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Road Wear and the Kilometre Charge

A Computable General Equilibrium Analysis

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Abstract

This paper investigates the effects of a re-introduction of a distance-related charge on heavy trucks in Sweden. The kilometre charge is set to cover the annual road maintenance costs and is calculated for 10 different truck and trailer configurations. Three scenarios are simulated in a CGE model of Sweden: (i) the charge alone is imposed; (ii) the charge is imposed while the sum of the annual Eurovignette charge and the annual vehicle tax is lowered to the minimum level set by the European Union; and (iii) as in the former but with twice the level of the kilometre charge. The results imply that the charge leads to significantly reduced road wear although it appears that most of the reduction stems from reduced trucking activity and not from substitution towards less damaging trucks. Extensive substitutions towards other modes take place and only between 56 and 78 per cent of the *ex ante* statically predicted amount of tax revenue could actually be expected to be collected once the charge is imposed. The effects seem to cancel out on aggregate.

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1.0 Introduction

As a step towards making each transport mode bear its own costs, a distance-related charge on heavy goods vehicles has been suggested.[1] Consequently, the European Union (EU) is preparing legislation to make it possible for member countries to levy distance-related charges and to let these replace the Eurovignette system.[2] But while the EU machinery is working on common guidelines, there are concerns among member countries about possible negative effects of any unilateral action. In Sweden the concern relates to the risk of outsourcing trucking to countries with lower costs, and the risk of diminished competitiveness in the transport industry and industries highly dependent on trucking.[3] Concern has also been raised against possible negative fiscal effects of the charges.[4] There is, however, no clear evidence that these effects will materialise. After all, the taxes or charges needed to make trucking bear its own costs represent a relatively small part of the industries' overall costs. Faced with this uncertainty, suggestions have been made to reduce other taxes or charges to offset the consequences of a distance-related charge. These suggestions usually point to the annual vehicle registration tax and the Eurovignette charge as suitable candidates.[5]

This study simulates the effects of implementing a distance-related charge, that is, a kilometre charge, in Sweden. The charge is designed to cover the costs of road wear and deformation. The level of the charge is determined by the status quo annual road maintenance cost and it is differentiated according to the so-called Fourth Power Law. The effects of a simultaneous reduction of the annual vehicle registration tax and the Eurovignette charge to the minimum level set by the EU are also simulated. Similar scenarios have been studied in, for example, Sweden (SIKA 2000), Switzerland (Ecoplan 1998), and in a joint British, Dutch, Swiss, and Norwegian project (European Commission 1998b). However, this study will be able to address a somewhat different set of issues than previous

[1] See European Commission (1995) and (1998a), and SOU 2001.

[2] The Eurovignette (EV) system consists of an annual charge on heavy trucks for the use of most of the major roads in Sweden, Denmark, Germany, and the Benelux countries. Currently, there are distance-related charging systems in operation, for example in New Zealand and Switzerland, and there are systems that have been abandoned, for example the system used in Sweden between 1974 and 1993. See Kågeson (2000) for the EU perspective. A description of New Zealand's system is found in Starkie (1988) and Switzerland's in Suter and Walter (2001). The former Swedish system is described in an official report to the Swedish Parliament, SOU 1969:45.

[3] See, for example, the official reports to the Swedish Parliament, SOU 1997:35, SOU 2000:8, and SOU 2001:61.

[4] See, for example, the official report to the Swedish Parliament, SOU 2001:61.

[5] See the official report to the Swedish Parliament, SOU 2001:61 and SIKA (2000).

studies. These include the effects on commodity output levels, substitution in the truck fleet and towards other modes of transport, fiscal effects, and effects on the overall economy of re-introducing a kilometre charge. To this end a Computable General Equilibrium (CGE) model is applied to a dataset especially developed for the purpose of this study. The model structure is similar to Steininger (2002), a study that also focuses on distance-related road pricing for heavy goods vehicles. However, that study does not include road wear and deterioration in the analysis.

The study will continue in Section 2 by outlining the design of the charge for a number of different truck categories and by presenting the scenarios that will be used in the model. In section 3, the results are discussed and in section 4 some concluding remarks are made.

2.0 The Charge and Scenarios

In this section a short background is provided to the theoretical principles that are at work in relation to road wear and deformation. This will in turn be used as input to the design of the kilometre charge (henceforth km-charge) in the model. The actual level of the charge is designed to cover the status quo annual maintenance cost of sealed roads (rigid and flexible pavement). The charge is then applied in a number of scenarios.

2.1 The idea behind a kilometre charge

Originating in a 1950s study by the American Association of State Highway Officials (AASHO) it has been suggested that road wear and deformation depend on the axle weight of the vehicles using the road.[6] Moreover, the relationship is highly non-linear and as a rule of thumb, based on the empirical tests, the Fourth Power Law has emerged. The results can be summarised as in Small *et al*. (1989, p.11): "Two technological facts are crucial to understanding road wear. First, the equivalence factor [road wear caused by a specific wheel axle] for an axle rises *very* steeply with its load [...]. [...] Second, it is the weight per axle that matters, not total vehicle weight." Although Small *et al*. question the AASHO result by suggesting "...our estimates show a somewhat less steep relationship between pavement life and axle load — closer to a third-power principle than to the fourth-power principle conventionally used...", they are referring to rigid surfaces. For flexible surfaces, such as the asphalt used

[6]For more on this, see AASHO (1962) or its successor, AASHTO (1993).

in Sweden, the famous rule of thumb from the AASHO study, the Fourth Power Law, seems to be verified by Small *et al.* (1989). It is also verified by the Swedish report to Parliament in the 1960s, outlining the km-charge that was introduced in 1974 and abolished in 1993. In that report, it is noted that the power varies extensively depending on the type of road body, but that a study had found a figure of 3.9 for asphalt roads.[7]

The present study acknowledges the principle that it is the axle load that is the main determinant of road wear and deformation. The same holds for model simulations in for example SIKA (2000), European Commission (1998b), Ecoplan (1998), SOU (1997) and in reports such as KFV (2000), DETR (1997), DETR (2000), Mayeres *et al.* (2001) and VTI (1997). Perhaps the most notable study in this area is Small *et al.* (1989).

The Fourth Power Law has several implications for the design of the charge. First, it implies that a charge has to be differentiated according to axle load. This means, for example, that the charge for driving a certain distance should be higher for a two-axle truck weighing 20 tons than for a 20 ton four-axle truck. But it also implies that a 60 ton eight-axle truck and trailer combination could cause less damage than the 20 ton two-axle truck. Hence, one would miss this aspect by categorising the trucks according to weight or if just a few categories were used.[8] Second, following the imposition of a charge, less road wear may be expected to occur for several reasons. One of them is substitution toward less damaging trucks. Hence, although the cost for operating the less damaging trucks increases because of the charge, the use of these trucks could possibly increase. Thus, it is important that this kind of effect could occur also in the model used for simulating the effects of the charge, such as for example in a CGE model.

In this study, the charge is calculated in the following way. First, the number of so-called equivalent standard axle loads (esals) for each of the ten truck categories used in the study are calculated according to:

$$ESALS_j = \sum_i x_i^{\alpha} \tag{1}$$

where for each truck category j the esals consist of the sum of the esal of each individual axle i and where in turn the esal of each individual axle,

[7]The coefficients were 3.241 for rigid and 3.652 for flexible surfaces in the Small *et al.* (1989) study. In a study by NCHRP (1993, p.12) it was found that "Rutting damage is proportional to axle load, and fatigue is roughly proportional to load raised to the fourth power." The results of the Swedish study can be found in SOU 1969:45. A decision to impose the km-charge as of 1 January 1974, was taken in Prop. 1971:153, SkU 1971:67 and rskr 1971:339. For this see SOU 1972:42. See also SOU 1970:36.

[8]As, for example, is the case of the Swiss kilometre charge that was imposed in 2001. It is basically differentiated according to weight and not axle load, see FCA (2000).

x^{α}, is the quotient between the actual axle weight and the standard axle of 8.172 metric tonnes (18 kip) raised to the fourth power (α). That is the meaning of equation (1). The use of double and triple axles is also taken into account, following Kenis and Cobb (1990), for example, and this means that the standard axle reference varies somewhat for double and triple axles.[9] Second, each truck category travelled z km the year in question. Hence, adding the product of the esals and kilometres performed for each truck category according to:

$$ESALKM = \sum_j (ESALS_j * z_j), \tag{2}$$

which gives the total number of esal-kilometres performed in the year. Third, the actual level of the charge is chosen so that the revenue from the charge would cover the annual road wear and deformation and as an approximation to this the annual status quo road maintenance cost is used.[10] The charge per esal-km is calculated according to:

$$\textit{Charge per esal-km} = \textit{road maintenance cost}/ESALKM. \tag{3}$$

Fourth, the charge for a particular truck is now simply determined by the product of the esals it incurs and the charge per esal, according to:

$$(\textit{Charge per vkt})_j = \textit{Charge per esal-km} * ESALS_j \tag{4}$$

where the left-hand side is the charge for the particular truck category. The number of standard axles it corresponds to then determines the charge for a specific truck category. These calculations can be performed by combining the data displayed in Johnsson (2003, Tables C1 and C2 of Appendix C). The result is 0.14 SEK per esal-km,[11] with a resulting km-charge for each category as displayed in Table 1 for each of the three scenarios.

[9] It is assumed that the weight of a truck equals its maximum weight permitted by the vehicle's registration.

[10] According to SOU 1997:35, on p.86 of the Supplement, the status quo annual maintenance cost of sealed roads was approximately 1,856 million 1990 SEK. This is the level of maintenance that keeps the roads in a condition that is in line with the expected life span of the road, that is, the road will be usable for the length of time expected in the investment plan. Road maintenance of sealed roads amounted to 1,889 million SEK in 1995, and this figure determines the level of the charge. The fourth power law implies that cars do not cause enough road wear to be subject to a charge. Buses are included in the data as if they were trucks, basically since no separate data were available.

[11] The status quo level of maintenance was 1,889 million SEK, and at a total of 13,305 million esal-km as a benchmark gives a cost of the road wear imposed of SEK 0.14 per esal-km. This means that it is assumed that the 0.14 is the marginal cost of an esal-km.

Table 1
The Km-charge in the Scenarios, SEK per Vehicle Kilometre

	L2	*L3*	*L4*	*LS21*	*LS22*	*LS23*	*LS32*	*LS33*	*LS34*	*LS44*
SC1	0.60	0.46	0.17	0.92	1.02	0.93	0.72	0.55	1.32	1.04
SC2	0.60	0.46	0.17	0.92	1.02	0.93	0.72	0.55	1.32	1.04
SC3	1.21	0.92	0.34	1.84	2.04	1.86	1.44	1.10	2.65	2.07

Note: The categories L2–L44 are explained in detail in Johnsson (2003, Table C2 of Appendix C). L2 = 2 axles, L3 = 3 axles, L4 = 4 axles, L21 = 2-axle truck with 1-axle trailer, and so on.

2.2 The scenarios

Three different scenarios are employed in the model and they are shown in Table 2. The first scenario, SC1, involves an imposition of the km-charge outlined above. The results of this scenario will show whether the concerns about adverse effects from imposing the charge unilaterally are justified, but also the desirable effects it will have. In the second scenario, SC2, the km-charge is accompanied by a simultaneous reduction of the annual vehicle registration tax and the Eurovignette charge to the minimum level of the European Union.[12] The results will demonstrate whether the suggestions made to alleviate the fiscal effects of the km-charge by reducing other taxes are necessary to offset the overall effect. The third scenario, SC3, is the same as SC2 except that the km-charge is doubled. This scenario is postulated by allowing for the case that the charge for some reason is to cover more than road wear and deterioration. The idea is to provide an alternative "high level" in case a more drastic policy is required at some future date.[13]

The figures in the last two columns of Table 2 are the *ex ante* consequences on tax and charge payments and the government budget implied by the scenarios. By *ex ante* is meant that they refer to implied changes *before* any adjustments to these changes are made by individuals. We see that in all scenarios, the km-charge leads to a net increase in tax payments and a positive effect on the government budget. They would thus at the

[12] This means that the latter two are together reduced by 83 per cent. See Johnsson (2003) Appendix D.

[13] A number of plausible alternative scenarios were considered. An equal yield scenario, where the vehicle registration tax and the Eurovignette charge were reduced to keep the overall government budget in balance was one alternative. However, since the revenue expected to be collected from the km-charge far exceeds the revenue from the vehicle registration tax and the Eurovignette charge, this would turn the latter into a subsidy and that would not be a desirable policy, one would expect. Yet another equal yield alternative would be to determine the level of the charge the other way around, that is, to impose a km-charge at a level that keeps the government budget in balance, while totally abolishing the vehicle registration tax and the Eurovignette charge (or perhaps lowering it to the EU minimum). But neither of these alternatives was judged to be more interesting than the current third scenario.

Table 2
The Scenarios; ex ante Changes (million SEK)

	Label	*Description*	*Tax payments*	*Government budget*
Scenario 1	SC1	Km-charge	+1,889	+1,889
Scenario 2	SC2	Km-charge	+1,889	
		Lowered tax	−730	+1,159
Scenario 3	SC3	Double km-charge	+3,778	
		Lowered tax	−730	+3,048

same time lead to higher taxes for the industries, and the lowered annual vehicle registration tax and the Eurovignette charge are not enough to offset this. However, these are the *ex ante* effects and an objective of this study is to simulate the *ex post* effects.

The km-charge is shown in more detail in Table 1. There we see the levels of the charge (the result of the computations outlined above). For example, in SC1 and SC2 we see that truck category L4 pays a charge of SEK 0.17 per kilometre while a truck in category L2 pays SEK 0.60, even though the latter weighs less, 18 tons as compared to 24. This stems from the fact that the weight applied to each axle is generally higher in the latter case.

3.0 The Model and Results

In this section the results of applying the scenarios in the CGE model are presented. We will start by reviewing the results with respect to the trucking activities, and then continue by reviewing the effects on different commodity output levels. From there we will move into more aggregate measures, such as overall welfare and labour supply. Finally, the results of the sensitivity analysis that has been performed will be reviewed. But first a few words about the model.

3.1 The model

The model is a static, small, open economy, computable general equilibrium (CGE) model, where "general" means that all markets, such as labour market, commodities market, clear, not one at a time as in a partial equilibrium, but simultaneously. Some further details about the model are presented in the Appendix. The main difference from that model is the inclusion of the truck categories discussed above, and this is done in the way implied in Johnsson (2003, Ch.2). The particular nesting structure

Table 3
Results with respect to Trucking; Effect on vkt and esal-km Performed

	Local			*Regional*					*Long-distance*	
	L2	*L3*	*L4*	*LS21*	*LS22*	*LS23*	*LS32*	*LS33*	*LS34*	*LS44*
Scenario 1 %	−10.3	−5.3	2.4	−21.7	−11.8	−9.7	−6.4	−3.5	−11.4	−7.2
Scenario 2 %	−10.2	−5.2	2.4	−21.7	−11.8	−9.6	−6.2	−3.3	−11.2	−7.1
Scenario 3 %	−15.2	−8.9	2.0	−26.8	−17.0	−14.8	−10.5	−7.1	−16.6	−11.9

Note: vkt = vehicle kilometres and esal-km = equivalent standard axle load-kilometres.

used in the model is shown in Figure A1 in the Appendix, together with the corresponding elasticities in Table A1. The elasticities with respect to the transport commodities are described in Johnsson (2003, Appendix F). It is assumed that some truck categories are primarily used locally, others regionally and some for long-distance transport. For example, a truck and trailer of 24 metres and 60 tons is assumed to be used other than locally and an 18-ton single truck is not used for long-distance hauling.

3.2 Effects on trucking

By looking at Table 3, we see the changes in the trucking activities that follow from the simulations. These imply the number of vehicle-km as well as the number of esal-km performed by the different truck categories (since that is exactly the assumption used to calculate the charge in the first place). In the first scenario, SC1, where the km-charge is imposed without any offsetting tax changes, we see that within each trucking nest there is a shift towards the less damaging truck categories. The use of the most damaging truck, the 2-axled 18-ton truck, decreases by over 10 per cent, almost twice as much as the somewhat less damaging truck, the 3-axled 24-ton truck, while there is an increase in the use of the 4-axled 24-ton truck, the least damaging truck category within the nest.[14] Shifts towards less damaging trucks also take place within the other nests, namely in the "regional" and the "long-distance" nests. But all of these shifts also include an overall drop in the total number of vehicle-km performed. In the second scenario, where the km-charge is imposed but the vehicle registration tax and the Eurovignette charge are lowered, the effects are very similar to the first scenario. There is a shift towards less damaging trucks, in the same way as in SC1. The activity of each truck category decreases to a slightly smaller extent in this scenario, as compared to SC1. In the third

[14] Here one of the major advantages of a CGE model becomes evident: there can be an increased activity even at a higher price. It is only within the general equilibrium framework this kind of effect is possible. The central principle at work is, of course, the principle that only relative prices are important.

Table 4
Effect on Road Wear

	vkt %	*esal-km* %	*Road wear* mSEK
Scenario 1	−8.5	−9.5	−179
Scenario 2	−8.4	−9.4	−177
Scenario 3	−13.0	−14.3	−270

scenario, identical to SC2 except that the level of the km-charge is doubled, there is a further move towards less damaging trucks but with a larger reduction in overall activity. The use of one category falls by 27 per cent. Notably, there is still an increased activity level in truck category L4.

The overall effects of the scenarios on vehicle-km and esal-km performed are summarised in Table 4, together with the implied changes in road wear. As the second and third columns show, the drop in number of esal-km performed closely follows the drop in number of vehicle-km performed. The only difference is that the esal-km performed drops by around one percentage unit more than the vehicle-km performed. This "extra" drop is caused by the shift towards less damaging trucks. If these figures are translated into the measure of road wear used in this study, that is, the status quo maintenance cost, the scenarios imply a drop in road wear, or maintenance cost, of between 179 million SEK and 270 million SEK, that is, by between 9.5 and 14.3 per cent. The bulk of this saving comes from the general drop in vehicle-km performed by heavy trucks, while only a smaller part comes from the shift towards less damaging trucks.

Table 5 shows the consequences for road wear in the scenarios once again, this time split up according to the different nests. The results are of course highly dependent on simplifying assumptions such as that only truck categories L34 and L44 are used for long-distance transport. Nevertheless, they might serve as an indication of what might happen in the local, regional, and long-distance trucking markets.

Table 5
Effect on Local, Regional and Long-distance Related Road Wear

	Local mSEK	*Regional* mSEK	*Long-distance* mSEK	*Total* mSEK
Scenario 1	−43	−38	−98	−179
Scenario 2	−43	−38	−96	−177
Scenario 3	−66	−58	−146	−270

Table 6
Non-transport Related Output

Industry/Commodity	*Output Billion SEK*	*Scenario 1 %*	*Scenario 2 %*	*Scenario 3 %*
Agriculture and fishing	32.66	−0.3	0.1	0.0
Forestry	26.30	−0.1	0.0	0.0
Mining	10.99	−1.5	−1.4	−2.5
Other industries	158.24	−0.4	0.0	−0.3
Pulp and paper mills	133.67	0.1	0.0	0.1
Chemical industries	69.13	0.3	−1.0	−1.2
Basic metal industries	60.45	0.4	0.3	0.5
Engineering	328.57	0.2	0.3	0.4
Electricity, gas and water	65.17	0.0	0.0	0.0
Construction	130.50	−0.1	0.0	0.0
Postal services	43.02	0.0	0.0	0.1
Real estate	275.27	−0.1	0.0	−0.1
Public service	476.93	0.2	0.1	0.3

Note: Output destined for both domestic and foreign markets.

Most of the reduction in road wear will appear in relation to the long-distance trucking. This means that most savings will occur on regional and inter-regional trunk roads, that is, on the network of roads used for long-distance transport. But it is possible that the savings will also occur on the not-so-major rural roads used for transporting lumber, for example, from forest areas. Regardless of where it occurs, it is the really heavy trucks that will be less used, or used in such a way as to cause less road wear, by using less damaging trucks.

3.3 Effects on a commodity basis

In the following review and analysis, we will focus on SC2 and only comment on the other two scenarios where this is considered appropriate. Table 6 shows that most of the output levels of the different non-transport related commodities are by and large left unaffected in all of the scenarios.[15] There are, however, commodity output levels that are affected negatively as well as those that are affected positively. The most negatively affected industries are the mining and chemical industries. This might be a little surprising since they are not perhaps perceived to be great users of trucking. Instead, it is possible to find an explanation in the structure of the use of trucks. The use of trucks in the mining industry is concentrated in

[15] Each commodity is primarily produced by the industry with the same name. For the transport related commodities, see Johnsson (2003).

categories L2–L4 and LS34–LS44, which together account for 87 per cent of the total vehicle-km performed. Within these nests, most of the activity is concentrated in the most damaging trucks, and it is exactly the use of these categories that involves the highest kilometre charges. The chemical industry has a somewhat different structure, where 73 per cent of the vehicle-km are performed by categories L2–L4 and the rest by category LS22. The model allows the industry to substitute towards less damaging categories within the L2–L4 nest. However, the model does not allow any substitution away from LS22 towards other truck categories within the nest since these zero-entries are simply treated as non-alternatives to substitute towards. This means that as a high charge is imposed on the highly damaging LS22 category, it is difficult for the chemical industry to adapt to this in the model.[16]

The effects on the transport related industries are shown in Table 7. As the charges are introduced, the for-hire trucking activity is reduced. But this effect is dealt with above since it is integrated in the overall trucking activity (in-house and for-hire) in a Leontief fixed share nest. Freight by bus is also reduced. This effect is implied by the drop in overall trucking activity, since the charge as it is designed in the model does not distinguish between heavy trucks and buses. Perhaps a surprising result is the reduction in bus passenger traffic. It is modelled as an intermediate substitute in production, so this cannot explain the result. Instead, the effect has to stem either from the final demand side or from the transformation elasticity between the outputs of the "Other land transport" industry.

There is substitution towards freight activity by rail as the "Railway freight" increases by 0.7 per cent. This effect is expected since the charges are levied on an obvious substitute. There is also a slight increase in railway passenger traffic, most probably stemming from the final demand side and not from the production side.

There are two major activities produced by the shipping industry, the freight and the passenger activities. The slight increase in the freight activity is to be expected since it is modelled as a substitute to trucking. However, the rather large reduction in passenger traffic by boat is perhaps surprising. It is not plausible that this stems from the intermediate demand side, but rather from the output transformation elasticity or the final demand side. Some could accrue to the former, but not much since the transformation

[16] Furthermore, there is a slight possibility that the use of trucks by these two industries is overestimated. For example, the mining industry uses a lot of underground transport and it is possible that this is treated as trucking in the dataset and the model. Also the chemical industry is highly dependent on petroleum products, for example as plastics are produced. Some erroneous accounting may also have taken place here.

Table 7
Transport Related Output

Industry/Commodity	*Output Billion SEK*	*Scenario 1 %*	*Scenario 2 %*	*Scenario 3 %*
Other land transport	69.1			
Bus passenger	11.76	−1.4	−1.2	−2.2
Bus freight	1.30	−0.6	−0.5	−0.9
For-hire trucking	47.57	−2.4	−2.3	−4.1
Taxi	7.23	−0.5	−0.4	−0.7
Car parking/car leasing	1.24	0.8	0.8	1.5
Railway	13.06			
Railway passenger	3.84	0.0	0.1	0.1
Railway freight	9.22	0.7	0.7	1.2
Shipping	18.66			
Shipping passenger	2.54	−1.4	−1.4	−2.2
Shipping freight	12.98	0.1	0.1	0.2
Route services	0.61	0.2	0.1	0.2
Stowage services	0.96	0.7	0.6	1.3
Harbour services	1.56	−0.2	−0.2	−0.2
Airline companies	16.9			
Air passenger	13.52	0.9	0.9	1.7
Air freight	3.38	1.3	1.1	2.2
Travel agencies/forwarding	13.77			
Travel agencies	3.19	0.8	0.9	1.6
Private international charter flights	4.48	−0.1	0.0	−0.1
Freight forwarding	6.10	0.9	0.9	1.7
Services	623.6			
Services less	614.61	−0.1	0.0	−0.1
Petrol for transport by households	8.99	−0.1	−0.1	−0.2
Petroleum refineries	7.79			
Petroleum products less	4.65	−0.4	−0.3	−0.5
Diesel for transport	0.86	0.4	1.8	1.9
Petrol for transport by industries	2.28	2.3	0.7	0.7

Note: Output destined for both domestic and foreign markets.

elasticity is close to a Leontief fixed share. Instead it is most likely that it stems from the latter. Freight by air increases somewhat and as a substitute to trucking, this is to be expected. We also see that passenger traffic by air increases. This effect most probably stems from the final demand side since it only plays a minor role in production.

The petrol used by households for transport purposes, mainly car-use, is hardly affected at all. This is perhaps to be expected since the kilometre charges are levied on heavy vehicles and households do not use heavy vehicles at all in the model. On the other hand, we see that the kilometre charge instigates substitution towards diesel for transport other than for heavy trucks, that is, mostly for lighter trucks, and towards vehicles fuelled by petrol. The latter might include heavy trucks fuelled by petrol, since

Table 8
Aggregate Measures

	Real Wage[a] %	*Labour supply* %	*Equivalent Variation* %
Scenario 1	−0.07	0.01	−0.12
Scenario 2	−0.02	0.01	−0.06
Scenario 3	−0.06	0.03	−0.13

[a]Wage/utility index.

these are not subject to the charges in the model, so the effect could be somewhat overestimated.

3.4 Aggregate measures

Table 8 reports the changes in the real wage, the labour supply and the Hicksian Equivalent Variation. The changes in real wage are counted in hundredths of a percentage point, that is, the tax changes seem to have close to zero effect on the real wage. The same holds for the labour supply. The Equivalent Variation welfare measure shows that the tax changes will result in a slight decrease in the welfare of the households. However, the changes are relatively small also in this case, especially in the main scenario. The result can be interpreted as the percentage of current income the consumers are willing to pay to have the tax changes, that is, they are close to neutral on the subject. Remember that these are not balanced budget simulations and that, *ex ante*, the overall tax payments increase (more on this below). This effect is perhaps to be expected, since, first of all, the households do not directly consume trucking activities and, second, since they would only be affected indirectly and as they have the possibility to substitute towards other commodities if a particular commodity is seriously affected and even if domestic producers are affected negatively, this will be offset to a certain degree by larger imports, so that the total supply is less affected. Another way for households to be affected would be via their income from labour and capital, but as the real wage proved to be largely unaffected, this explanation seems unlikely. In addition, please be careful to note which are the welfare effects included in the model. For example, there are no environmental or congestion welfare effects included in these results.

The fiscal effects, that is, the effects on total tax payments and the government budget are shown in Table 9. To understand this table, we start by recognising that it is divided into *ex ante* and *ex post* effects. The *ex ante* effects simply state that in SC2, for example, the revenue from the vehicle registration tax and the Eurovignette charge are together

Table 9
Tax Payments and Changes in the Government Budget

				Total change
Costs	*SC1 — Government*		*Revenue*	*Ex ante — static*
Road maintenance	0	..	Vehicle reg. + EV charge[a]	
		+1,889	Km-charge	
	0	+1,889		+1,889
Costs	*SC2 — Government*		*Revenue*	
Road maintenance	0	−730	Vehicle reg. + EV charge[a]	
		+1,889	Km-charge	
	0	+1,159		+1,159
Costs	*SC3 — Government*		*Revenue*	
Road maintenance	0	−730	Vehicle reg. + EV charge[a]	
		+3,778	Km-charge	
	0	+3,048		+3,048
Costs	*SC1 — Government*		*Revenue*	*Ex post — dynamic*
Road maintenance	−179	..	Vehicle reg. + EV charge[a]	
		+1,710	Km-charge	
		−696	Other tax payments	
	−179	+1,014		+1,193
Costs	*SC2 — Government*		*Revenue*	
Road maintenance	−177	−730	Vehicle reg. + EV charge[a]	
		+1,712	Km-charge	
		−254	Other tax payments	
	−177	+728		+905
Costs	*SC3 — Government*		*Revenue*	
Road maintenance	−270	−730	Vehicle reg. + EV charge[a]	
		+3,508	Km-charge	
		−1,340	Other tax payments	
	−270	+1,438		+1,708

[a]Benchmark payments amount to 877 for industries and 216 for households.

reduced by some 730 million SEK, while the revenue from the km charge means an addition of 1,889 million SEK. At the same time, nothing is done with the cost of road maintenance, for example. Hence, the government budget would increase by a total of 1,159 million SEK. This is the change in the budget that we can say will occur prior to any substitutions, that is, *ex ante*. These figures were also shown in Table 2 above.

If we turn to the *ex post* results, we see in SC2 that the adjustment to the new tax scheme causes the km charge payments to decrease by 177 million SEK from the *ex ante* 1,889 million SEK to a net increase of 1,710 million SEK. At the same time, the cost of road maintenance is reduced by the same 177 million SEK, also strengthening the government budget. The reduction of the vehicle registration tax and the Eurovignette charge by 730 million SEK is followed by another 254 million SEK in reduced payments from other taxes. The latter could be explained as, for example, lower CO_2 tax payments as trucks are used less. In all, we see that the government budget is strengthened by 905 million SEK in the second scenario.

The simulated tax changes result in changes in the government budget of +1,193, +905 and +1,708 million SEK in scenarios SC1, SC2, and SC3 respectively. This amounts to respective increases of +0.2, +0.2, and +0.3 per cent in the modelled government budget. Hence, we see that the changes that occur in all three scenarios are small in relation to the overall government budget in the model. The fears that the km-charge would leave holes in the government budget would thus seem to be unfounded. There is, however, another important lesson to be drawn from these simulations. We see that the *ex ante* changes in tax revenue are not at all the revenue that one could expect to be able to collect. Of the *ex ante* revenue increases, only 63, 78, and 56 per cent were actually collected.

3.5 Sensitivity analysis

The aim of the sensitivity analysis is to try to see how robust the results are with regard to certain assumptions about parameter values, in particular the elasticities. The procedure, a so-called unconditional systematic sensitivity analysis, follows Harrison and Vinod (1992). The idea is that the model is solved over and over again with some key parameters being simultaneously perturbed.[17] The sensitivity analysis is limited to the main scenario, SC2, for the sake of briefness.

[17]The key parameters are those elasticities assigned a distribution in Table A1 of the Appendix. Following Harrison and Kriström (1997) and Hill (1998), the sample size, that is, the number of times the model is solved, is set to 1,000. As for example Harrison *et al.* (1993) explain, the procedure is said to test the "robustness" of the results. Note that not all distributions are assumed to be normal, and the critical *t*-values presented here are therefore valid only asymptotically.

Table 10
Trucking

	L2	*L3*	*L4*	*LS21*	*LS22*	*LS23*	*LS32*	*LS33*	*LS34*	*LS44*
SC2	−10.15	−5.21	2.41	−21.73	−11.84	−9.55	−6.18	−3.32	−11.22	−7.06
t-value[a]	24.97	30.61	28.11	13.54	33.95	36.45	41.95	36.75	29.25	27.11

[a]Over 1,000 solutions.

Table 11
Equivalent Variation[a]

	Result
SC2, %	−0.06
t-value[b]	−1.93

[a]Results of 1,000 solutions.
[b]*t*-value computed as (point estimate − 0)/standard deviation over 1,000 solutions.

Turning first to Table 10, we see that the change for each truck category appears to be robust and the *t*-value seems to indicate that the results are statistically significant at a 5 per cent level of statistical significance.

The result of the sensitivity analysis with regard to the Hicksian Equivalent Variation welfare measure is shown in Table 11, where we see that the small change in Equivalent Variation of SC2 proved in fact to be insignificant at a 5 per cent level of statistical significance.

Thus, we see that the results presented in the tables seem to be robust with respect to the assumptions made about the key parameters in the model. The results that proved to be not significant do not affect the main results of the simulations.

4.0 Concluding Remarks

The results presented in this study give an indication of the effects that can be expected from an introduction of a km-charge based on the Fourth Power Law. There are some interesting conclusions that can be drawn from the results presented so far. First, imposition of the km-charge will lead to lower road wear and the decrease in road wear will occur in all the scenarios. Second, by comparing SC1 and SC2 we can conclude that the effects on road wear are not influenced by the simultaneous reduction of the vehicle registration tax and the Eurovignette charge to any large extent. This is perhaps to be expected, since the vehicle registration tax and the Eurovignette charge are not in any strong relation to the actual use of the road, and are thus not expected to influence the road wear if lowered. Third, the results indicate that the effect of the km-charge will largely come from a general reduction in trucking activity, that is, less heavy truck traffic, and only to a lesser extent from shifts towards less damaging trucks. This follows from the fact that the changes in vehicle-km are about the same as the changes in esal-km, a result that is perhaps surprising. It also indicates that most of the effect would occur even if the tax was only a weight–distance related charge, as opposed to the axle-load–distance related charge used here.[18] This actually contradicts the importance of the Fourth Power Law since the results indicate that most of the decrease would occur even if a first power were used (because a first power would imply a weight–distance charge). Finally, the major part of the decrease in road wear is related to the decrease in long-distance trucking.

We have also seen how a km-charge could affect the output level of different commodities. For example, we have seen that modal shifts towards freight by rail, ship and air may occur as in-house and for-hire trucking decrease. Moreover, in-house road transport fuelled by petrol and that fuelled by diesel, other than the heavy trucks, also increases. Furthermore, the imposition of the km-charge and the simultaneous reduction in the vehicle registration tax and the Eurovignette charge do not seem to affect overall real wages, labour supply, or household welfare. Finally, we have seen that the *ex ante* changes in expected tax revenue are possibly overstated and perhaps only 56 to 78 per cent of the *ex ante* amounts could actually be expected to be collected. This means that as road maintenance is fully covered, although at a lower level due to the effects of the charge, other tax revenue fall (such as energy taxes). On the other hand, the amounts involved do not affect the overall government budget to any large extent.

Thus, in short, road wear will decrease, mainly because fewer vehicle-km are performed, but also because of modal shifts and shifts toward other road transport than heavy trucks. The effects seem to cancel out on aggregate, leaving households unaffected. The overall government budget is only affected in a limited way, although the tax revenue is not as large as one could expect beforehand.

[18] Once again this applies, since the effect largely comes from decreased activity and not shifts to less damaging trucks. This has been ascertained in Johnsson (2003, Ch.5).

These results may add some new insights into the possible effects of a km-charge. In the future, it might be interesting to follow up on the indication that was found in this study about the apparently limited importance of the Fourth Power Law. Most of the effects seem to be driven by the overall level of the charge and not so much by the non-linearity that was integrated into the design of the charge.

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Appendix: The Model

The model is a static, small, open economy, computable general equilibrium (CGE) model in the Shoven and Whalley (1972) tradition, calibrated to fit the Swedish input–output (IO) matrices of 1995.

Based on neo-classical micro-economic theory, there are several profit maximising firms producing commodities using intermediate inputs (that is, other commodities as well as some of the same commodity) as well as labour and capital inputs. The production exhibits constant returns to scale and the output is sold on so-called "perfectly" competitive commodity markets. This can be described as:

$$Y_j = G_{ji}(I_{ji}, VA_j) \tag{A1}$$

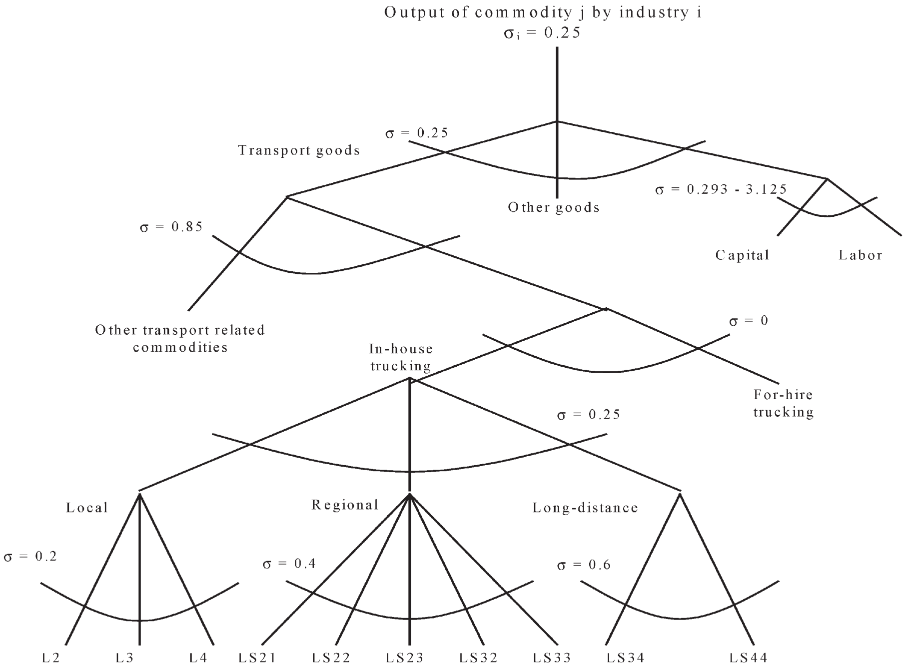
where the jth industry, Y, produces one or more commodities, G_i, using intermediate inputs, I_i, and value added, VA. The subindices j and i denote an industry and a commodity, respectively. The value added consists of capital and labour input according to:

$$VA_j = VA_j(K_j, L_j) \tag{A2}$$

where K and L denote capital and labour inputs respectively. The production functions are Leontief, Cobb-Douglas, or CES. The output of each commodity is designated to the export or the domestic market. Together with the imported commodities the output designated for the domestic market form the domestic supply. The imports are modelled according to the Armington (1969) assumption, meaning that imported and domestic commodities are not perfect substitutes, but rather only close substitutes. For symmetry reasons the same applies for the exports.

The labour market is modelled as a competitive market that is cleared by adjustment of the real wage rate. The labour supply function is calibrated according to Ballard (1999), whereby the labour supply function is calibrated to the desired labour supply elasticity. As Ballard points out, the labour supply elasticity determines the elasticity of substitution between commodities and leisure in the utility function. Or, conversely, by choosing

Figure A1



the latter, one indirectly determines the former, something that often seems to have been overlooked in CGE modelling. Ballard shows that this is of great importance, among other things for the welfare results.[19]

The domestic supply is either consumed as intermediate input, as an investment commodity, or consumed by the government or by a representative consumer. The final demand of the representative consumer is represented according to a utility function:

$$U = U(G, l) \tag{A3}$$

where the consumer derives utility from consuming commodities, G, and leisure, l. The consumer finances the purchases by selling their endowments of capital and labour to the producers in the labour and capital markets. In addition, the consumer also receives transfers from the government and the consumer carries out the investments. The government finances its consumption by collecting taxes from producers and the consumer. The model is closed by balancing the current account, keeping it at the benchmark level by adjusting the real exchange rate.

[19]See Johnsson (2003, Appendix B) for a fuller description of Ballard's point in relation to the current model.

Table A1
Some Key Elasticities used in the Model

Description	*Value*	*Std.*[d]	*Distribution*
Production			
Elasticity of substitution between intermediate inputs and the composite of primary factors	0.25	(0.0, 0.5)	uniform
Elasticity of substitution between labour and capital input	0.293–3.125[a]	0.0268–0.2411	normal
Elasticity of transformation between commodities for domestic market and goods for export market	4.0		
Elasticity of transformation between diesel for different truck uses in PETR sector	4.0		
Armington elasticity of substitution between imported and domestically produced commodities	4.0[b]		
Elasticity of substitution between input of "local" trucks	0.2	(0.0, 0.4)	uniform
Elasticity of substitution between input of "regional" trucks	0.4	(0.2, 0.6)	uniform
Elasticity of substitution between input of "long-distance" trucks	0.6	(0.4, 0.8)	uniform
Elasticity of substitution between transport modes	0.85	(0.09, 1.52)	uniform
Private consumption			
Elasticity of substitution between aggregate leisure and a composite of all commodities	1.33[c]	See[c]	See[c]
Elasticity of substitution between different commodities	1		
Government consumption			
Elasticity of substitution between commodities	0.0		

[a] Harrison *et al*. (1993).
[b] Equal in production and consumption. This is the so-called Armington elasticity after Armington's (1969) article.
[c] Implies an uncompensated labour supply elasticity of 0.1 in the benchmark data. This estimate is perturbed in a uniform (0.05, 0.15) distribution. The uncompensated labour supply elasticity is used, as opposed to the compensated labour supply elasticity, because of the notion that the consumers are not compensated for any losses incurred as a result of the new charge.
[d] For the uniform distributions the value within the parenthesis signifies the boundaries. The 0.1 value of the uncompensated elasticity is in line with, for example, Wikström (1996).

The nested production structure is given by Figure A1, where also the point estimates of the elasticities are shown.

In Table A1 the key elasticities are shown, together with their assumed distributions. For more about the elasticities, see Johnsson (2003, Appendix F).