EXTERNALITIES AND PARTIAL TAX REFORM: DOES IT MAKE SENSE TO TAX ROAD FREIGHT (BUT NOT PASSENGER) TRANSPORT? *

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Abstract

Externalities such as pollution and road congestion are jointly produced by the use of intermediate inputs by firms and the consumption of final goods by households. Remarkably, to cope with such externalities policy proposals often suggest very partial tax reforms. A pertinent example is the current EU proposal to introduce congestion taxes for freight transport on major roads while, for political or technical reasons, failing to similarly address passenger transport. This paper uses a simple general equilibrium model to explore the effects of such a partial tax reform in a second-best setting. The theoretical model shows that the welfare effect of higher freight taxes is positive, unless passenger transport is severely under-taxed and the tax reform attracts substantially more passenger transport. Moreover, the optimal freight tax may be below or above marginal external cost; the former holds if passenger transport is under-taxed and the freight tax does not strongly affect labour supply. Budgetary neutral tax reform exercises with a numerical simulation model for the UK suggest that, under a wide variety of parameter values, higher freight transport taxes are indeed welfare increasing. The welfare gain of freight tax reform rises with the level of the passenger tax, but the optimal freight tax declines at higher taxes on passenger transport. Substantial net benefits of tax reform are obtained only under labour tax recycling of the revenues.

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1. INTRODUCTION

External costs often depend on the total use of specific goods by both households and firms. For instance, road congestion depends on both freight transport by firms and passenger transport by individual consumers. Similarly, air pollution levels depend on energy consumption by industry and the domestic sector, ground-water quality depends on the use of chemicals by industry as well as households, etc. Interestingly, due to technical and unspecified political constraints, many recent government proposals imply a very partial tax reform to cope with the relevant external costs. Several proposals limit tax reform to dirty intermediate inputs only, while leaving taxation of the final good (that jointly contributes to the same externality) unaddressed. For example, recent suggestions within the EU for the introduction of new taxes to cope with congestion on motorways apply only to freight, and not to passenger, transport. Germany already introduced a kilometre tax for freight transport on its motorways as of January 2005, and the U.K. considered analogous plans to introduce a freight charge along all major roads in the near future. In energy policy, similar proposals have been suggested and implemented. For example, the U.K. Climate Change Levy (CCL), introduced in 2001, implies a tax on the energy use by industry only; it does not apply to the domestic sector[1].

The purpose of the current paper is to analyze the desirability of this type of tax reform within a simple general equilibrium framework in a second-best environment, i.e., in the presence of tax distortions on the labour market and the markets for final goods. For purposes of concreteness we focus on the case of freight transport taxation to cope with congestion throughout the paper. The congestion externality is non-separable to consumer demand, it depends jointly on intermediate and final consumption, and it enters both the utility function of consumers and the production function of firms. Note, however, that relaxing some of these assumptions makes the model applicable to various other policy reforms. For example, very often (e.g., fertilizers, pesticides, etc), the externality is produced by the intermediate input only. Also, some externalities do not imply feedbacks in demand and/or do not affect

[1] On the energy tax, see the official website http://www.defra.gov.uk/environment/ccl/intro.htm. Interestingly, the revenues from this tax are used to cut employers social security contributions and to promote energy efficiency.

production costs (e.g., emissions of various pollutants). Such cases can be interpreted as special cases of the more general formulation here.

The ‘partial’ nature of freight transport tax reform raises interesting questions that have not been studied in detail in the literature. Given that passenger transport appears to be sub-optimally taxed in many European countries (De Borger and Proost (2001)), what are the welfare effects of raising road freight transport taxes to cope with congestion and pollution? 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., employment) the transport market? Do higher taxes on passenger flows imply higher or lower optimal freight taxes? With these questions in mind, the specific objectives of this paper are twofold. First, to derive a simple analytical expression for the welfare implications of a budgetary neutral intermediate input tax reform to correct an externality under the described conditions. A second objective of the analysis is to illustrate the theory numerically by examining a practical policy issue, namely the taxation of road freight transport in the UK.

This paper builds upon, and contributes to, several strands of the recent literature. Firstly, it fits in with the literature on the general equilibrium effects of tax reform in the presence of externalities. This literature has convincingly shown that the efficiency implications of externality tax reform strongly depend on pre-exisitng distortions in the economy. Important contributions include, among many others, Ballard and Medema (1993), Parry (1995), Bovenberg and Goulder (1996), Fullerton and Mohr (2003) and Babiker, Metcalf and Reilly (2004). For a recent survey we refer to Schöb (2003)[2]. Unlike this literature, however, our formulation considers a partial tax reform when final and intermediate goods jointly produce an externality, starting from a generally distorted vector of final and intermediate taxes. Secondly, the paper contributes directly to the recent transport pricing literature, see, Mayeres and Proost (1997, 2001), and Parry and Bento (2002a, 2002b)). These studies either explicitly consider an urban environment and simply abstract from freight transport, or they do include freight, but do not study the interaction between passenger and freight transport markets. Third, the paper relates to the literature on congestion taxes in the presence of restrictions on the tax instruments (Marchand (1968) and Verhoef,

[2] The analysis of tax reform in the presence of externalities has generated a huge literature on the existence of a double dividend. For surveys of this work one can also refer to, among others, de Mooij (1999) and Bovenberg and Goulder (2001).

Nijkamp and Rietveld (1996)). This literature mainly focuses on pricing one road link in the presence of an un-priced alternative, a distinctly different problem from the one considered here. Finally, the analysis of this paper bears some resemblance to recent literature on the welfare effects of imposing single lane tolls on multiple lane highways. For example, Small and Yan (2001) show that the welfare effects of single lane tolls are reduced by traffic diversion onto un-priced lanes and, hence, higher congestion on these lanes. This strongly reduces the efficiency of single lane tolls. Note that, although conceptually related, the topic of the current paper is distinctly different. The second-best nature of the problem is not the result from demand shifts towards an un-priced alternative; instead, it stems from not tolling a type of traffic that uses the same infrastructure.

Our findings can be summarized as follows. First, we show that the joint contribution of freight and passenger transport to congestion and the existence of feedbacks in demand implies that the welfare effects of an externality tax on freight transport are, on theory grounds alone, not necessarily positive. The reason is that the externality tax partially corrects a distortion on the market for freight transport, but it also affects existing distortions on the labour and (especially) the passenger transport markets. The conditions for the tax reform to be welfare improving can be clearly identified, however. It is found that raising the tax on freight transport will be welfare improving, unless passenger transport is severely under-taxed and the tax reform attracts substantially more passenger transport. Second, if passenger transport is substantially under-taxed and the freight tax does not strongly affect labour supply then we find that the optimal freight tax is below marginal external cost. Moreover, the optimal tax will be lower in countries where passenger transport is very important. Third, introducing road pricing on passenger transport might increase or reduce the optimal freight charge. Intuitively, higher passenger taxes imply lower congestion, hence the benefits of higher freight taxes decline. At the same time, however, they lower the distortive wedge between tax and marginal external cost on the passenger market; this reduces the downward pressure on freight taxes to correct this distortion. If the direct effects on congestion dominate, higher taxes on passenger transport reduce the optimal freight transport tax. Fourth, to obtain more insight a numerical model for the UK economy is used to study freight transport tax reform. We find that raising freight transport taxes from current levels does appear to be welfare-improving for a wide range of parameter values. We also show that the gain in welfare from an optimal freight charge increases locally with the tax on passenger transport. Finally, in line with Parry (1995) and Mayeres and Proost (1997) we find that the results are quite sensitive to the recycling instrument used. In fact, it appears that raising freight taxes can only be significantly welfare improving if revenues are recycled via lower labour taxes.

The paper unfolds as follows. In Section 2, we present the structure of the model. We then proceed by deriving the welfare effects of a tax reform in the freight transport sector (see Section 3) in a second-best environment with existing distortions on all markets, including the passenger transport market. In Section 4 we present the main characteristics of the numerical simulation model that is calibrated to the UK economy, and carefully discuss empirical results. Finally, Section 5 summarises the main conclusions.

2. THE ANALYTICAL MODEL

Consumer Behaviour

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 'dirty' consumption good D, in the sense that its production intensively uses road freight transport, passenger transport (T), and leisure (ℓ):

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

Freight and passenger transport jointly produce an externality, interpreted as congestion. Adding other road-transport externalities such as local and global air pollution, noise or accidents is conceptually straightforward. However, we prefer to focus on congestion issues, which have been shown empirically to be the largest externality (De Borger and Proost, 2001). Moreover, they are quite general in the sense of causing feedback effects on demand.

The consumer 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 ($i \in \{D,T\}$), w is the net wage, L is labour supply, and G is a lump-sum transfer from the government. Second, a time constraint

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

allocates the total time available ($\overline{L}$) over labour, leisure and travel time. The congestion function $\phi(.)$ gives the travel time needed per unit of T; this depends on total traffic flow, namely passenger transport (NT) and freight (F) demand. We have simplified notation by assuming that only the total traffic flow determines congestion. Of course, the numerical application in Section 4 below does follow standard practice by assuming that the impact of one truck on congestion levels exceeds that of a passenger car. Also note that specifications (1)-(2)-(3) implicitly fix the value of time at the net of tax wage w[3].

We assign multipliers λ and γ to the consumer 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 $\frac{\partial V}{\partial \phi} = -\gamma T$.

Producer Behaviour

The production structure of the economy is kept as simple as possible. For all goods except the dirty good, we assume a linear aggregate production function:

$$N(T + C) + F + X \leq LN \tag{4}$$

in which units are adjusted such that the marginal rate of transformation between goods, and hence producer prices, are equal to one. The dirty good is produced, for a

[3] Since in the empirical model described in the next sections the net of tax wage is 70% of the gross wage, the implied value of time is in the upper part of the range of values recently inferred from the empirical literature. For example, Calfee, Whinston and Stempski (2001) use stated preference data and find time values to be much below the net of tax wage, around 4 USD per hour. Most recently, however, Small, Winston and Yan (2005) apply mixed logit estimation techniques to a combination of revealed and stated preference data, and they report generally much higher time values. Moreover, they find that estimated medians are much higher for revealed than for stated preference data; in the former case, median values of about 21 USD are found. For British evidence on time values, see Wardman (2001).

given level of externality, under constant returns to scale, combining freight transport and a clean intermediate good (X):

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

To ease notation, 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 interpretation holds for the other input X. We allow for intermediate good taxes $\tau_i \;\; i \in \{F, X\}$, set by the government. In the case of freight demand, τ_F can be interpreted as a tax per mile (or kilometre) or per ton-kilometre, depending on the units in which demand is measured. Since pre-existing variable transport taxes consist to a large extent of fuel taxes, it is instructive to point out that kilometre taxes are not equivalent to fuel taxes. The latter are less efficient than distance-based taxes because they induce improvements in fuel economy rather than reduced driving. This reduces the congestion benefits of fuel taxes (see Parry and Small (2005) for recent evidence).

With the above setup, input demands depend on the taxes on the intermediate goods F and X, and on congestion levels. The unit cost function of good D, c_D, can be written as:

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

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

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 $V(\cdot)$. While it is conceptually straightforward to incorporate equity concerns into the model, we prefer to focus on efficiency aspects of freight transport tax reform. Mayeres and Proost (1997) show that optimal intermediate dirty input taxes reflect equity concerns via weights on the marginal damage to final consumers. Their numerical results suggest that equity concerns have a significant impact on the welfare effects of different revenue uses, but only a minor effect on optimal tax adjustments.

The government has in principle the authority to set taxes on all markets though, without loss of generality, we take the numeraire as untaxed. Therefore, consumer prices are given by:

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

Similarly, input prices are given by:

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

Again, note that the tax on passenger transport is to be interpreted as a tax per passenger or passenger kilometre.

Finally, we assume the government is required to maintain a balanced budget. This requires:

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

3. WELFARE EFFECTS OF A CONGESTION TAX ON FREIGHT TRANSPORT

In this section, we study the general equilibrium welfare implications of raising the tax on freight transport in the presence of distorted markets. We first derive a general expression for the welfare effect of a congestion tax on freight transport use. Next we carefully study the desirability of this partial tax reform in the presence of under-priced passenger transport and distortions on the labour market. Finally, we discuss optimal freight transport taxes, conditional on given taxes on labour and on passenger transport, and we analyze the effect of higher passenger taxes for the optimal tax on freight.

Following, among many others, Bovenberg and Goulder (1996) and Parry and Bento (2002a), we assume throughout this section that the revenues of the tax reform are used in a budgetary neutral way to reduce labour taxes. Using labour taxes as the recycling instrument seems plausible in this model, given the high marginal welfare cost (per unit of tax raised) of labour taxes[4]. The numerical model below also explores the efficiency loss from recycling via a lump-sum instrument compared to labour tax recycling.

[4] Although models that incorporate both labour and capital taxation often find the tax on capital to be the most distortive component of the tax system, labour taxes are known to be highly distortive (see, e.g., Jorgenson and Yun (1990)). Since our model does not include capital, recycling via the distortive labour tax seems plausible.

The General Result

Consider the welfare effect of a revenue-neutral marginal increase in the tax on freight transport, in which the government budget constraint (6) is respected by recycling any additional tax revenues via lower labour taxes. The manipulations to derive the welfare cost of the tax reform are standard but rather extensive; they are therefore given in Appendix 1. There it is shown that the welfare effect (expressed in terms of consumer income) can be written as:

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

In this expression MEC is the 'full marginal external cost' of an additional transport trip; it accounts for increased production costs, consumer time delays and changes in government revenues. It is defined as:

$$MEC \equiv \phi' N \zeta\left[D\frac{\partial c_D}{\partial \phi} + \frac{\gamma}{\lambda}T - \frac{\partial R}{\partial \phi}\right] \qquad (8)$$

where R denotes government tax revenues and ζ is the feedback term, defined as:

$$\zeta = \frac{1}{1-\phi' N\{\frac{\partial T}{\partial \phi} + \frac{\partial T}{\partial q_D}\frac{\partial c_D}{\partial \phi} + D\frac{\partial F_{ND}}{\partial \phi} + F_{ND}\left\{\frac{\partial D}{\partial \phi} + \frac{\partial D}{\partial q_D}\frac{\partial c_D}{\partial \phi}\right\}\}} \qquad (9)$$

It accounts for the impact of changes in congestion levels on transport demand. Higher congestion itself reduces demand for both passenger and freight transport. The feedback term would be equal to one if the externality did not affect demand.

Note the simple structure of the welfare cost of the tax reform, as summarized by (7). It consists of the sum of welfare effects on the five distorted markets; the effect on each market equals a distortive tax wedge multiplied by the general equilibrium change in demand. However, it is important to realize that the MEC appearing in this expression itself depends on transport taxes, as is apparent from our definition of MEC (expression (8))[5]. Low transport taxes raise demand and hence increase MEC for two reasons. First, they increase the number of passengers and trucks suffering from time losses; i.e., the term between square brackets in (8) rises in T and F. Second, given convexity of the congestion function ($\phi'' > 0$), the larger the number of trips made, the higher the marginal increase in average trip time.

Before turning to a more detailed interpretation of (7), note that one simple observation immediately follows. Since at the first-best tax structure the marginal welfare effect of increasing the freight transport tax is obviously zero, (7) illustrates that the first best can be implemented by taxing the externality creating activities at marginal external cost and setting all other distortive taxes equal to zero.[6]

Freight Transport Tax Reform And Market Distortions

In this sub-section we focus on some of the central questions raised in this paper. Assume, as seems to be the case in many European countries (see De Borger and Proost (2001) and the UK data given below for empirical support), that both freight and passenger transport by road are priced below marginal external cost. This raises some questions that cannot be answered on the basis of the available models in the literature. First, what are the welfare effects of recent policy proposals to raise the tax on freight transport (kilometre taxes) on major European roads but leave passenger transport taxes unaffected? Note that such a tax reform affects passenger transport demand and labour supply through changes in congestion, through changes in the price of the dirty consumption good, and through recycling of the tax revenues.

[5] In fact, we tried to express (7) in a way which explicitly shows the impact of taxes on MEC. Unfortunately, this destroys the nicely additive structure of the distortive effects on the different markets and does not yield expressions that are transparent and easy to interpret.

[6] As suggested by the work of Fullerton and Mohr (2003), there are other ways to attain the first-best. These authors showed the equivalence of an optimal tax on an externality-generating intermediate input and an optimal combination of subsidies to clean inputs and taxes on output. In our model, one easily shows that, in the absence of a tax on freight transport, the first best can indeed also be obtained by a passenger transport tax together with an output tax on the dirty good D and a subsidy to the clean input X. Details are available from the authors.

The answer is therefore not trivial. For example, if raising the tax on freight transport increases the demand for passenger transport then the resulting increase in the distortion on the passenger transport market raises the welfare cost of the policy reform. In this case, the net benefit of higher freight transport prices may well be exhausted at a level below the MEC of freight transport. Second, how does the desirability of raising freight transport taxes depend on the current level of taxes on passenger transport? Third, how does the welfare effect of freight transport tax reform interact with distortions on the labour market? To get some intuition concerning these issues, we consider the interaction between freight transport taxes, passenger transport taxes and labour taxation in a distorted economy. Specifically, we assume an initial situation where $\tau_T < MEC, \quad \tau_F < MEC, \quad \tau_L > 0$. To keep the discussion well-focused, we do simplify by assuming $\tau_D = \tau_X = 0$[7].

Under the assumptions made, it follows from (7) that the welfare cost of the freight tax reform is given by:

$$\frac{1}{\lambda}\frac{dW}{d\tau_F} = \left(\tau_F - MEC\right)\left(\frac{dF}{d\tau_F}\right) + \left(\tau_T - MEC\right)\left(\frac{dT}{d\tau_F}\right) + \tau_L\left(\frac{dL}{d\tau_F}\right) \tag{10}$$

where

$$\frac{dF}{d\tau_F} = D\left(\frac{\partial F_{ND}}{\partial \tau_F}\right) + F_{ND}\left\{\left(\frac{\partial D}{\partial q_D}\right)F_{ND} - \frac{\partial D}{\partial w}\frac{d\tau_L}{d\tau_F}\right\} \tag{11}$$

$$\frac{dT}{d\tau_F} = \frac{\partial T}{\partial q_D}F_{ND} - \frac{\partial T}{\partial w}\frac{d\tau_L}{d\tau_F} \tag{12}$$

$$\frac{dL}{d\tau_F} = \frac{\partial L}{\partial q_D}F_{ND} - \frac{\partial L}{\partial w}\frac{d\tau_L}{d\tau_F} \tag{13}$$

Expression (10) shows that the welfare effect of a tax increase on freight transport depends on the distortions on the three markets (freight transport, passenger transport, and labour). It will be instructive for the interpretation to first consider the role of distortions on the three markets separately, and then summarize the overall welfare effect implied by (10).

[7] Relaxing these assumptions is discussed in an earlier version of this paper. For example, there we also look at the interaction between freight transport tax reform and taxes on the dirty output D.

Distortions on the market for freight transport

Let us first focus on the role of distorted freight transport markets only. Suppose specifically that freight is taxed below marginal external cost ($\tau_F < MEC$) and that the freight tax does not affect distortions on other markets, so that only the first term on the right hand side of (10) is nonzero. For example, let passenger transport be priced at marginal external cost and assume for the sake of the argument that the tax reform does not affect the labour market. It then follows from (10) that increasing the tax on freight is welfare improving as long as higher freight taxes decrease freight transport demand. This is of course what one would intuitively expect. Moreover, equation (11) suggests that the general equilibrium effect of higher freight transport taxes on the demand for this type of transport is negative. This expression indicates that the freight tax affects the demand for freight transport through three channels. First, the input substitution effect of a higher freight tax gives a non-positive impact on freight demand at given production levels of D; the first term on the right hand side of (11) is therefore non-positive. Second, if D is a normal good the second term, capturing the output effect, is non-positive as well. Finally, the third term reflects the effect on freight transport demand associated with recycling the freight tax revenues. It will be positive if the increase in the freight tax allows a reduction in labor taxes and D is a normal good.

In sum, then, (11) shows that higher freight taxes will reduce freight transport demand as long as the direct negative effects on demand (input substitution and output effects) are not fully offset by the effect of recycling the tax revenues. If this condition holds then the policy implication is clear: raising freight transport taxes from a level below marginal external cost is welfare improving.

The Role Of Under-Priced Passenger Transport

What is the importance of distorted passenger transport markets for the welfare effect of higher taxes on freight transport? Suppose that passenger transport is taxed below marginal external cost. The second term on the right hand side of (10) shows that if a higher tax on freight raises the demand for passenger transport, the existing distortion on the passenger transport market reduces the welfare improvement of a higher tax on freight transport. This is quite intuitive, since in that case the freight tax increases the distortion on the passenger transport market: attracting more passenger transport raises congestion and hence marginal external cost. This reduces the desirability of the reform.

To find out what the effect is of higher freight transport taxes for the demand for passenger transport, consider (12). This expression shows there are two direct channels through which the demand for passenger transport is affected by the increase in the price of freight. The final term on the right hand side again captures the recycling effects: lower labour taxes increase the net wage, which affects transport demand. This term is highly plausibly positive. The first term on the right hand side of (12) captures the cross-price effect on passenger transport demand: the freight transport tax raises the price of the dirty consumption good, which affects the demand for passenger transport. The sign of this effect depends on the nature and composition of transport demand. For example, if passenger transport consists to a large extent of commuting trips then one expects higher commodity prices to reduce real wages and, hence, reduce the demand for commuting trips. If, however, transport demand is mainly demand for non-commuting trips, these may be substitutes or complements for consumption of the dirty good; if they are substitutes, passenger transport demand will increase.

Summarizing the information given by (12), we find that higher taxes on freight transport will plausibly raise the demand for passenger transport. A sufficient condition is that passenger transport is not a very strong complement to the dirty consumption good. Numerical estimates used below suggest that at the aggregate level for the UK economy a tax increase on freight transport has indeed positive, although quite small, effects on the demand for passenger trips. The policy implication is clear: any positive effect of a higher freight transport tax on passenger transport demand reduces the welfare improvement of the tax reform.

Distortions on the labour market

Consider the relation between the welfare effect of the freight tax reform and the distortions on the labour market. The literature on the double-dividend (see, among many others, Parry (1995), Bovenberg and Goulder (1996), de Mooij (1999)) has shown that in a general equilibrium setting the case for imposing environmental taxes above or below MEC depends critically on labour market effects. Our findings are consistent with this statement. The third term on the right hand side of (11) shows that a distorted labour market raises the welfare benefit of higher freight transport taxes if the reform raises labour supply. To find out the effect of freight transport taxes on labour supply, consider (13). The tax increase raises the price of the dirty good D, reducing real wages and hence plausibly reducing labour supply (first term on the right hand side). The second term captures the recycling effect. Lower labour taxes raise wages and therefore stimulate labour supply. In sum, if we assume that the dirty good is not too strong a substitute for leisure and that the labour supply curve is upward sloping, then (13) suggests that increasing the tax on freight indeed tends to raise labour supply[8]. The numerical analysis for the UK below confirms this.

The Overall Welfare Effect Of A Freight Transport Tax Increase

In view of the previous discussion and the complexity of the interactions between the different markets, it should not come as a surprise that the overall welfare effect of a higher freight transport tax, as given in (10), is theoretically ambiguous. Indeed, this is the rule rather than the exception in general equilibrium tax reform models (for a recent and very careful analysis see, e.g., Goulder and Williams (2003)). However, expression (10) does nicely identify the relevant economic parameters. This allows us to identify the conditions under which the welfare effect is likely to be positive. For example, assume that the freight tax reduces freight transport demand, that it increases passenger transport demand, and that it raises labour supply. These conditions seem to be consistent with the empirical information for the U.K., see the numerical application below. Suppose we contemplate raising the freight tax from current levels, which are below marginal external cost. This reduces the distortion on the freight market because the deviation between tax and marginal external cost declines and freight transport demand goes down; the effect on the freight market is therefore welfare-improving (see the first term on the right hand side of (10)). If the reform raises labour supply this also increases the desirability of the higher freight tax (see the third term of (10)). However, the effect on the passenger market goes in the opposite direction. Under-priced passenger transport implies that raising the freight tax increases the existing distortion on the passenger transport market, which is welfare-reducing (second term of (10)).

[8] As noted by a referee, it seems reasonable to assume that the uncompensated labour supply elasticity is positive. Although estimates strongly differ between males and females, average values that take account of decisions on participation and hours worked seem to indicate economy-wide positive elasticities. For a summary of US and UK studies, see Blundell and McCurdy (1999).

Summarizing the above discussion we find that, as long as the direct effect of the higher tax on the market for freight transport dominates the indirect effect on the passenger transport market, increasing the tax on freight transport will indeed be welfare-improving. The policy implication that follows is clear: raising the tax on freight transport only will be a good idea from a welfare perspective, unless passenger transport is severely under-taxed and the tax reform attracts substantially more passenger transport. Whether, and to what extent, these conditions hold is an empirical matter; it depends, among others, on initial tax policies and on the structure of the transport market in the country under consideration.

Optimal freight transport taxes with distorted markets

In this subsection we reconsider the welfare effects of higher taxes on freight transport in a slightly different way by analyzing the 'optimal' tax on freight, conditional on given labour and passenger taxes[9]. Manipulating (10), we have:

$$\tau_F = MEC + \frac{\varepsilon_{TF} T}{\varepsilon_{FF} F}(MEC - \tau_T) - \tau_L \frac{\varepsilon_{LF} L}{\varepsilon_{FF} F} \tag{14}$$

where ε_{iF} gives the total price elasticity of market i with respect to an increase in the price of freight. Interpretation is as follows. First, assume that the labour market is undistorted. Moreover, let passenger transport be under-priced, so that $\tau_T < MEC$. It then follows that, if the own-price (total) elasticity of freight transport demand is negative ($\varepsilon_{FF} < 0$) and the cross price (total) elasticity of passenger transport demand is positive ($\varepsilon_{TF} > 0$), the optimal freight transport tax will be below MEC. Moreover, note that in this case the optimal tax declines at higher levels of passenger transport demand, because the latter implies a higher initial distortion. Second, note that the optimal tax on freight transport need not necessarily be smaller than marginal external cost in a strongly distorted labour market. Consider, for example, an economy with a high labour tax. If increasing the freight tax increases labour supply ($\varepsilon_{LF} > 0$) and, hence, reduces the labour market distortion, then this raises the optimal tax on freight

[9] We recognise that this terminology is potentially confusing: the tax is only optimal conditional on not being able to alter the level of other tax instruments available in the economy. It is the tax rate at which the right-hand-side of expression (10) equals zero.

transport. If passenger transport is not strongly under-taxed, the optimal freight tax may in that case easily exceed marginal external cost.

This leads us to the final question we want to answer in this section: how does the optimal freight tax vary with the level of the tax on the passenger market? The answer is policy relevant in view of a potentially stepwise introduction of congestion taxes. How should freight taxes be adjusted if governments overcome public opposition and raise passenger taxes over time? The answer is not obvious. The reason is that raising the passenger transport tax from a level below marginal external cost reduces the distortion on this market, but it also affects congestion and hence the level of the externality. To elaborate on this, consider again expression (14) and, for the sake of the argument, assume again $\varepsilon_{FF} < 0; \varepsilon_{TF} > 0; \varepsilon_{LF} > 0$. An increase in the tax on the passenger transport market at constant marginal external cost then raises the optimal freight transport tax, see the second term on the right hand side of (14). The intuition is that there is now less downward pressure on the optimal freight tax to correct the distortion on the passenger transport market. However, the higher passenger transport tax reduces congestion and hence MEC; this reduces the distortions on both the market for freight and for passenger transport, reducing the optimal freight transport tax. If the congestion effect dominates, higher taxes on passenger transport reduce the optimal freight tax.

Under some strong simplifying assumptions the previous two effects can be made even more transparent. First, rewrite (14) in terms of the general equilibrium tax effects as follows:

$$\tau_F = MEC\left[\frac{\frac{dF}{d\tau_F}+\frac{dT}{d\tau_F}}{\frac{dF}{d\tau_F}}\right]-\tau_T\left[\frac{\frac{dT}{d\tau_F}}{\frac{dF}{d\tau_F}}\right]-\tau_L\left[\frac{\frac{dL}{d\tau_F}}{\frac{dF}{d\tau_F}}\right] \qquad (15)$$

Now assume for simplicity that the general equilibrium tax effects are constant[10]. With a slight abuse of notation, differentiation of the optimal freight tax with respect to the exogenous tax on passenger transport then reveals:

[10] Of course, this is not necessarily realistic; however, performing the fully general comparative statics exercise around the optimal freight tax condition complicates matters, and it does not overcome the simple ambiguous relationship, captured in equation (16).

$$\frac{d\tau_F}{d\tau_T}=\left[\frac{\frac{dF}{d\tau_F}+\frac{dT}{d\tau_F}}{\frac{dF}{d\tau_F}}\right]\left[\frac{dMEC}{d\tau_T}\right]-\left[\frac{\frac{dT}{d\tau_F}}{\frac{dF}{d\tau_F}}\right]$$

The first term on the right hand side is plausibly negative; it suffices that a freight tax increase reduces total transport demand and higher passenger transport taxes reduce marginal external costs. To the extent that higher passenger taxes reduce congestion, the benefits of higher freight taxes decline, reducing the optimal freight transport tax. However, the impact of the second term goes in the opposite direction if the freight tax raises the demand for passenger transport. This reduces the marginal cost of a freight transport tax increase, raising the optimal freight tax.

The implications from the discussion in this subsection are clear. First, if passenger transport is substantially under-taxed and the freight tax does not strongly affect labour supply then the optimal freight tax is below marginal external cost. Second, under these same conditions the optimal tax on road freight transport will be lower in countries where passenger transport is very important. Indeed, in that case the tax reform encourages the demand for passenger transport where the initial distortion is already large. Third, higher taxes on passenger transport will reduce the optimal freight transport tax if the direct effects of raising τ_T on congestion dominate. Fourth, since the signs of some of the effects discussed above remain an empirical matter it is crucial to consider numerical applications of the theory presented to gain further insight into the welfare effects of a partial tax reform on freight transport. This is what we turn to next.

4. TAX REFORM FOR ROAD FREIGHT TRANSPORT: AN ILLUSTRATIVE NUMERICAL APPLICATION FOR THE UK.

We used a numerical simulation model to gain further insight into the welfare effects of freight tax reform. In this section we first describe some relevant features of the model; more details on the model structure are given in Appendix 2[11]. Next we provide some information on the relation between taxes and marginal external costs in the reference situation. The rest of the section is devoted to a detailed analysis of the

[11] The complete code for the model is available from the authors.

empirical results obtained for a number of tax reform exercises under various different scenarios.

Basic Features Of The Numerical Model

The model is a simple applied general equilibrium model of the UK economy. A standard nested CES structure is employed to model household utility. Given the dependence of the optimal freight tax on cross-price effects, this is an important restriction. 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, where dirty refers to an intensive use of freight transport. Given this setup, three elasticities-of-substitution are exogenously given in the utility tree. We denote them by σ_i , where $i = 1, 2, 3$ corresponding to the level of the tree. These values are chosen such that own and cross-price elasticities correspond with the empirical literature. More details are in Appendix 2.

INSERT FIGURE 1 AROUND HERE

Congestion is modelled via a relationship between road speed S and passenger and freight transport flows $S = f(F,T)$, where both first derivatives are negative ($f_T, f_F < 0$). Passenger trips T are further produced using combinations of the clean input X (i.e. money expenditures) and time, which is determined by the inverse of speed. Freight transport is produced using the clean input X, labour and time. 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 production function for the dirty good D has freight and the clean input as arguments; it is specified as constant elasticity of substitution.

We calibrated 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 for this year 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. The relationship between freight and passenger transport demand and speed is calibrated to recently published U.K. government statistics. Finally, information on benchmark transport taxes is drawn from a recent U.K. study. The reference economy we consider is characterised by (excise and ownership) taxes on both passenger and freight transport at rates of 35 per cent; the tax on labour supply is put at 30 per cent. In addition, consumption goods are taxed at the standard rate of value-added tax, which amounts to 17.5 per cent. As before, more details are delegated to Appendix 2.

Taxes And Marginal External Costs At The Reference Equilibrium

The theoretical analysis in the Section 3 above suggests that the welfare effects of freight tax reform will crucially depend on deviations between taxes and marginal external costs for both passenger and freight transport in the reference situation. To facilitate later interpretation it seems instructive, therefore, to report these deviations. To do so, we transform percentage tax rates into euros per passenger-kilometre and ton-kilometre for passenger and freight transport, respectively, evaluated at the reference transport flows observed. Moreover, marginal external costs of an extra passenger- and an extra ton-kilometre were determined following the procedures in De Borger and Proost (2001, Chapter 7).

In Table 1 we report the comparison between taxes and MEC as calculated for the reference economy. As described in Appendix 2, taxes include ownership taxes and user taxes. The fuel tax component was expressed per passenger and ton kilometre by using average fuel efficiencies[12]. It is clear that the benchmark situation is characterized by taxes that are too low relative to marginal external cost. This holds for both types of transport. The deviation is somewhat larger for passenger transport (the tax equals 0.1 euro, the MEC 0.26 euro per passenger-kilometre) than for freight (tax and MEC are estimated at 0.03 and 0.07 per ton-kilometre, respectively). These findings combined with the small but positive cross-price elasticity of passenger transport demand with respect to the freight tax (Appendix 2 reports an estimate of 0.08 in the reference case) suggests that raising freight taxes will indeed reduce the

[12] For example, a fuel tax of 0.5 euro per liter results, given fuel efficiency of, say, 7 liter per 100 kilometre, in a fuel tax of 0.035 euro per vehicle kilometre.

distortion on the freight market but at the same time raise it on the passenger transport market.

INSERT TABLE 1 AROUND HERE

Tax Reform For Road Freight Transport: Numerical Results

In what follows, we discuss results of a series of tax reform exercises on freight transport. As noted before, the tax reform refers to adjusting the tax per ton-kilometre on freight transport. Unless otherwise noted the government is constrained to maintain the real-value of the benchmark transfer to the representative consumer; the labour supply tax is endogenously adjusted.

For ease of interpretation we report the results of the tax reforms graphically. Figure 2 summarises the relation between the percentage welfare change of a given tax reform on freight transport (vertical axis) and the size of the reform (horizontal axis). Remember that the benchmark tax rate on freight is 35 per cent. A range of reforms is considered where the benchmark value was raised to values between 75 to 115 per cent. This range allows us to also illustrate the ‘optimal’ freight tax rate. Note that in performing the reform exercises all other taxes except the labour tax are kept at their benchmark values. Moreover, the tax reforms are performed under three different scenarios with respect to the sensitivity of passenger transport demand for changes in the price of freight. Varying this price sensitivity is potentially important. Indeed, recall from the theory that the marginal benefit from raising the freight tax needs to be weighed against the marginal 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. The reference cross price elasticity of passenger transport demand with respect to the freight tax of 0.08 was used in the benchmark scenario (labelled ‘bmk’). By varying parameter values, 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 with respect to price sensitivities, raising the tax on freight above its reference level of 35 per cent is welfare-improving. Second, however, the welfare change of a given freight tax adjustment does strongly depend on the cross-price elasticity with the passenger transport market. For example, for a freight tax rate of 75 per cent, the high sensitivity scenario (0.2) generates larger welfare gains than the benchmark or low elasticity scenarios. However, for a freight tax 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 with the passenger transport market, the higher the marginal costs of a freight tax reform and, for any given marginal benefit, the lower the optimal level of freight tax. This intuition is confirmed by the model. Under the benchmark scenario, welfare is maximised by increasing the tax on freight to around 95 per cent; this amounts to approximately a two-and-a-half fold increase in the current rate. The optimal tax rate on freight is lower, approximately 85 per cent, in the high elasticity case and higher (115 per cent) in the low price sensitivity case. The fact that these optimal taxes are substantially higher than in the reference situation is obviously consistent with the benchmark tax on passenger transport being below marginal external cost (see Table 1 above). Finally, note that the monetary value of the increase in welfare is nontrivial. For the benchmark elasticity scenario, raising the tax from its initial value to its optimal value of 95% yields an equivalent variation measure of welfare change estimated at approximately 715mEURO in 1995 prices[13].

In Figure 2, the excise tax on passenger transport remained 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 of various freight transport tax reforms for three widely 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

[13] A referee notes the recent UK proposal to replace the fuel tax by a per mile charge for freight transport that would strongly differ between urban and rural areas. One might speculate that this would diminish marginal external cost and, hence, optimal freight taxes. Of course, the efficiency gains from such regional differentiation are not captured by the current model.

curves show social welfare when passenger transport excise taxes are (i) 50% of the benchmark level (the lowest curve), and (ii) twice 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 cutting passenger taxes increases the optimal freight tax to 105 per cent. To interpret this latter finding, recall that raising the passenger transport reduces both the cost and the benefit of a freight tax increase so that the overall effect is ambiguous. The information in Figure 3 therefore suggests that 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. As suggested before, this finding may have relevant policy implications for a stepwise introduction of congestion pricing on both passenger and freight transport. If in the future 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.

As previously suggested, Figure 3 also shows that higher social welfare levels can be achieved by raising passenger transport taxes. 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 simulation model, computing welfare levels under a large number of alternative assumptions concerning the two tax rates. We find that welfare is optimised by combining a large increase in freight transport tax (to approximately 82%) with a more modest increase in the tax on passenger transport (an increase by a third, to approximately 48%).

We conclude this section by presenting some numerical results on the use of the revenues. The theory developed in Section 3 and all numerical results presented so far are based on recycling through labour tax reductions. However, under reasonable assumptions, returning revenues via labour taxes rather than lump-sum unambiguously reduces the marginal cost of the policy reform because of its more favourable labour supply effects. This point has been made several times before in the double dividend literature (see, e.g., Parry (1995), Bovenberg and Goulder (2001)[14]. To understand it, remember how higher freight transport taxes affect labour supply. They raise consumer prices of the dirty good D, reducing real wages and hence plausibly reducing labour supply. If tax revenues are recycled in the form of lower labour taxes, then this counteracts the initial negative effect (see (13) above); recycling therefore stimulates labour supply. However, if recycling is performed via lump sum reimbursement of tax revenues, this is likely to reduce labour supply. If leisure is a normal good higher lump-sum transfers will increase the demand for leisure and reduce the incentive to work. Formally, one easily shows that, in the case of recycling via the lump sum transfer G, the equivalent expression to (13) is:

$$\frac{dL}{d\tau_F} = \frac{\partial L}{\partial q_D} F_{ND} + \frac{\partial L}{\partial G}\frac{dG}{d\tau_F}$$

The second term on the right hand side is plausibly negative, unlike with labour tax recycling. Thus we might expect higher freight taxes and welfare levels when revenues are recycled via labour taxes than via lump-sum distribution.

Figure 4 confirms this to be the case. However, the differences between recycling instruments are quite dramatic. Recycling via the lump-sum instrument raises welfare only marginally compared to labour tax recycling. With a slight overstatement one could argue that freight transport tax reform to cope with congestion is a good policy only if revenues are recycled via labour tax reductions. Moreover, note that 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.

INSERT FIGURE 4 AROUND HERE

[14] Note that the superiority of recycling via reduction of distortionary taxes may not hold in more general models. In a recent paper, Babiker et al. (2004) show that this weak form of the double dividend (viz., the proposition that the welfare improvement from an environmental tax reform with recycling via a reduction in a distortionary tax must be greater than the welfare effect when lump sum recycling is used) does not necessarily hold in a world with a large number of pre-existing distortions.

5. CONCLUSIONS

This paper explored the welfare effects of a balanced budget increase in an intermediate input tax to cope with an externality that is due to the joint use of the input and the consumption of a final good by households. A simple general equilibrium model was developed to analyse this question in a second-best setting; the revenues of the tax increase were assumed to be recycled through lower labour taxes. The level of externality depends upon both intermediate and final consumption and enters consumer welfare as well as the production function of firms. The motivation for the analysis are the recent proposals in Europe for increases in freight taxation, which may be adopted against a background of currently under-priced passenger transport.

Our qualitative conclusions are as follows. First, in a second-best setting, the sign of the welfare effect of a tax increase on freight transport is ambiguous in general. It will be more likely be positive to the extent that it is successful in strongly reducing freight transport demand, that it raises labour supply, and that it does not increase demand for (under-priced) passenger transport by too much. Secondly, the relationship between the optimal freight tax and the exogenous tax on passenger transport is also ambiguous. We showed that higher passenger transport taxes decrease both the marginal benefits and the marginal costs of a freight tax reform; the ultimate outcome is an empirical matter.

A numerical model of the UK economy is then used to gain quantitative insight. A number of conclusions emerge. First, under a wide range of scenarios it was found that raising freight transport taxes is indeed welfare improving, even if passenger transport is currently substantially under-priced. Second, the higher the indirect cross-price 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. Finally, the welfare benefits are drastically reduced with lump-sum instead of labour tax recycling.

Finally, let us emphasize that the research reported in this paper has some obvious limitations that raise a number of interesting issues for further research. For example, the model considered a highly aggregated transport market, and it focused on congestion as the only relevant externality. Further research might include disaggregating transport according to congestion levels (e.g., differentiation between peak ond off-peak conditions, regional differentiation) and incorporating other externalities such as pollution and accident risks. Finally, the treatment of the labour market may be improved upon. In many European countries, for example, wage bargaining is the rule rather than the exception[15].

[15] See De Borger (2006) for a first attempt to model optimal transport taxes in a model with imperfectly competitive labour markets in which wages and employment are the result of bargaining between unions and firms. That model, however, focuses on the implications of taxation for the morning and evening commutes; it does not include freight transport.

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Tables and Figures

	Passenger transport	Freight transport
Tax	0.10	0.03
Marginal external cost	0.26	0.07

Table 1: Taxes and marginal external costs in the reference economy

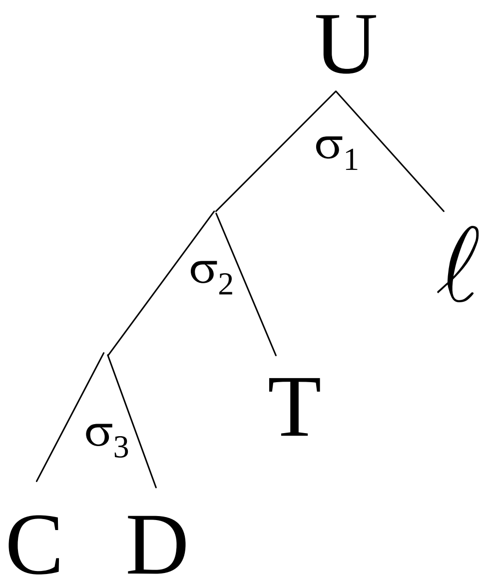

Figure 1: the utility tree

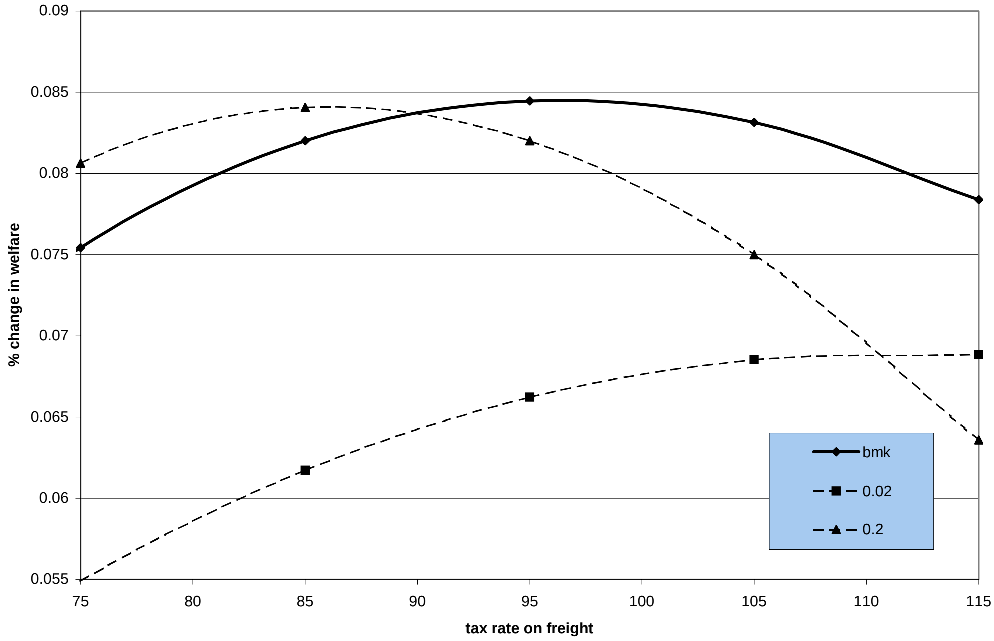

Figure 2. Tax reform on the freight transport market: welfare changes as function of freight tax rates (for different price elasticities of passenger transport demand with respect to freight taxes).

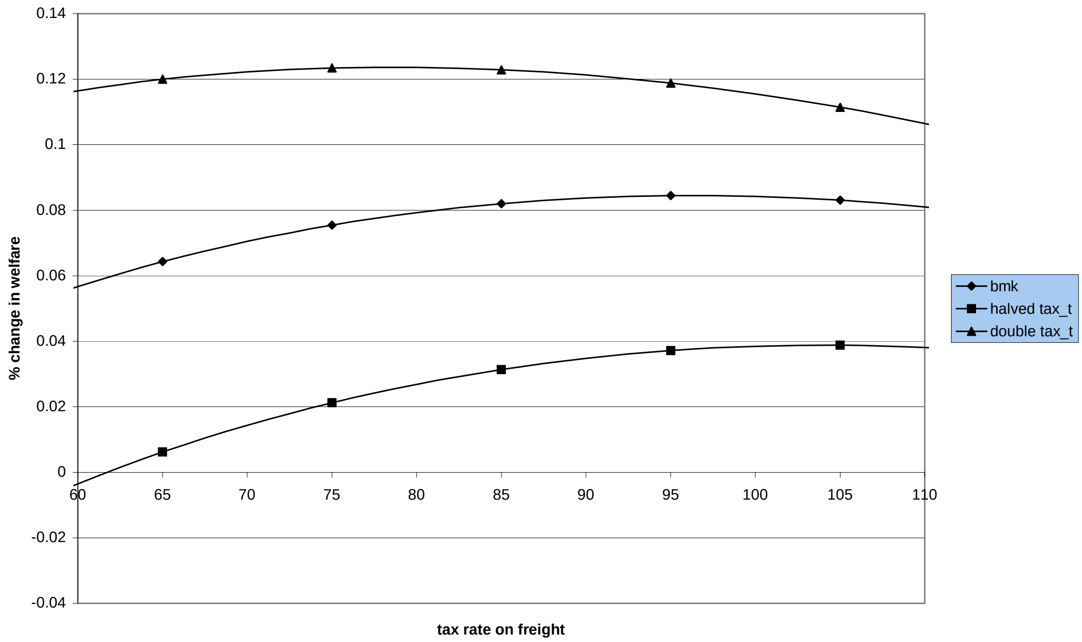

Figure 3. The impact of the exogenous tax on passenger transport

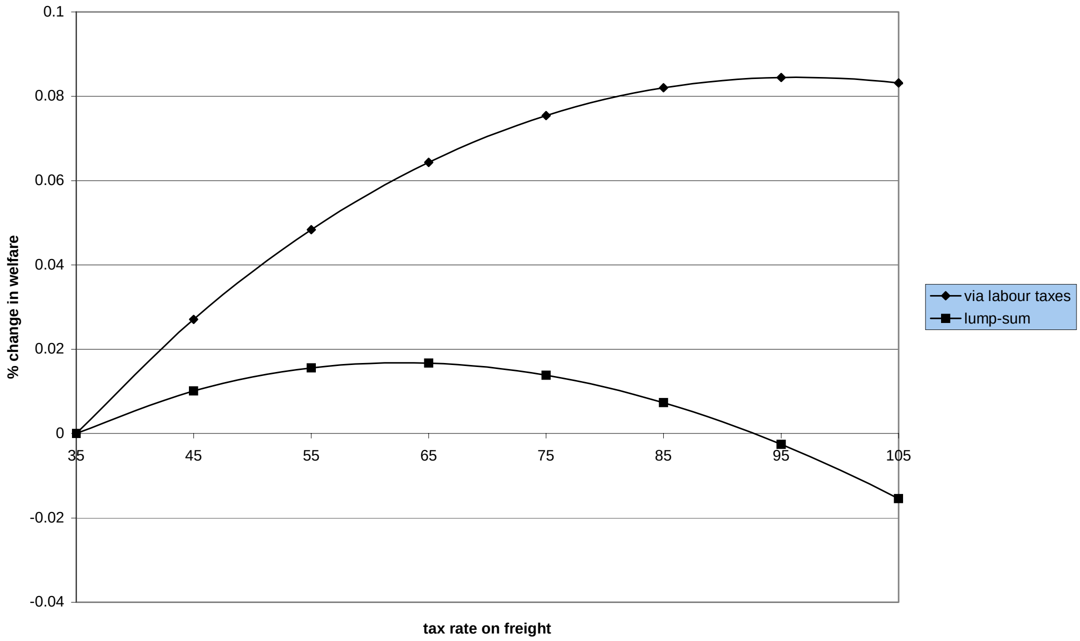

Figure 4. Freight transport tax reform: comparing the welfare effects of lump-sum and labour tax recycling of the tax revenues

Appendix 1: Derivation of the welfare effect of a freight transport 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 τ_F on freight transport, when recycling is via the tax on labour. It can in general be written as:

$$\frac{1}{\lambda}\frac{dW}{d\tau_F} = \frac{1}{\lambda}\frac{\partial V}{\partial \tau_F}\bigg|_{\overline{\tau_L}} + \frac{1}{\lambda}\frac{\partial V}{\partial \tau_L}\bigg|_{\overline{\tau_F}} \frac{d\tau_L}{d\tau_F} \tag{A1}$$

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 of a balanced budget increase in the freight transport tax on the labour tax. It measures the potential for 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:

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

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

$$\frac{1}{\lambda}\frac{\partial V}{\partial \tau_L}\bigg|_{\overline{\tau_F}} = -L - (D\frac{\partial c_D}{\partial \phi} + \frac{\gamma}{\lambda}T)\frac{d\phi}{d\tau_L} \tag{A3}$$

Here $\frac{d\phi}{d\tau_L}$ captures the full effect of the labour tax on congestion. Substituting (A2) and (A3) in equation (A1) yields:

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

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

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

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

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

Using this expression in (A4) and manipulating the result, we find after straightforward algebra

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

(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 τ_F and τ_L yields, respectively:

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

$$\frac{d\phi}{d\tau_L} = \phi' N\zeta\{\frac{\partial T}{\partial \tau_L} + F_{ND}\frac{\partial D}{\partial \tau_L}\} \qquad \text{(A8)}$$

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

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

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 brackets 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

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

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, the associated welfare cost equals γT. Dividing by the consumer's marginal utility of income λ 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

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

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

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:

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

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 τ_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 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 A.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 suggests that the bias may be rather limited. A recent survey of road goods transport by the U.K. government (UK DETR, 2001a) suggests that, in 1991, approximately 90 per cent of road transport freight is attributable to the chosen six sectors[16].

Table A.1 – The composite dirty good D

Sector	% of 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

<u>Benchmark expenditures shares on consumption goods and leisure</u>

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.

<u>Benchmark input expenditure shares</u>

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

[16] This is based on Chart B of the survey. Differences in definitions complicate matters: however, we have summed 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.

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).

Benchmark taxes

We assume that the average tax rate on wage income is 30 per cent. This corresponds closely to the GEM-E3 database. It reflects an average of personal income taxes as well as employer and employee national insurance contributions. 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 elasticities of substitution are set equal to unity.

The uncompensated 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)[17]. Table A.2 reports the matrix of own- and cross-price effects on T, F and D. Note that the reported elasticities are computed numerically as

[17] Note that this figure is directly computed from the model. It is not derived from analytical expressions based on the relevant elasticity of substitution, an exercise which is very complex in the case of feedback effects.

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 A.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[18] 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, 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.

[18] 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.

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, and T and F are measured in vehicle kilometres. We further follow the standard approach in the literature and convert freight vehicle-kilometres into car-equivalents (but see Arnott (2001) for an interesting challenge of this procedure); it is assumed henceforth that k_4 is equal to 2[19]. 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 A.3. Here 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, see above.

Table A.3 – UK speed-flow data

time period	mPCUs /hr	Speed (km/hr)
am peak	22.66	74
inter-peak	18.49	83.3
Freeflow	0	110

[19] This is a very crude approximation that corrects the much larger congestion effect of an extra truck kilometre. This effect probably exceeds a factor 2. However, this is partially compensated by the smaller share of freight traffic in the peak and in urban environments.