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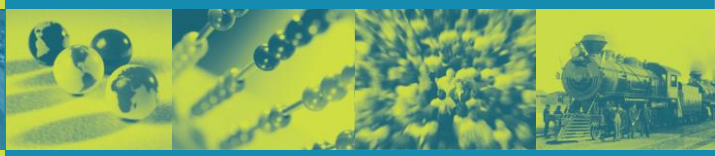

Why truck distance taxes are contagious and drive fuel taxes to the bottom

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Energy, Transport and Environment

Faculty of Economics
And Business

Why truck distance taxes are contagious and drive fuel taxes to the bottom [1]

Svante Mandell[a] and Stef Proost[b]

Abstract

This paper analyzes how countries with international and local truck traffic decide to switch from a simple fuel tax system to a dual system of fuel and kilometer taxes. We show what drives a country to switch and how this affects the level of fuel taxes and the incentives for the other countries to also adopt the dual system. The model is partially able to explain the gradual extension of kilometer charging for trucks in Europe. The model also shows that, in the absence of diesel cars, the gradual introduction of kilometer charges will make fuel taxation for trucks virtually disappear and will lead to a system where truck use is (1) taxed mainly based on distance, but (2) is taxed too heavily. When the fuel tax must in addition serve as an externality tax for diesel cars, the introduction of distance charges for trucks will give rise to diesel taxes that are lower than the external cost of diesel cars. For trucks, this leads to a sum of diesel taxes and distance charges that are higher than the external cost of trucks.

Keywords: Diesel taxes, fuel taxes, kilometer charges, tax competition, pricing of trucks

JEL codes : H23,H73,L91,R48

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1. Introduction

This paper addresses how international competition affects the choice of tax instruments for road freight transport. The main tax instrument used in most countries is still an excise tax on diesel fuel. As international trucks can decide in which country to refuel, this has given rise to international fuel tax competition. This has been the case in Europe over the last 25 years, where member states kept almost full authority on excise taxes while the international road freight haulage expanded strongly as a result of EU trade integration. Since 2000, the diesel excise tax has been supplemented in several EU countries by a distance charge. Many other federal governments where member states can add state gasoline taxes face the same policy issue (US, India, Australia,..).

The main purpose of this paper is to provide a deeper understanding about the dynamics of the tax competition game when a kilometer charge for trucks becomes available. Using a simple analytical setting with two countries, we analyze how the addition of a kilometer charge for trucks changes the tax competition game. Distance charges, unlike diesel taxes, must be paid when a truck uses the roads of that country. Consequently, any country that introduces the distance charge can reduce its fuel taxes while threatening the tax base of those neighbors that have not yet enacted a distance charge. As a response, the neighboring countries will also implement distance charging, resulting in the spread of high distance charges and very low fuel charges.

More precisely, we offer the following results. We distinguish between the case where the diesel fuel tax is an important policy instrument for diesel cars too and the case where it is not. Consider first the case where there are other tax instruments than fuel excises available for taxing diesel cars. Then if diesel taxes are the only instrument available to tax trucks, in the Nash equilibrium, the diesel taxes may be lower or higher than the external and infrastructure costs of trucks. The taxes will typically be low in countries of equal size when there is intensive fuel tax competition. When countries differ in size, the tax in the smaller country will be lower than that in the larger country. This confirms results from literature (Kanbur & Keen, 1993). When distance charges are also available and their implementation costs are low, all countries adopt distance charges for trucks and fuel taxes are driven to the bottom. The distance charges will all be higher than the external costs while the margin will be highest in the smaller countries. Moving from diesel taxes to distance charges can therefore be welfare decreasing as one adds a very powerful instrument for tax exporting.

Consider next the case where the diesel excise is also the main instrument to regulate the use of diesel cars. As diesel cars are a good substitute for heavily taxed gasoline cars, it is now important to take into account the side effects on the car market of diesel excise changes. If there are no distance charges, the

fuel tax will have to balance out the optimal taxation of diesel cars and trucks. As only one instrument is used, it is impossible to set the diesel fuel tax equal to the external costs of trucks and of cars and the tax will be a weighted average of the external costs of diesel cars, trucks and margins on international trucking. Again the tax competition effects on the fuel market for international trucks may increase or decrease the tax but diesel use by cars is typically less vulnerable to tax competition because cars make less international trips. The result will be that the diesel tax in one country reacts less strongly to tax changes in a neighboring country. Introduce now distance charges for trucks. Both countries will use distance charges and fuel excises. The sum of distance charges and fuel excises will be higher than the external cost for trucks and the diesel tax will be lower than the external costs of diesel cars. Again there is no guarantee that the introduction of distance charges improves pricing from a welfare perspective.

The paper is organized as follows. In section 2 we illustrate some of the recent truck charging developments. In section 3 we review the literature. In section 4 we set up the model. Section 5 is devoted to the analysis of the game with fuel taxes as the only instrument but where diesel cars are unimportant or can be taxed using other instruments. Section 6 analyses the effects of the introduction of a distance charge. Section 7 presents a small numerical illustration. Section 8 introduces diesel cars that must also be taxed using a fuel tax. Section 9 concludes.

2. Charging trucks for road use

Almost all countries charge excises for diesel fuel used by trucks. Because trucks can cover 1000 to 2000 km with a single tank, countries or regions engage in fuel tax competition. In the US, state diesel excise taxes represent 50% or more of the total diesel excise. In India, states are also responsible for an important part of the total diesel excise. Within the EU, some smaller countries chose a strategy of low excise taxes, which has brought the EU to negotiate a minimum tax level for diesel fuel. In 2012, Germany charged an excise of 0,589 $/liter while Luxemburg, a tiny neighbor, charged only the EU minimum of 0,343 $/liter (IEA, 2013). In addition to the diesel excise taxes, the EU member states can charge road user fees using three mechanisms: toll roads (France, Spain, Italy...), distance-based charges (charge per km via electronic tracking) and finally by a time based vignette (annual, monthly, or weekly payment per vehicle). The main conditions were that the payment system was non-discriminatory and charged for infrastructure costs. Later it was also allowed to charge for external costs (air pollution, noise, congestion)[2] (see Vierth & Schleusser, 2012). In Europe, the Eurovignette paid in one country allowed the user to travel in the network of other participating countries. This was originally introduced in 1999 in 12 countries. As all participating countries were obliged to agree to an amount, it took many years to agree

[2] See directive 1999/62/EC followed by directives 2006/38/EC and 206/103/EC.

on subsequent amendments for inflation and environmental damage estimates[3]. This resulted in low amounts for the Eurovignette and many countries dropping out. Only five countries (Belgium, Denmark, Luxemburg, Netherlands and Sweden) continue to use the Eurovignette system.

Technological progress in charging techniques meant that several countries with transit wanted to introduce distance-based charging and to quit the Eurovignette system. In 2001, Switzerland (not an EU member) replaced its vignette system by a km charging system that charged trucks much more than before. The neighboring countries followed: Austria (a transit country parallel to Switzerland) in 2004, Germany in 2005 (although it wanted to start earlier), Czech Republic in 2007, Slovakia in 2010 and Poland in 2011. Other countries (Belgium...) are preparing its introduction. Some other EU countries had already developed a tolling system for most of their motorways (France, Italy, Spain) but considered adding electronic distance charging for the non-tolled trunk roads. Appendix A represents the different charging systems in place in Europe in 2012. This shows a clear pattern, as the introduction of distance charges was strongly correlated geographically. The member states in the center of Europe tend to use distance-based charges. The transaction costs associated with a distance-based system vary between 10 and 20% of the revenues (see Hamilton & Eliasson, 2013), which is probably much larger than the transaction costs of fuel excise taxes. Peripheral states use vignettes or no charges at all apart from fuel taxes. These observations are our main motivation for analyzing why one country moves to the more costly dual system, how this may force other countries to follow suit, and what the tax levels are that this may generate.

Figure 1 (OECD 2013) presents the total charges on road use for a 40-ton truck with a domestic haul of 400 km. This calls for several observations. First, the overall charge has been on the rise since 2000. Second, the countries with the lowest charges are those that do not have distance charges or tolls and rely only on fuel taxes and the Eurovignette.[4]

[3] Weismann (2013) describes the long negotiation process (3 years) to reform the Eurovignette directive. The negotiation process involved the Commission, the Parliament and the Council.
[4] Ireland (very high registration tax for trucks) and the UK (high fuel tax) are exceptions. As islands, however, they can afford different tax levels.

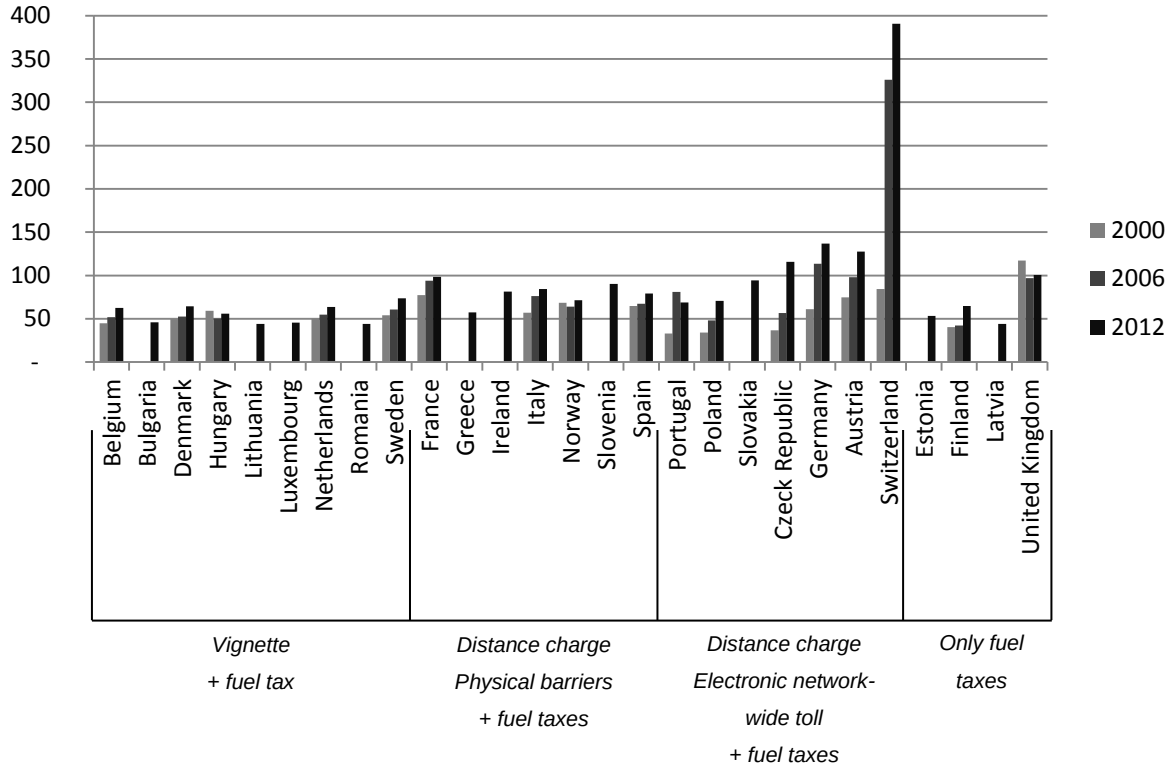

Figure 1 Total charges in Euro for a standard domestic haul of 400 km by a 40-ton truck. Charging policy as of 2012 (source OECD, 2013)

Using table 1, which gives most national distance charges, there are three interesting transition features to note. First, all distance-based charging generated much more revenues than the vignettes it replaced. In Germany distance charge revenues were 6.5 times larger than the previous Eurovignette revenues. This is curious as both systems are meant to pay for the actual costs of road building and maintenance as well as for environmental costs. The reason that the Eurovignette system generated such low revenues was that it was the lowest common denominator on which all countries could agree. The second point we note is that the distance charging schemes discriminate much more in function of conventional air pollution than do the Eurovignette systems. In the case of Germany, this was disguised "favoring" the home carriers since the German government gave large subsidies for cleaner German trucks. Finally, if one compares the distance charges in Table 1, one finds that Switzerland charges 10 times more per kilometer than the EU countries and that in addition Austria charges significantly more than the others. Of course, infrastructure costs may be higher in these countries but the main reason for this is the strategic position of Switzerland as a transit country. Austria is also a transit country but it is a slightly less interesting route and is moreover bounded by the EU cap on truck charges while Switzerland is not.

There are also subtle differences in the composition of the total charge paid in each country. Take the case of Austria and Germany. They have overall the same total charge for a standard haul, but Austria charges a higher distance charge and a lower fuel excise. This looks like an ideal mix for a small country that faces a lot of transit traffic and tries to maximize its share in the fuel market for international trucking.

Table 1 Distance charges in different countries (source: Vierth & Schleussner, 2012)

Country	*Year of introduction of distance charges*	*Charged weight class*	*Average toll rate (Euro/km)*	*Diesel fuel tax (Euro/liter)*
Switzerland	2001	*> 3.5 tons*	2.23	0.63
Austria	2004	*> 3.5 tons*	0.269	0.40
Germany	2005	*> 12 tons*	0.16	0.47
Czech republic	2007	*> 12 tons*	0.07	0.44
Slovakia	2010	*3.5 > 12 tons* *> 12 tons*	0.076 0.175	0.37
Poland	2011	3.5 > 12 tons > 12 tons	0.076 0.096	0.39

3. Literature review

We will rely on three types of literature. There is the more general public finance literature on tax competition. There is the literature on policy competition and pricing in transportation networks. Finally, there is the empirical literature on tax competition for diesel fuel.

The major insights we will use from the tax competition literature. This literature is surveyed in Wilson (1999) and Zodrow (2003). We will mainly draw upon the insights from Kanbur and Keen (1993). They show how the tax setting behavior of Leviathan governments depends on the relative size of a country. Smaller countries can gain by undercutting their neighbors as they have more to gain from cross-border shopping than from domestic tax revenues.

The literature on policy competition between governments in the transport sector has been reviewed in De Borger & Proost (2012). More in particular, they review the competition of private or public agents that can each control part of a transport network. The simplest model setups are the parallel network and the serial set up. In the parallel setup (De Borger, Proost, Van Dender, 2005), international trucks can choose between two links (countries) and the countries compete in tolls (and in infrastructure capacity), taking into account that there is also domestic traffic on the network. Each country will charge more than the external cost but the margin will be restricted by the competition for transit traffic and by the deadweight loss on domestic traffic. We will use, more intensely, a serial network type set up (De Borger, Dunkerley, Proost, 2007) where a truck must go through at least two countries to complete its trip. In this case each

country charges a monopoly margin that is limited by the deadweight loss on domestic traffic. Overall, there is a risk of double marginalization and thus of overcharging the use of the road network. In these two papers, trucks are charged per trip and they cannot escape the charge if they use the road network of a given country. In our paper we drop this assumption and include two tax instruments in the analysis. We start with the fuel excise taxes that can be escaped by fuelling abroad and give countries the option to add a distance charge. We will mainly deal with pricing the use of existing capacity and do not discuss the relation between kilometer charges, congestion levels and infrastructure supply. The European regulation capped distance charges to the average infrastructure charges, which can be important for forcing member countries to introduce efficient charges (see Van der Loo & Proost (2013) and Grahn-Voorneveld (forthcoming)).

The competition on excise taxes for diesel fuel in the EU has been studied intensively. All authors assumed Leviathan behavior for the governments. Evers, de Mooij and Vollebergh (2004) studied a panel data set for 17 countries (1978-2001) and estimated Nash reaction functions for diesel excises. They found strong evidence of tax competition. When neighboring countries increase their fuel excise tax by 10%, an average EU country increases its tax by 2 to 3%. They also found that the imposition of minimum tax rates has increased overall excise levels but the intensity of tax competition has not decreased. Rietveld & van Woudenberg (2005) analyzed the setting of gasoline and diesel taxes and found strong tax competition effects for diesel excise taxes in Europe. Paizs (2010) confirms the evidence on diesel excise competition. He also finds that larger countries react more aggressively to changes in their neighbors' tax rates and that smaller countries tend to charge lower fuel excise taxes as predicted by Kanbur and Keen. The focus in our paper is not on empirical validation but on understanding the transition to another charging system other than fuel excises for road use by trucks.

4. Assumptions and model elements

Assumptions

We use four simplifying assumptions.

First we assume that the fuel efficiency of trucks is fixed. This is only a minor assumption as trucks are designed to be used in many countries and their fuel efficiency will be a function of the expected fuel taxes and fuel efficiency regulations in the different countries where the truck is used.

The second assumption is that the trucks are homogeneous and the external cost of trucks differs among countries while being constant per kilometer and independent of the amount of total truck use in a given region. We consider three types of external costs: wear & tear of infrastructure, local air pollution and

congestion. The homogeneity assumption is problematic for road damage that depends on the design and loading of the truck. In principle congestion also depends on the volume of truck use and is therefore not fixed. There are two lines of defense for this assumption. Consider first the short term: as trucks are only 5 to 20% of total volume of road use, small variations in the total truck volume due to truck tax variations may justify somewhat the constant external cost assumption. Consider next the long term with variable road capacity; if we have constant returns to scale in infrastructure extension, the external congestion cost becomes a constant. For this reason we will use external congestion cost and infrastructure cost as synonyms throughout this text. Trucks also differ in the emission of traditional air pollutants, which is more or less a transition problem as new regulations are only imposed on new trucks.

The third assumption is that we use a model consisting of only two countries; *A* and *B*. We assume that both countries take the behavior of the other country as given. This is more easily justified in the case of many countries. As long as all countries are identical, we can easily generalize the model to *n* countries that interact. For instance we could consider a Löshian model where space is filled with identical countries that have a hexagonal shape: where every country has always six neighbors that generate international traffic and set fuel taxes and distance charges. We could also consider a setting with one big country, surrounded by *n* smaller neighbors.

The fourth assumption is that we can isolate the charging of trucks and of cars. This can be justified by assuming that either the share of diesel cars is negligible or that governments use other types of car taxes (registration or purchase taxes) to align the taxation of diesel cars to the taxation of gasoline, as it is in their interest to separate both users of diesel fuel. We will relax this assumption later.

Our assumption of constant fuel efficiency, combined with homogeneous trucks, implies that a fuel tax and a distance charge would be perfect substitutes for domestic transport. This is a strong assumption but assists us in making our point.

Objective function of the governments

We assume that country governments maximize the sum of the consumer surplus of domestic trucking plus part of the consumer surplus of international truck transport plus the total tax revenues minus the total external costs within the country (infrastructure costs plus external congestion costs on local car use and local environmental costs). As all international trips correspond to a transaction where both countries gain, we assume that they both share equally in the gains.

Using the sum of consumer surplus plus tax revenues minus external costs is a rather normative approach for government behavior. A popular alternative among economists is the Leviathan assumption (Kanbur

& Keen, 1993) where governments simply aim to maximize total tax revenues. The Leviathan assumption is also at the basis of the empirical work on diesel excises cited above but the Leviathan assumption itself is not tested empirically in that empirical work. There is however some factual evidence for our less extreme assumption. First, whenever there is a proposal to raise the level of fuel excises, local truck drivers lobby strongly in opposition and governments often give in, meaning the consumer surplus of trucks counts to some extent. Second, the distance charges are strongly differentiated as a function of the emission rates of trucks (Vierth & Schleusser, 2012). This implies that environmental benefits also matter.

Behavior of domestic and international trucks

In each country there are domestic truck trips and there are international truck trips. The entire trucking industry is competitive. Domestic truck traffic only uses the local road network and buys fuel locally[5]. International trips use the road network at home and the road network of another country. The international hauler buys more fuel in the cheapest country. Figure 2 presents the model set up.

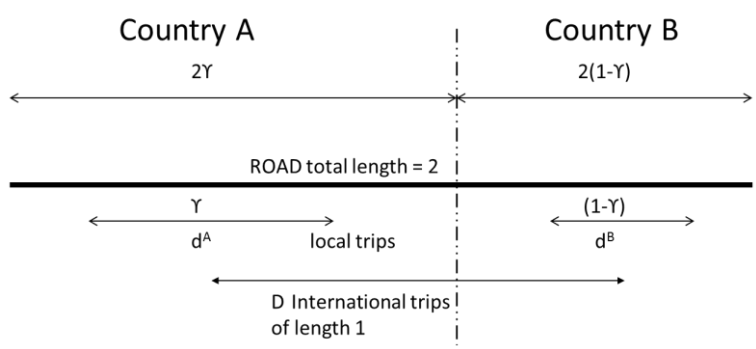

Figure 2. Model set up

Total length of the road running through both countries equals 2. All countries have the same spatial density. Whenever countries differ in size, we always take country *A* as the bigger country. Country *A* has size 2γ and country *B* has size $2(1-\gamma)$, where $\gamma \in [0,1]$. On average, domestic trips will cover a distance γ in country *A*. In country *B*, trips will be of length $(1-\gamma)$. International trips will be of length 1 with a part γ in country *A* and a part $(1-\gamma)$ in country *B*. The trip length is fixed but the number of trips will be variable.[6]

[5] In some tax competition models (Kanbur & Keen, 1993 and others), tax competition takes the form of shopping abroad, so incurring transport costs to buy goods abroad. This makes more sense for consumer goods (tobacco, alcohol). In the case of trucks the additional costs of the driver and truck makes it unlikely for domestic truck trips to make this pure shopping trip.

[6] Charging more for fuel or per mile may make trips shorter and may substitute international trips by shorter domestic trips. This is not considered in this paper.

The number of international trips will, by construction, be the same in both countries. We allow for the number of domestic trips in country *A* to be proportionally larger than in country *B* as a large country offers proportionally more internal trade opportunities. If $1/\zeta_A$ represents the relative number of trips in country *A*, we have that there are relatively more domestic trips in the larger country (*A*):

$$\frac{\zeta_B}{\zeta_A} \leq \frac{\gamma}{1-\gamma} \tag{1}$$

Trucks face three types of costs (all expressed per unit length): costs before taxes *c*, fuel tax t_i (*i*=*A*,*B*) and a kilometer charge T_i (*i*=*A*,*B*). The total cost is denoted by *g* for the generalized cost for local trucks and by *G* for international truck traffic.

The local demand functions (number of trips) equal:

$$\begin{aligned} d_A &= a - \zeta_A b\, g_A \\ d_B &= a - \zeta_B b\, g_B \end{aligned} \tag{2}$$

Where *a* and *b* are non-negative parameters. The international demand function (number of trips) is:

$$D = \alpha - \beta . G \tag{3}$$

Where α and β are non-negative parameters. However, for ease of presentation, we will sometimes use the assumption that international truck demand is totally inelastic.

The generalized costs of a domestic trip take into account its relative distance[7]:

$$\begin{aligned} g_A &= \gamma(c + t_A + T_A) \\ g_B &= (1-\gamma)(c + t_B + T_B) \end{aligned} \tag{4}$$

And the generalized cost of international trips equals the sum of costs in both countries:

$$\begin{aligned} &G = c + \gamma T_A + (1-\gamma)T_B + \sigma(t_A, t_B)\, t_A + \big(1 - \sigma(t_A, t_B)\big)\, t_B \\ &\sigma(t_A, t_B) = \gamma - \rho(t_A - t_B) \\ &\sigma(t_A, t_B) = 1 \; when \; t_B - t_A \geq (1-\gamma)/\rho \\ &\sigma(t_A, t_B) = 0 \; when \; t_A - t_B \geq \gamma/\rho \end{aligned} \tag{5}$$

International haulers minimize their fuel costs by buying more fuel in the cheaper country they drive through. We use a simple reduced form formulation for this cost minimization process of the haulers. (5)

[7] An alternative set up would be that all domestic trips have the same length irrespective of the country.

represents the refueling choices of the haulers by use of a simple linear formulation for the share of fuel $\sigma(t_A, t_B)$ bought in country A. When the difference in taxes is larger than a given constant, a hauler only buys fuel in the cheapest country. The parameter ρ is a measure of the intensity of tax competition: a small ρ means that an increase in the fuel tax difference does not strongly affect the market share σ in the international trucking fuel market.

When fuel taxes are equal in both countries, the fuel purchases are proportional to the size of the country. One could also use more complex formulations like the logistic function but results do not truly depend on this. The fuel market share function implies that the generalized cost of the international haulers is a non-decreasing function of the fuel taxes in both countries:

$$\begin{aligned} &\frac{\partial G}{\partial t_A} \geq 0,\ \frac{\partial G}{\partial t_B} \geq 0 \\ &\frac{\partial G}{\partial t_A} = \sigma - \rho(t_A - t_B) \\ &\frac{\partial G}{\partial t_B} = (1-\sigma) + \rho(t_A - t_B) \end{aligned} \tag{6}$$

For solutions to be interesting we need to assume that there is at least one solution with positive local and international truck demand.

5. Fuel Tax setting behavior of governments in the absence of diesel cars

We now have all the elements to study the behavior of governments. We first concentrate on the fuel tax as the only instrument and study the Nash equilibrium for this situation. In the next section we will add distance charging as a tax instrument. Throughout sections 5 and 6 we will assume that there are either no diesel cars or that they can be taxed using additional instruments so that they do not intervene in the optimal fuel tax for trucks.

The structure of the first order condition

Each country government maximizes the sum of consumer surplus of local trips (*cs*) plus half of the consumer surplus (*CS*) of international trips. As all international trips correspond to a transaction where both countries gain, we assume that they both share equally in the gains. In addition, governments take into account their own tax revenues minus the external costs and the implementation costs[8]. As we always have fuel taxes, we only consider the implementation costs (IT_i) of kilometer charges. External costs may differ among countries.

[8] Our formulation neglects the general equilibrium effect of road taxes and fuel taxes on the price of products. A competitive international haulage sector will pass on the large part of its additional taxes onto consumers and producers. This may be a motive for a government to restrict taxes on road freight to the marginal external costs.

The objective function of the country government *A* becomes**:**

$$cs_A\{g_A\{.\}\} + d_A\{.\}(\gamma\, t_A + \gamma\, T_A - \gamma\, ec_A) + 0.5\, CS\{G\{.\}\} + D\{.\}(\sigma\, t_A + \gamma\, T_A - \gamma\, ec_A) - IT_A \quad (7)$$

Note the difference between the tax revenue per trip and the external cost. The external cost is fixed per trip (or per mile) and the only way to reduce it is to reduce the volume of trips via the fuel tax or the distance charge.

In order to study the Nash equilibrium in fuel taxes, we derive the first order condition with respect to fuel tax t_A and set the distance charges T_A and T_B to zero. Taking country *A* and differentiating the objective function (7) with respect to t_A, we get the following optimality condition:

$$-\gamma\, d_A + \gamma \frac{\partial d_A}{\partial t_A}(t_A - ec_A) + \gamma\, d_A - 0.5\, D\, \frac{\partial G_A}{\partial t_A} + \frac{\partial D}{\partial t_A}(\sigma\, t_A - \gamma\, ec_A) + \frac{\partial \sigma}{\partial t_A} D\, t_A + \sigma\, D = 0 \qquad (8)$$

The left hand side consists of seven terms. The first term captures the change in consumer surplus on the market for domestic transportation. This is entirely cancelled out by the tax revenues from domestic transportation in the third term because this is a transfer within the country. Remaining effects on the domestic market are captured by the second term, which multiplies the change in domestic transport demand (measured as length γ times the number of trips) with the taxes net of external costs.

The last four terms deal with international transport. First, note that the change in consumer surplus (fourth term) and the change in tax revenues (last term) do not cancel out in a way corresponding to what we see on the domestic market. This is not surprising since part of the tax is paid by haulers from country *B*. The tax effect consists of three parts. The first, in term five, follows from the change in demand due to the change in tax. The second, in term six, follows from the change in tax that influences the choice of where to fuel. The last effect, in term seven, is the direct tax revenue effect capturing the share of total international demand that will buy fuel in country *A*.

We explore this problem in three steps. We start by discussing the case where demand for truck trips is inelastic (PROP 1). Next we analyze the case of price elastic truck demand but where countries are fully symmetric (PROP 2), and in the last step we discuss the more general asymmetric case (PROP 3).

Fuel tax equilibrium with price inelastic truck demand

If both domestic and international trips are fixed, the objective function of both governments reduces to maximizing fuel tax revenues from international traffic. The reason is that total external costs are fixed

and taxes on national trucking are a pure transfer for a government pursuing national welfare. This leads to the following proposition:

PROP 1 When domestic truck demand and international truck demands are fixed, the reaction functions for the truck diesel taxes $t_A(t_B)$, $t_B(t_A)$ and the Nash equilibrium in pure strategies t^N_A , t^N_B are:

$$t_A(t_B) = \frac{\gamma}{3\rho} + \frac{t_B}{3} \qquad t_B(t_A) = \frac{1-\gamma}{3\rho} + \frac{t_A}{3}$$
$$t_A^N = \frac{1}{8\rho} + \frac{2\gamma}{8\rho} \quad t_B^N = \frac{1}{8\rho} + \frac{2(1-\gamma)}{8\rho} \tag{9}$$

where an equilibrium in positive fuel taxes always exists.

Proof: see Appendix 2

The reaction functions and the Nash equilibrium are represented in Figure 3. The reaction functions are upward sloping: as total demand is fixed but fuel demand is price sensitive, both countries follow their neighbor's tax increases, but only partially, so in order to gain market share. The Nash equilibrium is also within the zone where both countries share the market. In the upper left zone (σ=0), the tax t_A is so much larger than t_B, that country B holds the entire international trucking fuel market. In the lower right zone (σ=1) country A holds the entire international fuel market.

The Nash equilibrium has two characteristics that will re-appear in many cases we will discuss. The first is that the tax rates are a decreasing function of the "openness" of the fuel market ρ. The openness will be larger when international trips are shorter (countries of smaller size) and when there are more options for using larger fuel tanks (some countries have attempted to prohibit them). The second feature is the role of the relative size of the countries. The tax rate of the larger country (A) is increasing in size (γ). This is the result of our fuel market share equation $\sigma(t_A, t_B) = \gamma - \rho(t_A - t_B)$. The market share equation has two parts: a base part (γ) and a competitive part ($-\rho(t_A - t_B)$). A larger country implies that international trucks cover, on average, a larger distance within the country, implying a larger market share when fuel taxes are equal: this is the larger base part (γ). The smaller country has more to gain by undercutting the large neighbor and in this way stealing part of its base. When both countries have the same size, the equilibrium taxes are equal to $\frac{1}{4\rho}$.

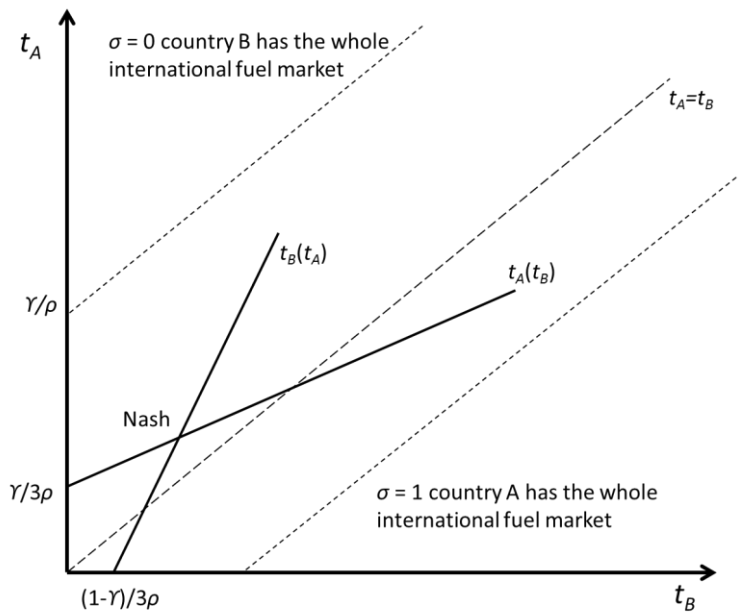

Figure 3 Reaction functions for truck fuel taxes when truck traffic is inelastic

Symmetric fuel tax equilibrium with elastic truck demand

We now add price sensitivity of the domestic and international truck market. Using again the first order condition (8), and imposing symmetry, we have an implicit solution for the Nash equilibrium:

PROP 2 When domestic truck demand and international truck demands are price dependent, and fuel tax competition is low $\rho<\rho^*$, the symmetric Nash equilibrium in pure strategies for fuel taxes is:

$$t_A^N = t_B^N = \frac{z}{z-2\rho D} ec - \frac{\gamma}{z-2\rho D} D \qquad (10)$$
$$\text{where } z = \left(\frac{\delta d}{\delta t_A} + \frac{\delta D}{\delta t_A}\right)$$

When the fuel tax competition is high $\rho>\rho^*$, no Nash equilibrium in pure strategies exists.

Proof in Appendix 3

(10) This is an implicit equation in t_A as the tax rates are still present in D.

<u>Consider first the case where fuel tax competition is not too strong</u> and allows for a Nash equilibrium in pure strategies. To understand the level of the fuel taxes consider the extreme case where there is no international traffic at all (D=0), and (10) reduces to charging the external cost. This is expected due to

the fact that fuel efficiency is fixed, meaning the external cost is strictly proportional to the distance driven. The best a policy maker can then do is charge the marginal external cost. This is in line with efficiency results for the production sector when there are externalities (Diamond & Mirrlees, 1971, Mayeres & Proost, 1997).

Whenever there is international truck transport, the equilibrium fuel tax, if it exists, will consist of two elements: an external cost component (first term with ec_A) and a tax revenue component (second term with D). We see that the first component is always smaller than the external cost and that the second component is always positive. This means that the fuel tax can be larger or smaller than the external cost. We have three elements playing a role in the size of the fuel tax compared to the external cost:

- Raising the fuel tax above the external cost distorts the allocation of domestic transport so that the more important domestic transport and its fuel price sensitivity are, the closer the fuel tax will stay to the external cost.
- A larger price-sensitivity of international traffic (ρ) restricts the possibility of making an extra margin on the fuel tax, therefore restricting the fuel tax (cfr; 2nd component of (10)).
- The more important the international truck volume D is, the larger the revenue raising component will be; t^N is increasing in D (proof in Appendix 3).

<u>Consider next the case where fuel tax competition becomes very intense</u>. We know that this lowers the fuel tax. To understand the non-existence of the Nash equilibrium in pure strategies, examine the components of the objective function of the tax setting government when the fuel tax competition increases. Assume that the number of international trips is fixed. Lowering the fuel tax below the external cost creates a welfare loss on the market of local truck trips as the tax becomes lower than the external cost; with price-sensitive demand this means a welfare loss. As international trips are fixed, the consumer surplus and external cost of international trips stay constant. The fuel tax revenue from international trips, however, decreases with lower taxes. So one component of the national welfare becomes more negative and the positive component of national welfare (tax revenues) decreases. There will exist a level of fuel tax where the national welfare is equal to the level of welfare that can be achieved by simply charging a fuel tax that is equal to the external cost and foregoing the revenue from fuel sales on international trips.

The critical value of the fuel tax when this tax generates the same amount of welfare as does charging the external cost (for fixed D) (proof in Appendix 3):

$$t_A^* = 0.5\left[2\,\mathrm{ec} + \frac{2D}{b} - \sqrt{\frac{2D}{b}}\sqrt{4ec + \frac{2D}{b}}\right] = t_A^N = \frac{0.5\,\mathrm{b}}{0.5\,\mathrm{b} + 2\rho^* D}ec + \frac{0.5}{0.5\,\mathrm{b} + 2\rho^* D}D \qquad (11)$$

The critical ρ^* is then defined as the ρ that produces t^*_A in equation (11). The critical ρ^* will be a function of the external cost *ec*, the price sensitivity of local traffic b and the importance of international traffic *D*. Consider as an example the following values: *ec*=4, *D*=10 and *b*=1, a critical fuel tax value of t^*_A=0.5 and thus ρ^* =0,675. When international truck traffic is less important (*D*=5), revenues from fuelling international trucks are also less important and the critical values become t^*_A=0.95 and ρ^* =0.42. We see that the critical fuel tax is well below the external cost since international fuel tax revenues compensate the deadweight loss of incorrect prices for domestic traffic. When international traffic becomes less important, a higher local tax is preferred and a switch into a regime where no Nash equilibrium exists becomes more likely.

Why can this fuel tax rate not be a Nash equilibrium? In a symmetric equilibrium and for a set of parameter values that imply $\rho=\rho^*$, the Nash equilibrium as defined by prop 2 implies such low fuel tax rates that for each of the two countries, they achieve the same welfare by foregoing the international trucking fuel sales and charging the local trucks the external cost *ec*. However, if one of the two countries (say A) does this, country B can benefit from increasing its tax rate but charging slightly less and maximizing revenues from the international fuel tax market. Then an equilibrium will no longer exist with country A, as it will slightly undercut the fuel tax of country B until arriving again at $t^*(\rho^*)$, and so on. As illustrated here, reaction functions are discontinuous in this point and no Nash equilibrium in pure strategies exists.

In a symmetric equilibrium, and given our assumptions, any fuel tax that is different from the external cost is inefficient for both countries. The driver of the inefficiency is the tax competition incentive. The following two figures help to convey the intuition for the symmetric case:

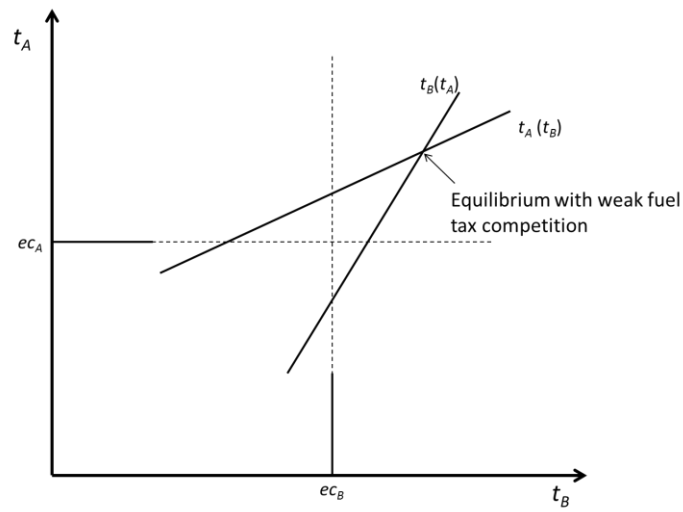

Figure 4, Equilibrium with weak fuel tax competition

To see the intuition of Figure 4, assume first that country *B* is charging the external cost, so that country *A* will find it profitable to have a fuel tax somewhat larger than the external cost since tax competition is relatively weak and foreign haulers pay extra taxes while the cost to local haulers is of a second order (the deadweight loss). The fuel tax will be above the external cost but both the tax competition, even if it is weak, and the deadweight loss to locals will ultimately limit the fuel tax.

We can also have a Nash equilibrium with very strong tax competition as long as $\rho<\rho^*$. This could be the case of smaller countries where there is relatively more international traffic and where the international fuel market share is very price sensitive (ρ large in (5)). This is illustrated in Figure 5. To see the intuition assume again that country *B* charges the external cost. Then it becomes profitable for country *A* to undercut country *B* as it can make international trucks buy fuel in country *A*. With a fuel tax lower than the external cost, the cost for country *A* is then the additional volume of local truck activity in country *A* that is not paying the full external cost, while the gain is the international haulers buying fuel for their trips in both country *A* and country *B*. For the additional trips in *B*, country *A* does not bear the external costs.

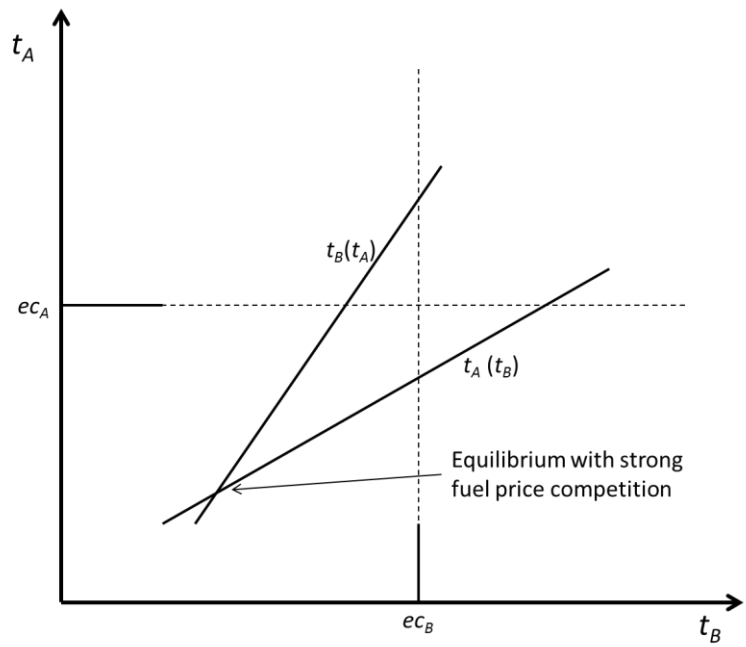

Figure 5, Equilibrium with intensive fuel tax competition.

Thus, the fuel tax equilibrium is able to generate too high as well as too low fuel taxes compared to external costs. Both cases thus involve inefficient pricing due to tax competition.

Asymmetric fuel tax equilibrium with price dependent domestic truck demand

Thus far, we have focused on the asymmetric case with fixed demand (PROP 1) and on the symmetric case with price dependent truck demand (PROP 2). PROP 1 was a simpler case because with fixed demand, external costs play no role. PROP 2 was also a simpler case because both counties were fully symmetric. We now relax both assumptions and come to the following result:

PROP 3 When domestic truck demand and international truck demand are price dependent, and fuel tax competition is low $\rho<\rho^*$, a non-symmetric Nash equilibrium where only fuel taxes are available to charge trucks is as follows:

Either $t_A >> t_B$ and $t_A = ec_A$

Or $t_A << t_B$ $t_A = (1-\frac{\frac{\partial D}{\partial t_A}(1-\gamma)}{\frac{\partial D}{\partial t_A}+\gamma\frac{\partial d_A}{\partial t_A}})ec_A + \frac{-0.5}{\frac{\partial D}{\partial t_A}+\gamma\frac{\partial d_A}{\partial t_A}}D > ec_A$ **and** $t_B = ec_B$

Or*

$$t_A = ec_A - \frac{D}{\frac{\partial d_A}{\partial t_A}} - \frac{\rho D}{\gamma\frac{\partial d_A}{\partial t_A}}t_B$$

$$t_B = ec_B - \frac{D}{\frac{\partial d_B}{\partial t_B}} - \frac{\rho D}{(1-\gamma)\frac{\partial d_B}{\partial t_B}}t_A$$

*This expression only holds for fixed international demand.

PROP 3 shows that several equilibriums are possible when countries differ in size and external costs. When would country *A* (by assumption larger in size than *B*) go for a particular equilibrium?

Charging the external cost ($t_A >> t_B$ and $t_A = ec_A$) may be a Nash Equilibrium when the external cost in *A* is much higher than in country *B* and there is no strong tax competition. When the tax in *B* is sufficiently lower than in *A*, all international traffic will fuel up in *B* and any marginal changes in t_A will not influence this. In that case, for country *A* it is not interesting to go for much lower fuel taxes as it would strongly distort its domestic traffic with no tax revenue gain.

Charging much less than the other country ($t_A << t_B$ and $t_A > ec_A$) can be an equilibrium when the external cost in *A* is much lower than in country *B*, or when for some other reason t_B is very high relative to t_A. We then have the opposite situation as above, i.e., all international transport will fuel up in *A*. In that

case, *A* will increase the tax above its external cost in order to charge a monopoly margin with the only restraint being the distortion on the domestic trucking market.

Finally, the equilibrium may consist of fuel taxes that are so different that both countries have a positive share in the fuel sales to international trucks. In this case taxes can be higher or lower than the external cost. One of the important elements is size. Figure 6 presents the equilibrium with fuel taxes only. Because *B* is a smaller country it can gain high revenues from international haulage by setting a low fuel tax. The bigger country has much more to lose when using low fuel taxes as the local trucking is proportionally much more important. From Kanbur and Keen (1993), we know this will be a Nash equilibrium when the smaller country undercuts the large country. The reason is that undercutting gives the small country access to a much larger tax base, while for the big country the home market remains proportionally more important. Note however that we have a different setting than Kanbur and Keen because, in our model, governments are not Leviathan and external costs and consumer surpluses count.

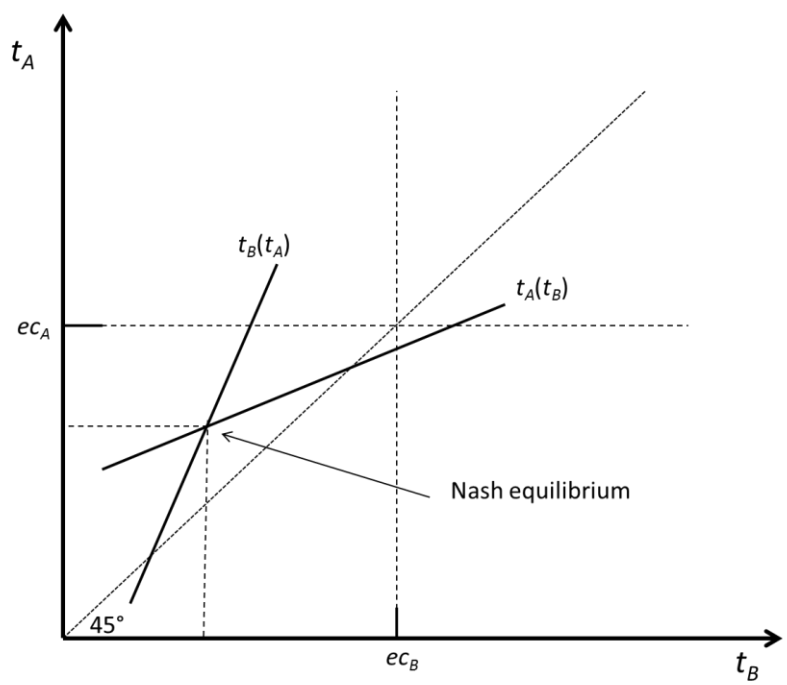

Figure 6, Equilibrium with fuel taxes only when B is smaller country, $t_A > t_B$

Making the government a Leviathan

Throughout the paper, the government is not only concerned with its tax revenues but also with the consumer surplus of its own inhabitants and the external cost. For comparison, it is interesting to derive

the result for a Leviathan Government. Consider again the symmetric case, and assume that only government tax revenues count. In the symmetrical Nash equilibrium, the fuel tax becomes:

$$t_A = t_B = \frac{2(D+d)}{\beta + b\gamma\xi + 4\rho D}$$

The level of the tax is again determined by the price sensitivity of local (b) and international transport demand (β) but also by the level of international tax competition: a high ρ value limits the overall fuel tax rate that can be charged. Therefore taxes are not necessarily higher than the external cost and infrastructure cost; this result holds for different objective functions of the government.

We can compare the Leviathan outcome in the symmetrical case with the outcome presented in PROP 2 equation (10). Starting with the assumption that the external costs, and thus also the first term in (10), are zero, we find that the Leviathan fuel tax is strictly higher than the tax in (10). This is driven by two major effects. First, in (10) the fuel tax on domestic transport is just a transfer and of no concern to the government. A Leviathan government – that does not care about consumer surplus for domestic transport – will implement a higher fuel tax and thereby also gain additional tax revenues from domestic transport. Second, the tax on international transport will also be higher under the Leviathan assumption since governments are not interested in the consumer surplus of international transport

On the other hand, however, when the external cost is larger than zero, the first term in (10) is also larger than zero. Thus, for large enough external costs, the first term will outweigh the two effects above and the Leviathan tax may even become lower than the tax in (10).

6 Adding the distance charge as a policy instrument in the absence of diesel cars

Thus far, we have addressed the implications of strategic interaction between governments on fuel taxes. However, the main subject of interest in this paper is how countries react when a distance charge becomes possible. In particular, we are interested in how the introduction of distance charges changes the governments' choice in fuel taxes and how the underlying mechanisms work.

To examine this, we start again from the objective function (7) of the country A government and derive first order conditions for t_A and T_A. Note that it is possible to use only one instrument. The first order condition for the fuel tax in A, conditional on its distance charge, then becomes:

$$-\gamma\, d_A + \gamma \frac{\partial d_A}{\partial t_A}(t_A + T_A - ec_A) + \gamma\, d_A - 0.5\, D\, \frac{\partial G_A}{\partial t_A} + \frac{\partial D}{\partial t_A}(\sigma\, t_A + \gamma\, T_A - \gamma\, ec_A) + \frac{\partial \sigma}{\partial t_A} D\, t_A + \sigma\, D = 0$$

Similarly, the first order condition for the distance charge, T_A, is given by:

$$-\gamma\, d_A + \gamma \frac{\partial d_A}{\partial T_A}(t_A + T_A - ec_A) + \gamma\, d_A - 0.5\, D\, \frac{\partial G_A}{\partial T_A} + \frac{\partial D}{\partial T_A}(\sigma\, t_A + \gamma\, T_A - \gamma\, ec_A) + \gamma\, D = 0$$

PROP 4 Assuming distance charges can be used, a Nash equilibrium cannot have diesel fuel taxes in both countries and $0 < \sigma < 1$. Furthermore, the equilibrium distance charges are larger than the marginal external cost:

$$t_A = t_B = 0$$

$$T_A - ec_A = \frac{0.5D}{\gamma(b+\beta)} > 0$$

$$T_B - ec_B = \frac{0.5D}{(1-\gamma)(b+\beta)} > 0$$

PROOF: See Appendix 5

Before showing the intuition behind this result, consider the equilibrium values of distance charges in the absence of fuel taxes. The distance charges will be larger than the external costs, and the mark-up on top of the external cost will be larger in small countries as they have more revenue to gain from international trips. In addition, the mark up in the distance charges will be smaller when domestic truck trips are very price sensitive and/or more important.

We can show the intuition behind the dominance outcome for distance charges using a thought experiment. Consider the effects of introducing a distance tax when a fuel tax is already present. Starting from Figure 4 we construct Figure 7.. Taking our departure from the initial equilibrium of fuel taxes only, we consider the gradual substitution of the initial equilibrium with fuel tax $t_A°$ by a combination of a smaller t_A and a small positive T_A while keeping the same sum $t_A + T_A = t_A°$ and the same $t_B°$. This substitution will not affect local traffic as it is only influenced by the sum of the two taxes.[9] The main

[9] If we allow for the tax influencing international transport demand, the substitution will generate a small increase in international haulage as haulers will benefit from lower fuel taxes in country *A* and *B*, which compensates the increase in T_A. There will be an additional external cost in both countries but this is undoubtedly covered in country *A* by the sum of the two taxes.

effect will be country *A* having larger tax revenues. The consumer surplus for international transport will also decrease, but by a smaller amount. What will make the major difference is a larger market share on the fuel market: country *A*'s revenues will increase. We did not alter the reaction function of country *B*, although this can change slightly since it is also a function of the level of T_A. The initial fuel tax in country *B* (t_B) is no longer the best response for country *B* so we will move to a new equilibrium of increasingly lower fuel taxes in both countries.

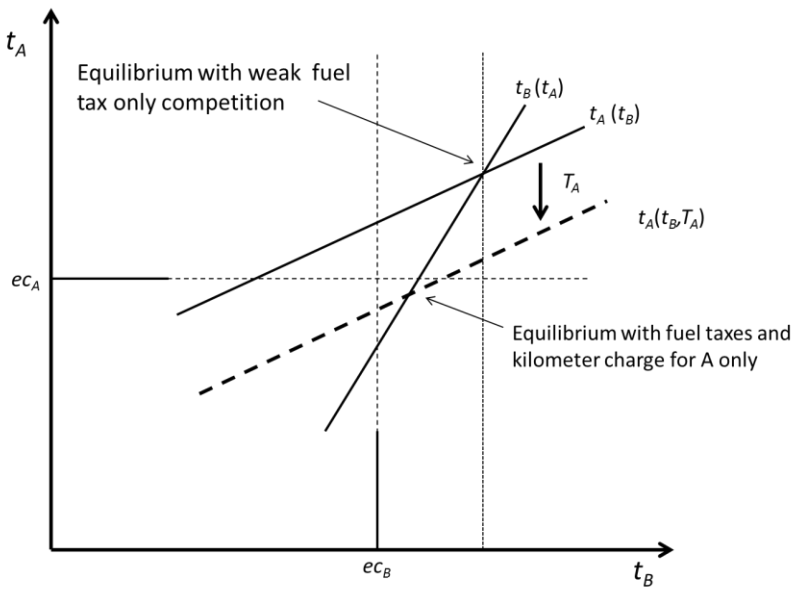

Figure 7, Equilibrium when country A also disposes on distance charge tax but country B only has a fuel tax.

The total tax for the use of the road in country *A* may increase strongly as the kilometer tax allows *A* to better charge for the external cost and to raise revenue on international traffic.

Let us start from another extreme equilibrium where both countries initially only use a kilometer charge. This equilibrium is one of the serial network type where both countries tax the same tax base (international traffic), which gives an equilibrium where distance charges are larger than the external cost (De Borger, Dunkerley, Proost, 2007). The reason is that part of the tax base of each country is foreign and will always be taxed above the external cost. If we allow for elastic international transport demand, the reaction function T_A (T_B) will be downward sloping because every increase in the kilometer charge in

the other country will decrease the international haulage volume and for this reason, the optimal distance charge will also decrease. Now, will one of the countries gain by re-introducing a fuel tax?

Consider Figure 8 where we start from an equilibrium ($T°_A$,$T°_B$) where only distance charges can be used and the fuel tax instrument is not. This is illustrated by the intersection of the two solid lines. Consider now a substitution of part of T_A by a fuel tax in country *A*. This corresponds to the dotted line parallel to the reaction function of country *A*. Clearly, country *A* cannot gain from such a substitution. For local traffic it will not make a difference, but international traffic will buy fuel in country *B* where it is not taxed, so that country *A* always loses tax revenues.

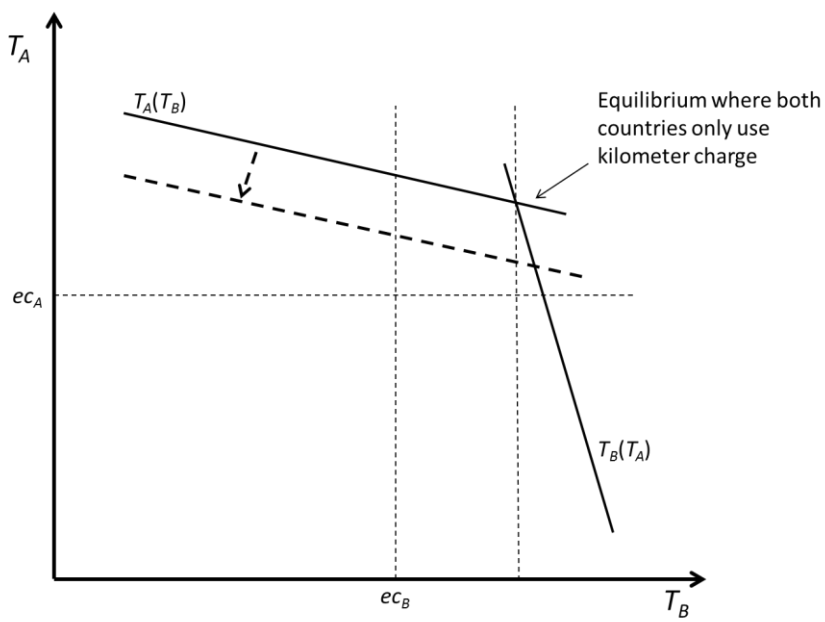

Figure 8, Equilibrium with only kilometer charges

Thus in equilibrium, when both countries can freely choose fuel tax levels and distance charges, they will both prefer a distance charge that is above the external cost while the fuel tax is driven to 0.

PROP 5 (conjecture) When there are other tax instruments for diesel cars, the option to introduce distance charges for trucks may be welfare decreasing in symmetric equilibrium

When we move from a fuel tax only system to a distance charge system, there are two differences. First there is the difference in implementation costs, where one can reckon that distance charges are more costly than fuel taxes. Second, the distance charges are always larger than the external cost while the deviation between the external cost and the fuel tax can be lower or higher than in the case of the distance

charge. Naturally, when the distance charge becomes smarter as well as time and place dependent, the charge becomes much more efficient; however, this is not the type of distance charge we consider here.

It is obvious that the large country can benefit from introducing a kilometer charge in order to escape the downward pressure of the small country on its fuel tax level. For the small country, however, the costs and benefits of the kilometer charge are less obvious as it is able to extract revenue from foreign international traffic in both systems.

Consider the case where only kilometer charges are used by countries that are different in size. This is represented in Figure 9. The solid lines in the figure illustrate the symmetric case, where the countries are of equal size. Consequently, the Nash equilibrium entails $t_A = t_B$ and thus lies on the 45 degree line. Here, we have chosen country *A* to be the smaller country. The reaction function of the smaller country *A* lies above the corresponding reaction function in the symmetric case. This is a result of the fact that country *A* has proportionally more foreign traffic on its roads and can benefit by charging more per kilometer. This is the reverse case with fuel taxes, where the smaller country undercuts the fuel tax of its large neighbor.

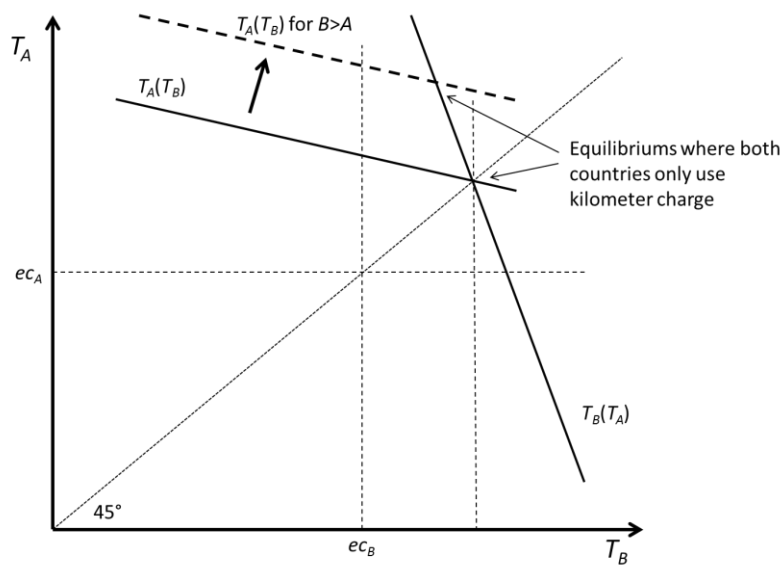

Figure 9, Equilibrium with kilometer charges only

7 Numerical illustration

It is useful to illustrate the analytical results numerically. We use Germany as a base for the calibration. In our calculations, getting the orders of magnitude to be correct is the most we are striving for.

The total amount of good transportation by road in Germany in 2012 amounted to around 307 000 million tonkm. Out of these, 80% was strictly domestic transport, while 20% was international (Eurostat[10]). We assume the cost of truck transport to be 35 euro per 1000 tonkm, out of which 20% stems from fuel costs, taken as the average in EU8. We employ a fuel price elasticity of 0.25 (based on De Jong et.al., 2010). This is the basis for the calibration of linear demand functions for domestic and international truck transport[11].

The external cost is set at 3 euro per 1000 tonkm (0.06 euro per vehiclekm, 20 ton per vehicle – computed from the 2014 EU handbook on external costs). We use these values to represent both Country A and B in our model. That is, we let two identical Germanys compete with each other, giving the fuel taxes and distance charges exhibited in table 2.

***Table 2**,Fuel taxes and distance charges in the Nash equilibrium when there are no diesel cars*.

	$\rho = 0.05$			$\rho = 0.5$		
	$t_A = t_B$	$T_A = T_B$	W_A	$t_A = t_B$	$T_A = T_B$	W_A
Fuel tax only, fixed demand	5	-		0.5	-	
Fuel tax only	4.1	-	781	0.67	-	775
Fuel tax and distance charges	0	8.29	737	0	8.29	737
	t_A ; t_B	T_A ; T_B	W_A	t_A ; t_B	T_A ; T_B	W_A
Trucks only, $t_B = ec$ and $T_B = 0$	0 ; 3	8.85 ; 0	851	2 ; 3	6.50 ; 0	918
Trucks only, $T_B = 0$	0 : 4.19	8.82 ; 0	844	0 ; 0.64	9.02 ; 0	888

The first row in table 2 exhibits the case of totally inelastic demand for international freight transport. As expected from Prop 1, the fuel tax is higher when tax competition is less intense (5>>0.5 for a 10 fold increase in ρ). The second row allows for elastic international demand, which in effect implies that the consumer surplus of trucks, the external cost as well as the share in international total revenues, become more important when setting the fuel tax. The result is that the fuel tax is reduced in the low tax competition case (ρ=0.05) in order to account for the consumer surplus of the international transport, but it is still higher than the external cost (ec=3). The Nash equilibrium tax is substantially lower in the strong

10 http://epp.eurostat.ec.europa.eu/statistics_explained/index.php?title=File:National_and_international_road_transport_of_goods,_2012_(1)_(%25_based_on_million_tkm_of_laden_transport)_YB14.png&filetimestamp=20140311101514

11 For the domestic demand, we set a = 552 and b = 8.8 and for the international demand we set α = 138 and β = 2.2. Given a total cost, including taxes, of 35 euro per 1000 ton, these assumptions yields a domestic annual transport of 244 billion tonkm and international volumes of 61 billion tonkm (to be compared to the actual values of 246 and 61, respectively, in 2012).

tax competition case, t=0.67, but it is actually higher than in the inelastic case because a higher tax allows for a decrease in the external costs of trucking.

The third row introduces distance charges as an additional instrument. The findings in Prop 4 are clearly visible, the fuel tax in both countries is zero, and the distance charge is set far above the external cost. It is worth noting that the distance charge is the same in the weak and strong tax competition case. This is not surprising as the tax competition only operates through fuel taxes, which are driven to the bottom for this very reason, i.e., the tax competition plays no intense role on the distance charge in the Nash equilibrium.

The lower part of table 2 illustrates the mechanism when country B's response is restricted. In the first of these rows, country B is not able to use a distance charge and is also restricted to applying a fuel tax equal to the external cost (equal to 3). Then, in the weak competition case we see that country A will apply a high distance charge and zero fuel tax. In the strong competition case we end up in a corner solution where A sets a fuel tax equal to 2 which will capture the entire international fuel market; A sets the distance charge such that the sum of the fuel tax and distance charge is close to what we find in the weak competition case.

The last row illustrates the more realistic case where B is not yet able to implement a distance charge, but will respond to A's policy by optimizing its fuel tax. Both in the weak and strong competition case, country A will implement a distance charge substantially above the external cost. B's best response is highly dependent on the level of tax competition. When tax competition is weak, B will set a fuel tax above the external cost. However, when tax competition is strong, B is forced to set a fuel tax far below the external cost. In all cases, A will only use distance charges in optimum.

W_A in table 2 is a measure of the welfare in country A calculated for those cases with elastic international demand and the absence of transaction and implementation costs. This is what country A strives to maximize when it decides on taxes and charges. Comparing this value for the different cases yields several interesting observations. First, note that W_A is lower in the third than in the second row. As these cases are symmetric the same applies for the welfare in B. Thus, in this particular setting, welfare decreases when both countries introduce distance charges.

This is a surprising result, because if introducing distance charges would decrease welfare, why do it? The answer is evident from the second part of table 2, where country B is restricted to using fuel taxes only. There we see that the welfare increase in A from introducing a distance charge – given that B does not follow – is large. This is particularly so if country B cannot even optimize its fuel tax. In that case country A will capture the entire fuel market *and* also charge international transport for the distance driven. In the

last case, where B optimizes its fuel tax, the welfare in B will be 676 (weak competition) and 633 (strong), respectively[12].

Table 3 highlights the prisoners' dilemma structure that is embedded in Table 2. The numbers refer to the strong tax competition case, but a similar situation is apparent under weak competition. The only Nash equilibrium is when both countries employ both instruments, in which case the welfare is less than if both countries would use fuel taxes only. Both countries would be better off sticking to only fuel taxes. However, given that one country sticks to a strategy of only using fuel taxes, there is much for the other country to gain in introducing a distance charge. Given that the second country chooses to implement the distance charge, the first country will gain from following suit.

Table 3, **Welfare for each policy combination displayed as a normal form game**

		Country B	
		Fuel tax only	*Both instruments*
Country A	*Fuel tax only*	(775 ; 775)	(633 ; 888)
	Both instruments	(888 ; 633)	(737 ; 737)

It is worth repeating that the results above do not include transaction or implementation costs. It may be that these costs are large enough to deter the introduction of a distance charge. In the strong competition case, if these costs exceed 113 (= 888 – 775), that would be enough to keep country A from implementing distance charges even if it knew that country B would stick to fuel taxes only. Similarly, given that B would have already implemented a distance charge, the costs for A must exceed 104 (= 737 – 633) in order for it to not be profitable for A to do the same. To put these costs into perspective, the revenues from the distance charge for either country when both use both instruments amounts to 575. Thus, in this particular setting, if the transaction and implementation costs associated with introducing a distance charge are around 20% or more of the revenue that the charge will create, it is not worth introducing it.

8 Introducing diesel cars

Thus far, we have shown that both countries face incentives to implement distance charges and set fuel taxes to zero. However, this is not what we see in real life. Several countries within the EU have adopted distance charges, but none have abandoned fuel taxes after this. There may be several reasons for this. One such, and arguably very important, is that it is not only trucks but also cars that use diesel. In this concluding analytical section of the paper, we extend the model to also take this into consideration.

[12] The welfare in B will of course be even less when it cannot optimize its fuel tax – 510 (weak) and 610 (strong), respectively.

Completing the model by adding diesel cars

If assuming that the gasoline fuel tax on cars is fixed and that there is no other tax on diesel cars other than the diesel fuel excise, it is necessary to adapt the model. This is in order to take into account the consumer surplus of diesel car users and the possible side effects of diesel taxes on the gasoline car market. We assume that cars do not fuel up abroad and that the gasoline tax is fixed. In order to complete the model, we must add a demand function for both diesel and gasoline cars. Let the demand functions for diesel and gasoline cars be:

$$x_A^d = a - b_A^d\, g_A^d + \varsigma\left(c^g + t_A^g\right)$$

$$x_A^g = a - b_A^g\, g_A^g + \psi(c^d + \theta^d t_A)$$

In this formulation, superscript *d* and *g* denote diesel cars and gasoline cars respectively, *x* represents the mileage of cars and *g* represents the generalized cost per trip. The generalized driving costs are equal to

$$g_A^d = \gamma\left(c^d + \theta^d t_A\right)$$

$$g_A^g = \gamma\left(c^g + t_A^g\right)$$

Where θ^d represents the relative consumption of fuel per mile by a diesel car compared to a diesel truck. Remember that t_A represents fuel tax paid per mile for a truck. So θ^d is typically ¼ or less. This matters since the same fuel tax has to price both the external costs of a truck and the external costs of a car. When $t_A = ec$ there is no guarantee to have $\theta^d t_A = ec^d$.

Next we must add three terms to the objective function (7): the consumer surplus of the local diesel car user (cs^d) as well as the fuel tax revenues and external costs for diesel and gasoline cars. Let ec^d and ec^g be the external costs per mile of diesel and gasoline cars:

$$cs_A\{g_A\{.\}\} + d_A\{.\}(\gamma\, t_A + \gamma\, T_A - \gamma\, ec_A) + 0.5\, CS\{G\{.\}\} + D\{.\}(\sigma\, t_A + \gamma\, T_A - \gamma\, ec_A) - IT_A + cs_A^d\,\{g_A^d, g_A^g\} + x_A^d\left(\gamma\theta^d\, t_A - \gamma\, ec_A^d\right) + x_A^g\left(\gamma\ t_A^g - \gamma\, ec_A^g\right) \quad (11)$$

When the fuel tax is the only instrument to tax diesel cars and diesel trucks

If a symmetric Nash equilibrium in fuel taxes exists, we obtain the following fuel tax:

$$t_A = t_B = \frac{\beta\gamma^2 + b\gamma\zeta_A}{\varphi} ec_A + \frac{\gamma\theta^d b^d}{\varphi} ec^d + \frac{\gamma^2}{\varphi} D + \frac{\partial x_A^g}{\partial t_A^d}\left(\frac{\gamma t_A^g - ec_A^g}{\varphi}\right)$$

Where $\varphi = \beta\gamma^2 + b\gamma\zeta_A + \rho D + \theta^d b^d$ (12)

We see that the diesel tax now brings four elements on board: the external and infrastructure cost for trucks (1st term) and the revenue-raising term for international truck transport (3rd term) were already discussed before. The new terms are the 2nd term, representing the external cost of diesel car use, and the 4th term, representing the effect of diesel tax changes on the distortion on the gasoline market. If the gasoline tax can be set optimally, the last term disappears. The diesel tax is then one instrument that is used to correct the external costs of two very different vehicles (cars and trucks) as well as to try to raise revenues from international transport. The externality correction objectives receive relatively more weight when domestic car and truck demand become more price-sensitive. The revenue-raising objective receives less weight when competition for international fuel sales is fierce (high ρ).

Introducing distance charges into the symmetric equilibrium

In the absence of diesel cars, introducing distance charges leads to an equilibrium where fuel taxes are driven to 0. When diesel cars can only be taxed using fuel taxes, using zero fuel taxes is not a candidate equilibrium since diesel cars would escape all fuel taxes. So we need a complex balance of the fuel tax between being an externality tax for diesel cars and a revenue-raising tax on international trucking. We proceed in two steps. First we intuitively explore the symmetric equilibrium and next discuss possible generalizations of the intuitive results. The easiest situation to start with is one where the fuel taxes are set equal to the external cost of a diesel car, the gasoline tax equals the external cost of a gasoline car, and the distance charges internalize the external costs from freight transports that are not handled by the diesel tax. This is represented in Figure 10 as $\theta^d t° = ec^d$ and $T° + t° = ec$ but cannot be an equilibrium. The reason is that international trucks can still decide where to buy fuel. Whenever there is a diesel tax, there are opportunities for each government to increase their fuel tax revenues by decreasing the fuel tax slightly. Also, there are incentives to increase the distance charge above the external cost, taking account of the diesel tax, as this increases tax revenues but only partially hurts domestic haulers. Consequently, in equilibrium, $\theta^d t^* < ec^d$ and $T^* + t^* > ec$. That is, the fuel tax will be below the external cost of diesel cars, but the sum of the distance charge and the fuel tax will be larger than the external costs of trucks.

It is difficult to compare this equilibrium with the equilibrium t^{**} when the only instrument available were fuel taxes. What we know is that t^{**} can be above or below the external cost of cars and trucks and that it will be lower than t^*+T^*. When the international fuel competition is strong, t^{**} will be low, and when the international fuel tax competition is weak, the fuel tax will be high. The sum of distance charges and fuel taxes will, however, always be higher than in the fuel tax only solution.

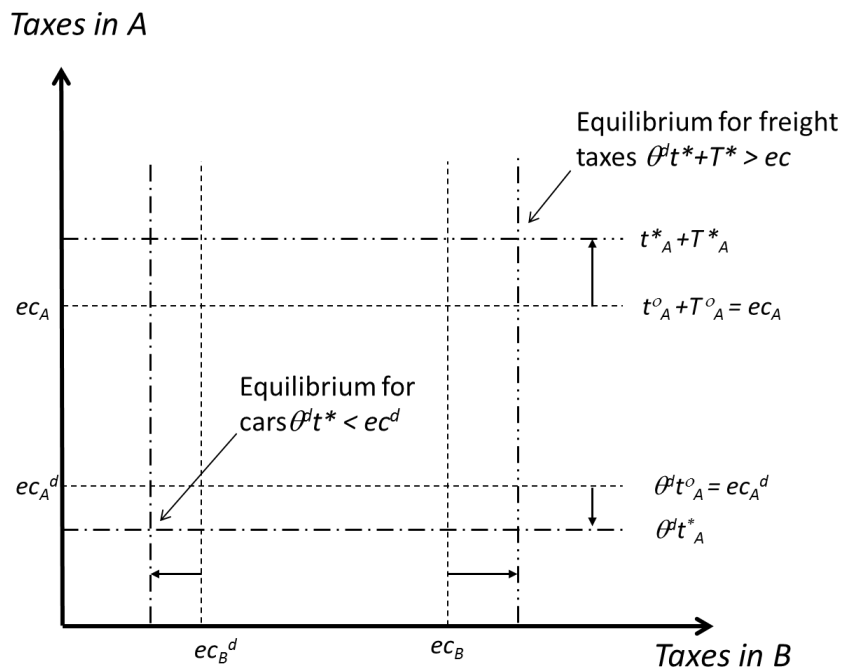

Figure 10, Equilibrium with distance charges and fuel taxes in the presence of diesel cars

We can discuss the introduction of distance charges in the presence of diesel cars more formally. Assuming that the gasoline tax equals the external cost of gasoline cars, we need to analyze two possible initial equilibria when only fuel taxes can be used.

In the first case the diesel tax charged is larger than the external cost of a diesel car:

$$\theta^d \boldsymbol{t_A^o} - ec_A^d > 0$$

which will be the case when diesel cars are rather clean and there is less of a tax competition for truck fuel. In this case, a substitution of diesel taxes by distance charges $dT_A = -dt_A > 0$, starting from $t_A, t_B > 0$ and 0 < σ < 1, is even more beneficial for country A than in the absence of diesel cars, since the pricing distortion on diesel cars decreases on top of the net revenue gain. So whenever $\theta^d \boldsymbol{t_A^o} - ec_A^d > 0$, this cannot be a Nash equilibrium.

Consider next the case where $\theta^d \boldsymbol{t_A^o} - ec_A^d < 0$. In the absence of distance charges for trucks, this may be an equilibrium when there is strong fuel tax competition for trucks and when the external cost of diesel cars is high. Country A can still benefit from a substitution $dT_A = -dt_A > 0$ but the total benefit will be smaller as the substitution must balance the increasing distortion for diesel cars.

9. Concluding remarks

This paper has analyzed a stylized case of two countries and often we restricted attention to the symmetric case. Real life offers many interesting special cases that we can discuss using our framework. Consider again Switzerland, Austria and Luxemburg, which were special due to geography (cfr. map in Annex 1).

Switzerland is a transit traffic country that has a strategic position in between Germany and Italy. Our two-country model is not designed to study the case of transit countries. However we can easily reformulate the government objective function (7) so that it comes close to the Swiss case. When international traffic is mainly transit traffic like in Switzerland, a country is not interested in the consumer surplus of international traffic. When we assume a very low excise tax, we find that the optimal distance charge is simply the revenue maximizing charge where it is only mitigated by the deadweight loss on the domestic traffic. As Switzerland is a small country but in a strategic corridor that is difficult to avoid, it can generate much more revenue from high distance charges than from undercutting diesel excise taxes. This can explain why it was among the first to introduce distance charges.

The best alternative on the route from Germany to Italy is to pass through Austria. Austria was the first (together with Germany) to follow the example of Switzerland by implementing a distance-charging scheme. As Austria is part of the EU, it must adhere to the cap on distance charges: charges cannot exceed the average infrastructure and air pollution costs. However, there is a provision in the directive that allows “mountainous areas” to charge more. The result is that the Austrian charge is higher than in other EU countries but is only one tenth of the Swiss charge. On the other hand, Austria uses a lower fuel tax than Germany and in this way, obtains a larger share of the international fuel market.

For Luxemburg it is the other way around: a truck can easily avoid passing through Luxemburg, therefore it is not interested in distance charges; instead, it has used the strategy of undercutting the fuel taxes of its neighbors and has blocked many EU proposals to increase the minimum excise rates on motor fuels. This strategy is now at risk. Paradoxically, now that its neighbors are adopting distance charges, Luxemburg may soon plead for minimum fuel excises for diesel in order to protect its revenue base.

Concluding, we have shown that when the only policy option is using a fuel tax for trucks, there is a large risk that countries will set the tax at an inefficient level due to tax competition. The tax may be set above or below the external costs depending on the characteristics of the countries and the market. Small countries may prefer low fuel taxes as this allows them to have more international trucks fuelling in their home country.

If an additional policy instrument is introduced in the form of distance charges, we show that a Nash equilibrium is likely to contain only distance charges. The same tendency will subsist if the fuel tax must also internalize the externalities of diesel cars: some fuel taxes will remain but they will decrease. The end result with distance charges for trucks will be a level of taxation of international trucking that is strictly larger than the external cost. The tax on the use of diesel cars will however be too small.

Our results are important for policy design. This is particularly true in the EU where we currently see strong tendencies towards the implementation of distance-based charges. Judging from geographical developments, the implementation seems to follow a sequential pattern; distance charges are contagious. The central EU states already have a distance-based charge in operation. Several states bordering the central ones are currently working towards implementing such a charge.

Distance charges clearly play an important role in internalizing external costs from freight transportation. However, they can be misused for tax exporting and are also costly to introduce and maintain and, hence, their implementation is not always welfare enhancing.

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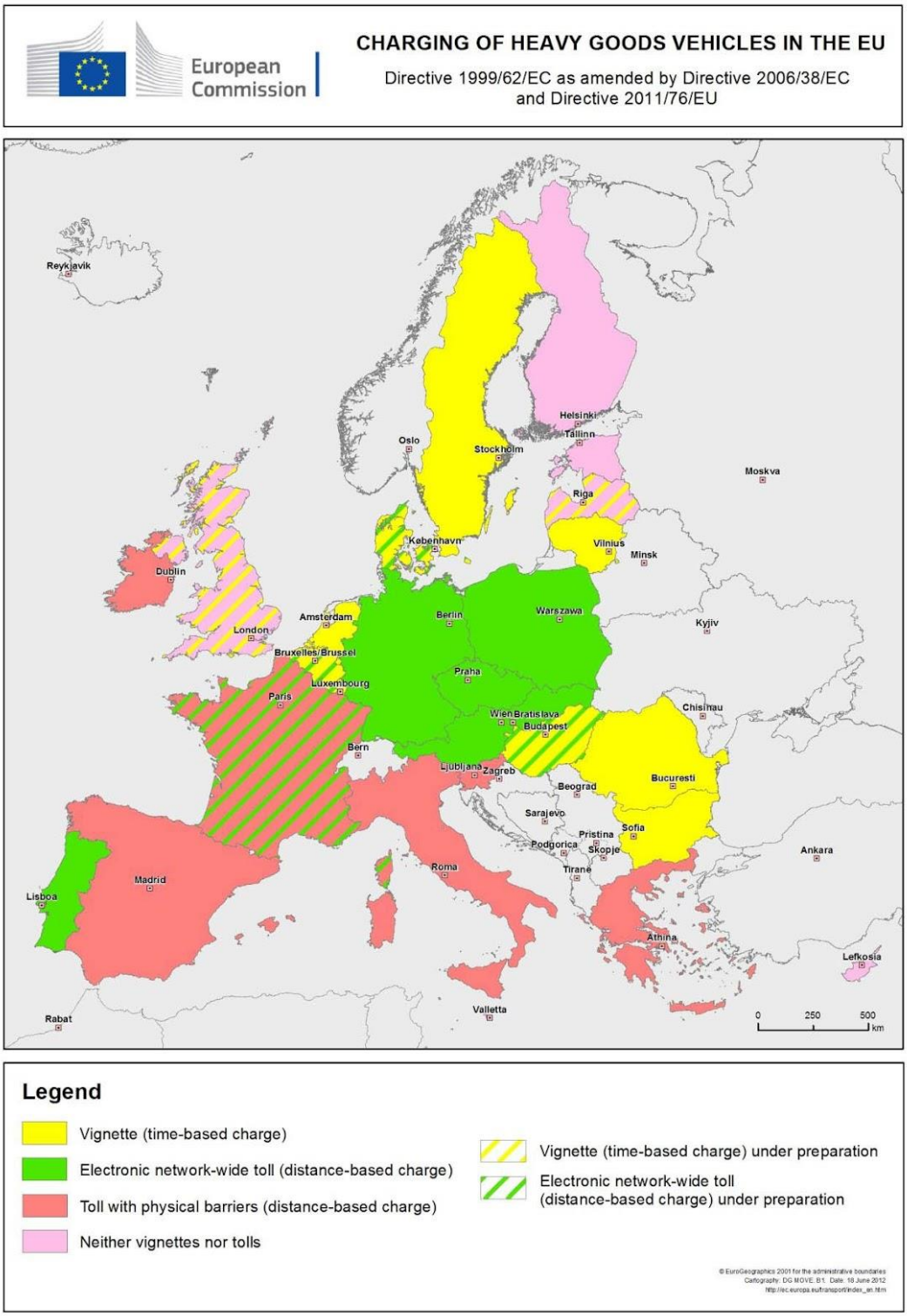
Appendix 1, map illustrating the policy mix in the EU.



Appendix 2 Proof of Proposition 1

Consider first an internal solution, where both fuel taxes are positive. When demand for truck trips is inelastic, the first order for a maximum of the national objective function of country A given by (7) reduces to

$$-0.5\frac{dG}{dt_A}D+\frac{d\sigma}{dt_A}\sigma Dt_A+\sigma D=0$$

Solving this equation with respect to t_A and repeating the exercise for country B gives the reaction functions and the candidate Nash equilibrium:

$$t_A(t_B)=\frac{\gamma}{3\rho}+\frac{t_B}{3} \qquad t_B(t_A)=\frac{1-\gamma}{3\rho}+\frac{t_A}{3}$$

$$t_A^N=\frac{1}{8\rho}+\frac{2\gamma}{8\rho} \quad t_B^N=\frac{1}{8\rho}+\frac{2(1-\gamma)}{8\rho}$$

This is a candidate Nash equilibrium in pure strategies. The Nash equilibrium exists because for acceptable parameter values $0<\gamma<1$ and $\rho>0$, the reaction functions are continuous and have a solution with positive taxes.

Consider next potential equilibriums where $t_A=0$ and $t_B>0$; can this be an equilibrium? No, as country A's objective function is for $t_A=0$ and $t_B>0$ always strictly increasing in t_A. The same reasoning holds for country B so the equilibrium has always positive fuel tax rates.

Appendix 3 Derivation of Prop 2

<u>Derivation of the Nash equilibrium</u>

Starting from the first order condition (7), imposing symmetry implies: $t_A=t_B$ and $\sigma=\gamma$, and one obtains, after multiplying by $(1/\gamma)$:

$$t_A\left[\frac{\delta d}{\delta t_A}+\frac{\delta D}{\delta t_A}-2\rho\right]=\left[\frac{\delta d}{\delta t_A}+\frac{\delta D}{\delta t_A}\right]ec-\sigma D$$

$$\boldsymbol{t}_A^N=\boldsymbol{t}_B^N=\frac{z}{z+2\rho D}\boldsymbol{ec}+\frac{\gamma}{z+2\rho D}\boldsymbol{D}$$

$$z=-(\frac{\delta d}{\delta t_A}+\frac{\delta D}{\delta t_A})$$

<u>Effect of increase in D on Nash equilibrium</u>

$$\frac{\delta t^N}{\delta D}=\frac{2\rho}{(-z-\rho D)^2}+\frac{-\gamma z}{(-z-\rho D)^2}>0$$

<u>Derivation of the critical value of t^*_A for which value there is no longer a Nash equilibrium in pure strategies</u>

We look for the value of t^N_A* such that it produces the same welfare as t_A= ec > t^N_B. Let the objective function of country A be $\Omega(t^N_A*, t^N_B*)$ when it charges the symmetric Nash equilibrium taxes and let $\Omega(t_A=ec, t^N_B*)$ be the value of the objective function when it switches to charging the external cost.

The two objective functions will have the same value when the deadweight loss from charging too low of a tax for local traffic equals the revenue from fuel sales to international trucks. This implies a value for the fuel tax that solves the following equation:

$$\frac{b\gamma}{2}(ec-t_A^*)^2=\gamma D t_A^*$$

With solution

$$t_A^*=0.5\left[2\,\mathrm{ec}+\frac{2D}{b}-\sqrt{\frac{2D}{b}}\sqrt{4ec+\frac{2D}{b}}\right]$$

But as this fuel tax is also a potential symmetric Nash equilibrium, it also must satisfy (10), which gives the implicit equation in ρ:

$$t_A^*=0.5\left[2\,\mathrm{ec}+\frac{2D}{b}-\sqrt{\frac{2D}{b}}\sqrt{4ec+\frac{2D}{b}}\right]=t_A^N=\frac{0.5\mathrm{b}}{0.5\mathrm{b}+2\rho*D}ec+\frac{0.5}{0.5\mathrm{b}+2\rho*D}D$$

Appendix 4 Proof of Proposition 3

We have three possible regimes for the fuel market share: σ=0, 0<σ<1 and σ=1.

We start with the two extreme cases.

If $t_A >> t_B$, we have σ=0, and the preferred $t_A = ec_A$.

If $t_A << t_B$, we have σ=1, and the preferred t_A is derived from the following first order condition for a maximum; using (8) and σ=1, we have:

$$\gamma \frac{\partial d_A}{\partial t_A}(t_A - ec_A) - 0.5D + \frac{\partial D}{\partial t_A}(t_A - ec_A) + D = 0$$

Which this leads to:

$$t_A = (1 - \frac{\frac{\partial D}{\partial t_A}(1-\gamma)}{\frac{\partial D}{\partial t_A} + \gamma \frac{\partial d_A}{\partial t_A}})ec_A + \frac{-0.5}{\frac{\partial D}{\partial t_A} + \gamma \frac{\partial d_A}{\partial t_A}} D$$

When we have an internal equilibrium we start again with the first order condition (8).

$$-\gamma d_A + \gamma \frac{\partial d_A}{\partial t_A}\left(t_A - ec_A\right) + \gamma d_A - 0.5D\frac{\partial G_A}{\partial t_A} + \frac{\partial D}{\partial t_A}\left(\sigma t_A - \gamma ec_A\right) + \frac{\partial \sigma}{\partial t_A} D t_A + \sigma D = 0$$

Simplifying for inelastic international demand, we obtain the two reaction functions:

$$t_A = ec_A - \frac{D}{\frac{\partial d_A}{\partial t_A}} - \frac{\rho D}{\gamma \frac{\partial d_A}{\partial t_A}} t_B$$

$$t_B = ec_B - \frac{D}{\frac{\partial d_B}{\partial t_B}} - \frac{\rho D}{(1-\gamma)\frac{\partial d_B}{\partial t_B}} t_A$$

Appendix 5 Proof of Proposition 4

PROP 4 Assume distance charges can be used and that there are other tax instruments for diesel cars; then a Nash equilibrium cannot have diesel fuel taxes in both countries and $0<\sigma<1$. The equilibrium distance charges are larger than the marginal external cost:

$$t_A = t_B = 0$$

$$T_A - ec_A = \frac{0.5D}{\gamma(b+\beta)} > 0$$

$$T_B - ec_B = \frac{0.5D}{(1-\gamma)(b+\beta)} > 0$$

PROOF

We examine the case where in a potential Nash equilibrium $t_A, t_B > 0$ and $0<\sigma<1$ the international fuel market is shared between the two countries. For this case we will show that a country can always gain by substituting one Euro of diesel tax per kilometer by one Euro of distance charges per kilometer and that therefore such a potential equilibrium cannot be an equilibrium. Next we discuss briefly what happens when $t_A, t_B > 0$ and $\sigma = 0$ or 1.

1. For $t_A, t_B > 0$ and $0<\sigma<1$ we will show that the value of the objective function of country A (the same reasoning holds for B):

$$cs_A\{g_A\{.\}\} + d_A\{.\}(\gamma\, t_A + \gamma\, T_A - \gamma\, ec_A) + 0.5\, CS\{G\{.\}\} + D\{.\}(\sigma\, t_A + \gamma\, T_A - \gamma\, ec_A) - IT_A$$

can be increased by a marginal substitution $dT_A = -dt_A > 0$ when the potential Nash equilibrium has $t_A, t_B > 0$ and $0<\sigma<1$.

We need to examine first the effect of this substitution on the generalized costs in the potential Nash equilibrium:

$$g_A = \gamma(c + t_A + T_A)$$

So the generalized cost of local truck trips g_A will not be affected by substituting t and T. The generalized cost of international traffic is:

$$G = c + \gamma T_A + (1-\gamma)T_B + \sigma(t_A, t_B)\, t_A + \big(1 - \sigma(t_A, t_B)\big)\, t_B$$

After the substitution we see that it also will not be affected:

$$dG = \gamma dT_A + (\gamma - \rho(t_A - t_B))dt_A - \rho t_A dt_A + \rho t_B dt_A = 0$$

We can now compute the effect of this (t,T) substitution on the value of the objective function of country A. There will be no effect on the two first terms of the objective function as local consumer surplus and net revenues on local trips are unaffected by the substitution. There will also be no effect on the consumer surplus of international traffic. The only effect will be on the revenues of international traffic of country A:

$$D\{\ \}\left[\gamma dt_A - \rho t_A dt_A + \gamma dt_A\right] = D\{\ \}\left[\rho t_A dT_A\right] > 0$$

So, as long as $t_A > 0$ one can increase the value of the objective function by this substitution, a Nash equilibrium cannot have $t_A, t_B > 0$ and $0 < \sigma < 1$.

2. Assume that a Nash equilibrium exists with $t_A, t_B = 0$ and we can use the first order optimal conditions for A and B that will characterize the Nash equilibrium:

$$-\gamma\, d_A + \gamma \frac{\partial d_A}{\partial T_A}(T_A - ec_A) + \gamma\, d_A - 0.5\, D\, \frac{\partial}{\partial T_A} + \frac{\partial D}{\partial T_A}(\gamma\, T_A - \gamma\, ec_A) + \gamma\, D = 0$$

$$-(1-\gamma)d_A + (1-\gamma)\frac{\partial d_B}{\partial T_B}\left(T_B - ec_B\right) + (1-\gamma)d_B - 0.5D\frac{\partial G}{\partial T_B} + \frac{\partial D}{\partial T_B}\left((1-\gamma)T_B - (1-\gamma)ec_B\right) + (1-\gamma)D = 0$$

Which gives:

$$T_A - ec_A = \frac{-0.5D}{\frac{\partial d_A}{\partial T_A} + \frac{\partial D}{\partial T_A}} = \frac{0.5D}{\gamma(b+\beta)} > 0$$

And

$$T_B - ec_B = \frac{-0.5D}{\frac{\partial d_B}{\partial T_B} + \frac{\partial D}{\partial T_B}} = \frac{0.5D}{(1-\gamma)(b+\beta)} > 0$$

Therefore the distance charge is always larger than the external cost and the mark-up on external costs is higher in the smaller country.

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