - q_2$	0.9
Commuting car trips – commuting bus trips	$q_3 - q_4$	0.6
Compensated price elasticities		
	E_{11}	-1.02
	E_{12}	0.03
	E_{21}	0.12
	E_{22}	-0.93
	E_{NN}	-0.19
	E_{34}	0.08
	E_{43}	0.52

3.2 Transport tax reform at the reference labour tax rate

The effects of optimising transport taxes for the given labour tax rate of 40% are summarised in table 2, where the optimal differentiated and optimal uniform transport taxes are compared to the reference equilibrium.

Table 2 Main effects of optimal transport taxes at the reference labour tax rate

	Reference equilibrium	Optimal differentiated transport taxes	Optimal uniform transport taxes
Welfare index	1	1.001299	1.000189
Transport tax (Euro/trip)			
(1) leisure car trips	4.240	7.407	4.840
(2) leisure bus trips	0.527	1.034	0
(3) commuting car trips	4.240	0	4.840
(4) commuting bus trips	0.527	0	0
Trip demand			
Total trip demand (index)	1	0.965	1.000
Share of commuting trips	53.0%	56.3%	52.8%
Modal split			
Share of car trips: leisure	75.0%	73.5%	74.0%
Share of car trips: commuting	67.0%	80.1%	58.8%
Share of car trips: all trips	70.6%	77.2%	66.0%
Taxes/marginal external congestion costs			
(1) leisure car trips	0.617	1.078	0.700
(2) leisure bus trips	1.533	2.983	0
(3) commuting car trips	0.617	0	0.700
(4) commuting bus trips	1.533	0	0

In the reference equilibrium, transport taxes are uniform across trip purposes. Car taxes are below marginal external congestion costs, while bus taxes exceed them. This situation is not optimal in the sense that a better use of uniform or differentiated transport taxes produces a welfare gain of 0.019% and 0.13% respectively. Clearly, welfare gains are limited in both cases, and close to negligible for optimal uniform transport taxes.⁶

⁶ The size of the welfare gains is mainly determined by the expenditure share of transport, the reference composition of the traffic flow, the congestion function and the labour supply elasticity. The influence of the

When differentiation of transport taxes is possible and the labour tax rate remains at the reference level, commuting transport is not taxed. Both types of leisure trips are taxed above marginal external congestion cost, however. Hence there is a clear shift to the taxation of relative complements to leisure. The main quantity effect of optimal differentiated transport taxes is the slight increase of commuting trips (and labour supply) and the decrease of leisure trip demand. This leads to a higher share of commuting trips in total trip demand. Total trip demand falls, but the marginal external congestion cost slightly increases because of the increased marginal value of time. The absence of a car commuting tax leads to an increase of the modal share of cars in commuting.⁷

The explanation of the welfare gain from optimal uniform transport taxes is different. Here the main effect is that the modal split in commuting is changed in favour of buses. Labour supply and commuting remain virtually unchanged with respect to the reference situation. Leisure trip demand increases slightly, and the modal split in leisure transport is only slightly affected. Hence the only effect of this policy is to reduce congestion by setting the bus tax at zero and by slightly increasing the reference car tax, so as to modify the overall modal split in favour of buses. The car tax remains below marginal external congestion costs, however, in order to avoid further increases in the effective tax on labour supply. The main problem of uniform transport taxes at the reference labour tax rate is that they can not generate a shift of the tax burden to relative complements of leisure. The welfare gain is accordingly low.

The next sections release the constraint on labour taxes. As will be seen, this leads to larger welfare improvements, both in the case of differentiated and uniform transport taxes. The essential insight is that the reference labour tax rate is too high to permit the realisation of the full potential of optimal (non-negative) transport taxes.

3.3 Optimal differentiated transport taxes with flexible labour tax rates

This section presents results from optimal differentiated transport taxes, as analysed in section 2.2.1. In contrast to the theoretical analysis, the numerical model requires taxes to be non-negative. The optimal differentiated tax structure can succinctly be written as in (12), where all taxes are the sum of a Ramsey term (R) and a Pigouvian term (P).

$$\begin{aligned} t_1 &= R_1 + P_{car} \\ t_2 &= R_2 + \alpha P_{car} + c_p \\ t_3 + t_L &= R_3 + P_{car} \\ t_4 + t_L &= R_4 + \alpha P_{car} + c_p \\ t_i &\geq 0, \quad i = 1, \dots, 4, L \end{aligned} \tag{12}$$

The following properties of the tax structure are worth repeating:

- The tax expressions take no account of interactions with distortions on other transport markets. This is possible as long as all instruments are available. The Ramsey terms take account of demand interactions between markets, as in equations (7) and (8).

latter is highlighted in section 3.5. Here we are mainly concerned with the relative performance of different policy types.

⁷ Recall that there is no waiting time for car trips, so the observed modal switch leads to time savings.

- Because of the complementarity constraint between labour supply and commuting trips, no separate expression is required for the labour tax. However, only the sum of labour and commuting transport taxes is defined. Also, R_3 and R_4 refer to the tax base formed by commuting and by labour supply.
- The marginal external congestion costs from a bus trip are proportional to those of a car trip. The factor of proportionality is given by α . The marginal external congestion cost of a car trip or a bus trip is not affected by the trip purpose.
- All taxes are bounded below at zero. For bus trips this means that no net subsidy is possible, as the tax is equal to the fare. For car trips the restriction implies that drivers will always incur the resource costs of the car trip.

From (12) it is clear that tax differentiation across trip purposes for a given transport mode only relates to the Ramsey component of the tax. It is well known that the Ramsey components crucially depend on the relative complementarity of the tax good with respect to (untaxed) leisure, in the sense that tax rates on relative complements to leisure are relatively high.⁸ The structure of the numerical model, see figure 1, of course implies that leisure trips are more complementary to leisure than commuting trips. Relatively high tax rates on leisure trips are therefore to be expected. However, the optimal commuting transport tax depends on the prevailing labour tax rate. When the labour tax rate is low, commuting transport taxes will act as pure labour taxes, so that they become relatively high. In other words, the tax base is different for leisure trips and for commuting trips, and the way in which this difference plays out depends on the labour tax rate.

The theoretical analysis did not rule out negative optimal transport taxes. In case an optimal tax should be negative, the lower bound of zero becomes binding in the numerical model, and we have a constrained optimal tax system. From (12) and from the discussion of the Ramsey terms, it can be inferred that the lower bound can only be reached when the labour tax rate is set too high. More precisely, as will be illustrated below, the lower bound will first be reached for the tax on bus commuting. Indeed, marginal external congestion costs for buses are low compared to those of cars, and bus commuting is a relative substitute for leisure. The numerical model hence implies a threshold value for the labour tax, above which the model becomes a constrained model: $t_L \geq R_4 + \alpha P_{car} + c_p$.

This has several implications:

- The effectiveness of the tax system is reduced, so that lower welfare gains are obtained.
- Once the first transport tax becomes zero, the first-order conditions (4.6) can no longer be applied unconditionally.
- The indeterminacy of the optimal taxes on labour and commuting trips no longer holds.

Given this a priori information, the main contribution of the numerical model lies in the identification of the threshold value for the labour tax, which here equals 32.5%. As this is below the reference labour tax rate of 40%, we can conclude that the full welfare potential from differentiated transport taxes can only be reached when the reference labour tax is substantially reduced. Table 3 compares the effects of transport tax differentiation without and with labour tax optimisation. The optimal labour tax rate is set at the upper bound of 32.5%. Because of the indeterminacy of the tax system,

⁸ This insight is not dependent on the particular normalisation of the model, cf. e.g. Munk, 1999.

the same gain can be achieved below the threshold labour tax, through a simple correction of commuting transport taxes for the decreasing labour tax. The optimal leisure transport taxes are constant for labour tax rates between 0% and 32.5%.

Table 3 **Main effects of optimal differentiated transport taxes without and with labour tax optimisation**

	Reference equilibrium	Optimal differentiation at reference labour tax ($t_L=40\%$)	Optimal differentiation and optimal labour tax ($t_L=32.5\%$)
Welfare index	1	1.001299	1.004208
Transport tax (Euro/trip)			
(1) leisure car trips	4.240	7.407	16.285
(2) leisure bus trips	0.527	1.034	8.823
(3) commuting car trips	4.240	0	5.457
(4) commuting bus trips	0.527	0	0
Trip demand			
Total trip demand (index)	1	0.965	0.900
Share of commuting trips	53.0%	56.3%	62.9%
Modal split			
Share of car trips: leisure	75.0%	73.5%	74.5%
Share of car trips: commuting	67.0%	80.1%	63.3%
Share of car trips: all trips	70.6%	77.2%	67.5%
Taxes/marginal external congestion costs			
(1) leisure car trips	0.617	1.078	2.302
(2) leisure bus trips	1.533	2.983	24.950
(3) commuting car trips	0.617	0	0.772
(4) commuting bus trips	1.533	0	0

With an optimal labour tax rate, transport tax differentiation achieves an increase in commuting trips and labour supply of 6%. The welfare gain is now 0.4% with respect to the reference situation, which is more than three times higher than in the case with the reference labour tax rate. The modal split is modified in favour of buses, but much more so for commuting than for leisure trips. More importantly, the decrease in leisure trip demand is large enough to generate a strong net decrease in transport demand. However, like in section 3.2, the improved tax system involves an increase in the marginal value of time savings, so that the marginal external congestion costs actually increase.

With respect to the transport taxes, note that all leisure transport is taxed well above marginal external congestion costs, the reverse holding for commuting transport. This is the consequence of the difference in the Ramsey terms across trip purposes. Note that the tax on commuting trips will increase as the labour tax decreases, without any further effects on the properties of the optimum. Finally, the difference between car and bus taxes is larger for leisure trips than for commuting trips. This is a consequence of the larger elasticity of substitution, implying larger own and cross-price elasticities, between cars and buses for commuting trips.

3.4 The welfare loss from the uniformity constraint with flexible labour tax rates

In section 3.2 the effectiveness of uniform transport taxes was seen to be much smaller than that of differentiated transport taxes, when the labour tax rate was fixed at the reference level. As is clear from section 3.3 the reference labour tax exceeds the threshold level, below which the full gains from differentiating transport taxes can be realised. It is therefore interesting to find out how the effectiveness of differentiated and uniform taxes compares at different levels of the labour tax rate. Figure 2 compares the welfare gains from both experiments for a range of labour tax rates between 0% and 45%.

In general the uniformity constraint is seen to be costly in terms of welfare. Uniform transport taxes generate less welfare improvement than differentiated transport taxes, for two reasons. First, the uniform tax is a weighted average of the differentiated taxes (cf. equation (11)), and is therefore less effective in correcting the modal split for both trip purposes. This effect is relatively small, as the difference between the substitutability between modes across trip purposes is rather small. Second, under optimal differentiation of transport taxes, the commuting taxes depend strongly on the prevailing labour tax rate. Therefore, when the labour tax rate calls for strong differentiation of transport taxes (because of the relative complementarities to leisure), the welfare cost of uniform transport taxes is relatively large. Indeed, the model results show that the deviation between the optimal uniform tax on cars and the optimal differentiated car taxes is very small at a labour tax rate of 24%. The analogous deviation for bus taxes is smallest between 25% and 26%. The best uniform transport tax system should therefore be found at labour tax rates between 24% and 26%. Furthermore, as the car mode is dominant, the best uniform system should be found closer to the labour tax rate of 24%, as is the case.

Figure 2 also illustrates that exceeding the threshold labour tax rate of 32.5% leads to welfare losses from optimal differentiated taxes. The performance of uniform taxes is affected as well, both because of the uniformity constraint as such and because of the level of the labour tax. The higher the labour tax rate becomes, the smaller the divergence between both types of transport tax reform. At very high levels of labour taxes, the transport taxes lose most of their potential. The explanation is that, as the labour tax increases, all transport taxes gradually fall to zero.

Figure 2 Welfare effects of optimal transport taxes for given labour tax rates

3.5 Sensitivity analysis

Elasticity of substitution between leisure and other commodities

As the preceding analysis suggests that the welfare effects of transport tax reform depend to a substantial degree on the interaction with labour taxes and labour supply, it is no surprise that the model results are mainly dependent on the elasticity of substitution between leisure and other goods. We summarise the basic impact of increasing and decreasing the elasticity of substitution (the compensated labour supply elasticity) from 0.7 (0.19) to 1.2 (0.28) and 0.3 (0.11) respectively.

The welfare potential of optimal tax reforms for constant tax revenue requirements increases with the labour supply elasticity, from 0.06% for the lowest and 1.13% for the highest elasticity. Traffic levels reduce less strongly as the labour supply elasticity rises, mainly because of a relatively higher number of commuting trips by car. Hence, the optimal congestion levels are an increasing function of the labour supply elasticity. Also, it is noteworthy that the level of leisure trips falls less drastically as the labour supply elasticity rises. This means that there is less need to ‘tax leisure trips off the road’ for higher elasticities of labour supply.

When computing optimal differentiation of transport taxes for constant labour taxes, it is the case for most values of the elasticity that the optimal car commuting tax is zero. However, when the labour supply elasticity is sufficiently small, the model suggests a qualitative change in the nature of the second-best policy. Instead of focussing on tax differentials between trip purposes in order to increase labour supply, it becomes preferable to set taxes such that the modal split for commuting trips is strongly changed, in favour of bus trips. This requires a positive car commuting tax. In other words, as the labour supply elasticity diminishes, the policy objective of reducing congestion for current labour supply levels becomes more important than the objective of increasing labour supply (with possibly increased congestion levels). The reduction of congestion is achieved by a transport

tax structure that promotes a modal shift towards buses. This is the same type of policy that was observed in section 3.2 for optimal uniform transport taxes at the reference labour tax rate.

Cross price elasticities between transport modes

Decreases in the elasticities of substitution between transport modes, in commuting and/or in leisure transport, have no major impacts on the welfare effects of the various policy experiments, nor on the values of the taxes. The most important changes are that (a) as the degree of substitutability between commuting by car and by bus decreases, leisure transport is decreased relatively more, so as to allow increases in both types of commuting, but at a higher aggregate congestion level; (b) as the degree of substitutability between leisure transport modes decreases, labour supply increases somewhat less compared to the central scenario while the optimal (equal yield) congestion level is slightly higher.

4. Conclusion

On the basis of the numerical implementation of a simple general equilibrium model for multi-modal and multi-purpose passenger transport, we find that the welfare effects of transport tax reform depend to a large extent on the impact on labour supply. In order to have a substantial impact on labour supply, transport tax reform should be accompanied by labour tax changes. When this is not possible through a direct change of the labour tax, the reform should treat commuting transport and leisure transport differently. In general, the results suggest that the relative welfare cost of uniformly taxing different trip purposes is substantial.

Optimal transport tax reforms lead to a combined increase of labour supply and a decrease in the total trip volume and the associated costs of congestion, with respect to the reference situation. In order to obtain the maximal welfare gain from transport tax differentiation, the labour tax should be low enough to sustain non-negative transport taxes. The volume of commuting trips increases, but this is more than compensated by a decrease in peak period leisure trips. It can be expected that in a multiperiod model, leisure trips will be seen to shift to offpeak hours, so that the total demand decrease becomes smaller.

Note that exogenous parameter values have large effects on the results, in quantitative and in qualitative terms. The results described here should be considered as exploratory. The sensitivity analysis suggests that the results of carefully implemented case studies will not be transferable across cases, both because of the impact of the reference composition of traffic flows and because of the elasticity values. For instance, in our illustration, the reference share of leisure trips is substantial, and it is assumed that a substantial shift of commuting trips towards buses is possible at constant marginal cost. These assumptions may not be valid for all urban areas. The gains from transport tax reforms will decrease when peak period traffic consists mainly of commuting trips, and when expansion of public transport supply is not possible at a constant marginal cost.

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