# TAX REFORM FOR DIRTY INTERMEDIATE GOODS: THEORY AND AN APPLICATION TO THE TAXATION OF FREIGHT TRANSPORT

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Abstract

The purpose of this paper is to study, within a general equilibrium framework, the welfare implications of a balanced-budget tax reform for an externality-generating intermediate input in a second-best economic environment. For purposes of concreteness, the focus is on tax reform for freight road transport to cope with congestion externalities; results for other types of externalities can be derived as special cases. The model takes into account that passenger and freight flows jointly produce congestion, it captures feedback effects in demand, and it allows for existing distortions on all other input and output markets, including the passenger transport market and the labour market. Moreover, it clearly shows that the welfare effects of the reform depend on the instruments used to recycle the tax revenues. A numerical version of the model is calibrated to UK data. The numerical results suggest, among others, that (i) the welfare gain of a given freight tax reform rises with the level of the tax on the market for passenger transport; (ii) the higher the rate of passenger transport taxation, the lower the optimal freight tax; and (iii) compared to lump-sum recycling, both the welfare effects of a tax reform and the optimal tax are substantially higher when revenues are recycled via labour taxes.

# I.  Introduction

It is well-known that under a number of stringent conditions on the structure of the economy, including constant returns to scale, the absence of externalities and the availability of a full set of tax instruments, intermediate inputs should not be taxed (Diamond and Mirrlees (1971)). More recently, it has become clear that relaxing the assumptions does provide a case for taxing intermediate inputs. First, if for administrative, political or technical reasons some final goods remain untaxed, Newbery (1986) has shown in a very general framework that intermediate input taxation is indeed desirable under relatively mild conditions. Second, taxation seems in order for intermediate inputs that generate externalities. For example, Bovenberg and Goulder (1996) construct a simple general equilibrium model to analyse optimal taxation of both final and intermediate goods in the presence of externalities. They show that dirty intermediate goods should be taxed at marginal external cost. This implies that, consistent with Diamond and Mirrlees (1971), production efficiency is maintained and that there is no additional revenue-generating role for taxes on intermediate inputs.

The purpose of this paper is to study the welfare implications, within a general equilibrium framework, of a balanced-budget reform of taxes on a dirty intermediate input in a second-best environment. Although the desirability of dirty input taxation has been investigated before in applied general equilibrium models (see, e.g., Ballard and Medema (1993)), fundamental questions remain as to the trade-offs involved in reforming such taxes[1]. For example, to what extent does the desirability of any one reform depend on the vector of existing commodity and input taxes? What if dirty output markets are not subject to an environmental tax, or if such taxes are clearly set at suboptimal levels? To what extent are the welfare gains from a tax reform on dirty inputs likely to depend on the instruments chosen to recycle the revenues? In this paper, we develop a simple yet general framework for studying dirty input tax reforms that allows us to provide answers to these and other relevant questions. Given the importance of intermediate inputs (energy, fertilizers, pesticides, freight transport, etc.) in the generation of externalities, developing such a framework seems to be a useful addition to the existing literature.

The model we develop is sufficiently general to capture a wide variety of different types of intermediate inputs and the corresponding externalities they generate. However, to make the presentation as concrete as possible, both the theoretical model and the numerical

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[1] Ballard and Medema (1983) introduce a Pigovian tax on air pollution from 11 sectors of the US economy. Pollution is modeled as both a production and consumption externality. They estimate that the marginal welfare cost of a pollution tax is significantly below one.

simulation model used for the empirical application are developed in terms of a particular example, viz., the problem of reforming taxes on freigth road transport in view of increasing congestion. In theoretical terms, there is little loss of generality in focusing on congestion-type externalities. Such externalities affect both consumers and producers and are well known to have feedback effects on demand. As will be highlighted below, a simplified version of the model can also be used to study a number of other input taxes, such as energy taxes, taxes on pesticides, etc. Importantly, however, in focusing on freight transport and congestion externalities, we are also able to contribute to the substantial recent literature on tax reform in the transport sector (see, e.g., Mayeres and Proost (2001), Parry and Bento (2002a,b)). Either these models explicitly consider an urban environment and do not incorporate freight transport, or they include freight transport but focus exclusively on tax reform for the passenger transport market.

The application of the theoretical model to freight transport tax reform is highly policy-relevant in view of recent discussions within the EU[2]. There the emphasis has shifted very much towards taxation of road freight transport instead of passenger transport. This is to some extent due to the feeling that, in the short run, charging passengers for the external costs they create seems infeasible at a European scale for both political and technical reasons. An additional explanation is that international traffic flows throughout Europe to a large extent consist of freight flows; as a consequence, taxing and regulating freight flows is seen more as a European and less as a local problem to be solved by individual countries. Obviously, the focus on freight transport tax reform raises a number of interesting policy questions. Given that passenger transport is sub-optimally taxed, which seems to be the case in many European countries (De Borger and Proost (2001)), how desirable is it to raise freight transport taxes to cope with external congestion and pollution costs? To what extent is the desirability of a tax reform on freight affected by the existence of distortions on other markets, both within (passenger transport) and outside (e.g., the labour market) the transport market? How sensitive is the optimal freight tax to changes in existing taxes on passenger flows? Do higher taxes on passenger flows imply higher or lower optimal freight taxes?

Although answering these questions seems to be a straightforward exercise in second-best reasoning, the analysis is complicated by at least four factors: (i) Taxes on intermediate inputs are partially used to correct a distortion on final goods markets; (ii) Intermediate goods taxes may have nonnegligible general equilibrium effects on all markets, including the labour

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[2] A recent white paper (European Community (2001)) provides an interesting overview of the current policy debate. While some member states have introduced a system of road-damage charges (vignettes), the availability of a new European Satellite Navigation System makes route-specific and time-specific charges technically feasible. Germany will be introducing kilometre taxes in the near future. The white paper also discusses how to use the revenues and seems to favour investing them within the transport sector.

market; (iii) Passenger and freight transport share the same infrastructure and hence jointly cause congestion. As a consequence, tax changes on one market automatically affect the marginal external cost on the other transport market; (iv) Congestion causes feedback effects in demand. The current paper develops a model that incorporates all these complications.

The paper unfolds as follows. In Section II, we present the structure of the model. We then proceed by deriving the welfare effects of a tax reform in the freight transport sector under different restrictions on the available tax instruments; moreover, several alternatives for the recycling of the tax revenues are considered (see Section III). A number of simplified cases are analysed that clarify the main intuition of the results. In Section IV we present the main characteristics of the numerical simulation model that is calibrated to the UK economy. Empirical results on the welfare effects of tax reform in the freight transport sector are derived and discussed in Section V. Finally, Section VI summarises the main conclusions.

## II.    The theoretical model

### II.1.    Behaviour of consumers

We assume N identical consumers. The consumer maximises a twice differentiable, strictly quasi-concave utility function defined over a clean good C (the untaxed numeraire in the model), a good associated with dirty production, (D), a good associated with dirty consumption (T), and leisure, denoted by $l$ :

$$U(C,T,D,l) \tag{1}$$

We interpret good D as an aggregate commodity that uses freight transport as an input in production, while T is interpreted as passenger transport. Freight and passenger transport demand jointly produce an externality, interpreted as congestion. Adding other external costs such as pollution and noise is straightforward and does not affect the results.

The individual faces two constraints. First, the budget restriction is formulated as

$$C + q_T T + q_D D = wL + G \tag{2}$$

where the $q_i$ are consumer prices, w is the net wage, L is labour supply, and G is a lump-sum transfer from the government.  Second, a time constraint

$$L + l + \phi(NT + F)T = \overline{L} \tag{3}$$

allocates the total time available ($\bar{L}$) over labour, leisure and travel time. The congestion function $\phi(.)$ gives the travel time needed per unit of T; this depends on passenger (NT) and freight (F) transport demand. Note that in the theoretical model we assume for simplicity that the contribution of passenger and freight transport to congestion is the same.

We assign multipliers $\lambda$ and $\gamma$ to the budget and time constraints, respectively. Utility maximising behaviour then leads to demand functions for all goods considered as functions of the exogenous prices, wages, the lump-sum transfer, and the level of congestion $\phi(.)$ which the consumer treats as exogenously given. The indirect utility function can similarly be written as $V(q_T, q_D, w, G, \phi)$. For later reference, note that the envelope theorem implies $\dfrac{\partial V}{\partial \phi} = -\gamma T$.

## II.2. Producer behaviour

The production structure of the economy is kept as simple as possible[3]. We assume a linear aggregate production function that relates the production of passenger transport, the clean consumption good, the dirty intermediate input (freight transport), and an extra clean intermediate input (X) to a single primary input, labour. Moreover, units are adjusted such that:

$$N(T + C) + F + X \leq LN \qquad (4)$$

For a given level of externality, we further assume that the dirty good is produced under constant returns to scale, combining freight and the clean intermediate good:

$$ND = CRS(F, X; \phi)$$

Under these assumptions, the producer prices for T, C, F, X and L all equal unity.

We denote inputs demand in unit terms: $F = NDF_{ND}$; $X = NDX_{ND}$, where $F_{ND}$ is the demand for freight transport per unit of production of the dirty good; a similar

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[3] We wish to capture two effects of a tax on the dirty input: firstly, an input substitution effect and, secondly, a switch in consumption as relative commodity prices change. Our model structure is the simplest which captures both effects. Note that the input tax will alter both the price of D and T since congestion affects the generalised price of passenger transport. We feel that a more general n-good Leontief production structure would give little additional economic insight, yet would significantly complicate the analysis.

interpretation holds for the other input X. Allowing for intermediate good taxes $\tau_i$ (i=F, X), set by the government, input demands depend on taxes and congestion levels. The unit cost function of good D, $c_D$, can be written as:

$$c_D(\tau_F,\tau_X,\phi) = (1+\tau_F)*F_{ND}(\tau_F,\tau_X,\phi) + (1+\tau_X)*X_{ND}(\tau_F,\tau_X,\phi) \qquad (5)$$

Under competitive assumptions, the producer price of good D equals this unit cost.

## II.3.  Role of the government

A benevolent government is assumed to maximise welfare, defined here as the value of the representative consumer's indirect utility function V(.). It has in principle the authority to set taxes $\tau$ on all markets though, without loss of generality, we take the numeraire as untaxed. Therefore, the different consumer prices are given by:

$$q_C = 1$$
$$q_T = 1+\tau_T$$
$$q_D = c_D(\tau_F,\tau_X,\phi)+\tau_D$$
$$w = 1-\tau_L$$

Similarly, input prices are given by:

$$q_F = 1+\tau_F$$
$$q_X = 1+\tau_X$$

We assume the government is required[4] to maintain a balanced budget. This requires:

$$N\left(\tau_T T+\tau_L L+\left[\tau_D +\tau_F F_{ND}+\tau_X X_{ND}\right]D\right) = NG \qquad (6)$$

# III.   Welfare effects of a tax reform on freight transport

In this section we consider the welfare impact of a revenue neutral increase in the tax on freight. For purposes of exposition, we initially assume that the tax revenues are recycled through raising the lump-sum transfer G. Later (see Section III.4 below) we also consider

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[4] This constraint is automatically fulfilled: combining the production possibility constraint, the consumer budget constraint and the unit cost function for the dirty good gives the government budget constraint (Walras' law).

recycling through a reduction in the distortionary labour tax. We first present the general result and then consider some specific examples to facilitate the interpretation.

Using standard but rather extensive manipulations it can be shown that the welfare effect of a freight transport tax increase recycled through the lump-sum transfer G can be written as:

$$
\begin{aligned}
\frac{1}{\lambda}\frac{dW}{d\tau_F} =\ & \left(MEC - \tau_F\right)\left[D\left(-\frac{\partial F_{ND}}{\partial \tau_F}\right) + F_{ND}\left\{\left(-\frac{\partial D}{\partial q_D}\right)F_{ND} - \frac{\partial D}{\partial G}\frac{dG}{d\tau_F}\right\}\right] \\
& -\tau_D\left(\left(-\frac{\partial D}{\partial q_D}\right)F_{ND} - \frac{\partial D}{\partial G}\frac{dG}{d\tau_F}\right) \\
& -\left(MEC - \tau_T\right)\left(\frac{\partial T}{\partial q_D}F_{ND} + \frac{\partial T}{\partial G}\frac{dG}{d\tau_F}\right) \\
& +\tau_X\left[D\frac{\partial X_{ND}}{\partial \tau_F} + X_{ND}\left\{\frac{\partial D}{\partial q_D}F_{ND} + \frac{\partial D}{\partial G}\frac{dG}{d\tau_F}\right\}\right] \\
& -\tau_L\left(\left(-\frac{\partial L}{\partial q_D}\right)F_{ND} - \frac{\partial L}{\partial G}\frac{dG}{d\tau_F}\right)
\end{aligned}
\tag{7}
$$

where MEC is the full marginal external cost of freight or passenger transport. The derivation of this result as well as the precise definition of the full marginal external cost, is explained in detail in Appendix 1. Note that the external costs of passenger and freight transport are assumed to be the same in order to simplify the theoretical analysis. This assumption will obviously be relaxed in the numerical exercise of the next sections.

In the remainder of this section we turn to the interpretation of (7). It consists of five terms. Each term can be considered as a distortive tax wedge multiplied by the general equilibrium change in demand that results from the tax reform. Unfortunately, since the model allows existing distortions on all markets simultaneously it is very difficult to derive general conclusions from this equation without simplifying assumptions. At this point, however, note the following immediate implications of equation (7). First, unlike in earlier work on transport tax reform, all effects that operate via input markets and production costs are explicitly incorporated. Second, (7) immediately implies that transport taxes equal to MEC and all other taxes equal to zero is consistent with the welfare optimum, since in that case the marginal welfare effect of an increase in the freight tax is zero. Third, suppose that all other taxes are at their first-best levels but that the tax on freight transport falls short of MEC. In that case welfare will increase if the tax on freight is marginally increased, provided that the general equilibrium impact of the freight tax is to reduce freight transport demand. Indeed, under those conditions (7) can be written as

$$\frac{1}{\lambda}\frac{dW}{d\tau_F} = \left(MEC - \tau_F\right)\left[ D\left(-\frac{\partial F_{ND}}{\partial \tau_F}\right) + F_{ND}\left\{\left(-\frac{\partial D}{\partial q_D}\right)F_{ND} - \frac{\partial D}{\partial G}\frac{dG}{d\tau_F}\right\}\right]$$

where the term between square bracketts is the full effect of the freight tax increase on freight demand. It consists of three terms. Increasing the price of freight has a non-positive impact on the demand for freight for a given production level of D, thus ensuring that the first element is non-negative. Assuming that D is a normal good, the (uncompensated) own price effect is non-positive, and hence the second-term is also non-negative. The third term reflects the effect on freight transport demand associated with recycling the freight tax revenues. Although without further restrictions this term is theoretically ambiguous, it is clear that, under the specified conditions, as long as the overall effect between the square bracketts is positive, an increase in the freight tax rate from any level below MEC raises welfare. Welfare gains are exhausted when the freight tax equals MEC.

To develop further intuition on the interpretation of (7) we turn to some special cases below. Before doing so, however, it is useful to point out that the applicability of (7) is not restricted to the case of congestion externalities and freight transport tax reform. With minor adjustments it can also be used to study tax reform for other intermediate inputs that generate other types of externalities. For example, unlike in the model considered above (where passenger and freight services jointly produce the externality), in many cases of practical relevance (e.g., fertilizers, pesticides, energy), the externality is produced by the intermediate input only. It then suffices to set $\tau_T = MEC$ and to re-interpret the tax $\tau_F$ in (7) appropriately as a tax on, e.g., fertilizer. As another example, some externalities do not imply feedbacks in demand and/or do not affect production costs (e.g., emissions of various pollutants). As shown in Appendix 1, such examples can also be interpreted as special cases of the more general formulation (7).

## III.1.  Under-priced passenger transport

As a first special case, we focus on the relation between the welfare effect of a freight transport tax reform and the level of taxation on the market for passenger transport. Indeed, a relevant question to ask in view of recent policy discussions is the following: given that passenger transport is below marginal external cost, under what conditions does it make sense to raise the tax on freight transport? If raising the tax on freight transport increases the

demand for passenger transport then there is an additional cost to the policy reform, viz., the resulting increase in the distortion on the passenger transport market. In this case the net benefit of higher freight transport prices may well be exhausted at a level below MEC. To get some initial intuition concerning this issue, we therefore consider the case where all taxes, except the transport taxes, are set at their first-best levels and where passenger transport is priced below marginal external cost. In other words, $\tau_D = \tau_X = \tau_L = 0$ and $\tau_T < MEC$. Under these conditions, the welfare impact of a marginal tax reform on freight is given by:

$$
\frac{1}{\lambda}\frac{dW}{d\tau_F} = \left(MEC - \tau_F\right)\left[ D\left( -\frac{\partial F_{ND}}{\partial \tau_F} \right) + F_{ND}\left\{ \left( -\frac{\partial D}{\partial q_D} \right)F_{ND} - \frac{\partial D}{\partial G}\frac{dG}{d\tau_F} \right\} \right]
$$
$$
-(MEC - \tau_T)\left( \frac{\partial T}{\partial q_D}F_{ND} + \frac{\partial T}{\partial G}\frac{dG}{d\tau_F} \right)
$$

(8)

Equation (8) illustrates the simple but important point referred to above: in judging the desirability of a freight transport tax increase, the general equilibrium effects of this change on existing distortions on the passenger transport market play a crucial role. They are summarised by the second line of (8). Higher freight taxes affect passenger transport demand via three channels. Firstly, at constant congestion levels, higher freight taxes raise the price of the dirty good, which alters demand for passenger transport; this is captured by the first term between brackets on the second line of (8). In general, of course, passenger transport can be either a substitute or complement to the dirty good (in uncompensated terms). This accords with well-known second-best rules about taxation of an externality in the presence of an incorrectly priced alternative (Marchand, 1968). Secondly, freight tax revenues allow the government to alter the lump-sum transfer to maintain the constant budget. Demand for passenger transport varies in response to this change in G-- see the second term between brackets. Importantly, there is a third, more indirect channel through which freight taxes affect passenger demand. An increase in freight taxes obviously affects congestion, and hence passenger demand is expected to rise at constant final goods prices. This effect is captured by the feedback term and taken into account in the definition of the MEC.

To see the role of the distortion on the passenger market most clearly, start from an initial situation where the tax on freight is equal to marginal external cost. Then (8) implies that social welfare can be increased or reduced by raising the tax on freight, depending on the overall impact of the tax reform on the demand for passenger transport, as previously discussed. If raising the price of freight transport increases the demand for passenger transport, welfare increases when the tax on freight is lowered below MEC. Untaxed passenger transport implies a distortion due to excessive congestion; under the stated condition reducing the tax on freight reduces this distortion. Likewise, if raising the price of

freight reduces demand for passenger transport, welfare would increase if one raised the tax on freight above MEC.

Of course, the above simple statements have to be qualified if the initial freight tax is above or below marginal external cost. In that case the effects of changing the freight tax affects both the distortion on the passenger market and on the freight market; these effects must be traded off against one another. For example, even if increasing freight taxes raised passenger transport and hence congestion, it might still be welfare-improving to increase freight taxes if freight was also strongly under-priced in the initial equilibrium. In that case, although raising the freight tax increases congestion by passengers and hence the distortion on this market, it reduces the distortion on the freight transport market.

To conclude the discussion of this special case, note that interpreting (8) from an optimal taxation viewpoint yields some simple additional insights. Under the assumptions made, the optimal freight tax would be obtained by setting $\dfrac{dW}{d\tau_F} = 0$. This gives

$$\tau_F = MEC - (MEC - \tau_T)\frac{\left(\dfrac{\partial T}{\partial q_D}F_{ND} + \dfrac{\partial T}{\partial G}\dfrac{dG}{d\tau_F}\right)}{\left[D\left(-\dfrac{\partial F_{ND}}{\partial \tau_F}\right) + F_{ND}\left\{\left(-\dfrac{\partial D}{\partial q_D}\right)F_{ND} - \dfrac{\partial D}{\partial G}\dfrac{dG}{d\tau_F}\right\}\right]}$$

This result has two straightforward policy implications. First, more congestion and hence a larger marginal external cost does not necessarily imply a higher optimal freight transport tax. The reason is that, although the larger distortion on the freight market induces higher freight taxes, the higher MEC (at a given passenger transport tax) also raises the distortion on the passenger transport market. This may necessitate lower freight transport taxes if this helps to reduce this distortion (this depends on whether passenger transport and the dirty good are complements or substitutes). Second, higher taxes on passenger transport may for the same reason both increase or decrease the optimal tax on freight transport. On the one hand, higher passenger transport taxes reduce congestion, which reduces the optimal freight transport tax. On the other hand, however, increasing the passenger transport tax reduces the distortion on the passenger market, which may induce higher freight transport taxes. In sum, even on the transport market alone it may be necessary to take into account important general equilibrium effects.

### III.2. Output taxes and subsidies on clean inputs

It is well known that when, for whatever reason, a tax cannot be placed on a dirty input, it may be replaced by an output tax combined with a subsidy to the clean input (Fullerton (1997), Fullerton and Mohr (2002))[5]. In this subsection, we explore the interaction between freight transport taxes, taxes on the dirty production good D, and subsidies to the clean input X. To do so, suppose that $\tau_L = 0$ and that passenger transport is priced at marginal external cost, $\tau_T = MEC$. Equation (7) can then be rewritten, after simple rearrangement, as

$$\frac{1}{\lambda}\frac{dW}{d\tau_F} = (MEC - \tau_F)\left[ D\left( -\frac{\partial F_{ND}}{\partial \tau_F} \right) + F_{ND}\left\{ \left( -\frac{\partial D}{\partial q_D} \right) F_{ND} - \frac{\partial D}{\partial G}\frac{dG}{d\tau_F} \right\} \right]$$
$$+ \tau_X D\frac{\partial X_{ND}}{\partial \tau_F} + (\tau_D + \tau_X X_{ND})\left( \frac{\partial D}{\partial q_D} F_{ND} + \frac{\partial D}{\partial G}\frac{dG}{d\tau_F} \right)$$

(9)

This expression summarises how the welfare effects of a freight tax change depend on the potential existence of dirty output taxes and clean input subsidies. To facilitate the interpretation, note that the freight tax affects demand for D via two channels: the increase in consumer price and the induced change of the transfer G. Both effects are captured by the final term between brackets in (9). If D is a normal good, the sign of this term is ambiguous. Plausibly, however, one expects the demand for good D to decline when the freight tax rises.

Let us start from a situation where freight is taxed at marginal external cost. Equation (9) then describes how the desirability of having freight transport taxes deviate from MEC depends on $\tau_D$ and $\tau_X$. More precisely, reducing the tax below MEC is welfare improving as long as the sum of the two terms on the second line of (9) is negative. First, assume that an output tax on D is in place. As long as higher freight transport taxes reduce the demand for D, (9) shows that the existence of $\tau_D > 0$ implies that reducing the tax on freight transport below MEC is welfare improving. One interpretation is that lowering the transport tax reduces the existing distortion on the output market. Another way to interpret the result is to note that, since freight transport is taxed at MEC, the existence of the output tax effectively implies that the externality caused by freight is 'overtaxed'; hence, reducing $\tau_F$ below MEC is welfare improving. Second, consider the existence of input subsidies on X ($\tau_X < 0$). Note from (9) that they affect the desirability of changing freight taxes in two opposite ways,

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[5] This is quite intuitive. Higher taxes on D and higher subsidies on X may, under some conditions, both serve to reduce freight transport demand and, hence, indirectly correct the congestion externality.

reflecting an input subsitution and an output effect. For a given output level D, raising the freight tax increases the demand for X and therefore increases the distortion on the clean input market. However, if the higher tax on freight ultimately reduces the demand for D, this reduces the existing distortion on the output market. If the input substitution effect dominates, (9) shows that the subsidy on the clean input also increases the desirability of reducing the freight tax below MEC. Third, in the case of combinations of dirty output taxes and clean input subsidies, note that a sufficient condition for reductions in freight transport taxes below MEC to be welfare improving is given by

$$\tau_D + \tau_X X_{ND} > 0$$

This condition states that the net implied tax per unit of D is positive.

Of course, if we evaluate the desirability of a freight transport tax change in a situation where freight transport is not paying the full marginal social cost, then the distortions on all tree markets have to be traded off. For example, (9) implies that an increase in the freight transport tax is justified if the initial tax is substantially below MEC and output taxes on freight-intensive goods are insufficient to capturing external congestion costs. Similarly, if there is little substitutability between inputs and a relatively large subsidy exists on the clean input, raising freight transport taxes is justified. Under these conditions, the clean input subsidy has little effect on externalities and acts as a pure distortion. Taxing freight reduces demand for D and thus X.

## III.3. A distorted labour market

As a third special case, we illustrate the role of potential distortions on the labour market associated with the existence of positive labour taxes. Specifically, assume that $\tau_L > 0$, $\tau_X = \tau_D = 0$, while $\tau_T = MEC$. Equation (7) becomes:

$$\frac{1}{\lambda}\frac{dW}{d\tau_F} = (MEC - \tau_F)\left[ D\left(-\frac{\partial F_{ND}}{\partial \tau_F}\right) + F_{ND}\left\{\left(-\frac{\partial D}{\partial q_D}\right)F_{ND} - \frac{\partial D}{\partial G}\frac{dG}{d\tau_F}\right\}\right]$$
$$-\tau_L\left(\left(-\frac{\partial L}{\partial q_D}\right)F_{ND} - \frac{\partial L}{\partial G}\frac{dG}{d\tau_F}\right) \tag{10}$$

Assume initially that the tax on freight is also set at marginal external cost. Then (10) tells us that lowering the tax on freight below MEC increases welfare if it boosts labour supply. Similarly, raising freight taxes seems desirable if it implies higher labour supply. The second line of (10) shows that labour supply is affected both via the increase in the price of the dirty good and from the redistributed revenues. If we assume that the dirty good is a substitute for

leisure (in uncompensated terms), and that leisure is a normal good then increasing the tax on freight tends to reduce labour supply and, therefore, it is welfare improving to reduce the freight tax below MEC. This results accords with the large double-dividend literature in which optimal externality taxes reflect pre-existing labour market distortions (Bovenberg and van der Ploeg, 1994). As before, however, note that these findings have to be qualified if the initial freight tax is above or below MEC.

### III.4. Alternative recycling instruments: recycling via labour taxes

Finally, the presence of the distortionary labour tax in second-best situations raises the issue of using alternative recycling instruments. Indeed, all previous exercises were based on equation (7), which was derived under the assumption that recycling operated via the lump-sum transfer G. In this subsection, however, we consider recycling of an increase in freight taxes via the labour tax. Using completely analogous procedures as those described in Appendix 1, it is easily shown that the welfare effect of a tax reform on freight transport in the case of labour tax recycling is given by

$$
\begin{aligned}
\frac{1}{\lambda}\frac{dW}{d\tau_F} &= (MEC - \tau_F)\left[ D\left(-\frac{\partial F_{ND}}{\partial \tau_F}\right) + F_{ND}\left\{\left(-\frac{\partial D}{\partial q_D}\right)F_{ND} + \frac{\partial D}{\partial w}\frac{d\tau_L}{d\tau_F}\right\}\right] \\
&\quad - \tau_D\left(\left(-\frac{\partial D}{\partial q_D}\right)F_{ND} + \frac{\partial D}{\partial w}\frac{d\tau_L}{d\tau_F}\right) \\
&\quad - (MEC - \tau_T)\left(\frac{\partial T}{\partial q_D}F_{ND} - \frac{\partial T}{\partial w}\frac{d\tau_L}{d\tau_F}\right) \\
&\quad + \tau_X\left[D\frac{\partial X_{ND}}{\partial \tau_F} + X_{ND}\left\{\frac{\partial D}{\partial q_D}F_{ND} - \frac{\partial D}{\partial w}\frac{d\tau_L}{d\tau_F}\right\}\right] \\
&\quad - \tau_L\left(\left(-\frac{\partial L}{\partial q_D}\right)F_{ND} + \frac{\partial L}{\partial w}\frac{d\tau_L}{d\tau_F}\right)
\end{aligned}
$$

where $\dfrac{d\tau_L}{d\tau_F}$ is the balanced-budget impact of raising the freight transport tax on the labour tax, taking account of all general equilibrium adjustments in demands. In other words, it reflects the potential for reducing labour taxes as a consequence of the freight tax increase.

To illustrate the crucial relevance of the recycling instrument let us consider the same assumptions as in the previous case III.3, viz. $\tau_L > 0$, $\tau_X = \tau_D = 0$, and $\tau_T = MEC$, and analyse the difference with lump-sum recycling for this simplified case. The equivalent of equation (10) for recycling via the labour tax becomes:

$$\frac{1}{\lambda}\frac{dW}{d\tau_F} = (MEC - \tau_F)\left[D\left(-\frac{\partial F_{ND}}{\partial \tau_F}\right) + F_{ND}\left\{\left(-\frac{\partial D}{\partial q_D}\right)F_{ND} + \frac{\partial D}{\partial w}\frac{d\tau_L}{d\tau_F}\right\}\right]$$
$$-\tau_L\left(\left(-\frac{\partial L}{\partial q_D}\right)F_{ND} + \frac{\partial L}{\partial w}\frac{d\tau_L}{d\tau_F}\right) \tag{11}$$

Interpretation of (11) is similar to (10). When freight is taxed at MEC, reducing the tax is welfare-improving if it increases labour supply. However, notice an important difference between the second lines of (11) and (10). Whilst returning revenues via G is likely to reduce labour supply because leisure is a normal good, using freight tax receipts to reduce labour taxes is much more likely to increase labour supply, assuming positive wage elasticities of labour supply. This suggests that reducing freight taxes are more desirable if recycling is through labour taxes than via G. Alternatively, it reflects the fact that using freight revenues to reduce labour taxes weakens the cost of raising the freight tax relative to the lump-sum instrument. Increasing the tax on freight results in higher welfare costs (from exacerbating the labour market distortion) when revenues are returned via G than via the labour tax.

## IV.    Basic Features of the Numerical Simulation Model

In the previous section we studied a simple framework to analyse the welfare effects of a freight transport tax reform in the presence of existing distortions on other markets, including the market for passenger transport. Although intuition could be gained by considering some simplified cases, the existence of various simultaneous distortions made an overall theoretical evaluation rather complicated. In this section, we therefore turn to the development of a numerical version of the analytical model that will be used in the next sections to perform some numerical simulations, based on data for the UK, to get more insight in the effects of transport tax reform.

The model that we construct adopts a standard nested constant-elasticity of substitution (CES) structure for both production and consumer utility. The benchmark equilibrium is constructed from three main sources of data: firstly, a detailed 18-sector input-output matrix of the U.K. economy is used to aggregate benchmark expenditures on the clean

and dirty good, passenger transport and freight inputs; secondly, the relationship between freight and passenger transport demand and speed is calibrated to recently published U.K. government statistics; and, finally, information on benchmark transport taxes is drawn from a recent U.K. study. Some of the details of the numerical model and its calibration to the available data for the UK economy are delegated to Appendix 2[6]. Here we simply describe some general features of the model.

## IV.1. Household behaviour

A standard nested CES structure is employed to model household utility. This choice implies that, for a given level of the externality, preferences are homothetic. The nesting structure is summarised in Figure 1. Utility is specified as a function of leisure and aggregate consumption. This composite good consists of passenger transport and non-transport consumption goods. The latter are further divided into clean and dirty consumption goods. Recall dirty consumer goods are goods that require freight transport services in production; the latter produce external costs.

INSERT FIGURE 1 AROUND HERE

Three elasticities-of-substitution are exogenously given in the utility tree. We denote them by $\sigma_i$, where $i = 1, 2, 3$ corresponding to the level of the tree. As with the production structure, these values are chosen such that own and cross-price elasticities correspond with the empirical literature (see Appendix 2). We experimented with a range of nesting structures: our choice in Figure 1 best replicates our desired elasticities.

## IV.2. Production technology

We adopt a standard method of introducing a congestion externality into an applied general equilibrium model. Congestion is modelled via the supply of road speed, $S$, which is treated like a public good available to the consumer. However, its quantity depends on the total demand for freight and passenger transport, $S = f(F, T)$, where both first derivatives

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[6] In addition, the code used in this model is available at http://home.jesus.ox.ac.uk/~ecalthro/

are negative ($f_T, f_F < 0$). The specific functional form chosen for this congestion function is detailed in Appendix 2 below.

Passenger trips T are produced using a fixed combination of the clean input X (i.e. money expenditures) and an aggregate time input, denoted by $Z_T$. In turn, this aggregate input is produced via a CES function combining road speed, $S$, and leisure, $l$. Specifically,

$$Z_T(S,l) = [\alpha_T S^{\rho_T} + (1-\alpha_T)l^{\rho_T}]^{1/\rho_T}$$

where $\alpha_T$ and $\rho_T$ are parameters. The latter parameter is a simple function of the elasticity-of-input-substitution parameter, $\sigma_T$; namely, $\rho_T = (\sigma_T - 1)/\sigma_T$. The value of the parameters is calibrated such that the resulting own-price and cross-price elasticities are in-line with the empirical literature (see Appendix 2).

The underlying micro-economics of the adopted approach is simple: reducing the quantity of road speed increases its shadow price, thus the representative consumer employs more leisure time in the production of any given number of passenger transport trips.

Freight transport is produced in an analogous manner using the clean input X together with an aggregate time input, $Z_F$. In contrast with the production of passenger transport, the time input for freight combines labour supply with $S$, rather than leisure time: i.e. $Z_F = CES(S, L)$. The clean final consumption good, $C$, and the clean input, $X$, are both produced using the single input labour. Finally, in accordance with our analytical model, the dirty good, $D$, is produced as a CES function of freight and the clean input: $D = CES(F, X)$, with an elasticity-of-input-substitution parameter, denoted by $\sigma_D$.

## IV.3. The benchmark equilibrium

The model is calibrated to a benchmark equilibrium. Total expenditures on consumption goods and inputs must be specified. We calibrate the model to the United Kingdom (excluding Northern Ireland) for 1995. This is chosen largely because we have access to a social accounting matrix (SAM) for the UK in 1995, constructed as part of a dynamic general equilibrium model for 14 member states of the European Union: *GEM-E3* (Van Regemorter and Capros, 2002). The SAM distinguishes 18 sectors – including freight transport. Aggregating this information allows us to specify expenditure shares for the 5 market commodities in our economy: C, D, T, F and X. Appendix 2 gives more detailed information on the procedure used. It also contains a matrix of benchmark own- and cross-

price elasticities, which is argued to be consistent in sign and magnitude with available econometric evidence.

# V.     Road freight tax reform: numerical results

The benchmark economy we consider is characterised by (excise and ownership) taxes on both passenger and freight transport (at rates of 35 per cent) and on labour supply (at 30 per cent). In addition, consumption goods are taxed at the standard rate of value-added tax (17.5 per cent). In reforming the tax rate on transport markets, we consider both recycling via the lump-sum transfer and via the labour tax. Initially, we assume labour tax recycling: the government is constrained to maintain the real-value of the benchmark transfer to the representative consumer; the labour supply tax is endogenously adjusted. Later in this section we also compare the results when government returns revenues in a lump-sum manner.

Figure 2 summarises the basic welfare implications of the model in the case of labour tax recycling[7]. The figure gives the percentage welfare change (vertical axis) as a function of the tax rate on freight transport, where all other taxes except the labour tax are kept at their benchmark values (a range from 75 to 115 per cent is considered on the horizontal axis; remember that the benchmark tax rate on freight is 35 per cent). Three different scenarios are considered, each one assuming different degrees of price sensitivity of passenger transport demand with respect to the price of freight. Varying this price sensitivity is potentially important. Indeed, recall the central result from our analytical model: that any benefit from raising the freight tax needs to be weighed against the cost from exacerbating the distortion on, amongst others, the passenger transport market. The magnitude of this cost depends, at least in part, on the sensitivity of passenger transport demand to an increase in the price of freight.

Section III.1 discussed three channels through which passenger transport demand is altered. The first channel is a standard gross-substitution effect: the (uncompensated) demand for passenger transport reacts to the increase in the price of the good D. Ignoring the impact of recycling tax revenues (the second channel), the third channel is a feedback effect: lower freight demand reduces the level of congestion, and thus reduces the generalised price of passenger transport. The magnitude of the effect via the first channel depends, within the framework of our model, to a large extent on the value chosen for the elasticity of substitution between passenger transport and other commodities ($\sigma_2$ in Figure 1), while the magnitude of

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[7] The sensitivity of the results with respect to some crucial parameters is summarised in Appendix 3.

the feedback effect depends significantly on the own-price elasticity of freight input-demand, which in turn depends on the value of the substitution parameter between freight inputs and other inputs ($\sigma_D$).

Under benchmark values for $\sigma_2$ and $\sigma_D$, Appendix 2 reports that the generalised-cross price elasticity of freight on passenger transport demand equals 0.08. This value was used in our benchmark scenario (labelled 'bmk'). In addition, by choosing alternative values for these parameters, we construct two additional scenarios: one in which the cross price elasticity is relatively low (equal to 0.02) and one in which it is relatively high (0.2). Given a lack of published estimates of this cross price elasticity, its 'true' value is essentially unknown.

INSERT FIGURE 2 AROUND HERE

Consider the results in Figure 2. Several interesting implications can be derived. First, for all three scenarios, raising the tax on freight above its reference level of 35 per cent is welfare-improving. This suggests that the reduction in the distortion on the freight market due to the tax increase more than offsets the increase in the distortion on the passenger market that the tax change causes. Second, the welfare change of a given freight tax adjustment strongly depends on the parameters that determine the price sensitivity of passenger transport demand with respect to the price of freight transport. For example, for a tax reform of 75 per cent, the high sensitivity scenario (0.2) generates larger welfare gains than the benchmark or low scenario. However, for a tax reform of more than 110 per cent, the high sensitivity scenario generates the lowest relative welfare gain. Third, we might expect that the higher the cross-price effect, the higher the marginal costs of a policy, for any given marginal benefit, and the lower the optimal level of freight tax. This intuition is confirmed by the model. Under the benchmark scenario, welfare is maximised[8] by increasing the tax on freight to around 95 per cent – a just over two-and-a-half fold increase in the current rate. The optimal tax rate on freight is approximately 85 per cent in the high case and 115 per cent in the low case. This result is obviously conditional on the benchmark tax on passenger transport being less than marginal external cost. This is the finding of much of the transportation literature and appears to the case for our model - at least for benchmark levels of freight taxation.

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[8] The value of the increase in welfare at the optimal freight tax (the equivalent variation) equates to approximately 715 mEURO in 1995 prices.

In Figure 2, the excise tax on passenger transport is fixed at its benchmark value of 35%. In Figure 3 we investigate the sensitivity of the results with respect to the passenger transport tax. We plot the change in social welfare as a function of the tax on freight (a range from 60 % to 110 % is considered) for three different levels of the passenger transport tax. The benchmark level of the passenger tax is given by the middle of the three curves, and is just a repeat of the benchmark curve on Figure 2. The two other curves show social welfare when passenger transport excise taxes are (i) one-half of the benchmark level (the lowest curve), and (ii) double the benchmark level (the highest curve).

INSERT FIGURE 3 AROUND HERE

Two findings stand out from the results reported in Figure 3. First, the welfare gain of a given freight tax reform rises with the level of the passenger tax. This reflects the fact that, over the range of freight transport taxes considered, raising the tax on passengers is still welfare improving. Second, it is found that the higher the rate of passenger transport taxation, the lower the optimal freight tax. For instance, doubling benchmark passenger taxes reduces the optimal freight tax to approximately 80 per cent, while halving passenger taxes increases the optimal freight tax to 105 per cent. To interpret this latter finding, recall that raising the passenger transport tax has two implications. First, as a lower MEC implies a smaller distortion on the market for freight transport, it reduces the marginal benefit of raising the freight tax. Moreover, ceteris paribus, lower optimal[9] freight taxes result. Second, however, a lower MEC and higher passenger transport taxes reduce the distortive wedge $(MEC - \tau_T)$ on the passenger transport market, and thus also reduce the marginal cost of the policy reform due to the higher passenger transport demand induced by higher freight transport taxes.

The information in Figure 3 therefore suggests that the first effect dominates in the determination of the optimal freight tax: higher passenger transport taxes reduce the marginal benefit of the policy reform by more than the cost, and hence the higher the rate of passenger transport taxation, the lower the optimal freight tax. This finding may have relevant policy implications for a stepwise introduction of congestion pricing on both passenger and freight transport. Suppose that it is currently not yet feasible, for political or technical reasons, to introduce congestion pricing in passenger transport and that the authorities start out by introducing an optimal freight tax, conditional on the current benchmark passenger tax rate. If

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[9] We recognise that the terminology here is potentially misleading. By optimal, we refer to the tax rate which maximises social welfare for any given level of other tax rates rather than the tax rate derived by optimising all taxes simultaneously. Our numerical model is a simulation model rather than a full optimisation model.

later on taxing passengers becomes acceptable and the authorities decide to move towards higher passenger transport taxes, then from a welfare viewpoint it may be desirable to accompany this tax change with a simultaneous reduction in freight transport taxes.

Given the range of passenger transport tax considered, it is perhaps surprising that the optimal freight tax is not more sensitive to these changes (optimal freight tax range between 80 per cent and 105 per cent ). This is due to the fact that the passenger tax also changes the marginal cost of the policy – focusing solely on the change in the marginal benefits of the policy reform may bias policy analysis to a significant extent.

As previously suggested, Figure 3 also shows that higher social welfare levels can be achieved by doubling passenger transport taxes than either maintaining benchmark levels or halving them. This naturally raises the question of what the optimal combination of passenger transport tax and freight tax might be. We perform a 'grid-search' with the simulatio n model: computing welfare levels under a large number of alternative assumptions concerning the two tax rates. We find that welfare is optimised by raising passenger transport taxes by a third to approximately 48% and freight taxes by a factor of two and a half, to 85%.

As noted in Section III.2, a possible alternative instrument to tackle the input externality is an output tax on the dirty good. Figure 4 plots social welfare against the tax rate on freight for two tax levels on the dirty good: firstly, the case when the dirty good tax is set at its benchmark level (labelled 'bmk'); secondly, the tax is raised by a amount equal to 5 per cent of the production cost (labelled '5 % tax on D').

INSERT FIGURE 4 AROUND HERE

There are three interesting results to be derived from Figure 4. First, at the benchmark level of freight taxation (35 per cent), the introduction of a 5 per cent tax on the dirty good is welfare improving[10]. Secondly, as stressed in equation (9), the presence of a tax on the dirty good raises the marginal cost of the reform of freight taxation - the freight tax further reduces demand for a consumption good which is already distorted. This result is confirmed by the model. The presence of the output tax reduces the optimal freight tax from approximately 95 per cent to 85 per cent. A third and final result is perhaps counter-intuitive. Figure 4 shows that welfare can be higher under the combination of a dirty good tax and a freight tax than under the freight tax alone. Using an additional tax instrument, only indirectly related to the externality-generating good, together with a direct externality tax can outperform the sole use of the latter. Recall, however, that two other distortions are present in the model: passenger

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transport taxes and labour taxes, both of which are set at (non-optimal) benchmark levels. Our result illustrates the general theory of the second-best.

We conclude this section by presenting some results on the use of the revenues. Numerical results presented so far are based on recycling through labour tax reductions. As Section III.5 stresses, under reasonable assumptions, returning revenues via labour taxes rather than lump-sum unambiguously reduces the marginal cost of the policy reform. Thus we might expect higher freight taxes and welfare levels when revenues are recycled via labour taxes. Figure 5 confirms this to be the case. The differences between recycling instruments are quite dramatic. Recycling via the lump-sum instrument raises welfare only marginally compared to labour tax recycling. Moreover, the optimal freight tax rate amounts to less than 65 per cent for lump-sum recycling as compared to about 95 per cent in the case of recycling through the labour tax. Note that, for our model, labour supply indeed increases in the tax on freight when revenues are used to reduce labour taxes, while it decreases when revenues are returned lump-sum. Appendix 3 provides more details on some of the numerical results discussed above.


INSERT FIGURE 5 AROUND HERE


# VI.    Conclusions


The purpose of this paper was twofold. First, we developed a simple general equilibrium framework for the analysis of tax reform on dirty intermediate inputs in the presence of other distortions in the economy, with a special emphasis on the taxation of freight transport services. In view of rising congestion, tax reform for freight transport is high on the political agenda in many European countries. Second, we illustrated the main findings using a numerical model calibrated and applied to the UK economy for 1995.

Our findings are easily summarised. The theoretical model shows that the desirability of raising taxes on dirty intermediate goods strongly depends on the presence of other distortions in the economy as well as on the instruments used to recycle the revenues of the tax reform. The numerical exercise produced the following findings. First, under a wide range of scenarios it was found that raising freight transport taxes is indeed welfare improving, even if passenger transport is substantially under-priced. Second, the higher the indirect cross-price

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[10] Rather obviously, setting too high a level for the tax on D can reduce welfare. We find in the model, for instance, that welfare declines, given a fixed benchmark tax on freight, for a tax on D greater than 8 per cent.

effect of freight taxes on passenger transport demand, the higher the marginal cost of a policy, for any given marginal benefit, and the lower the optimal level of freight tax. Third, the welfare gain of a given freight tax reform rises with the level of the passenger tax. Fourth, the higher the rate of passenger transport taxation, the lower the optimal freight tax. For instance, doubling benchmark passenger taxes reduces the optimal freight tax to approximately 80 per cent, while halving passenger taxes increases the optimal freight tax to 105 per cent.

Finally, it was shown theoretically and illustrated numerically that, under reasonable assumptions, returning revenues via labour taxes rather than lump-sum, unambiguously reduces the marginal cost of the policy reform. As a consequence, higher freight taxes and welfare levels result when revenues are recycled via labour taxes. Numerically, the differences between recycling instruments are quite dramatic. Recycling via the lump-sum instrument raises welfare by only a small fraction of the gain made possible by labour tax recycling. Moreover, the optimal freight tax rate amounts to less than 65% under lump-sum recycling, compared to almost 90% for labour tax recycling.

# References

Arnott, R., 2001, *The Economic Theory of Urban Traffic Congestion: a microscopic research agenda*, paper presented at CESifo Venice Summer Institute, Workshop on Environmental Economics.

Ballard C.L. and S.G.Medema, 1993, The marginal efficiency effects of taxes and subsidies in the presence of externalities: a computational general equilibrium approach, *Journal of Public Economics*, **52**, 199-216.

Bovenberg, A.L. and van der Ploeg, F., 1994, Environmental policy, public finance and the labour market in a second-best world, *Journal of Public Economics*, **55**, 349-390.

Bovenberg, A.L. and L. Goulder, 1996, Optimal Environmental Taxation in the Presence of Other Taxes: General-Equilibrium Analysis, *American Economic Review*, **86(4)**, 985-1000.

De Borger, B. and S.Proost (eds), 2001, *Reforming Transport Pricing in the European Union: A modelling approach*, Edward Elgar.

Dahl, C.A., 1995, Demand for transportation fuels: a survey of demand elasticities and their components, *The Journal of Energy Literature*, **1(2)**, 3-27.

European Commission, 2001, *White Paper - European Transport Policy for 2010: time to decide*, Luxembourg: Office for Official Publications of the European Communities.

Fuchs, V.R., A.B.Krueger and J.M.Poterba, 1998, Economist's views about parameters, values and policies: survey results in labor and public economics, *Journal of Economic Literature*, **36**, 1387-1425,

Fullerton, D., 1997, Environmental levies and distortionary taxation: comment, *American Economic Review* **87**, 245-251.

Fullerton, D. and R.Mohr, 2002, *Suggested subsidies are sub-optimal unless combined with an output tax*, NBER working paper 8723, Cambridge.

Friedlaender, A.F. and R.H.Spady, 1981, *Freight transport regulation*, MIT Press, Cambridge.

Goodwin, P.B., 1992, A review of new demand elasticities with special reference to short and long-run effects of price changes, *Journal of Transport Economics and Policy*, **26**, 155-169.

Marchand, M., 1968, A note on optimal tolls in an imperfect environment, *Econometrica*, **36(3-4)**, 575-581.

Mayeres, I. and S.Proost, 2001, Marginal tax reform, externalities and income distribution, *Journal of Public Economics*, **79**, 343-363.

Parry, I. and A.Bento, 2002a, Estimating the welfare effects of congestion taxes: the critical importance of other distortions within the transport system, *Journal of Urban Economics,* **51(2)**, 339-366.

Parry, I. and A.Bento, 2002b, Revenue recycling and the welfare effects of road pricing, *Scandinavian Journal of Economics*, **103(4)**, 645-671.

Peirson, J., D.Sharp and R.Vickerman, 2001, *What is wrong with transport prices in London*?, chapter 14 of De Borger and Proost (eds), 2001.

Small, K., 1992, *Urban Transport Economics*, Harwood Academic Publishers, Chur. Switzerland.

U.K. Department of Transport, Local Government and the Regions (DETR), 2001a, *Transport of Goods in Great Britain 2001: Annual Report of the continuing survey of road goods transpor*t, The Stationary Office, London.

U.K. Department of Transport, Local Government and the Regions (DETR), 2001b, *Transport Statistics Great Britain 2001*, The Stationary Office, London.

U.K. Department of Transport, Local Government and the Regions (DETR), 1998, *Transport Statistics Great Britain 1998*, The Stationary Office, London.

Van Regemorter, D. and P.Capros, 2002, *GEM-E3: constructing the social accounting matrices for the EU-14*, internal report, Centre for Economic Studies, K.U.Leuven, Belgium.
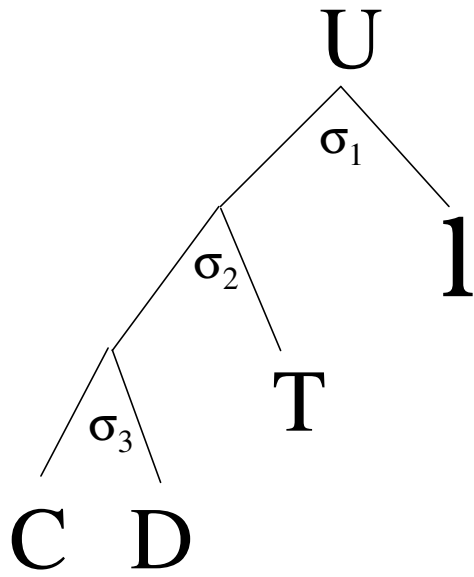
# Figures



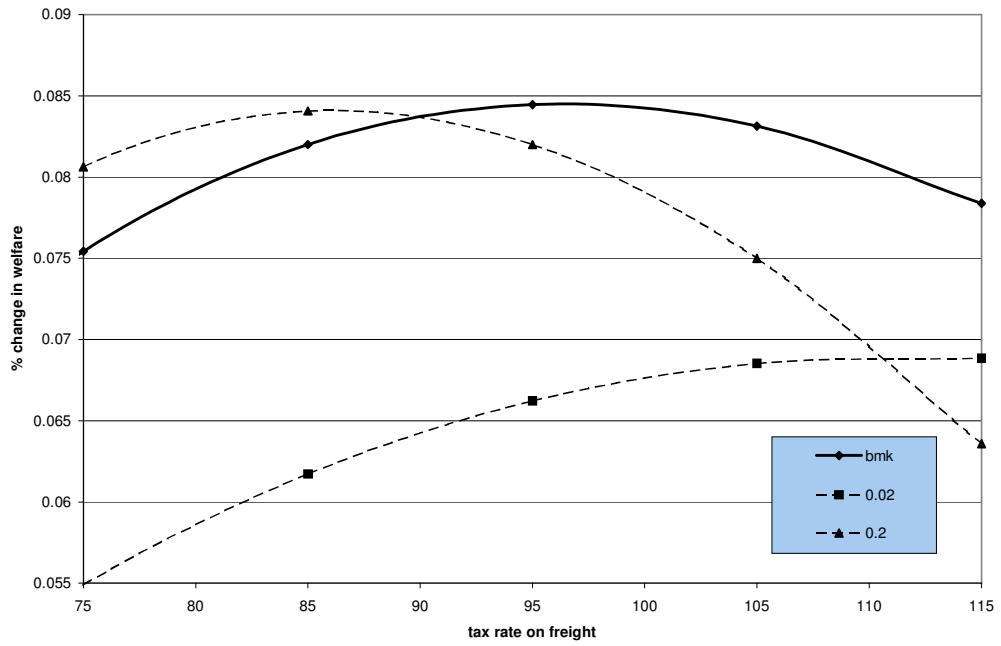**Figure 1**: the utility tree

**Figure 2 Tax reform on the freight transport market: changes in the level of welfare**
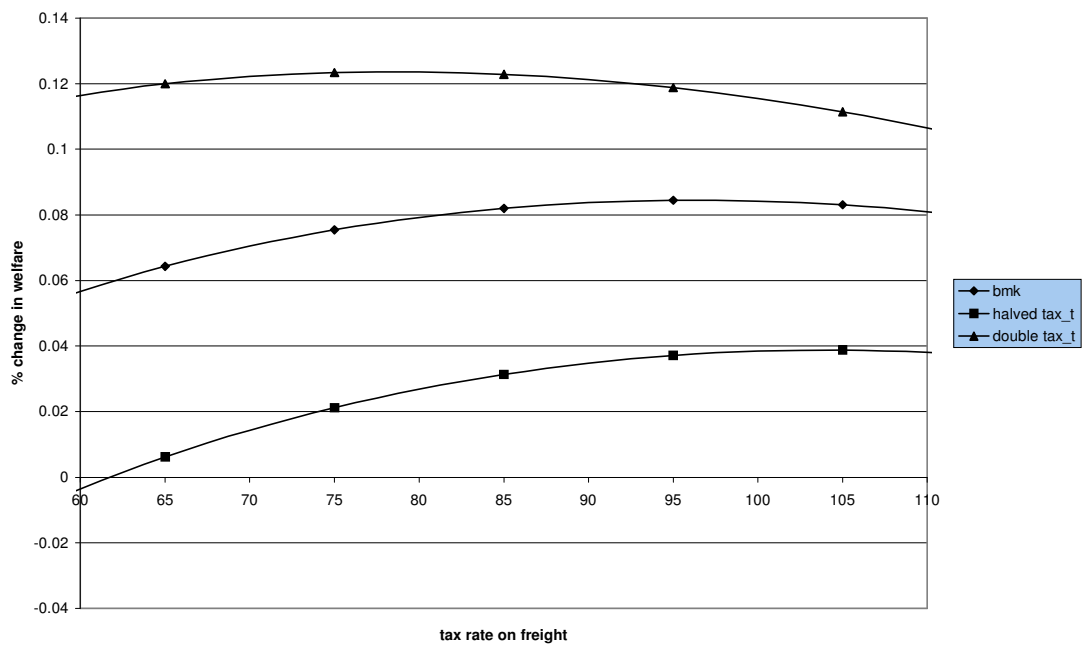


**Figure 3 Altering the level of the exogenous tax on passenger transport**
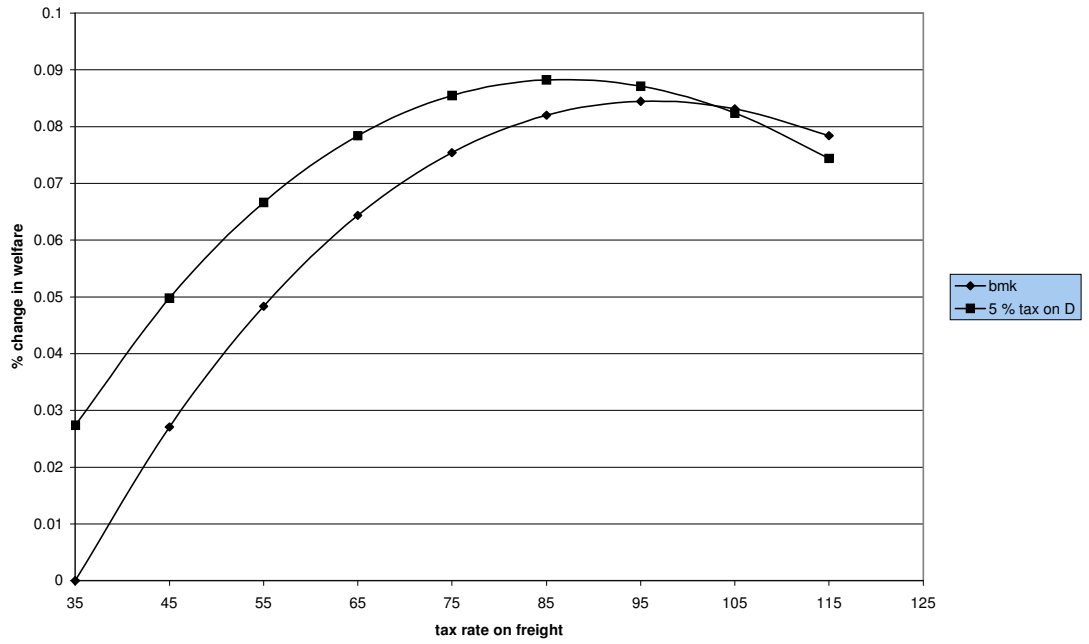
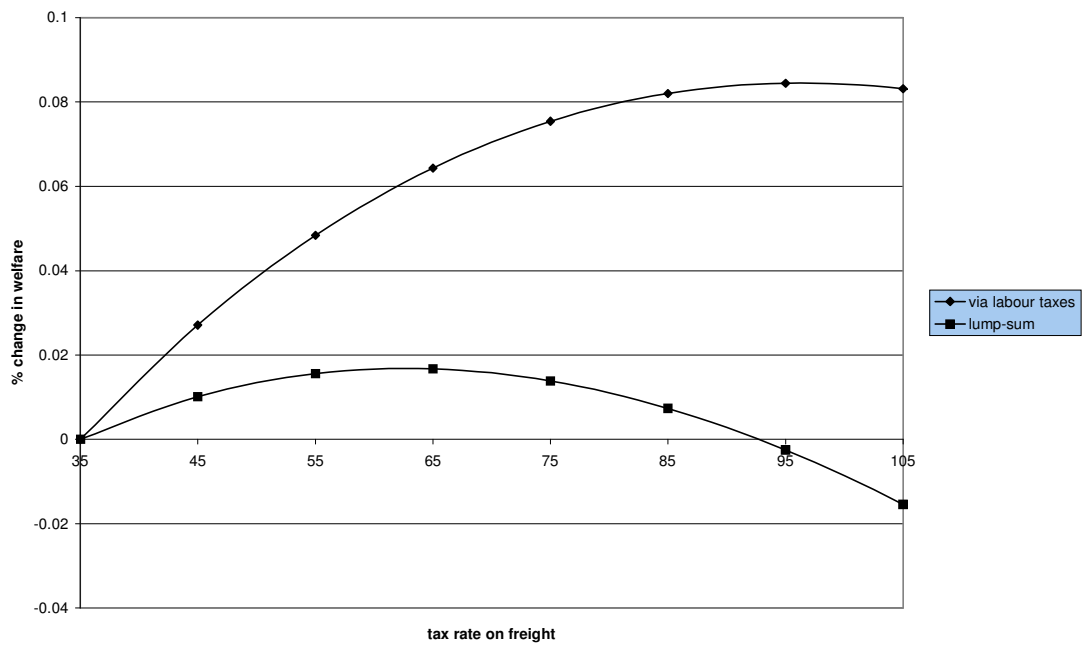**Figure 4 – Freight transport tax reform in presence of an output tax on the dirty good D**



**Figure 5 Freight transport tax reform: comparing the effects of lump-sum and labour tax recycling of the tax revenues**

## **Appendix 1: Deriving the welfare effect of a freight tax reform**

In this appendix we derive expression (7), which captures the change in welfare (measured in consumer income terms) from a tax-neutral increase in the tax rate $\tau_F$ on freight transport, the dirty intermediate input. It can in general be written as:

$$\frac{1}{\lambda}\frac{dW}{d\tau_F} = \frac{1}{\lambda}\frac{\partial V}{\partial \tau_F}\bigg|_{\bar{G}} + \frac{1}{\lambda}\frac{\partial V}{\partial G}\bigg|_{\bar{\tau}_F}\frac{dG}{d\tau_F} \tag{A1}$$

In this notation, the variable after the vertical bar is held constant when taking the appropriate partial derivative. The last term on the right hand side gives the general equilibrium impact on the lump sum transfer of a balanced budget increase in the freight transport tax. It measures the potential for lump sum recycling made possible by the tax reform.

Using Roy's rule and Shephard's lemma, it is easy to show that the first term on the right hand side of (A1) can be rewritten as:

$$\frac{1}{\lambda}\frac{\partial V}{\partial \tau_F}\bigg|_{\bar{G}} = -DF_{ND} - (D\frac{\partial c_D}{\partial \phi} + \frac{\gamma}{\lambda}T)\frac{d\phi}{d\tau_F} \tag{A2}$$

where $\dfrac{d\phi}{d\tau_F}$ is the total effect of the tax increase on congestion. Similar standard manipulations allow us to show that:

$$\frac{1}{\lambda}\frac{\partial V}{\partial G}\bigg|_{\bar{\tau}_F} = 1 - (D\frac{\partial c_D}{\partial \phi} + \frac{\gamma}{\lambda}T)\frac{d\phi}{dG} \tag{A3}$$

Here $\dfrac{d\phi}{dG}$ captures the full effect of the lump sum transfer on congestion. Substituting (A2) and (A3) in equation (A1) yields:

$$\frac{1}{\lambda}\frac{dW}{d\tau_F} = -DF_{ND} - (D\frac{\partial c_D}{\partial \phi} + \frac{\gamma}{\lambda}T)\frac{d\phi}{d\tau_F} + \left[1 - (D\frac{\partial c_D}{\partial \phi} + \frac{\gamma}{\lambda}T)\frac{d\phi}{dG}\right]\frac{dG}{d\tau_F} \tag{A4}$$

The general equilibrium impact of a balanced budget freight tax increase on the lump-sum transfer, $\dfrac{dG}{d\tau_F}$, can be obtained by differentiating the government budget constraint. Denote

$$R(\tau_T, \tau_L, \tau_D, \tau_F, \tau_X, G, \phi) = \tau_T T + \tau_L L + (\tau_D + \tau_F F_{ND} + \tau_X X_{ND})D \tag{A5}$$

where the dependency of the tax revenues per individual on all taxes, on the lump sum transfer and on congestion is made explicit. Moreover, note that congestion itself depends on taxes and transfers. Rewriting the government budget constraint as

$$R(\tau_T, \tau_L, \tau_D, \tau_F, \tau_X, G, \phi) = G,$$

and using the implicit function theorem then immediately implies

$$\frac{dG}{d\tau_F} = -\frac{\left.\frac{\partial R}{\partial \tau_F}\right|_{\bar{\phi}} + \frac{\partial R}{\partial \phi}\frac{d\phi}{d\tau_F}}{\left.\frac{\partial R}{\partial G}\right|_{\bar{\phi}} + \frac{\partial R}{\partial \phi}\frac{d\phi}{dG} - 1}$$

Manipulating this expression gives

$$\frac{dG}{d\tau_F} = \left.\frac{\partial R}{\partial \tau_F}\right|_{\bar{\phi}} + \frac{\partial R}{\partial \phi}\frac{d\phi}{d\tau_F} + \left[\left.\frac{\partial R}{\partial G}\right|_{\bar{\phi}} + \frac{\partial R}{\partial \phi}\frac{d\phi}{dG}\right]\frac{dG}{d\tau_F}$$

which can be substituting into (A4). We find after straightforward algebra

$$\frac{1}{\lambda}\frac{\partial W}{\partial \tau_F} = -DF_{ND} - \left[D\frac{\partial c_D}{\partial \phi} + \frac{\gamma}{\lambda}T - \frac{\partial R}{\partial \phi}\right]\left[\frac{d\phi}{d\tau_F} + \frac{d\phi}{dG}\frac{dG}{d\tau_F}\right] + \left.\frac{\partial R}{\partial \tau_F}\right|_{\bar{\phi}} + \left.\frac{\partial R}{\partial G}\right|_{\bar{\phi}}\frac{dG}{d\tau_F}$$

$$(A6)$$

To arrive at (7) it now suffices to work out the various terms and to appropriately define the marginal external cost of an increase in traffic. First, note that totally differentiating $\phi(NT + F)$ with respect to $\tau_F$ and G yields, respectively:

$$\frac{d\phi}{d\tau_F} = \phi' N \zeta \left(D\frac{\partial F_{ND}}{\partial \tau_F} + F_{ND}\left\{\frac{\partial T}{\partial q_D} + F_{ND}\frac{\partial D}{\partial q_D}\right\}\right) \qquad (A7)$$

$$\frac{d\phi}{dG} = \phi' N \zeta \left\{\frac{\partial T}{\partial G} + F_{ND}\frac{\partial D}{\partial G}\right\} \qquad (A8)$$

In these expressions, $\zeta$ represents the feedback effect of altered congestion levels on the demand for transport. It is defined as:

$$\zeta = \frac{1}{1 - \phi' N\left\{\frac{\partial T}{\partial \phi} + \frac{\partial T}{\partial q_D}\frac{\partial c_D}{\partial \phi} + D\frac{\partial F_{ND}}{\partial \phi} + F_{ND}\left\{\frac{\partial D}{\partial \phi} + \frac{\partial D}{\partial q_D}\frac{\partial c_D}{\partial \phi}\right\}\right\}}$$

The denominator captures the effects of increases in congestion on demand for both passenger and freight transport, and hence indirectly back on congestion. We assume that the denominator exceeds one, so that the feedback reduces the marginal external cost of an increase in transport flow: the resulting increase in congestion itself reduces transport demand and hence congestion. Note that the underlying assumption is mild, because every term in the curly bracketts is expected to be negative except the second. In other words, we implicitly assume that T is so large a substitute for D so as to make the denominator smaller than one.

Second, define the full marginal external cost MEC of an increase in transport demand as[11]

$$MEC \equiv \phi' N \zeta \left[ D \frac{\partial c_D}{\partial \phi} + \frac{\gamma}{\lambda} T - \frac{\partial R}{\partial \phi} \right] \tag{A9}$$

An increase in freight or passenger transport raises congestion for all consumers (first two terms). The initial effect, however, is reduced by the feedback on demand (third term). Finally, the term between square brackets captures the individual welfare cost to the consumer of the ultimate increase in congestion, expressed measured in terms of consumer income. This welfare effect consists of three distinct effects. First, more congestion increases the time required for making passenger transport trips. Using the envelope theorem (also see Section II.1), the associated welfare cost equals $\gamma T$. Dividing by the consumer's marginal utility of income $\lambda$ to translate this cost in terms of consumer income we have $\frac{\gamma}{\lambda} T$. Second, higher congestion also raises the price of the dirty good via adjustments in input use and, therefore, in production costs. Using Roy's identity, the welfare cost of this price increase, again expressed in terms of consumer income, is easily shown to be $D \frac{\partial c_D}{\partial \phi}$. Finally, congestion has an impact on final consumption demands and thus on total tax revenues to the government. The value of the induced tax payments to the government is captured by $\frac{\partial R}{\partial \phi}$.

Third, use (A5) to work out the impact of the freight tax and the lump sum transfer on overall tax revenues at constant congestion levels. Using Shephard's lemma, i.e., $\frac{\partial c_D}{\partial \tau_F} = F_{ND}$, and some simple algebra it is easy to find

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[11] Note that expression (A9) is closely related to the concept of the net-social Pigouvian tax defined by Bovenberg and van der Ploeg (1994), who measure the welfare cost in terms of government revenue rather than consumer income.

$$\left.\frac{\partial R}{\partial \tau_F}\right|_{\bar{\phi}} = \tau_T \frac{\partial T}{\partial q_D} F_{ND} + \tau_L \frac{\partial L}{\partial q_D} F_{ND} + \left[\tau_D + \tau_F F_{ND} + \tau_X X_{ND}\right]\frac{\partial D}{\partial q_D} F_{ND}$$
$$+ DF_{ND} + \tau_F D \frac{\partial F_{ND}}{\partial \tau_F} + \tau_X D \frac{\partial X_{ND}}{\partial \tau_F} \tag{A10}$$

$$\left.\frac{\partial R}{\partial G}\right|_{\bar{\phi}} = \tau_T \frac{\partial T}{\partial G} + \tau_L \frac{\partial L}{\partial G} + \left[\tau_D + \tau_F F_{ND} + \tau_X X_{ND}\right]\frac{\partial D}{\partial G} \tag{A11}$$

Finally, substitute (A7), (A8), (A10) and (A11) into (A6) and use (A9). The result can be written, after simple manipulation and rearrangement, as equation (7) in the main body of the paper:

$$\frac{1}{\lambda}\frac{dW}{d\tau_F} = \left(MEC - \tau_F\right)\left[D\left(-\frac{\partial F_{ND}}{\partial \tau_F}\right) + F_{ND}\left\{\left(-\frac{\partial D}{\partial q_D}\right)F_{ND} - \frac{\partial D}{\partial G}\frac{dG}{d\tau_F}\right\}\right]$$
$$- \tau_D\left(\left(-\frac{\partial D}{\partial q_D}\right)F_{ND} - \frac{\partial D}{\partial G}\frac{dG}{d\tau_F}\right)$$
$$- \left(MEC - \tau_T\right)\left(\frac{\partial T}{\partial q_D} F_{ND} + \frac{\partial T}{\partial G}\frac{dG}{d\tau_F}\right) \tag{A12}$$
$$+ \tau_X\left[D\frac{\partial X_{ND}}{\partial \tau_F} + X_{ND}\left\{\frac{\partial D}{\partial q_D} F_{ND} + \frac{\partial D}{\partial G}\frac{dG}{d\tau_F}\right\}\right]$$
$$- \tau_L\left(\left(-\frac{\partial L}{\partial q_D}\right)F_{ND} - \frac{\partial L}{\partial G}\frac{dG}{d\tau_F}\right)$$

It is useful to emphasize that this equation is quite general and encompasses a number of more specific examples as special cases. As a consequence, it can be used to also study tax reform for markets that generate other types of externalities. First, many externalities do not imply feedbacks in demand. The welfare effect of a tax reform on an intermediate input creating this kind of externality (e.g., many types of emissions) is obtained by setting $\zeta = 1$ in the definition of the marginal external cost, see (A9) above. Second, a pure consumer externality (i.e., the externality does not affect production) could be studied by setting $\frac{\partial c_D}{\partial \phi} = 0$ in (A9). Finally, unlike in the model considered above (where passenger and freight services jointly produce the externality), in many cases of practical relevance (e.g., fertilizers, pesticides, energy), the externality is produced by the intermediate input only. It then suffices to set $\tau_T = MEC$ and to re-interpret the tax $\tau_F$ in (A12) appropriately as a tax on, e.g., fertilizer.

## Appendix 2: Benchmark equilibrium and parameter values of the numerical model

In this appendix we provide more details on the specification of the benchmark equilibrium (definition of clean and dirty consumption goods, expenditure and cost shares, benchmark tax rates, etc.) and on the parameter values and congestion function used in the numerical model.

### A. The benchmark equilibrium

Defining goods C and D.

The structure of our numerical model, in turn reflecting the analytical model, makes the simplifying assumption that all freight expenditures are attributable to good D. It is therefore necessary to allocate each of the non-transport sectors in the GEM-E3 database to either aggregate good C or D.

We allocate the six sectors with the highest expenditures on freight inputs to good D, and the remaining sectors to the clean good. Table 1 shows the sectors allocated to D and their respective shares of freight inputs in total freight expenditure (excluding non-market services, such as freight by the armed services). Approximately 80 per cent of total freight expenditures accord to good D.

Ascribing all road freight expenditures to six sectors – which the data shows generate only 80 per cent of freight expenditures – is a potential source of bias in our model. Judgment is made more difficult by the failure of the GEM-E3 data to distinguish between road freight and other types of freight (rail, waterways etc).

Consulting additional data-sources[12] suggests that the bias may be rather limited. A recent survey of road goods transport by the UK government (UK DETR, 2001a) suggests that, in 1991, approximately 90 per cent of road transport freight is attributable to the chosen six sectors[13].

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[12] The availability of such additional information was one of the key reasons why we calibrated the numerical model to the UK.

[13] This is based on Chart B of the survey. Differences in definitions complicate matters: however, we have sum the road freight usage of the following industries: food, drink and tobacco; bulk products (including building materials and iron and steel products); and, chemicals, petrol and fertilizers.

**Table 1 – The composite dirty good D**

| Sector | share in total freight expenditures |
|---|---|
| distribution | 0.54 |
| consumer goods | 0.08 |
| energy-intensive industry | 0.08 |
| chemicals | 0.04 |
| oil and petroleum | 0.04 |
| construction | 0.02 |
| Total | 0.8 |

Benchmark expenditures shares on consumption goods and leisure

Based on the GEM-E3 data, and adopting the definition of good D and C discussed above, results in the following shares of total expenditure on consumption goods: good D has approximately 55 per cent; good C has 40 per cent; and the remaining 5 per cent is on good T. The value of leisure is assumed to equal one-half of the total expenditures on commodities.

Benchmark input expenditure shares

The share of freight in the production expenditures of good D is calculated on the basis of the GEM-E3 database to equal approximately 15 per cent. Recalling that this dataset does not distinguish between road freight and other modes of freight transport, we assume expenditures are divided between modes in accordance with the ratio of total tonne-kilometres between road and all other freight modes. The UK Government (U.K. DETR (2001b) - Table 1.14) report that, in 1995, approximately two-thirds of all freight tonne-kilometres are attributable to road freight. Hence we assume that 10 per cent of the value of good D production is attributable to road freight. This implies that the share of road-freight in the overall value of commodities equals 5 per cent. This is slightly lower than, but still

comparable to, a recent study for the Belgian economy, in which total freight expenditures are taken to equal 8 percent of commodity expenditures (Mayeres and Proost, 1997, Table 2a).

<u>Benchmark taxes</u>

We assume that the average tax rate on wage income is 30 per cent. This corresponds closely to the GEM-E3 database. Passenger and freight transport are subject to ownership taxes and excise duty. In addition, passenger transport is subject to the standard rate of VAT. Using 1995 data from Peirson *et al.* (2001), we compute that the average rate of taxation (excluding VAT) on a passenger car trip 35 per cent. The corresponding figure for road freight is also 35 per cent. In addition, the standard rate of VAT in the U.K. is 17.5 per cent.

## B. Calibrating the model: the choice of Elasticities of Substitution

It is necessary to make assumptions about the values of the elasticities of substitution employed in the numerical model: three in the consumer utility tree; and three in the production technology. It is standard to choose these values in such a way as to replicate as closely as possible any empirical estimates of own- and cross-price elasticities. The following values have been adopted for the utility tree: $\sigma_1 = 0.8$; $\sigma_2 = 0.6$ and $\sigma_3 = 1$. On the production side: $\sigma_D$, $\sigma_T$ and $\sigma_F$ are all set equal to unity.

The partial elasticity of labour supply resulting from the model equals 0.31, which seems within the range of estimates in the literature (see, for example, Fuchs *et al.*, 2000). Table 2 reports the matrix of own- and cross-price effects on T, F and D. Note that the reported elasticities are computed numerically as a linear approximation to the benchmark elasticities. They are *general equilibrium* elasticities: demands vary in response to both the change in consumer price of the good and the level of congestion.

**Table 2 Matrix of own and cross-price effects**

|            | T     | F     | D     |
|------------|-------|-------|-------|
| price of T | -0.25 | 0.08  | 0.03  |
| price of F | 0.08  | -0.39 | -0.01 |
| price of D | 0.27  | -0.4  | -0.42 |

The resulting estimates appear reasonable in sign and magnitude. The upper-left cell of the matrix gives the own-price elasticity of car use. There is a considerable literature on this topic and a reasonable range[14] seems to be -0.1 to -0.6. The cross-price effect on demand for freight is larger than for the dirty good: this reflects the greater attractiveness of freight inputs as congestion levels fall in response to higher passenger transport prices.

Turning to the freight market, we note that the elasticity with respect to freight demand is much larger (in absolute level) than dirty good demand, reflecting the relatively high degree of input substitutability . We have been unable to find much empirical literature on the price elasticity of freight use. In a study for central and northeastern United States, Friendlander and Spady (1981) estimate the long run own-price elasticity of trucking manufactured goods to be –0.9 and for bulk goods –0.88. Our model is better suited to short-run responses[15], and hence it is reasonable that our figure is (in absolute terms) smaller than Friendlander and Spady's. However, as reported in Figure 1, we employ sensitivity analysis around our benchmark value.

Finally, for the dirty good, feedback effects via the congestion function ensure that the own-price elasticity (of the dirty good) is larger (in absolute terms) than the elasticity with respect to freight input demand.

## C. The congestion function

Implementation of the model requires a particular functional form mapping the demand for freight and passenger transport to the time required per trip: the so-called congestion function. We adopt an exponential function: this is supported empirically on the basis of an aggregation exercise with urban network models (Mahony and Kirwan, 2001) and has been used in a number of recent studies of transport pricing (De Borger and Proost, 2001). Thus the time required to travel a kilometre is assumed to be given by:

$$time = \frac{1}{speed} = k_1 + k_2 Exp[k_3(T + k_4 F)]$$

where $k_1$, $k_2$ and $k_3$ are unknown parameters, $T$ and $F$ are measured in vehicle kilometres, while $k_4$ converts freight vehicle-kilometres into car-equivalents, and, as appears to be

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[14] Standard references include Small (1992) and Goodwin (1992). In addition, Dahl (1995) reviews 39 aggregate econometric studies on the price elasticity of gasoline demand for fuel in the U.S. and concludes that the median short-run estimate is –0.13, while the median long-run estimate is –0.65. However, given improving fuel-efficiency, we might well expect that the elasticity with respect to kilometres travelled is smaller than that with respect to fuel demand.

[15] As is well known, CES models impose a unity income elasticity, which makes them often unsuitable for long-run prediction.

standard[16], is assumed henceforth to equal 2. Benchmark vehicle flows are based on government statistics (U.K. DETR, 2001b) suggesting that only one-fifth of vehicle flows are from freight.

We calibrate the 3 unknown parameters to 3 point estimates of speed and demand aggregated across all English motorways and major arterial roads (UK DETR, 1998), reported in Table 3.

**Table 3 – UK speed-flow data**

| time period | mPCUs /hr[17] | speed (km/hr) |
|---|---|---|
| am peak | 22.66 | 74 |
| inter-peak | 18.49 | 83.3 |
| Freeflow | 0 | 110 |

## Appendix 3: Detailed model output

The model produces, for each simulation exercise performed, a large number of potentially interesting results on all of the central variables in the model. Table 4 presents greater detail on some crucial model variables for a few of the simulations underlying the results reported above. The variables considered are welfare, speed, labour supply, demand for the dirty good, and demand for both for passenger and freight transport. For three levels of the tax on freight (the benchmark level of 35 per cent, a tax rate of 75 per cent and a rate of 115 per cent) we give the percentage change in each variable relative to the reference case where all variables were at their benchmark levels. Moreover, three scenarios are presented: the column marked 'BMK' refers to the benchmark scenario; the column marked ' $\tau_D = 0.05$, refers to introduction of a 5 per cent tax on the dirty good; and, finally, the column marked 'lump-sum recycling' refers to a scenario in which revenues are returned in a lump-sum manner rather than via reduced labour taxes.

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[16] Arnott (2001) challenges this type of approach. He argues that trucks are more usefully seen as reducing road capacity. He shows that this implies that the number of car equivalents of a truck is increasing in the number of trucks.

[17] mPCUs refers to million passenger-car units. Demand from buses, vans and trucks, therefore, is converted into equivalent units of car demand via fixed ratios.

To illustrate the interpretation of the Table, consider as an example the impact of a few simple scenarios on passenger and freight transport demand and on welfare. First, with labour tax recycling and in the absence of a tax on the dirty good, raising the freight transport tax from 35 to 75 per cent raises passenger transport demand by slightly more than 2 per cent; freight transport goes down by 9.66 per cent. Welfare rises by 0.075 per cent. Second, in the presence of an additional tax on D, the same increase in freight tax raises passenger transport demand by 3.71 per cent and reduces freight demand by 11.57 per cent. Welfare increases a bit more (by 0.085), reflecting that a 75 per cent tax on freight is still short of the welfare optimum: an additional dirty goods tax is welfare-improving. Third, the same freight tax increase would hardly affect welfare if recycling were through the lump-sum instrument: welfare rises by 0.014 per cent compared to 0.075 per cent in the case of recycling via the labour tax.

**Table 4 Example of more detailed model output**

| Variables | $\tau_F$ | BMK | $\tau_D$=0.05 | lump-sum recycling |
|---|---|---|---|---|
| **Welfare** | 35 | 0 | 0.027 | 0 |
| | 75 | 0.075 | 0.085 | 0.014 |
| | 115 | 0.078 | 0.074 | -0.031 |
| **Speed** | 35 | 0 | 0.65 | 0 |
| | 75 | 4.05 | 4.62 | 4.13 |
| | 115 | 7.42 | 7.92 | 7.56 |
| **L** | 35 | 0 | 0.2 | 0 |
| | 75 | 0.32 | 0.28 | -0.01 |
| | 115 | 0.57 | 0.74 | -0.04 |
| **D** | 35 | 0 | 1.37 | 0 |
| | 75 | -0.67 | 3.71 | 2.31 |
| | 115 | -0.77 | 5.65 | 4.22 |
| **T** | 35 | 0 | 1.37 | 0 |
| | 75 | 2.37 | 3.71 | 2.31 |
| | 115 | 4.33 | 5.65 | 4.22 |
| **F** | 35 | 0 | -2.03 | 0 |
| | 75 | -9.66 | -11.57 | -9.8 |
| | 115 | -18.07 | -19.85 | -18.32 |