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Transport tax reform, commuting and endogenous values of time*

By

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Abstract

Previous studies of transport tax reform have typically assumed that the reform itself does not affect the marginal value of time. In this paper we consider a model of urban transport with two trip purposes, commuting and non-commuting, to analyse the effects of transport tax reform on the value of time and marginal external congestion costs. The theoretical results suggest that the assumption of multiple trip purposes implies that these effects are non-trivial. Consequently, assuming exogenous time values may lead to inaccurate estimates of optimal congestion taxes and of the welfare effects of transport tax reform. Empirical work using Belgian data illustrates the potentially large effect of transport tax reform on time values. In fact, the majority of the tax reform exercises studied reduce traffic levels but raise time values and marginal external congestion costs.

Keywords: tax reform, congestion, value of time

JEL codes: H23, R41, R48

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1. Introduction

Widespread concern about the external costs associated with increasing transport demand has generated a large literature on optimal externality taxes and optimal tax reform in the transport sector. Examples include Keeler and Small (1977), Glaister and Lewis (1978), Small (1983), Viton (1983), Kraus (1989), Arnott, De Palma, and Lindsey (1993), De Borger et al. (1997), Proost and Van Dender (2001), and Small and Yan (2001). These models implicitly or explicitly assume that the value of time is unaffected by the proposed policy changes. Also, although some studies take account of different transport markets (according to mode, time of day, car type, etc.), they do not distinguish between trip purposes such as commuting and non-commuting. The few models that do allow for endogenous values of time (Mayeres and Proost (1997), where the endogeneity is explicit, and Parry and Bento (2001), where it is implicit) are based on a single trip purpose. This paper aims to show that explicitly distinguishing between trip purposes implies that transport policies may have non-negligible effects on the value of time. As a consequence, realising that in most countries commuting is indeed an important trip purpose during peak hours, the welfare effects suggested by models assuming either constant values of time or single trip purposes may be inaccurate.

Since the seminal papers by Becker (1965) and Gronau (1977), economists have devoted serious attention to the determinants of the value of time (for a recent survey, see Jara-Diaz, 2000). Theoretical research and empirical analysis of large-scale surveys suggest that the value consumers place on time savings not only depends on income or wage levels, but also on many socio-economic characteristics. Relevant references include Clifford and Whinston (1998), Ramjerdi, Rand and Saelensminde (1997) and de Jong and Gunn (2001). Moreover, time values vary according to the specific circumstances under which the time saved is actually spent (see, e.g., De Donnea, 1972, Hague Consulting Group, 1990, de Jong and Gunn, 2001). Somewhat surprisingly, however, the potential dependency of the value of time on the level of transport prices has received little attention. It has not explicitly been analysed how a tax reform itself affects the values of time, marginal congestion costs and the welfare effects of the reform. Using endogenous values of time is especially relevant in optimal tax models and in tax reform exercises in the transport sector, where the prevalence of congestion externalities may require large price adjustments, and where the road is simultaneously used for several trip purposes that differ in their complementarity to leisure.

Using a simple model with two trip purposes, this paper finds that transport taxes may substantially affect the value of time. In particular, policies that combine transport tax increases with adjustments in labour taxes to reduce the distortions from the tax system (see, e.g., Bovenberg and Goulder, 1996) are likely to increase the marginal value of time. The size of the effect depends on the share of commuting trips in overall traffic and on the price sensitivity of transport demand. With endogenous time values, a joint tax reform on the transport and labour markets may yield lower traffic levels, less congestion, but higher marginal external congestion costs. This contrasts with the popular view that directly associates decreases in traffic levels on a congestible facility with reductions in marginal external congestion costs.

The above findings imply that models with constant time values and models that inappropriately ignore multiple trip purposes, produce inaccurate results. If commuting trips are a non-negligible share of traffic and a model with one trip purpose and an exogenously fixed values of time is used, the time values and marginal external congestion costs at the post-reform equilibrium are underestimated, while the welfare effects are overestimated.

The paper is structured as follows. Section 2 considers the value of time and marginal external congestion costs in a stylised model of consumer choice with two trip purposes. Section 3 illustrates the interactions using a more elaborate numerical model, with two transport modes and two trip purposes, calibrated on stylised Belgian data. The effects of optimal taxes and of various types of tax reform are considered. Section 4 concludes.

2. Transport taxes, the value of time and marginal external congestion costs in a model with two trip purposes

We present the theoretical model and then study the impact of transport and labour tax reforms on the marginal value of time and on marginal external congestion costs.

2.1 A simple model with two trip purposes

Let a representative consumer care about two types of trips, a general consumption good, and leisure. Preferences are given by $u(q_0, q_1, q_2, N)$, where q_0 is a composite commodity with price normalised at one, q_1 are non-commuting trips, q_2 are commuting trips (the journey-to-work), and N is leisure time. The model focuses exclusively on peak period travel, when congestion is worst and both trip purposes are relevant (LRC, 1994, US Federal Highway Administration, 1995). To make the distinction between the two trip motives as transparent as possible, commuting is assumed to be directly proportional to labour supply L, i.e. $q_2 = L$. This says that each day of work requires one morning peak trip, assumed for simplicity to be one kilometre long. Labour supply is elastic in terms of the number or days of labour, but the length of each workday is fixed.

There is only one transport mode (and only one car type). Transport prices per trip (or per kilometre) are p_1 and p_2 for non-commuting and commuting, respectively. The prices are different if, e.g., commuting expenses are tax deductible (cf. Wrede, 2001). In the absence of tax deductibility both prices are identical. Commuting and non-commuting transport share a congestible road network, and therefore jointly determine travel time $a = a(F)$, where *a(.)* is the congestion function, $F = n(q_1 + q_2)$, and n is the number of consumers. We normalise *n=1* throughout.

The consumer maximises utility subject to a budget and a time constraint:

$$q_0 + p_1 q_1 + p_2 q_2 = (1 - t_L) L + S \qquad [\lambda] \tag{1}$$

$$N + L + (a(F))(q_1 + q_2) = \bar{L} \qquad [\gamma] \tag{2}$$

where t_L is the labour tax rate (wages are normalised to 1 without loss of generality), L is labour time, S is a fixed lump sum transfer, and $\bar{L}$ is the time endowment. Finally, λ and γ are the Lagrange multipliers for the budget and time constraints.

Using $q_2 = L$ and assuming that the representative consumer neglects his own impact on congestion, we obtain the first-order conditions (3), where subscripts indicate partial derivatives

$$\begin{aligned} u_0 &= \lambda \\ u_1 &= \lambda p_1 + a\gamma \\ u_2 &= -\lambda(1 - t_L - p_2) + (1 + a)\gamma \\ u_N &= \gamma \end{aligned} \tag{3}$$

The marginal utility of non-commuting trips is positive. However, the marginal utility of commuting trips, which can also be interpreted as the net marginal utility of time spent working, may take either sign. Following Jara-Diaz (2000) we define the marginal value of time by $MVOT \equiv {u_N}/{u_0}$. Using the system of first-order conditions (3), we can write:

$$MVOT \equiv \frac{u_N}{u_0} = \frac{\gamma}{\lambda} = \frac{\frac{u_2}{\lambda} + (1 - t_L - p_2)}{1 + a} \qquad (4)$$

The marginal value of time, which at the optimum is independent of the activity in which it is spent, equals the net real wage per unit of time, corrected for the marginal (dis-)utility of commuting.[1] The net real wage captures the cost of commuting and the time input per hour of work includes commuting time.

Although we study the issue more formally below, the potential impact of transport pricing reform on the value of time in this model can be seen from (4). The value of time directly depends on congestion and on commuting costs. Since reducing congestion is often a major reason for transport tax reform, and since large transport tax changes are required to cope with external congestion costs, the impact of price changes for *non-commuting* transport on the value of time through changes in congestion can be large. A *commuting* tax has an additional direct effect on time values through the net real wage. Finally note that, since transport prices are also likely to affect labour supply and commuting, the marginal utility of income and of commuting cannot be assumed to be constant.

[1] Slightly different expressions for the value of time are obtained depending on the exact specification of the utility function (e.g., explicitly including travel time or labour supply as an extra argument of utility). See Jara-Diaz (2000) for an overview. The main point of this paper, viz. that distinguishing trip purposes has implications for the impact of tax changes on the value of time, is not affected.

Observe that the impact of transport prices on time values is explicitly due to the assumption of two trip purposes, one of which is commuting. If all transport were aggregated and treated as non-commuting transport (i.e. assuming $q_2 = 0$ and ignoring $q_2 = L$), then the model implies a value of time equal to the net wage, $MVOT \equiv \gamma / \lambda = 1 - t_L$. In that case equilibrium transport prices do not affect values of time, and the labour tax reduces the time value on a one-to-one basis.

2. 2 Taxes and the value of time with multiple trip purposes

We now consider more formally the impact of price and tax changes on the value of time. To simplify the analysis we impose some extra structure on preferences.[2] An outline of the analysis for the general case is relegated to Appendix 1. Specifically, assume that utility is quasi-linear in the numeraire good and that commuting is additively separable from other consumption goods and leisure:

$$u(q_0, q_1, q_2, N) = q_0 + U(q_1, N) + g(q_2)$$

These assumptions imply that the marginal utility of income is constant and equal to one ($u_0 = \lambda = 1$) so that $MVOT \equiv u_N / u_0 = \gamma$. Substituting q_0 from the budget constraint into the utility function and using $\lambda = 1$, the system of first-order conditions now reads:

---

[2] In general, the results depend on all second derivatives of the utility function. This obscures the interpretation, because many of the cross-effects of the marginal utilities are difficult to sign a priori.

$$
\begin{aligned}
&u_1 = p_1 + a\gamma \\
&u_2 = -(1 - t_L - p_2) + (1+a)\gamma \\
&u_N = \gamma \\
&\overline{L} = N + aq_1 + (1+a)q_2
\end{aligned}
\tag{5}
$$

where the final equation is the time restriction.

The consumer's optimisation problem implies that system (5) holds at given prices, taxes and an exogenous congestion level *a=a(F)*. However, we are interested in the impact of taxes on demand and on the value of time γ, taking into account the effect of taxes and prices on congestion levels. Differentiating (5), capturing price effects on *a* via demand changes, and using matrix notation yields:

$$
\begin{bmatrix}
u_{11} - \gamma a' & -\gamma a' & u_{1N} & -a \\
-\gamma a' & u_{22} - \gamma a' & 0 & -(1+a) \\
u_{N1} & 0 & u_{NN} & -1 \\
-(a + a'F) & -(1 + a + a'F) & -1 & 0
\end{bmatrix}
\begin{bmatrix} dq_1 \\ dq_2 \\ dN \\ d\gamma \end{bmatrix}
=
\begin{bmatrix} dp_1 \\ dt_L + dp_2 \\ 0 \\ 0 \end{bmatrix}
\tag{6}
$$

where, as before, $F = q_1 + q_2$ is total transport demand and $a' = {da(F)}/{dF}$ is the slope of the congestion function.

The solutions for $dq_1, dq_2, dN, d\gamma$ can be obtained by Cramer's rule. Here we only report the impact of transport prices and labour taxes on the value of time γ (see Appendix 2 for more details on the effects of price and tax changes on transport and leisure demand). We find:

$$
\frac{d\gamma}{dp_1} = \frac{1}{\Delta}\left\{ u_{22}\left[(au_{NN} - u_{1N}) + a'Fu_{NN} \right] + \gamma a'(u_{1N} + u_{NN}) \right\} \tag{7}
$$

$$
\frac{d\gamma}{dt_L} = \frac{d\gamma}{dp_2} = \frac{1}{\Delta}\left\{ (u_{NN}u_{11} - u_{N1}^2)(1 + a + a'F) - \gamma a'(u_{NN} + u_{N1}) \right\} \tag{8}
$$

where Δ is the determinant associated with the system in (6). In Appendix 2 it is shown that a mild restriction on the feedback effects of congestion on demand guarantees that it is negative. We assume this condition to hold and we assume throughout that marginal utility is non-increasing, i.e., $u_{NN} \leq 0$, $u_{11} \leq 0$ and $u_{22} \leq 0$.

Consider the impact of the price of non-commuting trips on the value of time (see (7)). In view of (4) it is not surprising that its sign strongly depends on how the price change affects commuting and overall congestion. To see this, first suppose that the marginal utility of commuting were constant, so that $u_{22} = 0$. An increase in the price of non-commuting will then raise or reduce the value of time, depending on the sign of $u_{1N} + u_{NN}$. As seen in appendix 2, $u_{1N} + u_{NN} < 0$ is a sufficient condition for more expensive non-commuting transport to reduce overall congestion. If this condition holds, the price increase raises the value of time. It would decline if the price increase actually caused congestion to rise, i.e. if the negative price effect on non-commuting demand were more than compensated by a large positive cross-price effect on labour supply and commuting demand. Next, if $u_{22} < 0$, the above statements must be amended depending on the change in commuting transport. Noting from appendix 2 that ($au_{NN} - u_{1N}$)<0 is a sufficient condition for ${dq_2}/{dp_1} > 0$, it is clear that a strong positive cross-price effect reduces the value of time.

An increase in the labour tax and in the price of commuting have the same impact on the value of time because they affect the net real wage identically.[3] Since $u_{NN}u_{11} - u_{N1}^2 > 0$ by the strict concavity of U(.), both will reduce the value of time as long as u_{1N} is not too positive, see (8). This is plausible: higher labour taxes reduce the value of time unless commuting demand and total congestion drastically decline.

---

[3] This is no longer true in the empirical model, where two transport modes are considered.

As seen in Appendix 2, a very large positive u_{1N} indeed implies strong reductions in commuting and labour supply; as a consequence, congestion declines while the marginal utility of commuting rises. Both effects raise the value of time.

In sum, the above discussion implies that under many circumstances raising the price of non-commuting transport will raise time values, whereas commuting or labour taxes are likely to reduce time values. According to (7), as long as an increase in p_1 reduces overall congestion and does not substantially raise labour supply, the impact on the value of time is positive. The larger the impact on labour supply, the smaller the effect on the value of time and the larger the likelihood that the value of time will actually decline. As suggested by (8), we expect labour or commuting taxes to reduce the value of time unless labour supply decreases substantially.

The results for $d\gamma / dt_L$ remain unaffected if we assume that commuting and non-commuting transport prices cannot be differentiated, either for technical reasons or because of political constraints. However, since the common transport price directly affects the net real wage, the impact of a higher transport price (p=p_1=p_2) on time values does change. Specifically, we find:

$$\frac{d\gamma}{dp} = \frac{1}{\Delta}\left\{\left[u_{NN}(u_{22}+u_{11}) - u_{N1}^2\right](1+a+a'F) - (u_{1N}+u_{NN})u_{22}\right\}$$

As the term between square brackets is positive, for a constant marginal utility of commuting (u_{22}=0) a price increase now reduces the value of time, contrary to the outcome with price differentiation. Even though the price increase reduces congestion (raising time values), this is more than compensated by the direct reduction in the real net wage. If u_{22}<0, the negative effect is counteracted by a positive effect that is larger for a larger reduction in commuting demand. The ultimate sign is indeterminate. Note also that we expect the price effect on the value of time to be smaller here than the price effect for non-commuting transport in the tax differentiation case.

Table 1 summarises the most relevant findings and compares them with the case of a single trip purpose (in which case $MVOT = 1 - t_L$; column 2) and with the case of two trip purposes with fixed labour supply (last column). In the latter case, labour or commuting taxes do not affect the value of time, as the quasi-linear utility structure implies that these taxes have no effect on any of the time-using commodities (transport, leisure). Only non-commuting transport prices affect the value of time. Although the sign of the effect is ambiguous, it is plausibly negative, because a transport price increase reduces the total time input associated with non-commuting.

Table 1 Plausible impact of prices and taxes on the marginal value of time

	Model type		
Impact of increasing:	Two trip purposes	One trip purpose (non-commuting)	Two trip purposes and fixed labour supply
Labour tax t_L	<0	-1	0
Non-commuting transport price p_1	>0	0	<0
Commuting transport price p_2	<0	Not relevant	0
Common transport price $p = p_1 = p_2$	<0 or >0	Not relevant	<0

2.3 Taxes and marginal external costs with endogenous time values

In this model, marginal external congestion costs *MECC* are the same for commuting and non-commuting. Driving one extra kilometre raises *F*, reduces travel speed and increases travel time per kilometre *a(F)*. The time losses apply to all kilometres driven and are evaluated at the value of time per time unit. So we can write:

$$MECC = (MVOT) * (a') * (q_1 + q_2) \quad (9)$$

where $a' = {}^{da(F)}\!\!\diagup_{dF}$. Taxes and transport prices affect congestion costs through traffic flows, the slope of the congestion function, and the value of time. Differentiating (9) and rearranging, we obtain the following expressions:

$$\frac{d(MECC)}{dt_L} = \left[MVOT\left((F*\frac{da'}{dF}) + a'\right)\right]\left(\frac{dq_1 + dq_2}{dt_L}\right) + \left[(a')*F\right]\left(\frac{dMVOT}{dt_L}\right) \tag{10}$$

$$\frac{d(MECC)}{dp_i} = \left[MVOT\left((F*\frac{da'}{dF}) + a'\right)\right]\left(\frac{dq_1 + dq_2}{dp_i}\right) + \left[(a')*F\right]\left(\frac{dMVOT}{dp_i}\right) \tag{11}$$

where *i=1,2*. The first term on the right-hand-side of (10)-(11) measures the impact of the tax or price change via its effect on the traffic flow *F*. At constant values of time, the change in traffic flow influences the number of users affected by a marginal traffic increase, and it affects the slope of the congestion function. Since both effects are plausibly positive, the first term indicates that a price or tax increase reduces marginal external congestion costs as long as it reduces congestion. The second term is the impact of tax changes on the marginal congestion cost via their effect on the value of time. These effects where derived before for a simplified setting.

It is clear, then, that ignoring changes in time values introduces errors in determining marginal external costs. For example, suppose an increase in the price of non-commuting transport reduces congestion and raises the value of time. Assuming exogenous values of time then leads to overestimating the reduction in MECC. Analogously, if an increase in the commuting tax reduces congestion but reduces the value of time then the reduction in MECC will be underestimated if exogenous time values are assumed. Note that if the value of time substantially rises, marginal congestion costs may actually increase despite the reduction in congestion brought about by the price increase. For the same reason it is conceivable that a joint transport-labour tax reform increases MECC even when traffic flow declines, due to its positive impact on the value of time.

Three implications of the above discussion are worth repeating. First, exogenous time values will lead to inaccurate assessments of the welfare effects of transport tax reforms and of optimal congestion taxes, when a nontrivial fraction of transport flows refer to commuting. A model that implicitly treats all transport as non-commuting and that imposes constant time values, is likely to overestimate the reduction in the MECC as well as the welfare effects. For the same reason, optimal taxation exercises focusing on the transport market but using exogenous time values are likely to underestimate optimal congestion taxes. Second, even with endogenous values of time, we expect combined transport and labour tax reforms to lead to quite different implications in models with multiple trip purposes as compared to models that treat all transport as non-commuting. Suppose a transport tax reform is accompanied by measures to reduce the distortion on the labour market (raising transport taxes rise but reducing labour taxes). In models with a single trip purpose this reform will raise time values. This plausibly also is the case higher non-commuting transport prices, in a model with two trip purposes. However, to the extent that the combined change in commuting and labour taxes ultimately reduces the net real wage (i.e., the commuting tax is not fully compensated by the labour tax reduction), this second effect counteracts the first and reduces the value of time. The impact on marginal congestion costs will therefore be dampened. Third, larger shifts in time values and external costs are expected if tax reforms allow differentiation between non-commuting and commuting taxes.

Although generalising these findings is difficult because of the simplicity of the model, there is no reason to expect that the interactions will disappear in more general models as they essentially follow from distinguishing several trip purposes. Whether the issue is empirically sufficiently important to be worried about is something to be found out, and this is the purpose of the numerical exercise in the next section.

3. A numerical application

We illustrate some of the theoretical results using a numerical model with two trip purposes and endogenous time values (see Van Dender, 2001, for an elaborate description). The model is calibrated using data representing peak period traffic flows and congestion for an average workday in a typical Belgian mid-size city.

3.1 Overview of the model

The applied model generalises the theoretical analysis in two respects. First, instead of a quasi-linear utility function, a nested-CES representation of preferences is used. Second, we allow for multi-modality by distinguishing car and bus trips. The separability assumption for commuting transport is retained, as in Parry and Bento (2001). The consumer's problem then becomes:

$$
\begin{aligned}
&Max \quad u = U\left(q_0, (q_1, q_2), N\right) + g(q_3, q_4) \\
&subject\ to\ \left(1-t_L\right)L + S = q_0 + \sum_{i=1}^{4} p_i q_i \qquad [\lambda] \qquad (12) \\
&\overline{L} = N + L + a\sum_{i=1}^{4} q_i \qquad [\gamma]
\end{aligned}
$$

where q_0 is the composite commodity (untaxed numeraire), q_1 are non-commuting car trips, q_2 are non-commuting bus trips, q_3 is car commuting, q_4 is bus commuting and N is leisure. Here, $a=a(F)=a(q_1+q_3+\alpha(q_2+q_4))$, as the congestion function is adjusted for the presence of buses. The parameter $\alpha<1$ indicates that an extra bus trip per passenger contributes less to congestion than a car trip.[4] One simplification of the numerical model is that a linear congestion function is used, so that a change in the traffic flow does not affect its slope.[5] This allows us to focus on the effect of tax changes on marginal values of time and congestion levels, see (10) and (11). Finally, the proportionality between commuting and labour supply now implies that $q_3+q_4=L$. Traffic flow data and congestion technology are derived from a network model for the city of Namur (Cornelis and Van Dender, 2001). The reference peak period speed is 30km/h, half the free flow speed. According to a national survey (Pollet, 2000) and a survey for Brussels (IRIS, 1993), the share of commuting in all peak hour trips is 53%; 67% of commuting trips and 75% of non-commuting trips use the car mode. These shares reflect the modal split when the public transport mode is easily accessible. The reference transport prices are based on Proost and Van Dender, 2001.

[4] Note the assumption that the bus occupancy rates are fixed, which is reasonable for peak hours.

[5] When the real congestion function is convex, using a linear approximation will overestimate the travel time reductions associated to decreases in traffic flow. In order to moderate this overestimate, the linear approximation was made at traffic levels below the reference flows. Newbery and Santos (2002) suggest that network-derived linear congestion functions perform well for an analysis of cordon pricing schemes on a network.

3.2 Results

3.2.1 The central scenario

We report empirical results for a number of tax reform and optimal tax exercises. The reference equilibrium (**REF**), representing the initial situation in Belgium, is described in the left-most column of Table 2. The labour tax is 40%, and both commuting and non-commuting car traffic are taxed at less than marginal external cost: taxes amount to 4.24 Euro (per round trip) as compared with marginal external congestion costs (MECC) of 6.87 Euro. For public transport, note that the model assumes, consistent with current practice in Belgium, that bus transport is government-supplied and that the production costs are financed out of general public funds. With the reference subsidy of 2.7 Euro/trip, the consumer price amounts to 0.53 Euro/trip.

The calibrated marginal value of time in the reference equilibrium is 7.67 Euro/hour, or 47% and 78% of the gross and the net hourly wage, respectively. The absolute and the relative levels are in line with the literature (e.g. Small, 1992). Other information (on traffic flows, labour supply, etc.) is presented in index or percentage form.

The tax reforms are balanced-budget from the government's perspective: the combinations of transport and labour tax changes leave total tax receipts unaffected. The lump-sum transfer remains constant. We look at the implications of balanced-budget labour tax reductions by 1% and 5%, allowing transport taxes to be optimally adjusted and taking account of external congestion costs. Bus fares and car prices are restricted to be non-negative, implying maximal subsidies of 3.22 Euro and 8.08 Euro, respectively[6]. For each tax reform exercise we distinguish the cases of tax differentiation between commuting and non-commuting, and of uniform taxes across trip purposes. For all tax changes analysed, the impact on welfare is measured by the post-reform value of the indirect utility function of the representative consumer.

Table 2 summarises the results. First consider scenarios **A** to **D,** which refer to the tax reform exercises. All experiments reported in the table lead to higher welfare (row (1)). The value of time and the marginal external congestion costs increase in all scenarios. The increases in MECC occur *despite* the decrease in the aggregate peak period traffic flow in three out of four scenarios.[7] In other words, the tax reforms often reduce congestion while marginal external congestion costs increase.

The tax adjustments and therefore the changes in the value of time strongly vary between scenarios. In the case of uniform taxes across trip purposes, the optimal response to a 1% reduction in labour tax is to increase car taxes, but to reduce bus prices slightly. A 5% labour tax reduction raises car prices more substantially, but it implies higher bus fares. As a consequence of these adjustments, labour supply rises slightly. Increasing non-commuting transport taxes and minor reductions in the net real wage lead to time values that rise rather modestly (by 1.2% and 5.3% for the 1% and 5% labour tax reductions, respectively).

The corresponding outcomes are quite different when differentiated taxes are introduced. In those cases, all non-commuting trips become much more expensive. Since the labour tax reductions of 1% and 5% fall short of the optimal labour tax

[6] This restriction becomes binding for bus fares if labour taxes are substantially above optimal levels. Since commuting is proportional to labour supply, the optimal transport tax reform will 'correct' excessive labour taxes by heavily subsidizing commuting transport.

[7] Only the 1% decrease in the labour tax, financed by differentiated transport tax changes, leads to an increase in the traffic flow. Intuitively, this is because the transport tax differentiation is too small to strongly influence commuting and labour supply.

adjustment (see below), there is strong pressure on commuting transport prices not to reduce the net real wage. The bus commuting fare reaches its lower limit of zero, and car commuting is heavily subsidized (at ca. 38% of its resource cost[8]). Labour supply rises by some 4%. The strong increases in non-commuting transport taxes and the reduction in the labour tax together imply much higher values of time: they increase by 9.9% and 10.3%, respectively. Note that the larger effects on time values in the case of differentiated taxes are consistent with the theoretical discussion.

Finally, consider the results for the optimal tax exercises. We only report values for differentiated taxes (see scenario **E**), as the welfare changes and the marginal values of time are not affected by the uniformity constraint.[9] The optimal labour tax reduction turns out to be 8%-point, reflecting the high initial labour tax. Optimal car commuting taxes are extremely high. All other transport taxes also rise relative to the reference situation, with the exception of the bus commuting tax. The marginal value of time is 14.3% higher than in the reference equilibrium. This is not a trivial change, and it is much larger than the impacts predicted by Mayeres and Proost (1997), where the time value is endogenous but there is only one trip purpose (so that time values only change due to labour tax adjustments).

The numerical model suggests that the endogeneity of the value of time is important when changes in marginal external congestion costs and in welfare are assessed. In all scenarios but one, it affects the size *and* the direction of the change in MECC. With constant values of time, marginal external congestion costs would have declined substantially because of the reduction in traffic demand after the tax changes.

[8] Calthrop (2001) and Wrede (2001) report optimal commuting subsidies of 50% and more than 100% of the resource cost, respectively.
[9] This is due to the direct relation between commuting and labour supply, cf. Van Dender (2001).

With endogeneity, marginal external congestion costs rise by up to 3%. Using fixed values of time hence leads to erroneous estimates of the adaptations of travel demand and modal split to transport tax changes.

Table 2 Impacts from simultaneously decreasing labour taxes and optimally adapting transport taxes for a constant government budget

		Unit	Reference	Tax reform				Optimal labour tax
			40% labour tax	1% labour tax decrease		5% labour tax decrease		8% labour tax decrease*
			REF	**A**	**B**	**C**	**D**	**E**
			Uniform transport taxes	Uniform transport taxes	Differentiated transport taxes	Uniform transport taxes	Differentiated transport taxes	Differentiated transport taxes
1	Welfare level	Index	1	1.0008	1.0022	1.0025	1.0037	1.0042
2	MVOT	Euro/h	7.67	7.76	8.43	8.08	8.46	8.77
3	MECC	Euro/round trip	6.87	6.92	6.95	7.00	7.06	7.07
4	Traffic flow in PCU	Index	1	0.90	1.04	0.89	0.94	0.86
5	Q1 level	Index	1	0.96	0.75	0.89	0.73	0.70
6	Q2 level	Index	1	1.03	0.77	0.92	0.82	0.72
7	Q3 level	Index	1	0.82	1.34	0.88	1.10	1.01
8	Q4 level	Index	1	1.36	0.48	1.31	0.96	1.18
9	Q1 market share	%	35.3	34.3	31.2	32.6	29.7	27.5
10	Q2 market share	%	11.8	12.2	11.1	11.2	10.4	9.4
11	Q3 market share	%	35.3	29.3	46.2	32.3	41.7	39.9
12	Q4 market share	%	17.6	24.2	11.4	23.9	18.2	23.2
13	Labour supply	Index	1	1.00	1.05	1.02	1.05	1.07
14	T1: car tax non-commuting	Euro/round trip	4.24	5.73	12.43	8.12	11.98	16.57
15	T2: bus tax non-commuting	Euro/round trip	-2.69	-2.85	-1.00	-0.57	1.71	5.86
16	T3: car tax commuting	Euro/round trip	4.24	5.73	-3.09	8.12	3.95	5.99
17	T4: bus tax commuting	Euro/round trip	-2.69	-2.85	-3.22	-0.57	-3.22	-2.73

* The optimal labour tax decrease with uniform transport taxes is approximately 18%.

3.2.2 *Alternative scenarios: some sensitivity results*

The elasticities of substitution and the reference composition of traffic in the previous section have been chosen in order to accord with the average urban context in Belgium. To provide some insight into the sensitivity of the results we report results from alternative scenarios. First, the effect of decreasing the share of non-commuting trips is considered. Second, the degree of substitutability between the composite commodity and leisure-related activities (including non-commuting transport) is varied.[10]

Varying the importance of non-commuting trips

The share of non-commuting trips in the central scenario is 47% of the total. Since the presence of multiple trip purposes was crucial in the theoretical analysis of Section 1, it is to be expected that the impact of transport tax reform on the marginal value of time strongly depends on the relative shares of commuting and non-commuting. The results in Table 3 support this claim. It gives for various shares of non-commuting trips the % changes in the marginal value of time, and the % change in welfare associated with two types of tax reforms, viz. (1) a 1% labour tax decrease with optimal differentiated transport taxes, and (2) optimal labour and transport taxes.

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[10] We also performed sensitivity analysis on the slope of the congestion function, the reference modal split, and the remaining elasticities of substitution. They were found to be less important for the problem at hand, so we omit them for reasons of brevity.

Table 3 The dependence of changes in welfare and in the marginal value of time on the reference level and share of non-commuting trips, with tax differentiation between trip purposes

Share of non-commuting trips	1% labour tax decrease		Optimal labour tax	
	% MVOT change	% welfare change	% MVOT change	% welfare change
47% (central sc.)	5.21 %	0.16 %	14.5 %	0.42 %
31%	5.18 %	0.14 %	6.9 %	0.18 %
18%	3.12 %	0.10 %	3.4 %	0.11 %
0.01%	0.37 %	0.03 %	0.37 %	0.03 %

The first row in Table 3 refers to the central scenario analysed before. The results show that as the importance of non-commuting transport decreases, the impact of tax adjustments on time values and the potential welfare gains decline. Reaching the maximal welfare gain requires smaller reductions in the labour tax rate when non-commuting transport becomes less important, as can be seen from the difference between the welfare change for a 1% labour tax decrease and the optimal labour tax decrease. This is so because the non-commuting transport tax base becomes smaller.

When the share of non-commuting trips is negligible (bottom row), the impact on time values is very small because in this case transport taxes are pure commuting taxes, which have the same effect on time values as labour taxes. The labour tax reduction and transport tax increases then hardly affect time values, and the only source of the (limited) welfare gain is the improvement of the modal split through modal tax differentiation. In the application this implies an increase in the share of car commuting (from about 67% to 75%) for a 1% reduction of the labour tax rate.[11]

The basic message from this experiment is that, as predicted by the theoretical analysis, the size of the impact of transport tax changes on the marginal value of time crucially depends on the presence and the quantitative importance of at least two trip

[11] Note that this change in the modal split has limited effects on travel times, as the level of leisure trips has decreased with respect to the central scenario, while the congestion function has been left unchanged.

purposes. Also, the results clarify that there is a close connection between the size of the welfare gain and the size of the change in marginal values of time.

Varying the elasticity of substitution between the composite commodity and leisure related activities

In the central scenario, the elasticity of substitution at the top of the CES-utility tree was equal to 0.7. To test the sensitivity of the results we vary this from 0.2 to 1.2. Intuitively, higher values lead to larger own price elasticities for the composite commodity, for pure leisure, and for non-commuting transport. Similarly, the cross-price elasticity between the composite commodity and the aggregate of leisure and non-commuting transport will also rise with this elasticity of substitution

Two findings stand out. First, a higher elasticity of substitution implies much higher increases in the value of time and higher welfare gains from transport tax reform. For the lowest value of the elasticity of substitution, the increase in the marginal value of time after implementation of the optimal policy is less than 1%, while for the highest value it is 26%. Similarly, if substitution possibilities between the composite commodity and leisure activities are very low, the welfare gain is very limited (0.06%), and allowing much more flexible substitution leads to a gain of 1.36%. Second, the labour tax reduction required to achieve the maximal possible welfare gain is increasing in the elasticity of substitution. When non-commuting trips become more price elastic, an equal exogenous reduction in the labour tax rate has larger benefits in terms of reducing congestion, while tax revenues are collected to meet the revenue requirement. However, the reduction in the traffic flow is *smaller* when the elasticity of substitution is larger (and labour taxes are sufficiently reduced). This is the result of combining a stronger reduction in non-commuting trips and a larger share of auto-commuting when the level of non-commuting trips is strongly reduced. To the reverse, when the elasticity of substitution is low, non-commuting trips are only slightly reduced and labour supply is increased by encouraging bus commuting.

Summing up, the effect of transport taxes on welfare, labour supply and the marginal value of time depend to a large extent on the price elasticity of non-commuting transport demand. When it is low, labour supply will be encouraged through manipulation of the modal split in commuting, rather than through reducing non-commuting trips. The effects of such a policy on welfare and on the marginal value of time are limited, however.

4. Summary and conclusion

The analysis suggests that transport tax reform to cope with external congestion costs in a second-best setting tends to increase consumers' marginal value of time savings, if account is taken of the simultaneous presence of commuting and non-commuting trips on the road. The fundamental reason is that the tax reform allows shifting part of the tax burden to relative complements to leisure, thereby increasing the opportunity cost of leisure. A numerical illustration for a prototype mid-sized Belgian city suggests that the effect of transport tax changes on the marginal value of time is significant. Effectively, marginal external congestion costs after the reform are higher than in the pre-reform equilibrium, because the increase in the marginal value of time more than compensates for the reduction in congestion costs due to lower traffic demand. It should be stressed that this increase is accompanied by a welfare increase. The effect also holds when optimal transport and labour taxes are considered. Finally, the increase in the value of time is smaller, but positive, when transport taxes cannot be differentiated across trip purposes.

Hence, assuming constant values of time in an analysis of transport tax reform may produce inaccurate results whenever the traffic flow consists of commuting and non-commuting transport. Traffic flows that are homogenous in terms of trip purpose will display a smaller sensitivity of the marginal time value to transport tax changes.

The analysis is subject to some caveats. First, the assumption of strict complementarity between peak-hour commuting trips and labour supply is restrictive. Relaxing it will affect the optimal values of the tax instruments and the resulting value of time, but the direction of the change can be expected to remain as discussed here. Assuming strict complementarity probably is to be preferred above treating transport as a standard commodity, when transport tax reform is analysed in a context of distortionary taxes on labour. Second, the analysis has abstracted from distributional considerations. Taking these into account may imply that alternative types of revenue use (e.g. increasing lump sum transfers instead of reducing labour taxes) become relatively more attractive. Finally, the numerical results are exploratory. The goal here is to illustrate the mechanisms at work in the theoretical analysis, using realistic orders of magnitude for the parameters. More realistic policy analysis would require more investment in the transport data (e.g. on the cost characteristics of the public transport sector).

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Appendix 1

This appendix outlines of the general procedure for determining the impact of price and tax changes on the value of time. Utility is given in general by $U(q_0, q_1, q_2, N)$ and, as before, the value of time is

$$MVOT = \frac{\gamma}{\lambda} = \frac{\frac{U_2}{\lambda} + (1 - t_L - p_2)}{1 + a}$$

The effect of a labour tax increase on the value of time can be written as:

$$\frac{d(MVOT)}{dt_L} = \frac{d(\frac{\gamma}{\lambda})}{dt_L} = \frac{\lambda \frac{d\gamma}{dt_L} - \gamma \frac{d\lambda}{dt_L}}{\lambda^2} = \frac{1}{\lambda}\left(\frac{d\gamma}{dt_L} - MVOT \frac{d\lambda}{dt_L}\right)$$

Using the first-order conditions $\lambda = u_0$ and $\gamma = u_N$ we have by differentiation:

$$\frac{d\lambda}{dt_L} = u_{00}\frac{dq_0}{dt_L} + u_{01}\frac{dq_1}{dt_L} + u_{02}\frac{dq_2}{dt_L} + u_{0N}\frac{dN}{dt_L}$$

$$\frac{d\gamma}{dt_L} = u_{N0}\frac{dq_0}{dt_L} + u_{N1}\frac{dq_1}{dt_L} + u_{N2}\frac{dq_2}{dt_L} + u_{NN}\frac{dN}{dt_L}$$

To find the impact of the labour tax on consumption and leisure demands, substitute $\lambda = u_0$ and $\gamma = u_N$ into the first-order conditions for commuting and non-commuting transport, and add the time and budget restriction to obtain the following system:

$$\begin{aligned}
&U_1 = U_0 p_1 + aU_N \\
&U_2 = -U_0(1 - t_L - p_2) + (1 + a)U_N \\
&q_0 + p_1 q_1 = (1 - t_L - p_2)L + S \\
&\overline{L} = N + aq_1 + (1 + a)q_2
\end{aligned}$$

Differentiating this system yields a system of four equations in four unknowns dq_0, dq_1, dq_2, dN. Solving for the unknowns allows evaluating the impact of tax and price changes on the solution obtained. This in turn allows evaluating $d\gamma/dt_L, d\lambda/dt_L$

and $dMOVT/dt_L$. A similar procedure holds for evaluating the effect of transport price changes. For an unrestrictedly general specification of preferences the results are not transparent, as they depend on all second derivatives of the utility function, many of which are difficult to sign. We therefore imposed some simplifying assumptions (quasi-linearity, separability) to obtain clear implications.

Appendix 2

As an example, applying Cramer's rule yields for dq_1:

$$dq_1 = \frac{1}{\Delta}\begin{vmatrix} dp_1 & -\gamma a' & u_{1N} & -a \\ dp_2 + dt_L & u_{22} - \gamma a' & 0 & -(1+a) \\ 0 & 0 & u_{NN} & -1 \\ 0 & -(1+a+a'F) & -1 & 0 \end{vmatrix}$$

where:

$$\Delta = \begin{vmatrix} u_{11} - \gamma a' & -\gamma a' & u_{1N} & -a \\ -\gamma a' & u_{22} - \gamma a' & 0 & -(1+a) \\ u_{N1} & 0 & u_{NN} & -1 \\ -(a+a'F) & -(1+a+a'F) & -1 & 0 \end{vmatrix}$$

Some matrix algebra yields the effect of an exogenous price or tax changes on non-commuting transport demand. We find:

$$\frac{dq_1}{dp_1} = \frac{1}{\Delta}\begin{vmatrix} u_{22} - \gamma a' & 0' & -(1+a) \\ 0 & u_{NN} & -1 \\ -(1+a+a'F) & -1 & 0 \end{vmatrix} = \frac{-1}{\Delta}\left\{(u_{22} - \gamma a') + u_{NN}(1+a)(1+a+a'F)\right\}$$

$$\frac{dq_1}{dt_L} = \frac{dq_1}{dp_2} = \frac{-1}{\Delta}\begin{vmatrix} -\gamma a' & u_{1N} & -a \\ 0 & u_{NN} & -1 \\ -(1+a+a'F) & -1 & 0 \end{vmatrix} = \frac{1}{\Delta}\left\{(a u_{NN} - u_{1N})(1+a+a'F) - \gamma a'\right\}$$

Assuming declining marginal utility for commuting transport and leisure ($u_{22} < 0, u_{NN} < 0$), it is clear that the own-price effect of non-commuting transport will be negative as long as $\Delta < 0$.[12] We assume this condition to hold and return to its interpretation below. Labour and commuting taxes have the same effect on demand since they identically affect the net real wage, but the effect is ambiguous. Loosely, it will be positive as long as u_{1N} is not too negative; it may be negative otherwise.

In a similar fashion, the impact of tax or price changes on labour supply (equal to commuting) and on leisure demand can be derived. We find:

$$\frac{dq_2}{dp_1} = \frac{-1}{\Delta}\left\{(1+a)\left[(u_{1N} - au_{NN}) - a'Fu_{NN}\right] + \gamma a'\right\}$$

$$\frac{dq_2}{dt_L} = \frac{dq_2}{dp_2} = \frac{-1}{\Delta}\left\{a u_{NN}(a + a'F) - u_{1N}(2a + a'F) + (u_{11} - \gamma a')\right\}$$

$$\frac{dN}{dp_1} = \frac{1}{\Delta}\left\{u_{1N}(1+a)(1+a+a'F) + u_{22}(a+a'F) + \gamma a')\right\}$$

$$\frac{dN}{dt_L} = \frac{dN}{dp_2} = \frac{-1}{\Delta}\left\{(u_{1N}a - u_{11})(1+a+a'F) + \gamma a'\right\}$$

These findings suggest that, as long as u_{1N} is not too negative, an increase in the labour or commuting tax reduces labour supply (i.e., the labour supply function is upward sloping), and it raises leisure demand. The cross-price effect of commuting demand with respect to non-commuting transport price and its impact on leisure demand can go either way. For the interpretation, observe that a sufficient condition

[12] This provides a clear interpretation for the stability condition Δ<0. It guarantees that the overall effect of an increase in p_1 on non-commuting transport demand, including all feedback effects of congestion on both the commuting and non-commuting markets, is negative. See below for details.

for the cross price effect of commuting with respect to the price of non-commuting to be positive is $(au_{NN} - u_{1N})$<0. Also, it can be shown that:[13]

$$\frac{dF}{dp_1} = \frac{-1}{\Delta}\left[u_{22} + (1+a)(u_{1N} + u_{NN})\right]$$

so that $u_{1N} + u_{NN}$<0 is a sufficient condition for the price of non-commuting transport to reduce overall transport demand and, therefore, congestion.

For completeness, consider the case where transport prices cannot or are not allowed to differ between commuting and non-commuting (i.e., $p_1 = p_2 = p$). All effects of the labour tax remain as before, and the price effects are given by

$$\frac{dq_1}{dp} = \frac{-1}{\Delta}\left\{(u_{NN} + u_{1N})(1 + a + a'F) + u_{22}\right\}$$

$$\frac{dq_2}{dp} = \frac{-1}{\Delta}\left\{(u_{NN} - u_{1N})(a + a'F) + (u_{1N} + u_{11})\right\}$$

$$\frac{dN}{dp} = \frac{-1}{\Delta}\left\{(u_{11} - u_{1N})(1 + a + a'F) - u_{22}(a + a'F)\right\}$$

The impact of a common transport price increase is the sum of the effects of the labour tax and the non-commuting transport price of the price differentiation case. Interpretation is as before.

Finally, we return briefly to the meaning of the condition $\Delta < 0$. By developing the relevant determinant one shows:

$$\begin{aligned}\Delta = \Delta_{a'=0} &+ u_{NN}\left\{\gamma a' - aa'Fu_{22}\right\} - \left\{(u_{NN}u_{11} - u_{1N}^2)a'(1+a)\right\} + \left\{\gamma a'(u_{11} + u_{22})\right\} \\ &+ u_{1N}\left\{a'Fu_{22} + 2\gamma a'\right\}\end{aligned}$$

where $\Delta_{a'=0} = -(u_{NN}u_{11} - u_{1N}^2)(1+a)^2 - u_{22}(u_{11} + a^2 u_{NN} - 2a)$ is the value of the determinant at constant congestion (a'=0). This is negative by the second-order

[13] Interestingly, note that the price effect on total transport demand is independent of congestion levels.

conditions of the consumer's optimisation problem. All terms in the definition of Δ are negative with the exception of the last one. Without a mild condition, therefore, it cannot be guaranteed that $\Delta < 0$ and, as a consequence, that $dq_1 / dp_1 < 0$. We assume throughout that this condition is satisfied. Intuitively, the condition is as a restriction on the size of feedback effects. To see this, note that the demand functions resulting from the consumer's problem can be written in general as functions of prices, the lump-sum transfer S and, since the consumer treats congestion as given, the congestion level (as captured by a):

$$\begin{aligned}
q_0 &= q_0(p_1, 1-t_L-p_2, a, S) \\
q_1 &= q_1(p_1, 1-t_L-p_2, a, S) \\
q_2 &= q_2(p_1, 1-t_L-p_2, a, S) \\
N &= N(p_1, 1-t_L-p_2, a, S)
\end{aligned}$$

Differentiating this system, taking account of the definition of $a = a(F) = a(q_1 + q_2)$, the full effect of a price change dp_1 on non-commuting demand can be written as:

$$\frac{dq_1}{dp_1} = \frac{\frac{\partial q_1}{\partial p_1}(1 - a'\frac{\partial q_2}{\partial a}) + a'\frac{\partial q_2}{\partial p_1}\frac{\partial q_1}{\partial a}}{1 - a'\frac{\partial q_1}{\partial a} - a'\frac{\partial q_2}{\partial a}}$$

If congestion were constant (a'=0), the total effect equals the partial effect. If congestion is not constant, the price-induced congestion changes generate feedback effects on demand, implying deviations between the partial and total effect. The denominator is plausibly positive because one expects more congestion to reduce travel demand. The numerator is negative unless the cross-price effect $\partial q_2 / \partial p_1$ is negative and large, so that the final term in the numerator more than offsets the first term, which is negative. The economic intuition of this extreme situation is clear. Suppose a price increase of non-commuting transport at constant congestion levels reduces non-commuting transport. But assume that the price increase also implies a large reduction in commuting demand which itself reduces congestion, raising the demand for non-commuting transport again. If this latter effect is so strong as to more than offset the initial negative impact, the numerator of the above expression becomes positive and the ultimate outcome may yield a positive price effect.

Energy Transport & Environment

The Center for Economic Studies (CES) is the research division of the Department of Economics of the Katholieke Universiteit Leuven. The CES research department employs some 100 people. The division Energy, Transport & Environment (ETE) currently consists of about 15 full time researchers. The general aim of ETE is to apply state of the art economic theory to current policy issues at the Flemish, Belgian and European level. An important asset of ETE is its extensive portfolio of numerical partial and general equilibrium models for the assessment of transport, energy and environmental policies.

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