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Transport Tax Policy Simulations and Satellite Accounting within a CGE Framework

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Abstract

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This thesis consists of an introduction and four self-contained essays:

Essay 1, *Transportation Satellite Accounts – Measuring the Size of the Transport Industry in Sweden in 1995*, develops Transportation Satellite Accounts, where an estimate of the expenditure on different in-house transportation activities is singled out from the Swedish 1995 input-output matrices of the National Accounts. The results show that for example in-house transportation amounts to 1.7% of GDP as compared to the for-hire figure of 1.9%.

Essay 2, *Transportation Industry Representation in CGE Modeling – Does it Matter?* addresses the question of whether the transportation industry representation has an impact on the results of tax policy simulations in CGE models. This is done by analyzing an equal yield CO_2 tax policy reform in two separate models, where only the transportation industry differs. The choice of transport industry representation might be significant, as the results were lessened, magnified, or even pointed in the other direction depending on the model used.

Essay 3, *Road Wear and the Kilometer Charge – A Computable General Equilibrium Analysis*, investigates the effects of a re-introduction of a distance-related charge in a CGE model of Sweden. The results imply that the charge leads to reduced road wear but also that it appears that most of the reduction stems from reduced trucking activity and not from substitution towards less damaging trucks. The overall effects were modest.

Essay 4, *The Cost of Relying on the Wrong Power – Road Wear and the Importance of the Fourth Power Rule*, investigates the effect on road wear and deformation of alternatives to the Fourth Power Law (i.e. the first through fifth powers) in a CGE model of Sweden. It also investigates the cost of designing a charge according to the wrong power. The results for example imply that the cost of choosing the wrong power is relatively small. And as designing the charge according to the first power amounts to a weight-distance charge rather than an axle-weight-distance, the results reveal that there are implicit costs of implementing the former.

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Acknowledgements

> ”Knowledge is the object of our inquiry, and men do not think they know a thing till they have grasped the 'why' of it (which is to grasp its primary cause).”
>
> – Aristotle, *Physics,* 350 B.C.
>
> “All things are subject to the law of cause and effect. This great principle knows no exception, and we would search in vain in the realm of experience for an example to the contrary.”
>
> – Carl Menger, *Principles of Economics*, 1871

When I was a young boy, my late mother always used to say that she wanted me to be a doctor, although I know she intended me to be a medical doctor. Somehow I have had this wish in the back of my mind and it has become more and more vivid during the last couple of years. And now my Ph.D. thesis is finally in print, something that I am certain would have made my mother immensely happy and proud. Personally, I regard this as one of my greatest achievements, if not the greatest, and it makes me happy and proud as well.

In addition to my own mental effort, one fundamental prerequisite for the existence of this publication is that I happen to be born and live in a place where some freedom of opportunity exists. The opportunities presented to each individual are basically unlimited, but without the freedom to seize any of them, they are of no value. Where there are no alternatives, there can be no values. Without the freedom to seize the opportunity presented to me, this thesis would not exist.

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I would like to cherish the love and memory of my dear mother, Bodil, by dedicating this publication to her.

Djursholm, January 2003

Richard Johnsson

Chapter 1 – General Introduction

This thesis consists of four separate essays. Although they are self-contained, they could very well be regarded as a monograph studying different aspects of a general problem. The essays are essentially about problems related to transportation. Economists often consider this area to contain a number of school examples of interesting economic problems. Of all these, the thesis basically deals with problems related to (i) accounting of transportation activity in the national accounting system, and (ii) a wider category of transport-related externalities and cost recovery. One of the essays falls into the former category and the other three into the latter. A short background will hopefully make the content clearer and also serve as a motivation for the existence of each separate paper.

Transport-related problems were often previously analyzed with the help of partial equilibrium models where the analysis focused primarily on the effects on the transport sector. With increasing computer capacity, the use of a general equilibrium for modeling the transport industry grew. The idea of a general equilibrium is present in a variety of different kinds of models in this area of research, many of which had a spatial dimension and were based on generalized costs. Swedish examples of this general class of models are Westin (1990), Hussain (1996), Johansson and Persson (1996) and Tapper (1997).

However, there was a need for a kind of general equilibrium model that could also include the more financial or fiscal effects, as expressed for example in Jansson and Wall (1994). When studying the effects of petrol tax changes, they noted that “in addition to all factors of uncertainty just mentioned, it should be added that the result stems from a partial analysis. In a general equilibrium analysis it would be possible to take into account a number of further effects that occur” when the petrol tax is changed[1]. They explain what they have in mind is that “to calculate the total effect of petrol tax changes on the financial balance of the ’consolidated public sector’, a number of additional factors have to be taken into account. Due to several ’leakages’ a petrol tax rise will make a rather modest improvement of that balance”[2]. By this they refer to the possibility that as one tax is increased,

[1] Jansson and Wall (1994), p. 53 (my translation).
[2] Jansson and Wall (1994), p. 80.

the new production and consumption patterns might very well lead to considerably lower overall tax revenue than is perhaps expected.

This need could be filled by using for example a so-called Computable General Equilibrium (CGE) model in the Shoven and Whalley (1972) tradition. This is a kind of model that is very often used by economists for analyzing changes in environmental taxes, for example a CO_2 tax. The kind of studies analyzing energy-related matters always indirectly analyze the transport industry as it is a heavy user of energy. Some studies have also attempted to analyze the transport industry more directly by using CGE models of this kind, for example Harrison and Kriström (1997) and Steininger (2002).

However, in attempting to do this, another problem emerges or becomes evident. The models in the Shoven and Whalley (1972) tradition are calibrated to a benchmark data set, and this data set is typically the input-output (IO) matrices of the National Accounts (NA). But in the NA system, there happen to be practices of accounting that could lead to a systematic under-valuation of the transport sector. One reason for this is the existence of so-called in-house transportation services. When a firm chooses to own and operate its own trucks, the value of that activity shows up as an output of the corresponding industry, and not as an activity of the transportation industry. This is a pure accounting problem, meaning that the transportation activities are actually accounted for, but in a way that make them appear at a smaller value than they really account for. The solution to this and other similar accounting problems goes under the name of satellite accounting, or Transportation Satellite Accounting (TSA) in this case. This process tries to rearrange the existing accounts by combining different data sources to fit a specific purpose.

Furthermore, as the IO data is developed to include more information on transport related issues, the question arises to what extent this development affects the overall results of the kind of CGE model used. And could earlier models have been providing us with the wrong results as they where based on the IO matrices that contained the systematic accounting bias? This issue could be studied by analyzing a tax change, for example in CO_2 tax, in two separate models, one calibrated to the original IO matrices and one calibrated to the TSA matrices.

One specific topic that could be analyzed in a CGE model calibrated to TSA matrices is the problem of road wear and deformation. In the 1990s, there was growing interest, both in Sweden and the European Union, in using road pricing to solve the problem of increasing infrastructure costs. The theoretical solution is suggested to be some kind of distance-related charge, mainly for heavy vehicles. This follows from a study conducted by the American Association of State Highway Officials (AASHO (1962)) in the 1950s and early 1960s, that resulted in what has come to be known as the Fourth Power Rule. According to this rule, road wear and deformation depend mainly on axle-weight rather than for example total vehicle weight, and the relation is highly non-linear.

However, over the decades since the original AASHO study, further research has pointed towards a number of factors that also influence road wear and deformation and that were perhaps not accounted for in the original study. One question was how the results of introducing an axle-weight charge were affected by the choice of other powers than the fourth. By studying this in a CGE model, it would be possible to get an indication as to whether the choice of power had any major impact on road wear and deformation at all. Furthermore, it would also be possible to obtain an indication of the costs involved if the wrong power was chosen, for example if the charge was designed according to The Fourth Power Rule and the true relation was the second power.

Before turning to a short summary of the essays, the general structure of the IO matrices is outlined. This will save the reader some thinking later on and will make it possible to present the papers on the assumption that the reader already knows something about IO matrices. In Table 1 the IO Make matrix (output matrix, production matrix) shows the value of the commodity output of the different industries in monetary terms. Each industry is the primary producer of the commodity with the corresponding name (the diagonal elements), but may also produce some secondary commodities (the off-diagonal elements). The row sum is the industry output and the column sum the commodity output. As indicated in the bottom right cell of the table, the total industry output is identical to the total commodity output. All entries in Tables 1 are fictional and are purely for educational purposes.

Table 1 - The TSA Make of Commodities by Industry*

		Commodity				
		Agriculture, forestry and fishing	Manufacturing	Transportation	Services	Total Industry Output
Industry	Agriculture, forestry and fishing	20				20
	Manufacturing		100	10	10	120
	Transportation			40		40
	Services			10	110	120
	Total Commodity Output	20	100	60	120	300

*The figures are in monetary terms

Table 2 displays the IO Use matrix (input matrix, consumption matrix), which could be divided into three sub-matrices. The italicized elements under the ‘Industry’ heading and on the ‘Commodity’ rows represent the intermediate inputs in the industrial production. The sub-matrix below it shows the industry imports and value added. Along a specific industry column we thus see the use of intermediate inputs, imports and value added used in the production of that industry’s output. The matrix on the right of the first matrix is the final demand matrix and it shows how the output not used for intermediate inputs is used. The row sum thus corresponds to the total commodity output.
Comparing Tables 1 and 2 we see that the row sums in Table 1 correspond to the column sums in Table 2 and vice versa. The total industry output is still identical to the total commodity output. This latter feature of the IO matrices is referred to as consistency, i.e. a matrix is consistent, throughout this publication.

Table 2 - The TSA Use of Commodities by Industries*

		Industry					Final Demand				
		Agriculture, forestry and fishing	Manufacturing	Transportation	Services	Total intermediate inputs	Private consumption	Government consumption	Investment	Exports	Total Commodity Output
Commodity	Agriculture, forestry and fishing	*1*	*3*	*0*	*0*	*4*	8	5	2	1	20
	Manufacturing	*0*	*15*	*2*	*3*	*20*	35	20	15	10	100
	Transportation	*1*	*5*	*3*	*1*	*10*	25	15	7	3	60
	Services	*1*	*10*	*3*	*21*	*35*	65	20	5	5	120
	Total intermediate inputs	*3*	*32*	*8*	*26*	*69*	---	---	---	---	---
	Imports	2	3	2	4	---	---	---	---	---	---
	Value Added (labor, capital, taxes)	15	85	30	90	---	---	---	---	---	---
	Total Industry Output	20	120	40	120	---	---	---	---	---	300

*The figures are in monetary terms

Chapter 2 of this thesis, *Transportation Satellite Accounts – Measuring the Size of the Transport Industry in Sweden in 1995*, develops Transportation Satellite Accounts, where an estimate of the expenditure on different in-house transportation activities is singled out from the Swedish 1995 IO matrices of the National Accounts. Measuring from the expenditure side of GDP, in-house transportation amounts to 1.7% of GDP as compared to the for-hire figure of 1.9%.

Chapter 3, *Transportation Industry Representation in CGE modeling – Does it Matter?* addresses the question of whether the transportation industry representation has an impact on the results of tax policy simulations in CGE models. This is done by analyzing an equal yield CO_2 tax policy reform in two separate models. The models are identical in every respect except for the transportation industry representation, where one model includes the TSAs presented in Chapter 2. The results indicate that the choice of transport industry representation might be significant, as the results were lessened, magnified, or even pointed in the other direction depending on what type of industry representation was used.

Chapter 4, *Road Wear and the Kilometer Charge – A Computable General Equilibrium Analysis*, investigates the effects of a re-introduction of a distance-related kilometer charge based on the Fourth Power Law. In a CGE model of Sweden some purely policy-oriented scenarios are simulated. The results indicate that the kilometer charge will lead to lower road wear, that the road wear is not influenced by a simultaneous reduction of the annual vehicle registration tax and the Eurovignette charge to the minimum level set by the European Union, that most of the reduction in road wear stems from reduced trucking activity and not from substitution towards less damaging trucks and that most of the reduction in road wear will occur due to less long-distance trucking. Furthermore, there might be some modal shifts in freight transport. The changes do not seem to affect overall real wages, labor supply or household welfare. Finally, it is demonstrated that the ex ante changes in expected tax revenue are overstated and perhaps only 56% to 78% of the ex ante amounts could actually be expected to be collected. This is explained by the substitutions that take place after the new charges are introduced and that these substitutions in turn lead to less revenue being collected.

Chapter 5, *The Cost of Relying on the Wrong Power – Road Wear and the Importance of the Fourth Power Rule*, addresses the effects of an introduction of an axle-weight-distance related kilometer charge, differentiated for ten different truck categories according to their contribution to road wear and deformation. The results on road wear of alternatives to the Fourth Power Rule are tested, i.e. the charge is designed according to the first through the fifth power. The charges are simulated in a CGE model of Sweden. Most of the effects of the charges appear to come from an overall decrease in trucking activities and are only to a lesser extent due to substitution towards less damaging trucks. However, the substitutions increase with the power, and might in some cases even lead to increased activity in one of the least damaging truck categories. The latter effect could not have been captured in a partial equilibrium model, thereby providing an example of some of the benefits of a CGE model. A decrease of between 8% and 9% in overall trucking activity and an extra 0.2% to 1.2% in reduced road wear costs occur in the model, where the extra reduction in road wear increases with the power. Furthermore, as designing the charge according to the first power amounts to a weight-distance charge rather than an axle-weight-distance, the results also imply something for this distinction. For example, the government revenue is 6% lower when the weight-distance charge is implemented compared to when an axle-weight-distance charges are implemented. Choosing the wrong power when designing the charge leads to a deviation from the effects that occur when the right choice is made, ranging from –0.8% to +0.2% of the annual road wear costs.

A number of appendices can be found at the end of this publication. These mostly relate to data and computations that are somehow used in all the essays, but there are also instances of matters that are judged to be of secondary importance to the presentation of an essay but nevertheless important for the full details and understanding.

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Chapter 2 – Transportation Satellite Accounts – Measuring the Size of the Transport Industry in Sweden in 1995

1. Introduction

The input-output (IO) matrices of the National Accounts generally misrepresent the size of the expenditure on the transport activity performed in the economy. One reason for this is the existence of so-called in-house transportation services. When a firm chooses to own and operate its own trucks, the value of that activity shows up as an output of the corresponding industry, and not as an activity of the transportation industry. This is a pure accounting problem, meaning that the transportation activities are actually accounted for, but in a way that make them appear at a smaller value than they really account for. However, this has been recognized for a long time. For example, Swedish economist Eli Heckscher wrote in 1954 that "Statistics do not fully reveal the extent of that change [i.e. the increase in transportation] because a good deal of the increase in commercial activities proceeded within industry itself and appears therefore as industrial expansion."[3] Another reason is the representation of the transportation industry in the National Accounts. The industry is often represented as one or just a few industries, whereas in reality there are considerable differences between modes of transportation that could justify a richer representation.

To solve these accounting problems, the IO matrices could be combined with other data sources and/or data at finer levels could be included. This method of developing the existing accounts goes under the name Satellite Accounting. It can be used for various purposes, for example, to analyze environmental, tourism and regional problems. Satellite accounts that relate to transportation are referred to as Transportation Satellite Accounts (TSAs). In these, a basic data set is extended to include some desired features of transportation services.

[3] See Heckscher (1954).

2. The Purpose, Method and Limitations of this Study

As already mentioned, satellite accounts have been created in several different fields, for a variety of purposes. Environmental satellite accounts supplement traditional National Accounts with monetary and physical environmental data (Hellsten et al. 1999) and tourism satellite accounts measure the flows that are related to travel and tourism activities in a wider context than the traditional National Accounts (Nordström 1999, Meis 1999). TSAs have been created by, for example, Madsen and Jensen-Butler (1999), Fang et al. (1998), Fang and Han (1999), Link et al. (2000) and Mayeres et al. (2000)[4]. Fang et al. (1998) provide a short definition of satellite accounts (p.16):

> "Satellite accounts rearrange information from the basic economic accounts for the purpose of analyzing important economic activities more completely than is otherwise possible. They expand the analytical capacity of the basic accounts without overburdening them with details or interfering with their general-purpose orientation".

This tells us, among other things, that there are not necessarily any similarities between satellite accounts of different kinds (other than the general method), since they are mostly created for totally different purposes. But what are the possible expansions that could be made in TSAs?

Transportation exhibits some special features that provide reasons for developing TSAs. For example, all transportation requires infrastructure of some kind, be it roads, airports, ports or rail. These stock variables do not generally show up in the IO matrices, other than as depreciation and capital expenditure. Moreover, all transportation is per definition conducted in space, and the spatial dimension is generally not represented in the IO matrices. There might be regional accounts available, but these often do not include flows between regions and, hence, does not provide very useful information from a transportation perspective (since it is the flows that involve transportation). Furthermore, although time is an essential feature of all imaginable activities[5], this becomes especially obvious when it comes to transportation activities. This is because transportation involves both time and space to an extent that other activities do not, and it is often conducted not for its own sake, but is derived from the desire to perform other activities. In addition, the IO matrices report figures on expenditure, i.e. quantities times prices. Whenever one wants to develop TSAs, one could run into the issue of having to make connections between transportation in

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[4] The latter provides an overview of other TSAs (Appendix G).

[5] Since activity means change and change requires the passage of time. Without any changes, i.e. inactivity, the concept of time becomes meaningless.

physical terms and in monetary terms. This requires prices, which may not always be available. But there are also dimensions of the quantities of commodities *per se* that are important for transportation issues as well. It is not only the number of commodities that is of interest, but also their weight and volume. Making connections to include things like this provide further reasons for the development of TSAs.

But there are two more reasons, reasons that arise from pure accounting procedures. First, all transportation related activities could be divided into for-hire and in-house transportation related activities. The first kind is the transport activities that result in an external transaction, i.e. the expenditure turns up as a receipt for a different industry. The second kind is the transport activity that does not result in an external transaction, i.e. the expenditure turns up within the same industry. For example, when a firm chooses to own and operate its own trucks, the expenditure on that activity shows up as an output of the same industry, and not as an activity of the trucking industry. In the IO matrices both kinds of expenditure are accounted for. However, the in-house transport activity of, for example, the service industry shows up in the IO Use matrix as an output of the service commodity. Hence, there is a systematic underestimation of the transportation activities taking place within a given year. According to a study by Fang et al. (1999) the total expenditure on transport related activities represent 5% of GDP in the U.S. in 1992, whereas only 3.1% according to the IO matrices. Thus, at least 1.9% of GDP is accounted for under the ‘wrong’ heading and these figures represent the expenditure on in-house transportation activities performed by industries. That study only included the in-house private trucking and bus operations performed by industries, but there are other in-house transportation activities as well. It is possible that industries might perform in-house transportation in regard to railways, shipping, and air transportation, including possible smaller infrastructure expenditure. The government expenditure on military transportation and different infrastructure expenditure, like highways, ports and airports are other kinds of in-house transportation expenditure.

But there is also an accounting problem present in the household sector that is related to in-house transportation (i.e. expenditure that does not render an external transaction). The main private transport mode, the car, is not accounted for as a specific good in the IO matrices. The expenditure connected to car use is present in the matrices but is spread out under different headings. One of the major expenses is fuel. Taking fuel and other commodities for car-use into account, one could therefore capture more of the transport related expenditure in the economy.

A second accounting reason for developing TSAs is that the transport industry is often represented as a single whole in the IO matrices, or at least not more than a handful of industries, so simply by including the underlying micro data, a richer representation of the industry is feasible.

As mentioned in Mayeres et al. (2000), when creating separate accounts for the transportation industry, it is crucial that the accounts are consistent with the national accounts to avoid the serious risk of general overestimation. This risk is present because, for example, as eager researchers try to show the importance of a specific industry, it is more likely that they overestimate the industry than underestimate it. And if this was done in every other area, it follows that the estimated value of total production would exceed the actual total production in the country. There simply is no way to be sure that the data is consistent. But by starting with the national accounts, this risk is completely avoided, the consistency is easily maintained, and any errors of over- or underestimation of the transportation activities would only be relative and not affect total national output.

To solve these pure accounting problems they have, of course, and first of all, to be recognized[6]. To the author's knowledge, TSAs for Sweden have not yet been attempted. The only reference I have come across mentions a level of expenditure on 'logistics' of 18% of GDP[7]. But in attempting to create TSAs, one must try to identify the significant in-house activities. In this study, some of the expenditure on in-house trucking performed by industries and some of the expenditure on fuel for private car use by households are included. From a general knowledge of the Swedish transport system, one can venture to say that the in-house transportation performed by industries and households in regard to railways, shipping, and air transportation could hardly be very significant, at least not enough to be included in a first attempt. Moreover, government expenditure on military transportation could possibly be included, but it was decided that this has to wait until later. The infrastructure expenditure is highly relevant for transport issues, but this expenditure is also excluded at this stage. Bear in mind, though, that these expenditures are present in the IO matrices, but under the 'wrong' heading.

The purpose of this study is to make a more accurate estimate of the size of the overall transport industry in Sweden. To do this, TSAs based on the 1995 IO matrices are developed, keeping the resulting matrices consistent. In this study some of the in-house transportation activities are accounted for, i.e. the expenditure on in-house trucking performed by industries and some of the expenditure on private car use by households. Moreover, it accounts for including micro data to enrich the transport industry representation. Hence, the study is limited to the purely accounting issues.

The study proceeds in section 3 by describing how the IO matrices are extended to include some aspects of the in-house transportation performed by industries and others. Section 4 explains how micro data could be

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[6] As in for example Madsen and Jensen-Butler (1999) and Mayeres et al. (2000).
[7] SOU (2001), p.70

included in the IO matrices. Section 5 discusses the results of the data manipulations and in section 6 some concluding remarks are made.

3. In-house Transportation Services

A first step towards finding an estimate of the in-house trucking activities is to estimate the fuel consumption of these in-house transports, i.e. basically diesel use. Statistics Sweden publishes a so-called Energy Use matrix that contains data over *physical quantities* of a number of energy-related commodities that are consumed by different industries in their production. The energy sources given in the Energy Use matrix of 1995 are shown in Table 3.1, together with prices and the percentage tax rates.

Table 3.1 – Energy sources and 1995 prices and tax rates

	Unit	Price, SEK	Energy tax, %	CO_2 tax, %	SO_2 tax, %
Petrol	cu.m	2 175	148	36	0
Diesel	cu.m	1 468	130	67	0
Light oil	cu.m	1 203	48	82	0
Heavier oil	cu.m	963	60	102	11
Coal	ton	319	77	268	56
Coke	ton	319	77	268	56
Light Petroleum Gas	ton	1 407	8	73	0
Natural gas	1000 cu.m	1 188	16	61	0

Source: SCB (a). An almost identical table can be found in the program code for Harrison and Kriström (1997) with cross-reference to the Ministry of Finance. Prices in SEK and tax rates as percentages of prices.

To find an estimate of the in-house transportation for each industry, the expenditure on diesel by each industry is estimated. The same thing is also made for the other energy sources. That is, the Energy Use matrix is combined with the prices, inclusive of tax, from Table 3.1. Then the share of the energy related expenditure of each industry that is used for diesel is used as an estimate of the amount of diesel expenditure by each industry. This amount is subtracted from the ‘petroleum’ commodity in the IO Use matrix and we now have a new commodity, ‘diesel’, while keeping the overall expenditure the same. In this way, the data from the physical quantities of the Energy Use matrix and the prices in Table 3.1 are made compatible with the IO Use matrix. For example, assume that the mining industry uses 10% of its overall energy expenditure for diesel. This share for the diesel expenditure is used to split up the expenditure on the ‘petroleum’ commodity in the IO Use matrix. Hence, if the latter amounts to 100, it is now replaced by a new commodity, ‘diesel’, at an amount of 10 and a ‘petroleum’ commodity at an amount of 90. The results of the manipulations are shown in Table 3.2[8].

Table 3.2 – Step 1 of the new use matrix

	Ind 1	Ind 2	…	Ind n
Commodity 1	a_{11}	a_{12}	…	a_{1n}
Commodity 2	a_{21}	a_{22}	…	a_{2n}
Petroleum	(a_{p1}- a_{d1})	(a_{p2}- a_{d2})	…	(a_{pn}- a_{nd})
.	.	.	…	.
Commodity n	a_{n1}	a_{n2}	…	a_{nn}
Diesel	a_{d1}	a_{d2}	…	a_{dn}

This provides an estimate of the diesel expenditure by each industry. But since not all diesel is used for transports but also, for example, for heating purposes, the new matrix is combined with data over how much diesel each industry uses for transportation purposes out of their total diesel use[9]. The result is that the 'diesel' commodity is split up into 'diesel tr' (for transportation purposes) and 'diesel non' (for non-transportation purposes). The result of the new manipulations is shown in Table 3.3.

Table 3.3 – Step 2 of the new use matrix

	Ind 1	Ind 2	…	Ind n
Commodity 1	a_{11}	a_{12}	…	a_{1n}
Commodity 2	a_{21}	a_{22}	…	a_{2n}
Petroleum	(a_{p1}- a_{d1})	(a_{p2}- a_{d2})	…	(a_{pn}- a_{nd})
.	.	.	…	.
Commodity n	a_{n1}	a_{n2}	…	a_{nn}
Diesel tr	(a_{d1}- a_{non1})	(a_{d2}- a_{non2})	…	(a_{nd}- a_{nonn})
Diesel non	a_{non1}	a_{non2}	…	a_{nonn}

This gives an amount of expenditure on the total diesel used for transports by each industry. But it might also be of interest how much of this expenditure that is used on for example heavy trucks and for other purposes[10]. By combining mileage data for heavy trucks with estimates of the distance-related diesel consumption[11], an estimate of the total diesel consumption by heavy trucks 1995 is obtained. Combined with the price of diesel in Table 3.1, this figure gives an amount of the total diesel expenditure for heavy trucks. Next, this amount is compared to the total amount of the diesel used

[8] Because of the large size of the IO matrices only the method used is presented while all the real figures finally reached are shown in Appendix A.
[9] This kind of information is found in SCB (b).
[10] A heavy truck is a truck over 3.5 ton according to Swedish legislation.
[11] See SCB (c) for data on mileage and Hammarström and Yahya (1999) for diesel consumption.

for transports for all industries in Table 3.3 (the sum of the 'diesel tr' row) and this provides an estimate of how much diesel is used by heavy trucks as a share of the total diesel used for transports. Thus, the 'diesel tr' is split up into 'diesel tr' and 'diesel hv'. The former now represents light trucks and other cars, insofar as they are fuelled by diesel. This is shown in Table 3.4, where $a_{tri} = a_{di} - a_{noni} - a_{hvi}$, i=i,..,n.

Table 3.4 – Step 3 of the new use matrix

	Ind 1	Ind 2	…	Ind n
Commodity 1	a_{11}	a_{12}	…	a_{1n}
Commodity 2	a_{21}	a_{22}	…	a_{2n}
Petroleum	$(a_{p1} - a_{d1})$	$(a_{p2} - a_{d2})$	…	$(a_{pn} - a_{nd})$
.	.	.	…	.
Commodity n	a_{n1}	a_{n2}	…	a_{nn}
Diesel tr	a_{tr1}	a_{tr2}	…	a_{trn}
Diesel hv	a_{hv1}	a_{hv2}	…	a_{hvn}
Diesel non	a_{non1}	a_{non2}	…	a_{nonn}

Finally, it is also possible to use the mileage and diesel consumption data to split up the amount of expenditure on the heavy trucks into further categories according to the shares of total heavy vehicle diesel expenditure in each category. However, the different industries use the different truck categories to different degrees. The service industry, for example, probably use more of the medium sized trucks for local or short distance transports, while the forestry industry probably use more of the large truck and trailer combinations. This fact also needs to be taken into account[12]. For example, if category 1 had a mileage of 100 km for a specific industry, a diesel consumption of 0.4 liter per km at 5 SEK/liter, the expenditure on diesel is 200 SEK. And if the sum of the expenditure over all categories amounts to 2000 SEK for this industry, category one stands for 10% of the total expenditure. 10% of the 'diesel hv' commodity is therefore subtracted and makes up the new commodity 'diesel c1'. This method gives ten new commodities at the expense of the earlier 'diesel hv' commodity. The result is shown in Table 3.5, where $a_{p'i} = a_{pi} - a_{di}$, i=i,..,n.

Next, the expenditure on petrol used by the industries for transport purposes is estimated. This amount is found in exactly the same way as the expenditure on diesel, i.e. by following steps 1 and 2.

[12] For example by including data on the use of trucks after axle configuration by each industry. See SCB (d).

Table 3.5 – Step 4 of the new use matrix

	Ind 1	Ind 2	…	Ind n
Commodity 1	a_{11}	a_{12}	…	a_{1n}
Commodity 2	a_{21}	a_{22}	…	a_{2n}
Petroleum	$a_{p'1}$	$a_{p'2}$	…	$a_{p'n}$
.	.	.	…	.
Commodity n	a_{n1}	a_{n2}	…	a_{nn}
Diesel tr	a_{tr1}	a_{tr2}	…	a_{trn}
Diesel c1	a_{c11}	a_{c22}	…	a_{c3n}
.	.	.	…	.
Diesel c10	a_{c101}	a_{c102}	…	a_{c10n}

Finally, a similar method is used to estimate the expenditure on fuel for private car use by households. According to the 1996 Swedish household expenditure survey, the household expenditure on fuel for car use amounted to 28 400 million SEK. It is important here to note that the expenditure of 28 400 is inclusive of tax and that the net amount would be 8 200 million SEK[13]. However, the expenditure on the petroleum commodity in the final demand matrix amounted to only 2 200 million SEK. This inconsistency would appear to be present in the 1995 matrix but not in the one from 1993, and does not therefore constitute a systematic problem. However, parts of the 1995 matrix are shown in Table 3.6. The column to the right represents the Final Demand matrix that attaches to the right of the Use matrix (the final demand for other purposes is not shown).

Table 3.6 – The expenditure on household car use

	Ind 1	Ind 2	…	Ind n	Household consumption
Commodity 1	a_{11}	a_{12}	…	a_{1n}	h_1
Commodity 2	a_{21}	a_{22}	…	a_{2n}	h_2
Petroleum	a_{p1}	a_{p2}	…	a_{pn}	2 200
Service	a_{r1}	a_{r2}	…	a_{rn}	185 800
.	.	.	…	.	.
Commodity n	a_{n1}	a_{n2}	…	a_{nn}	h_n
Petrol	a_{pe1}	a_{pe2}	…	a_{pen}	0

A plausible explanation for this might be that households buy their fuel from gas stations, as opposed to from the petroleum industry, and these are 'hidden' under the service industry. The 2 200 million SEK of petroleum products bought from the petroleum industry, probably to a large extent represent the oil used for heating purposes. Thus, by creating a new

[13] The CO_2 tax was 109%, the SO_2 tax 67% and the VAT on to the total is 25%. the figure of 8 200 million also includes diesel, although this turns out to be a negligible amount for households.

commodity, 'Petrol', and subtracting the amount from the service industry, we have found a commodity that corresponds to the car fuel use, while keeping the matrix consistent. See Table 3.7.

Table 3.7 – The expenditure of household car-use

	Ind 1	Ind 2	…	Ind n	Household consumption
Commodity 1	a_{11}	a_{12}	…	a_{1n}	h_1
Commodity 2	a_{21}	a_{22}	…	a_{2n}	h_2
Petroleum	a_{p1}	a_{p2}	…	a_{pn}	2 200
Service	a_{r1}	a_{r2}	…	a_{rn}	185 800-8 200
.	.	.	…	.	.
Commodity n	a_{n1}	a_{n2}	…	a_{nn}	h_n
Petrol	a_{pe1}	a_{pe2}	…	a_{pen}	8 200

4. Transport Industry Representation in the National Accounts

Another major reason for creating TSAs is the fact that the whole transport industry is often represented in the National Accounts by a single industry or a small number of industries. This prevents comparison between the amounts spent on different transport services and also affects the case where the data is used to perform economic analysis. If for example we want to study what might happen were the current CO_2 tax doubled, the different 'CO_2 dependence', i.e. the different use of fuel that emits CO_2, of different transport modes might lead to modal shifts, shifts that cannot be captured at a more aggregate level, and thus might lead to completely different results. Hence, by expanding the number of transport activities, more correct results are generally to be expected. In the Swedish 1995 IO matrices, the transport activities are represented by five industries and five corresponding commodities. These are rail, other land transport, shipping, air transport and forwarding. This study divides these into 17 commodities, still produced by the original five industries, by collecting the underlying micro data[14]. The micro data is listed in Table 4.1 together with the corresponding industries.

[14]There is even more disaggregate micro data available, but according to Statistics Sweden reliability at that level is weak. Reliability at lower levels might be better in a larger country such as the U.S..

Table 4.1 – Industries in the 1995 IO Use matrix and commodities in the micro data

Producing industry	Commodity in micro data
Railway companies	Railway passenger
	Railway freight
Other land transport	Bus passenger
	Bus freight
	Trucking
	Taxi
	Car parking/Car leasing
Shipping	Shipping passenger
	Shipping freight
	Route services
	Stowage services
	Harbor services
Airline companies	Air passenger
	Air freight
Travel agencies/forwarding	Travel agencies
	Private international charter flights
	Freight forwarding

Source: SCB (e)

5. Results

The results of the manipulations presented thus far, using the real figures of the 1995 IO Use matrix, are presented in Appendix A. Here, the results are summarized, starting with the in-house transportation as part of total intermediate inputs and then continuing with in-house as part of final demand and GDP. Before starting to analyze and compare the figures in Table 5.1, one has to remember that the figures are pre-tax. A general sales tax of 25% was and still is applicable, with some exceptions. But then some commodities are also subject to other taxes. The taxes on energy sources are of especial interest when it comes to transportation and these taxes were stated earlier in Table 3.1. For example, we already know that the 8 200 million SEK of pre-tax household expenditure on petrol for transport purposes amounts to a tax-inclusive figure of 28 400 million SEK.

The total expenditure on in-house trucking, other diesel for transport use, petrol for transport, the commodities in the micro data, and the remaining expenditure on the petroleum and service commodities by industries is shown in Table 5.1. The rest of the IO Use matrix corresponds to the original matrix. The table also shows the corresponding share of total intermediate expenditure. Note how the inclusion of the micro data makes the table more much more informative and allows richer comparison.

Table 5.1 – Intermediate input of transport related commodities, million SEK*

Commodity	Intermediate inputs	Share of total intermediate, %
In-house related		
Diesel, heavy vehicle	1 604	0.2
Diesel, other transport	992	0.1
Petrol, transport	3 396	0.3
Petroleum'	5 130	0.5
Service'	82 151	8.4
Micro data		
Railway passenger	851	0.1
Railway freight	7 073	0.7
Bus passenger	2 023	0.2
Bus freight	1 208	0.1
Trucking	42 276	4.3
Taxi	5 004	0.5
Car parking/Car leasing	1 157	0.1
Shipping passenger	35	0.0
Shipping freight	4 287	0.4
Route services	345	0.0
Stowage services	1 646	0.2
Harbor services	1 827	0.2
Air passenger	11 333	1.2
Air freight	3 392	0.3
Travel agencies	1 684	0.2
Private international charter flights	0	0.0
Forwarding	5 744	0.6
Total pre-tax expenditure	974 796	100.0

*Petroleum'=adjusted petroleum commodity, Service'=adjusted service commodity.

The table shows that the pre-tax expenditure on diesel for transport purposes by industries, i.e. the 'Diesel, heavy vehicles' and the 'Diesel, other transport' commodities amount to 1604+992=2596 million SEK. Corresponding to 0.2+0.1=0.3% of total intermediate inputs, although a small share, the amount is larger than a number of other expenditures on other transport related inputs. When we include the petrol used for transport by industries, we arrive at 0.2+0.1+0.3=0.6% of total intermediate expenditure on inputs. This may appear to be economically insignificant. But if we also observe that the figure includes the fuel expenditure by the for-hire land transport producing industry (excluding the railways), i.e. the 'Other land transport' industry, it is possible to find a relation between in-house excluding for-hire and the for-hire industry. In other words, we can estimate the proportion of 'real' in-house fuel expenditure to for-hire fuel expenditure. The results are shown in Table 5.2.

Table 5.2 – Fuel expenditure of in-house and for-hire land transportation, million SEK

Commodity	Intermediate inputs (a)	Of which 'Other land transport' industry (b)	Remaining Expenditure i.e. 'real' in-house (c)	In-house / for-hire, % 100 * (c) / (b)	Total in-house / for-hire, % 100 * (c) / (b)
Diesel, heavy vehicle	1 604	855	749	88	
Diesel, other transport	992	529	463		248
Petrol, transport	3 396	338	3 058	905	
Sum	5 992	1 722	4 270		

Subtracting the 'Other land transport' expenditure on diesel for transport purposes (855+529=1 384) from the total intermediate diesel expenditure column (1 604+992=2 596) gives 749+463=1 212 million SEK. This in-house diesel expenditure for transport purposes amounts to 88% of the corresponding total expenditure of the for-hire land transport industry of 1384 million SEK. A perhaps somewhat less interesting result is that the in-house petrol used for transport purposes by industries, once again excluding for-hire, amounts to 905%. Adding up the total in-house intermediate fuel expenditure, excluding for-hire, and putting it in relation to the corresponding for-hire amount, gives the result that the in-house expenditure is 248% of the for-hire. These figures represent a first indication of the significance of the in-house transportation. Considering that the total intermediate inputs of the 'Other land transport' industry amounted to 29 472 million SEK and the total output 64 749 million SEK, we can conclude that the in-house production plays a not insignificant role. Moreover, the significance of the in-house intermediate transportation indicated here could be compared to a study referred to by a Swedish Commission (SOU (2001), p.70). According to the Commission, it was estimated that the size of the expenditure for 'logistics' exceeded 50 000 million SEK. If by 'logistics' the commission means trucking, we could compare the amount to the sum of the intermediate expenditure on for-hire trucking and the in-house fuel expenditure, the latter two making a total of 42 276+4 270=46 546 million SEK. Judging from the amounts of for-hire and in-house transportation found in the present study the figures would seem to be plausible[15].

[15] However, the commission also states that 18 % of GDP is expenditure on 'logistics'. But then they have mistakenly mixed up the total expenditure with GDP. Since intermediate input is not included in GDP, the figure of 18% is misleading. GDP only includes, and logistics hardly constitutes a large part of final demand. Instead, logistics might represent 18% of the total expenditure on intermediate inputs or even 18% of total expenditure, i.e. total production, a figure even more significant (since total production exceeds GDP by roughly the intermediate inputs).

Next, we continue with in-house as part of final demand and GDP. Table 5.3 displays the intermediate input, household consumption, government consumption / investments / exports (G+I+X) as well as the total commodity output for the same commodities as in Table 5.1. Household consumption together with the G+I+X column represents the final demand. To arrive at GDP from the expenditure side, the total imports are subtracted from the sum of household consumption and the G+I+X column. GDP was 1 649 920 million SEK 1995.[16]

Table 5.3 – Final demand of transport related commodities, million SEK*

Commodity	Intermediate inputs	Household Consumption expenditure	G+I+X	Total Commodity output
In-house related				
Diesel, heavy vehicle	1 604	0	0	1 604
Diesel, other transport	992	0	0	992
Petrol, transport	3 396	8 200	0	11 596
Petroleum'	5 130	2 233	9 835	17 198
Service'	82 151	115 148	59 038	256 337
Micro data				
Railway passenger	851	2 199	158	3 208
Railway freight	7 073	123	504	7 700
Bus passenger	2 023	7 475	1 406	10 904
Bus freight	1 208	0	0	1 208
Trucking	42 276	336	1 809	44 421
Taxi	5 004	1 696	0	6 700
Car parking/Car leasing	1 157	359	0	1 516
Shipping passenger	35	2 330	1 993	4 358
Shipping freight	4 287	0	17 948	22 235
Route services	345	0	705	1 050
Stowage services	1 646	0	0	1 646
Harbor services	1 827	353	497	2 677
Air passenger	11 333	3 940	2 658	17 931
Air freight	3 392	0	1 100	4 492
Travel agencies	1 684	486	1 717	3 887
Private international charter flights	0	5 458	0	5 458
Forwarding	5 744	0	1 672	7 416
Total pre-tax expenditure	974 796	614 960	1 351 356	2 941 112
Imports	376 236	96 640	96 325	569 201
Taxes	44 852	128 228	10 606	183 686
Total expenditure	1 395 884	839 828	1 458 287	3 693 999

*Petroleum'=adjusted petroleum commodity, Service'=adjusted service commodity, G+I+X=government consumption, investment and exports.

[16] To be exact; an undistributed item of 78 994 millions SEK must also be subtracted. The GDP figure has later been revised.

The pre-tax expenditure on petrol by households of 8 200 million SEK, the 'Petrol, transport' of the 'Household consumption expenditure' column, is alone greater than the expenditure on a number of the other for-hire transport commodities. The same holds to an even greater degree when it comes to the tax-inclusive expenditure on petrol by households, since the taxes on petrol far exceed consumer taxes on the other commodities. The only in-house expenditure that is included in GDP in this study is therefore the pre-tax fuel expenditure by households. Taking GDP from the expenditure side, we add the in-house household petrol expenditure to the expenditure on the for-hire transport related commodities and then subtract the imports of these commodities to end up with 8 200+56 922-24 804=40 318 million SEK, i.e. 2.4% of GDP (the imports are the imports by the for-hire producing industries). Taking the household expenditure tax inclusive gives a figure of 28 400+56 922-24 804=60 518 or 3.7%. The in-house share is 0.5 and 1.7% respectively for pre-tax and tax inclusive, leaving about 1.9 for for-hire transportation.

The results presented here could be compared to the Fang et al. (1998) and Fang and Han (1999) studies that estimated the in-house transportation share of GDP from the production side, i.e. by estimating the value added of the in-house transportation. By this means they were able to come up with an amount of value-added of 1.9% of GDP, as compared to the for-hire share of 3.1%. A deeper comparison with the U.S. results is probably not possible because of differences in methodology etc. However, one could say that the size of the overall transportation expenditure, as related to both total intermediate inputs and to GDP, is much larger than the IO matrices indicate also in Sweden.

6. Concluding Remarks

The main findings of the satellite accounting performed here are first of all that the in-house diesel expenditure for transport purposes amounts to 88% of the corresponding total expenditure of the for-hire land transport industry. Second, the total in-house transportation fuel expenditure estimated, i.e. including the expenditure on petrol for transport purposes, amounts to 248% of the for-hire industry's expenditure, but represents only 0.6% of total intermediate inputs. Third, taking GDP from the expenditure side, we find that the tax-inclusive expenditure on in-house transportation amounts to 1.7%, whereas the for-hire industry accounts for about 1.9%of GDP (net of imports).

Although this study has made it clear that the transport industry is underestimated in the input-output matrices of the National Accounts, the satellite accounting performed here is far from complete or fully reliable. However, it could be seen as a first step. Future work might include capital expenditure on infrastructure and equipment (vehicles), other possible sources of in-house transportation, such as example military transport expenditure, other transport related expenditure besides fuel, the regional dimension, as well as other stock and flow variables.

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(e) Transport Micro Data 1995 (Unpublished material, Ann-Marie Bråthen, SCB)
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(g) Make and Use Matrices 1995 (Unpublished material, Ann-Marie Bråthen, SCB)

Chapter 3 – Transportation Industry Representation in CGE modeling – Does it Matter?

1. Introduction

Computable General Equilibrium (CGE) models in the Shoven and Whalley (1972) tradition are generally calibrated to fit the input-output (IO) matrices of a particular year. When doing this, one inherits the merits and weaknesses of the IO matrices and, as for example Fang et al. (1998), Fang and Han (1999) and Johnsson (2003) show, the transportation industry representation is a general weakness of these matrices. This means that in CGE models the transportation industry is represented as a single industry, or at most by a handful of industries[17]. But one could argue that there are essential differences between for example freight by rail and freight by sea, or between passenger transport by rail and freight transport by rail. Furthermore, the IO matrices do not take into account the transportation that takes place on its own account, by trucks owned within an industry for example. The expenditure that corresponds to this in-house transportation shows up instead as an output of the industry in question[18].

Hence, there is a case for developing the transportation industry before performing CGE modeling. By not including the aspects just mentioned one runs the risk of missing certain effects that could be of crucial interest to, for example, the issue of CO_2 emissions. Allowing for a richer transportation industry representation introduces new ways of adapting to an increase in CO_2 tax, for example, and this could possibly affect the overall outcome of the policy simulation.

But now the following question arises; how far are the results affected by the fact that all the models have hitherto used the somewhat simpler transportation industry representation? This is what this paper investigates.

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[17] Like for example Harrison and Kriström (1997a and 1997b), Hill (1998) and Conrad (2002). A search in databases Econlit and TRANSPORT gives no result to the contrary.

[18] Conrad (2002) explicitly recognizes this problem and handles it very much in the same way as in this paper.

By studying a radical increase in the CO_2 tax by 138% in two separate models, where the only thing that differs is the transportation industry representation, it is possible to test the impact of settling for the simpler transportation industry representation. The models are based on the 1995 Swedish IO matrices.

The study continues by outlining the model and then presents the results. Finally, some concluding remarks are made.

2. The Model

In this section, the two models used for the policy simulation are presented. Since the general structure of both the models is the same, it is convenient to start by describing the model with the simpler transportation industry representation. I will refer to this model as the 'Aggregate model'. Next, the richer transportation industry of the other model is described. I will refer to this model as the TSA model (an abbreviation of Transportation Satellite Accounting).

The basic model is a static, small open economy, computable general equilibrium (CGE) model. First of all, by the epithet 'static' means that there is no explicit time dimension in the model. Instead, any adjustments made in the model can implicitly be taken as happening after a time period of about five years. Second, the epithet 'small open economy' simply means that since Swedish foreign trade is a too small a part of world trade to be able to influence the prices of commodities on the world market, these are taken as given. Third, the CGE epithet means that all markets, i.e. labor market, commodities market etc, clear not one at a time as in a partial equilibrium, but rather simultaneously, all at the same time.

Based on neo-classical micro economic theory, there are a number of profit maximizing firms producing commodities using intermediate inputs (i.e. other commodities as well as some of the same commodity) as well as labor 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:

$$Y_j = G_{ji} (I_{ji} , VA_j) \qquad (1)$$

where the j^{th} 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 labor input according to:

$$VA_j = VA_j (K_j , L_j) \qquad (2)$$

where K and L denote capital and labor 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 modeled 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 labor market is modeled as a competitive market that is cleared by adjustment of the real wage rate. The labor supply function is calibrated according to Ballard (1999), whereby the labor supply function is calibrated to the desired labor supply elasticity. As Ballard points out, the labor supply elasticity determines the elasticity of substitution between commodities and leisure in the utility function. Or, conversely, by choosing the latter, one indirectly determines the former, something often overlooked in CGE modeling. 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:

$$U = U(G, l) \tag{3}$$

where the consumer receives utility from consuming commodities and leisure, *l*. The consumer finances the purchases by selling their endowments of capital and labor to the producers in the labor 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.

The adjustment process in the policy simulation is determined by the elasticities. Table 2.1 displays the key elasticities in the model. The elasticity of substitution between capital and labor in the value added nest ranges between 0.293 and 3.125 according to Harrison et al. (1993). The elasticity of substitution between value added and intermediate inputs is set to 0.25, i.e. close to a Leontief fixed share tradition, as is the elasticity within the nest of intermediate inputs. This figure is the same in both models. However, one might argue that when developing the transport related side of the model, one should also use a different nesting structure and elasticities for this part of the model. On the other hand, although the point is a reasonable one, since

[19] See Appendix B for a fuller description of Ballard's point.

the purpose is to compare the two models it could be argued that it becomes an end to vary as little as possible between the models. Hence, to put the transportation industry representation in focus, as opposed to the choice of nesting structure, it was decided to use a flat structure. The Armington elasticity and the transformation elasticity between output intended for the domestic and the foreign markets are set to 4.0, as shown in the table. On the consumption side, the elasticity of substitution between aggregate leisure and the composite of all commodities is determined by the Ballard (1999) calibration of the labor supply function. The result is an elasticity of 1.33, implying an uncompensated labor supply elasticity of 0.1. The uncompensated labor supply elasticity is used, as opposed to the compensated labor supply elasticity, because of the notion that the consumers are not directly compensated for any losses due to the raised tax. The elasticity of substitution between different commodities is set to 0.25, i.e. once again close to a fixed share. The elasticity of substitution between different commodities for the government's consumption is set to zero, i.e. to a Leontief nest.

The nesting structure is rather straightforward, as for example in Harrison and Kriström (1997a and 1997b), Hill (1998) and Steininger (2002). Most of the elasticities in the model will be subject to a systematic sensitivity analysis according to Harrison and Vinod (1992) and Harrison et al. (1993). For these, apart from the point estimate, also a distribution and a standard deviation are specified. These are also displayed in Table 2.1.

Table 2.1 – Key elasticities in the model

Elasticity	Value	Std. dev	Distri
Production			
Elasticity of substitution between intermediate inputs and the composite of primary factors	0.25	(0.0,0.5)	uniform
Elasticity of substitution between labor and capital input	0.293-3.125[a]	0.0268-0.2411	normal
Elasticity of transformation between commodities for domestic market and commodities for export market	4.0		
Armington elasticity of substitution between imported and domestically produced commodities	4.0		
Private Consumption			
Elasticity of substitution between aggregate leisure and a composite of all commodities	1.33[b]	See [b]	See [b]
Elasticity of substitution between different commodities	0.25		
Government consumption			
Elasticity of substitution between commodities	0.0		

Sources: a. Harrison et al. (1993) b. Implies an uncompensated labor supply elasticity of 0.1 in the benchmark data. This estimate is perturbed in a uniform (0.05,0.15) distribution. The 0.1 value of the uncompensated elasticity is in line with e.g. Wikström (1996).

The energy side in the model is based on data from the so-called Energy Use matrix. This matrix shows the amounts of various energy sources each industry used in production, by industry and measured in physical units. The energy sources given in the Energy Use matrix are shown in Table 2.2.

Table 2.2 – Energy tax rates and prices

	Unit	Price	Energy %	CO2 %	SO2 %
Petrol	m3	2175	148	36	0
Diesel	m3	1468	130	67	0
Light oil	m3	1203	48	82	0
Heavier oil	m3	963	60	102	11
Coal	ton	319	77	268	56
Coke	ton	319	77	268	56
Natural gas	1000 m3	1188	16	61	0
Light Petroleum Gas	ton	1407	8	73	0

Source: Statistics Sweden (2000). An almost identical table can be found in the program code for the Harrison and Kriström (1997a) model with cross-reference to the Ministry of Finance.

The table also reveals some other important data, namely prices and tax levels of these energy sources for 1995, the benchmark year of the data set. Some further tax rates are also shown in Table 2.3.

Table 2.3 – Some further tax rates

	Tax rate
Households	
Labor income tax	0.46[a]
Capital income tax	0.30
Producers	
Wage or pay roll tax	0.23 – 0.445[b]
Corporate income (profit) tax	0 – 1.285[c]
VAT	0.25[d]

a. According to ESO (1997, p.71). b. Figures in Harrison and Kriström (1997a), pp. 89-90 suggest levels on average of 32.86. c. Figures in Harrison and Kriström (1997a), pp. 89-90 suggest levels on average of 0.25. The figures are net of any subsidies and range from zero to an extreme case of 1.285. Most of the figures are below 0.1. d. Some industries have a lower VAT rate.

Thus far the Aggregate and the TSA models are identical. The differences could be explained with the help of Table 2.4, which lists the industries and the commodities in the two models. First, from the first and the last columns we can see that there are 20 industries in both models, and that the Aggregate model contains 20 commodities while the TSA model has 35. This is because the underlying micro data for the original transportation industry commodities and some of the in-house expenditure on transportation are included. All the commodities produced by Railway, Other land transport, Shipping, Airline companies and Travel agencies/freight forwarding industries fall into the first category, and the expenditure on diesel and petrol used for transport purposes by industries and households, expenditure that does not show up as receipts of the ordinary transportation industries, fall into the second category.

Table 2.4 – Industries and Commodities in the two models

	Aggregate model		TSA model		
	Industries	Commodities	Industries	Commodities	
	Non-transport related		*Non-transport related*		
1	Agriculture and fishing	Identical	Agriculture and fishing	Identical	1
2	Forestry	Identical	Forestry	Identical	2
3	Mining	Identical	Mining	Identical	3
4	Other industries	Identical	Other industries	Identical	4
5	Pulp and Paper mills	Identical	Pulp and Paper mills	Identical	5
6	Chemical industries	Identical	Chemical industries	Identical	6
7	Basic metal industries	Identical	Basic metal industries	Identical	7
8	Engineering	Identical	Engineering	Identical	8
9	Electricity, gas and water	Identical	Electricity, gas and water	Identical	9
10	Construction	Identical	Construction	Identical	10
11	Postal services	Identical	Postal services	Identical	11
12	Real estate	Identical	Real estate	Identical	12
13	Public service	Identical	Public service	Identical	13
	Transport related		*Transport related*		
14	Petroleum refineries	Identical	Petroleum refineries	Other petroleum products	14
				Diesel used for transport purposes	15
				Petrol used for transport purposes, by industries	16
15	Railway	Identical	Railway	Railway passenger	17
				Railway freight	18
16	Other land transport	Identical	Other land transport	Bus passenger	19
				Bus freight	20
				Trucking	21
				Taxi	22
				Car parking/Car leasing	23
17	Shipping	Identical	Shipping	Shipping passenger	24
				Shipping freight	25
				Route services	26
				Stowage services	27
				Harbor services	28
18	Airline companies	Identical	Airline companies	Air passenger	29
				Air freight	30
19	Travel agencies/forwarding	Identical	Travel agencies/forwarding	Travel agencies	31
				Private international charter flights	32
				Freight forwarding	33
20	Services	Identical	Services	Other services	34
				Petrol used for transport purposes, by households	35

This exposition would hopefully give the general structure and differences between the models[20]. We turn next to the results of the simulated CO_2 tax increase in both models.

[20] For more on this, see Johnsson (2003). For a fully detailed exposition, the reader is referred to the program code, which is largely self-explanatory. The software used is called GAMS and the code developed for this study is obtainable upon request.

3. Results of the Policy Simulations

The CO_2 tax level was set at 0.25 SEK/kg CO_2 emitted when it was introduced in 1991 and has continually increased to the present 0.63 SEK/kg (Ministry of Finance (2002), p.2). In the infrastructure planning process a considerably higher figure of 1.50 SEK/kg is used and this figure serves as guidance for setting the actual CO_2 tax (SIKA (2002)). This level corresponds to an increased tax level of 138%. Although this seems to be a dramatic increase, considering the increase from 0.25 to 0.63 SEK/kg, i.e. an increase of 152% over the last ten years or so, the figure is perhaps not as radical as it first appears to be.

However, earlier increases in the CO_2 tax have often been accompanied by a simultaneous reduction in some other tax to alleviate the effects of the increase. Following this tradition, the policy scenario that will be run in both models will be revenue neutral. This means that an equal yield constraint is placed on government revenue in the models. The extra revenue from the increased CO_2 tax is balanced by a reduction in the labor tax rate to keep the government tax revenue at the benchmark level. This is summarized in Table 3.1.[21]

Table 3.1 – The counterfactual scenario

Scenario	CO_2 tax, SEK/kg emitted	Increase in CO_2 tax, %	Decreasing tax
Benchmark	0.63	…	…
Counterfactual	1.50	138	Labor tax rate

The results of the sensitivity analysis are shown in relation to each of the tables displaying the results[22]. When reviewing the results, the focus is on the *differences* between the results of the two models and the signs or the sizes of the changes are generally not commented on *per se*.

In Table 3.2, the results at the aggregate level are displayed. We see that the higher CO_2 tax is offset by a lower labor tax, by 8.1% and 8.3% of the original levels respectively[23]. The real wage increases more in the Aggregate model and the difference of 0.5% is not an economically insignificant figure.

[21] In 1995, the benchmark year of the data set, the CO_2 tax was set at 0.34 SEK/kg. To overcome this data issue, the percentage changes in the taxes are applied to the 1995 data set, i.e. the 0.34 SEK/kg is raised by 19% and 138% respectively.

[22] Note that not all distributions are assumed to be normal, so that the critical t-values are valid only asymptotically.

[23] The original level differs between sectors, ranging from 44.5% in the Petroleum producing industry to 23% for the Airline companies. This means for example that an 8.1% cut in the labor tax for the petroleum producing industry translates into a new level of 44.5*(1-0.081)=40.9%, i.e. a cut of 3.6%.

The higher real wage in the Aggregate model also leads to a higher labor supply compared to the TSA model. However, these changes do not result in any significant changes in the Equivalent Variation (EV) welfare measure.

Table 3.2 – Results at Aggregate Level

	Aggregate model	TSA model
Change in labor tax rate, % of existing level	-8.1	-8.3
Real wage[a]	+1.2	+0.7
Labor supply	+0.7	+0.5
Equivalent Variation, % [b]	+0.2	-0.1

a. Wage/Utility index. b. None of the changes are statistically significant at a 5% level.

Continuing to Table 3.3, we see the results of the simulations for the non-transport industries, at an industry / commodity level.

Table 3.3 – Results for Non-transport Related Output

Industry / Commodity	Domestic output Billion SEK	Aggregate model[a] Change %*	TSA model[b] Change %
1 Agriculture and fishing	32.66	-3.1	-3.1
2 Forestry	26.3	-1.4	-1.4
3 Mining	10.99	-13.6	-13.6
4 Other industries	158.24	-3.0	-3.0
5 Pulp and Paper mills	133.67	0.4	0.5
6 Chemical industries	69.13	-34.7	-33.3
7 Basic metal industries	60.45	-13.3	-13.5
8 Engineering	328.57	11.7	11.2
9 Electricity, gas and water	65.17	-1.1	-1.2
10 Construction	130.5	-0.2	-0.3
11 Postal services	43.02	1.2	1.1
12 Real estate	275.27	0.7	0.5

a. All figures are statistically significant at a 5% level except the change in construction. b. All figures are statistically significant at a 5% level except the change in real estate output.

We see that there are some differences between the models, although the directions of the changes and the sizes of the changes are similar in both models[24]. The satellite accounting procedure does not appear to have any major overall effect in this regard. However, turning to Table 3.4, we can see that the results with regard to the transport related industries and commodities differ between the models.

[24] A reservation has to be made at this point. The output of a specific commodity is not produced solely by the corresponding industry as is assumed in Table 2.4. However, the main producer of a specific commodity is always the industry with the corresponding name. To include this dimension of the results would be over-burdening the reader with details.

Table 3.4 – Results for Transport Related Output

	Industry / Commodity	Domestic output Billion SEK	Aggregate model[a] Change %*	TSA model[b] Change %
1	Petroleum refineries	7.79	-3.4	-7.78
1.1	Petroleum products less	4.65	…	-6.1
1.2	Diesel for transport	0.86	…	-22.5
1.3	Petrol for transport by industries	2.28	…	-6.0
2	Railway	13.06	-0.4	-0.22
2.1	Railway passenger	3.84	…	0.2
2.2	Railway freight	9.22	…	-0.4
3	Other land transport	69.1	-1.4	-1.04
3.1	Bus passenger	11.76	…	-0.9
3.2	Bus freight	1.3	…	0.0
3.3	Trucking	47.57	…	-1.3
3.4	Taxi	7.23	…	-0.1
3.5	Car parking/Car leasing	1.24	…	1.3
4	Shipping	18.66	-6.9	-4.47
4.1	Shipping passenger	2.54	…	-14.2
4.2	Shipping freight	12.98	…	-2.4
4.3	Route services	0.61	…	-6.4
4.4	Stowage services	0.96	…	0.0
4.5	Harbor services	1.56	…	-7.9
5	Airline companies	16.9	-1.5	0.1
5.1	Air passenger	13.52	…	0.6
5.2	Air freight	3.38	…	-1.9
6	Travel agencies/forwarding	13.77	6.2	3.0
6.1	Travel agencies	3.19	…	6.0
6.2	Private international charter flights	4.48	…	1.0
6.3	Freight forwarding	6.1	…	2.9
7	Services	623.6	0.7	0.54
7.1	Services less	614.61	…	0.6
7.2	Petrol for transport by households	8.99	…	-3.5

a. All figures are statistically significant at a 5% level except the changes in petroleum and railway. b. All figures are statistically significant at a 5% level except the changes in railway passenger, bus freight, taxi, storage services, air passenger and petrol used by industries.

Table 3.4 shows first of all that the output of the domestic petroleum producing industry (1) falls by 3.4% in the Aggregate model, and by as much as 7.78% in the TSA model. We see that the results are different for different uses of diesel, petrol and other petroleum products, where the diesel used for transport purposes (1.2) is reduced by as much as 22.5%, while the other two commodities are reduced by around 6% (1.1 and 1.3). This result seems plausible because the substitution possibilities of for example a local retailer using his own truck is clearly of another nature compared to a factory that chooses between different kinds of energy sources for production or heating purposes. However, this is an effect that simply could not have been have been present in the Aggregate model and thus stresses the importance of a well-represented transportation industry.

Next, we see that the railways' production (2) is somewhat less affected in the TSA model than in the Aggregate model. Focusing on the railway commodities in the TSA (2.1 and 2.2), we see that the railway passenger commodity actually increases while it is the decrease in freight by rail that causes the overall reduction. Thus, we see that the possibility of substitution between the production of different kinds of commodities helps alleviate the overall reduction in output.

The same effect can be observed in Other land transport (3). The overall reduction in output is alleviated by the substitution possibilities in production. The output level of some commodities falls, for some it remains unchanged and for some it increases. A similar result can be seen in the shipping industries (4). The overall reduction in output is lessened by the substitution possibilities. Passenger traffic (4.1) is down by a significant amount while freight (4.2) decreases by a far smaller percentage.

One of the most interesting differences between the models appears in the air transport industry (5). In the Aggregate model, there is a reduction in output of 1.5%. In the TSA model there is an overall increase of 0.1%, due to an increase in the passenger commodity (5.1) and a decrease in the freight commodity (5.2). The results go in the opposite direction, from a decrease to an increase! This is once again purely a result of the transportation satellite accounting making further substitution possible.

In the traveling agencies industry (6) there is an increased overall output in both models, but the increase is smaller in the TSA model, with significant differences between the increases in the commodity output. Finally, the same holds for the service industry (7), with the exception that the petrol expenditure by households is down by 3.5% while the remaining and predominant part of the overall output increases.

A further insight must be commented on in relation to the result presented here. A disaggregation of the transportation industry is perhaps generally expected to lead to more substitution possibilities in the model, since 'more commodities' implies 'more commodities to substitute among'. However, there are numerous cases where industries have a zero input of a specific transport related commodity. This means that in the model, it is impossible to substitute to these inputs. The same holds in the cases where there is only a small input of a specific transport related commodity. It is then, of course, only possible to substitute away from that commodity down to a level of zero. The presence of both these limitations to the substitution possibilities is enhanced as the data is disaggregated. This is an effect of calibrating the model to the specific data set. However, this feature is not totally unrealistic. Zero input in the data set of a transport related commodity, for example freight by railway, could simply mean that the railway is no option for the industry in question. Hence, while the disaggregation in some instances increases the substitution possibilities, it also limits them in others. And this is a further reason for disaggregating the transportation industry.

The question now arises as to how far the results of these simulations can be generalized. In other words, we have to determine whether the Aggregate model could be viewed as representing the structure of previous models that did not have the richer transportation representation of the TSA model. To do this, a comparison is made with three models, Harrison and Kriström (1997a and 1997b) and Hill (1998). These are chosen since they are also based on Swedish data sets and because the structure of the models happens to be rather widespread.

In the Aggregate model, the transportation industry is represented by five industries. In Harrison and Kriström (1997a and 1997b), the transportation industry is represented by one industry (Transport and Storage) and in Hill (1998) as well (Transport). The Harrison and Kriström (1997b) model singles out the use of diesel and petrol as separate commodities and simulates different changes in the taxes levied on diesel relative to the taxes levied on petrol. The Harrison and Kriström (1997a) and Hill (1998) models levy taxes on energy commodities but do not single out the energy sources used for transportation. Hence, we see that the Aggregate model in some respects has a more detailed transportation industry representation, but a less detailed one in other respects. It is perhaps possible to conclude that the representation in the Aggregate model represents some kind of average.

There is another possible source of difference – these earlier models did not account for the Ballard (1999) calibration of the labor supply function (they did after all appear before 1999). This means, according to Ballard, that one could expect large differences in the welfare measures. The result of the present study with respect to the EV measure is perhaps somewhat surprising, i.e. that such a significant increase in the CO_2 tax did not result in any significant changes in the EV measure. The results in Hill (1998) appear to point towards an EV decrease in the region of 0.5% as the tax is increased by similar figures as in the present study (see Hill (1998), Table 4.2, p. 16). Harrison and Kriström (1997a and 1997b) found decreases ranging from 0.2-0.6% for different kind of households as a result of a doubled CO_2 tax, i.e. larger EV decreases although a smaller increase in the CO_2 tax (see Harrison and Kriström (1997a), Table 8, p. 80 and Harrison and Kriström (1997b), Table 8, p. 43). To see if these differences are caused by not calibrating the labor supply function according to Ballard (1999), the Aggregate model is solved with the same labor-leisure elasticity as was used in Harrison and Kriström (1997a and 1997b). The result is that the EV change proved to be insignificant also in this version of the Aggregate model.

There are some differences between the Aggregate model of the present study and earlier models, but these differences appears to be of minor importance for the purpose of comparison between the Aggregate and the TSA models. Hence, the results just presented could possibly be generalized.

4. Concluding Remarks

This paper has presented the simulated effects of raising the CO_2 tax level by 138% in two different CGE models; one where the transportation industry is represented by five separate industries and five corresponding commodities, and another where the transportation industry is represented by 22 transport related commodities according to Johnsson (2003). By using two different models we are able to study the impact of the transportation industry representation in CGE models.

According to the results, some differences appeared between the models depending on the transportation industry representation. Although the change in such an important welfare measure as the Equivalent Variation was found to be similar (insignificant) in both models, there were some differences with regard to changes in the real wage and labor supply. Moreover, the differences with respect to certain industry output levels were significant, as the use of the richer transportation industry representation made changes in output levels smaller, greater or even caused them to change sign. This was especially the case for the transport related industries. These changes could be explained not only by greater substitution possibilities as more commodities are employed, but also by fewer substitution possibilities as this introduces some substitution impossibilities (by means of relatively small or zero entries in the data set).

The results of the model could be generalized insofar as the Aggregate model could be regarded as a representative for earlier models, which seems plausible. Thus, we found that the choice of transport industry representation actually might be significant, especially when studying issues that have a bearing on energy and fuel related matters. A consequence of this result could be that earlier studies, using a less rich transportation industry representation, might have reported results that were lessened, magnified or even pointed in the wrong direction when it comes to important parameters. The transportation industry representation does matter.

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Chapter 4 – Road Wear and the Kilometer Charge – A Computable General Equilibrium Analysis

1. Introduction

As a step towards making each transport mode bear its own costs, a distance-related charge on heavy goods vehicles has been suggested[25]. 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[26]. 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[27]. Concern has also been raised against possible negative fiscal effects of the charges[28]. There is, however, no clear evidence that these effects will materialize. 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

[25] See e.g. European Commission (1995) and (1998a), and SOU 2001:61, p. 287.
[26] The EV system consists of an annual charge 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.
[27] See for example the official reports to the Swedish Parliament, SOU 1997:35, pp. 150-151, SOU 2000:8, pp. 41-42 and 145-146 and SOU 2001:61, p. 13.
[28] See for example. the official report to the Swedish Parliament, SOU 2001:61, p. 296.

to the annual vehicle registration tax and the Eurovignette charge as suitable candidates[29].

This study simulates the effects of implementing a distance-related charge, i.e. a kilometer 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 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 kilometer charge. To this end a Computable General Equilibrium (CGE) model is applied to a data set 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. 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 kilometer 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.

i. The Idea behind a Kilometer 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[30]. Moreover, the

[29] See the official report to the Swedish Parliament, SOU 2001:61, p. 249 and SIKA (2000, p. 7).

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

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 summarized as in Small et al. (1989, p. 11): "Two technological facts are crucial to understanding road wear. First, the equivalence factor [i.e. 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 pavements. For flexible pavements, such as the asphalt used 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 back 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.[31]

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, paragraph 3.52), Ecoplan (1998, p. A7), SOU 1997:35 (p. 88 in the supplement) and in reports such as KFV (2000, p. 38), DETR (1997, paragraph 8), DETR (2000, p. 4), Mayeres et al. (2001, p. 35) 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, it is not sufficient to categorize the trucks as for example 20 ton two-axle trucks, 30 ton three-axle trucks, 40 ton five-axle trucks and 60 ton eight-axle truck and trailer combinations[32]. Second, the fourth power relation is estimated with reference to a standard axle of 18 thousand pounds (kip), i.e. 8.172 metric tons. Using a standard axle of 10 metric tons could be misleading and possibly even dubious. Third, following the imposition of a

[31] The coefficients were 3.241 for rigid pavements and 3.652 for flexible pavements 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 SOU1969:45 p. 134. A decision to impose the km-charge as of January 1, 1974, was taken in Prop. 1971:153, SkU 1971:67 and rskr 1971:339. For this see SOU 1972:42, p. 229. See also SOU 1970:36.

[32] As, for example, is the case of the Swiss kilometer charge that was imposed in 2001. It is basically differentiated according to weight and not axle load, see FCA (2000, p. 4).

charge, less road wear is to 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[33]. First, the number of so-called equivalent standard axle loads (esals) for each truck category used in the study is calculated according to:

$$ESALS_j = \Sigma_i \, x_i^{exp} \qquad (1)$$

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, x^{exp}, is the quotient between the actual axle weight and the standard axle of 8.172 metric tonnes (18 kip) raised to the fourth power (exp). 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. Second, each truck category traveled z km the year in question. Hence, adding the product of the esals and kilometers performed for each truck category according to:

$$ESALKM = \Sigma_j \, (ESALS_j * z_j) \qquad (2)$$

gives the total number of esal-kilometers 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[34]. The charge per esal-km is calculated according to:

$$\text{Charge per esal-km} = \text{road maintenance cost} / ESALKM \qquad (3)$$

[33] A distance-related charge could take several forms. One is a charge per unit of distance regardless of the vehicle weight. A second is a charge per unit of distance that is differentiated according to the vehicle weight. A third is a charge per unit of distance that is differentiated according to the vehicle axle weight, not total weight. In the first case a car pays the same charge as a truck, in the second a heavier truck pays more than a lighter truck or car, and in the third case a lighter truck might pay more than a heavier truck, or vice versa, according to the load and the axle configuration.

[34] 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, i.e. the road will be usable for the length of time it was expected to 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.

Hence, the level of the charge is determined by (i) aggregating the total number of esal-km, i.e. the total number of kilometers performed by the standard load, and then, (ii) to divide the annual road wear and deformation cost with this number. The result is the implied charge of one esal-km. 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:

$$(\text{Charge per vkt})_j = \text{Charge per esal-km} * \text{ESALS}_j \qquad (4)$$

where the left hand side is the charge for the particular truck category. In other words, the road wear cost of 1889 million SEK is divided by the total number of esal-kilometers and the result is the charge for driving a standard axle one kilometer. 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 Tables C1 and C2 of Appendix C. The result is 0.14 SEK per esal-km[35], with a resulting km-charge for each category as displayed in Table 2.2 below.

ii. The Scenarios

Three different scenarios are employed in the model and they are shown in Table 2.1. 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 motivated, 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[36]. The results will demonstrate whether the suggestions made to alleviate the fiscal effects of the km-charge by reducing other taxes is motivated as to offset the overall effect. The third scenario, SC3, is the same as SC2 except that the km-charge is doubled. This scenario is motivated by simply 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.[37]

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[35] The status quo level of maintenance was 1 889 million SEK, and at a total of 13 305 million esal-km in benchmark, gives a cost of the road wear imposed of SEK 0.14 per esal km.

[36] This means that the latter two are together reduced by 83%. See Appendix D.

[37] 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

Table 2.1 – The scenarios; ex ante changes (million SEK)

	Label	Description	Tax payments	Government budget
Scenario 1	SC1	Km-charge	+1889	+1889
Scenario 2	SC2	Km-charge	+1889	
		Lowered tax	-730	+1159
Scenario 3	SC3	Double km-charge	+3778	
		Lowered tax	-730	+3048

The figures in the last two columns 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 adjustment 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 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 expressions *ex ante* and *ex post* are here used in their Latin sense).

The km-charge is shown in more detail in Table 2.2. 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 kilometer 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.

Table 2.2 – The km-charge in the scenarios, SEK per vehicle kilometer

	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

* The categories L2-L44 are explained in Table C2 of Appendix C

3. The Model and Results

In this part 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, like

be to determine the level of the charge the other way around, i.e. 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 were judged to be more interesting than the current third scenario.

overall welfare and labor supply. Finally, the results of the sensitivity analysis that has been performed will be reviewed. But first a few words about the model.

i. The Model

The model is a static, small open economy, computable general equilibrium (CGE) model, where 'general' means that all markets, i.e. labor market, commodities market etc, clear, not one at a time as in a partial equilibrium, but rather simultaneously, all at the same time. The model structure is outlined in Johnsson (2003b). The main difference from Johnsson (2003b) is the inclusion of the truck categories discussed above, and this is done in the way implied in Johnsson (2003a). The particular nesting structure used in the model is shown in Appendix E together with the corresponding elasticities. The elasticities with respect to the transport commodities in Appendix E are motivated in 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 meters and 60 tons is assumed to be used other than locally and an 18 ton single truck is not used for long-distance hauling.

ii. Effects on Trucking

Starting by looking at Table 3.1, we see the changes in the trucking activities that follow from the simulations. These imply the number of vehicle kilometers as well as the number of esal-km performed by the different truck categories (since that is exactly the assumption used to model the distance 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%, almost twice as much as the somewhat less damaging truck, the 2-axled 24 ton truck, while there is an increase in the use of the 3-axled 24 ton truck, the least damaging truck category within the nest[38]. Shifts towards less damaging trucks also take place within the other nests, i.e. in the 'regional' and the 'long-distance' nest. But all of these shifts also include an overall drop in the total number of vehicle kilometers 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

[38] 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.

extent in this scenario, as compared to SC1. In the third 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%. Notably, there is still an increased activity level in truck category L4.

Table 3.1 - Results w.r.t. 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

* vkt=vehicle kilometers and esal-km=equivalent standard axle load-kilometers.

The overall effects of the scenarios on vehicle kilometers and esal-km performed are summarized in Table 3.2, together with the implied changes in road wear. As the second and third column show, the drop in number of esal-km performed closely follows the drop in number of vehicle kilometers performed. The only difference is that the esal-km performed drops by around one percentage unit more than the vehicle kilometers 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, i.e. 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, i.e. by between 9.5 and 14.3%. The bulk of this saving comes from the general drop in vehicle kilometers performed by heavy trucks, while only a smaller part comes from the shift towards less damaging trucks.

Table 3.2 – 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

Table 3.3 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 like, for example, 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 3.3 – Effect on local, regional and long-distance related road wear

	local mSEK	regional mSEK	long-dist mSEK	Total mSEK
Scenario 1	-43	-38	-98	-179
Scenario 2	-43	-38	-96	-177
Scenario 3	-66	-58	-146	-270

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, i.e. 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, i.e. by using less damaging trucks.

iii. 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 3.4 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[39]. 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.

Table 3.4 – 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

* Output destined for both domestic and foreign markets.

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

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 to categories L2-L4 and LS34-LS44, which together account for 87% of the total vehicle kilometers performed. Within these nests, most of the activity is concentrated to the most damaging trucks, and it is exactly the use of these categories that involves the highest kilometer charges. The chemical industry has a somewhat different structure, where 73% of the vehicle kilometers 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[40].

The effects on the transport related industries are shown in Table 3.5. 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. A perhaps surprising result is the reduction in bus passenger traffic. It is modeled 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%. This effect is expected since the charges are levied on an obvious substitute. There also is a slight increase in railway passenger traffic, most likely stemming from the final demand side and not from the production side.

There are two major activities produced by the shipping industry, i.e. the freight and the passenger activities. The slight increase in the freight activity is to be expected since it is modeled 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

[40] Furthermore, there is a slight possibility that the use of trucks by these two industries is overestimated. For example, the mining industry use a lot of underground transportation and it is possible that this is treated as trucking in the data set 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.

could accrue to the former, but not much since the transformation elasticity is close to a Leontief fixed share. Instead it is most likely that it stems from the latter.

Table 3.5 – 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
Harbor 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

* Output destined for both domestic and foreign markets.

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 likely stems from the final demand side since it only plays a minor role in production.

The petrol used by households for transport purposes, i.e. mainly car-use, is hardly affected at all. This is perhaps to be expected since the kilometer 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 kilometer charge instigates substitution towards diesel used for transports other than for heavy trucks, i.e. mostly for lighter trucks, and towards vehicles fuelled by petrol. The latter might include heavy trucks fuelled by petrol, since these are not subject to the charges in the model, so the effect could be somewhat over-estimated.

iv. Aggregate Measures

Table 3.6 reports the changes in the real wage, the labor supply and the Hicksian Equivalent Variation. The changes in real wage are counted in hundredths of a percentage point, i.e. the tax changes seem to have close to zero effect on the real wage. The same holds for the labor 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, i.e. 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 labor and capital, but as the real wage proved to be largely unaffected, this explanation seems unlikely.

Table 3.6 – Aggregate measures

	Real Wage* %	Labor 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

* Wage/Utility index.

The fiscal effects, i.e. the effects on total tax payments and the government budget are shown in Table 3.7. To understand this table, we start by recognizing that it is divided into ex ante and ex post effects. The ex ante effects simply state that in for example SC2, the revenue from the vehicle registration tax and the Eurovignette charge are together reduced by some 730 million SEK, while the revenue from the km charge means an addition of 1889 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 1159 million SEK. This is the change in the budget that we can say will occur prior to any substitutions, i.e. ex ante. These figures were also shown in Table 2.1 above.

Table 3.7 – Tax payments and changes in the government budget

Ex ante					Total change
SC1 Costs		Government		Revenue	
	Road maintenance	0	..	Vehicle reg.+EV charge*	
			+1889	Km-charge	
		0	+1889		+1889
SC2 Costs		Government		Revenue	
	Road maintenance	0	-730	Vehicle reg.+EV charge*	
			+1889	Km-charge	
		0	+1159		+1159
SC3 Costs		Government		Revenue	
	Road maintenance	0	-730	Vehicle reg.+EV charge*	
			+3778	Km-charge	
		0	+3048		+3048
Ex post					
SC1 Costs		Government		Revenue	
	Road maintenance	-179	..	Vehicle reg.+EV charge*	
			+1710	Km-charge	
			-696	Other tax payments	
		-179	+1014		+1193
SC2 Costs		Government		Revenue	
	Road maintenance	-177	-730	Vehicle reg.+EV charge*	
			+1712	Km-charge	
			-254	Other tax payments	
		-177	+728		+905
SC3 Costs		Government		Revenue	
	Road maintenance	-270	-730	Vehicle reg.+EV charge*	
			+3508	Km-charge	
			-1340	Other tax payments	
		-270	+1438		+1708

* Benchmark payments amount to 877 for industries and 216 for households.

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 1889 million SEK to a net increase of 1710 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 +1193, +905 and +1708 million SEK in scenarios SC1, SC2 and SC3 respectively. This amounts to respective increases of +0.2%, +0.2% and +0.3% in the modeled 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% were actually collected. This kind of analysis is probably only possible to perform within a CGE framework.

v. 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[41]. The sensitivity analysis is limited to the main scenario, i.e. SC2, for the sake of briefness.

Turning first to Table 3.8, 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% level of statistical significance.

Table 3.8 – 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*	24.97	30.61	28.11	13.54	33.95	36.45	41.95	36.75	29.25	27.11

* Over 1000 solutions.

The result of the sensitivity analysis with regard to the Hicksian Equivalent Variation welfare measure is shown in Table 3.9, where we see that the small change in EV of SC2 proved in fact to be insignificant at a 5% level of statistical significance.

Table 3.9 – Equivalent Variation*

	Result
SC2, %	-0.06
t-value**	-1.93

* Results of 1000 solutions.
** t-value computed as (point estimate – 0) / standard deviation over 1000 solutions.

[41] The key parameters are those assigned a distribution in Table F3 of Appendix F. Following Harrison and Kriström (1997) and Hill (1998), the sample size, i.e. the number of times the model is solved, is set to 1000. 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.

Thus, we see that the results presented above 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. 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, i.e. 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 kilometers 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 were only a weight-distance related charge, as opposed to the axle-load-distance related charge used here[42]. 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 transportation 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, labor supply or household welfare. Finally, we have seen that the ex ante changes in expected tax revenue are possibly overstated and

[42] Once again; since the effect largely comes from decreased activity and not shifts to less damaging trucks.

perhaps only 56-78% of the ex ante amounts could actually be expected to be collected. 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 kilometers are performed, but also because of modal shifts and shifts toward other road transportation 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.

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 as much by the non-linearity that was integrated into the design of the charge.

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Chapter 5 – The Cost of Relying on the Wrong Power – Road Wear and the Importance of the Fourth Power Rule

1. Introduction

When it comes to road wear and deformation, it is perhaps surprising how influential the American Association of Highway and Transportation Officials (AASHO (1962)) study, conducted back in the 1950s and 1960s, still is. The study found that road wear and deformation was largely related to axle weight rather than vehicle weight. The study also found that the relationship of road wear and deformation to axle weight was highly non-linear and the so-called Fourth Power Rule emerged.

Using the same data set as the original AASHO study, the relationship has been re-estimated and largely confirmed by Small et al. (1989) and other studies have extended the original study by including new axle configurations. But no new empirical data similar to, and as extensive as, the AASHO data has been collected. Instead, yet other studies have highlighted other characteristics affecting the relationship between road wear and deformation and the use of the road. These studies have for example focused on tire characteristics, suspension systems, axle spacing, the use of liftable axles and the use of triple axles (tridems)[43]. The result is that the Fourth Power Rule has been questioned. Is it really a fourth power, or is it rather a third if the effect of the axle spacing is included? Etc, etc, etc.

National road administrations in many countries are considering the possibility to use an axle weight-distance related kilometer charge to cope with costs related, for example, to road infrastructure and maintenance. It has been suggested that there is no real alternative to the AASHO Fourth Power Rule (see Martin (2000, p. 90)). But is it the 'right' power rule? What if the true relation is better represented by, for example, a second power rule? This study will analyze the implications of the design of a charge according to a specific power rule, while allowing for the possibility that the true relation is represented by another power. This will provide an indication

[43] See for example FHWA (1995), DETR (2000), and Kenis and Cobb (1990).

as to whether the issue is of any practical interest at all. The analysis will be made by implementing a charge designed according to the first through the fifth power and for ten different truck categories, in a computable general equilibrium (CGE) model of Sweden.

In section 2 the study proceeds to discuss a number of aspects, beside axle-weight, that have been suggested as affecting road wear and deformation. In section 3 the charge is calculated, and in section 4 the simulation results are presented. Section 5 concludes the study.

2. The Fourth Power Rule?

The results of the AASHO (1962) study and the Fourth Power Rule can be summarized, as in Small et al. (1989, p.11): "Two technological facts are crucial to understanding road wear. First, the equivalence factor for an axle rises *very* steeply with its load – roughly as its third power. […] 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 pavements. For flexible pavements, such as the asphalt used in Sweden, the AASHO rule of thumb, the Fourth Power Law, seems to be verified by Small et al. (1989). It is also verified by a report to the Swedish Government back in the sixties, report designing the kilometer charge that was introduced in 1974 and abolished in 1993. The report noted that the exponent (i.e. the power) fluctuates widely depending on the type of road body, but that a study had arrived at an exponent of 3.9 for asphalt roads when applying the AASHO formula under Swedish conditions.[44]

Since the AASHO study, however, several other factors have been identified as influencing the road wear. These include tire characteristics, suspension systems, the use of liftable axles, axle spacing and the use of triple axles (tridems) and the fact that the road types are a major determinant of the exponent. And there have naturally been many changes in truck characteristics since the AASHO study.

First of all, for commercial considerations, tires have generally become lighter, smaller in diameter and able to carry a greater load. This has for example resulted in the use of radial instead of bias-ply tires, higher tire pressure and more frequent use of dual tires. When it comes to tires, it is a

[44] The coefficients in the Small et al. study were 3.241 for rigid pavements and 3.652 for flexible pavements. 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 p. 134.

known fact that higher tire pressure reduces the size of a tire's 'footprint' on the pavement, so that the weight of the wheel is distributed over a smaller area, suggesting greater road wear. The wide single tires bring about savings in fuel costs but might result in higher road wear than otherwise identical dual tires. On the other hand, although dual tires could be expected to cause less road wear than single tires, in reality one of the tires may often be overloaded due to unequal tire pressures, uneven tire wear, or pavement crown. This to some extent offsets the expected advantage of dual tires. Another effect of dual tires is the effect of randomness in the lateral placement of the truck on the road. This means that the single tire often wander sideways over the lane, spreading the wear out sideways. A dual tire lessens this 'positive' effect. FHWA (1995) summarizes this in the following way (p. 16): "Taking all of these findings into consideration suggests that the relative damage potential [of single tires] is much less than commonly believed, and conceivably the wide base [single] tires might be less damaging than duals." This is a conclusion not found in for example DETR (2000), hinting at the major uncertainties in the field.

A second truck characteristic that has changed since the AASHO study is the suspension systems. Again quoting FHWA (1995): "As a heavy truck travels along the highway, axle loads applied to the pavement surface fluctuate above and below their average values. […] On the assumption that the pavement wear effects of dynamic loads are similar to those of static loads and follow a fourth-power relationship, increases in the degrees of fluctuation increase pavement wear." Thus, better suspension systems might decrease the road wear, but, as noted in DETR (2000), this is for example conditional upon the suspension system being "maintained at a specified level in order to maximize those benefits" (p. 70). Thus, there is a large uncertainty in how the suspension system might affect road wear and the Fourth Power Rule.

A third truck characteristic influencing the road wear that was not accounted for in the AASHO study is the use of liftable axles. Liftable axles "provide the vehicle operator with the opportunity of reducing tire wear and fuel consumption at times when the vehicle is substantially less than fully laden", but there is "a risk that the lift axle can be misused or abused" (DETR (2000), p. 76). This is because it is conceivable that an operator will take the opportunity to reduce tire wear and fuel consumption also when the truck is fully loaded. FHWA (1995) also mentions the use of liftable axles to get around the – often employed – charges determined by the combination of weight and the number of axles. Charging the liftable axles as if they were rigid axles could of course, solve this problem. But that perhaps introduces other problems. Anyhow, there is a great uncertainty in this area as well.

Fourth, the axle configuration also affects road wear in different ways. For example, it is unlikely that axle spacing affects rutting, but is more likely to affect the fatigue. If axles are placed close enough together, they start to act as an entity and it is suggested in the FHWA (1995) study (p. 18) "that the AASHTO[45] esal [equivalent standard load] values appear to understate the damaging effect of dual and triple axles in comparison to single axles." FHWA (1995) also mentions studies that question the AASHTO (1993) values for tridems. The road wear factor for tridems used in the present study are based on Kenis and Cobb (1990). Hence, there is a great deal of uncertainty in this field, too.

Finally, the value of the exponent seems to be determined to a high degree by the road type. DETR (2000) refers to results where the exponent has been allowed to vary between three and nine, that is, to a very high degree. In the Swedish study referred to above, the exponent for road types built on different types of soil ranges from 1.16 to 8.52 with a weighted average of 3.30 (SOU 1969:45, pp. 136-7). The exponent seems to be lower where most of the transport by heavy truck is conducted (which in turn is a reflection of the fact that roads are often better where traffic is heavy). However, there might be exceptions to the last point[46]. But let us now proceed to the next section, which outlines how the charge is calculated.

3. The Charge

The charge is calculated according to the first, second, third, fourth and fifth power. However, this is not as straightforward as it might seem and requires some explanation. First of all, the number of so-called equivalent standard axle loads (esals) for each truck category used in the study (L2-L44) is calculated according to:

$$ESALS_j = \Sigma_i x_i^{exp} \quad (1)$$

where the truck category j is the sum of the esal of each individual axle i and where the esal of each individual axle, x^{exp}, is the quotient between the actual axle weight and the standard axle of 8.172 metric tonnes (18 kip) raised to the exponent in question (1^{st}, 2^{nd}, 3^{rd}, 4^{th} or 5^{th}). Second, each truck category traveled z km the year in question. Hence, adding the product of the esals and kilometers performed for each truck category according to:

$$ESALKM = \Sigma_j (ESALS_j * z_j) \quad (2)$$

gives the total number of esal-kilometers performed over the year. Third, the actual level of the charge is set to cover the annual road wear and

45 American Association of State Highway and Transportation Officials (AASHTO) is the predecessor to AASHO.

46 An example could be the extensive timber trucking on secondary and tertiary roads, for example in the Swedish northern inlands.

deformation and as an approximation to this, the annual status quo road maintenance cost is used[47]. The charge per esal-km is calculated according to:

$$\text{Charge per esal-km} = \text{road maintenance cost} / \text{ESALKM} \qquad (3)$$

Hence, the level of the charge is determined by aggregating the total number of esal-km, i.e. the total number of kilometers performed by the standard load (step (1)-(2)), and then to divide the annual road wear and deformation cost with this number (step (3)). The result is the implied charge of one esal-km. After this, and fourthly, 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:

$$(\text{Charge per vkt})_j = \text{Charge per esal-km} * \text{ESALS}_j \qquad (4)$$

where the left hand side is the charge for the particular truck category. In other words, the road wear cost of 1889 million SEK is divided by the total number of esal-kilometers and the result is the charge for driving a standard axle one kilometer. This procedure is repeated for each exponent. The charges are thus all designed to recover the maintenance cost.

The levels of the charges are shown in Table 3.1. The first two columns show the power rule (exponent) with the corresponding scenario in the model. The table shows that for some truck categories, increasing the exponent means a lower charge (L3, L4, LS22, LS23, LS32, LS33, LS44) while the reverse holds for other categories (L2, LS21, LS34)[48]. It is assumed that some truck categories are used locally, others regionally and some for long-distance transport, as explained in Johnsson (2003c). The main implication of this is with regard to the substitution possibilities between the different truck categories. The nested production structure and the elasticities employed are outlined in Appendixes E and F respectively. Further details of the model and the benchmark 1995 data set are provided in Johnsson (2003a-c).

Before turning to the results, an important implication from the choice of powers has to be mentioned. Using the first power when calculating the

[47] According to SOU 1997:35, on p. 86 of the supplement, the status quo annual maintenance cost of sealed roads is stated as approximately 1856 million SEK at 1990 prices. 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, i.e. the road will be usable for the period expected in the investment plan. The road maintenance of sealed roads amounted to 1889 million SEK in 1995, and this figure determines the level of the charge. This is considered to be the best estimate of the road wear available.

[48] The truck categories are explained in Appendix C. L2=2 axles, L3=3 axles, L4=4 axles, L21=2-axle truck with 1-axle trailer, etc.

charge, (1)-(4) above collapse into a weight-distance charge, rather than an axle-weight-distance charge. A weight-distance charge is different in some aspects from an axle-weight charge. First, considerably less information is needed to implement the charge. For example, the existing vehicle registration tax registers would probably contain the necessary information. Second, collection of the charges would probably impose a lower burden on the involved parties. The vehicles could, for example, be weighed before driving up onto a toll road, something that would be more difficult were axle-weight charges to be employed. On the other hand, we would expect some of the advantages from an axle-weight charge to be diminished were a weight-distance charge to be imposed instead. The simulations will help give an indication of the relative sizes of these offsetting effects.

Table 3.1 – The kilometer charge in SEK per vehicle kilometer

		Local			Regional					Long-distance	
Scenario	Exponent	L2	L3	L4	LS21	LS22	LS23	LS32	LS33	LS34	LS44
Scenario 1	1	0.47	0.44	0.37	0.73	0.93	0.9	0.85	0.75	1.00	0.93
Scenario 2	2	0.55	0.48	0.32	0.87	1.06	1.00	0.89	0.72	1.22	1.06
Scenario 3	3	0.57	0.47	0.24	0.90	1.05	0.96	0.80	0.62	1.28	1.05
Scenario 4	4	0.60	0.46	0.17	0.92	1.02	0.93	0.72	0.55	1.32	1.04
Scenario 5	5	0.63	0.45	0.12	0.94	1.00	0.90	0.65	0.50	1.35	1.02

4. Results

i. The Results on Road Wear

Table 4.1 shows the changes in vehicle kilometers and esal-kilometer for each truck category in each scenario. First, in the first scenario, where the first power was used to determine the level of the charge, we see that the vehicle and esal-kilometers decreased for all truck categories, but that the decrease is different for different categories. It is the activity of the most damaging truck categories that decreases most. Secondly, we see that these results repeat themselves in the second, third, fourth and fifth scenario, only now the decrease in the activity of the most damaging truck categories is larger, and the decrease in the activity of the least damaging truck categories is smaller, than in the first scenario. We see that this effect is enhanced as the power used to design the charge increases. Moreover, the activity of the least damaging truck category within the 'local' nest, L4, even turned into positive figures in SC3-SC5. In relation to the latter result, one of the major advantages of CGE model becomes apparent; there may be more activity even at a higher price. It is only within the general equilibrium framework this kind of effect is possible. In a partial equilibrium framework, a higher price generally implies less activity. The central principle at work is, of course, the principle that only relative prices are important.

Table 4.1 - Results w.r.t. trucking; percentage change in vkt and esal-km

		Truck category									
		L2	L3	L4	LS21	LS22	LS23	LS32	LS33	LS34	LS44
Benchmark value	mSEK	399.4	306.0	23.4	4.4	21.3	41.3	49.0	162.4	520.8	64.1
SC1	%	-8.5	-5.3	-1.6	-18.9	-10.4	-9.1	-8.4	-7.3	-8.9	-7.9
	t-value	27.02	33.81	47.40	13.05	33.98	38.66	41.21	38.09	35.63	34.63
SC2	%	-9.6	-5.6	-0.4	-20.9	-11.7	-10.0	-8.5	-6.1	-10.5	-8.2
	t-value	25.04	30.98	38.24	13.02	33.04	37.36	40.97	36.83	30.77	29.41
SC3	%	-9.9	-5.5	1.1	-21.4	-11.8	-9.8	-7.4	-4.6	-11.0	-7.7
	t-value	24.95	30.68	32.52	13.36	33.58	37.22	41.96	37.09	29.51	27.73
SC4	%	-10.3	-5.4	2.4	-21.7	-11.8	-9.7	-6.4	-3.5	-11.4	-7.2
	t-value	24.82	30.37	28.03	13.57	33.43	35.93	41.20	36.13	28.7	26.59
SC5	%	-10.7	-5.2	3.4	-22.1	-11.7	-9.6	-5.3	-2.8	-11.6	-6.8
	t-value	24.67	29.98	25.02	13.74	33.01	34.59	39.84	34.95	28.31	25.99

If the figures in Table 4.1 are transformed into figures of road wear they result in Table 4.2. There we find, in the right hand column, that road wear decreases in all scenarios, ranging from 155 to 181 million SEK. The differences between the scenarios are thus rather small, at least in relation to the overall road wear of 1889 million SEK.

Table 4.2 – Effect on road wear

	vehicle kilometers %	esal-kilometers %	road wear mSEK
Scenario 1	-8.0	-8.2	-155
Scenario 2	-8.7	-9.2	-174
Scenario 3	-8.6	-9.3	-176
Scenario 4	-8.5	-9.5	-179
Scenario 5	-8.4	-9.6	-181

The table also shows that the total esal-kilometers performed decrease to a larger extent than the vehicle kilometers performed and that this result holds for all the scenarios. However, we see that most of the effects come from the overall decrease in vehicle kilometers performed, and only to a lesser degree by shifts to less damaging truck categories. This is manifested by the relatively small differences between the decreases in esal-kilometers and the vehicle kilometers performed, ranging "only" to an additional 0.2% on top of the 8.0% in scenario 1, to 1.2% on top of the 8.4% in scenario 5. These figures also reveal that the shifts towards less damaging truck categories increase as the power used to design the charge increases. Finally, we see that employing a weight-distance charge in scenario 1 leads to a smaller decrease in both vehicle and esal-kilometers performed, and that the difference between these measures is smaller. The latter effect is perhaps expected, but the former is not as obvious.

Table 4.3 shows the effect on the government budget in all scenarios. The ex ante static effect is that another 1889 million SEK will be raised to cover road maintenance. However, after the adjustments to the charge, ex post, it turns out that only 56-63% of the 1889 million SEK will flow into the government budget.

Table 4.3 – Tax payments and changes in the government budget

Ex ante						Total change
SC1-SC5	Costs		Government		Revenue	
	Road maintenance	0		+1889	Km-charge	
		0		+1889		
Ex post						+1 889
SC1	Costs		Government		Revenue	
	Road maintenance	-155		+1734	Km-charge	
				-826	Other tax payments	
		-155		+908		
SC2	Costs		Government		Revenue	+1 063
	Road maintenance	-174		+1715	Km-charge	
				-697	Other tax payments	
		-174		+1018		
SC3	Costs		Government		Revenue	+1 192
	Road maintenance	-176		+1713	Km-charge	
				-696	Other tax payments	
		-176		+1017		+1 193
SC4	Costs		Government		Revenue	
	Road maintenance	-179		+1710	Km-charge	
				-695	Other tax payments	
		-179		+1015		+1 194
SC5	Costs		Government		Revenue	
	Road maintenance	-181		+1708	Km-charge	
				-696	Other tax payments	
		-181		+1012		+1 193

Once again we see that the weight-distance charge of scenario 1 leads to a different result. The net positive effect on the government budget is about 120 million SEK less compared to the other scenarios. This amount is an economically relevant figure in this context since the reduction in road wear in the first scenario amounts to 155 million SEK. When choosing a weight-distance charge designed according to the first scenario over an axle-weight charge, the 120 million SEK has to be weighed against the more practical advantages of the former (as discussed above).

So far we have implicitly assumed that the charge actually was designed according to the true relation between truck characteristics and road wear. Let us relax that assumption. Table 4.4 provides an example in relation to the fourth power. In the second row of the table, we see the resulting changes for each truck category following the imposition of a charge designed according to the fourth power, which is most commonly assumed to be the true relation (these figures were also given in Table 4.1). In the first column, we find the true power, ranging from 1 to 5. If the charge was designed correctly, the results of the two rows next to "true=4" would hold. These are the results presented above for the fourth scenario, and we see that the 9.5% decrease in road wear equals the decrease in esal-kilometers in the fourth scenario in Table 4.2. But Table 4.4 also shows the effects on road wear when the charge is designed according to the fourth power but when the true relation is something else. The right hand column shows that the reduction in road wear range from 8.9% to 9.6% as the true relation varies from the first to the fifth power.

Table 4.4 - Charge designed according to the 4th power and true power varies between 1 and 5

		L2	L3	L4	LS21	LS22	LS23	LS32	LS33	LS34	LS44	Total	%
	%	-10.3	-5.4	2.4	-21.7	-11.8	-9.7	-6.4	-3.5	-11.4	-7.2		
	Esal-km*	1 098.9	672.8	32.2	23.4	170.6	266.1	561.7	1 207.7	3 478.4	292.5	7 804.3	
true=1	change	-112.9	-36.0	0.8	-5.1	-20.1	-25.8	-35.8	-42.3	-396.2	-21.0	-694.5	-8.9
	Esal-km*	1 298.4	742.6	28.2	28.0	194.7	295.4	585.9	1 154.7	4 264.4	334.9	8 927.4	
true=2	change	-133.4	-39.8	0.7	-6.1	-22.9	-28.7	-37.4	-40.5	-485.7	-24.0	-817.8	-9.2
	Esal-km*	1 624.1	864.8	25.0	34.8	229.5	341.5	632.7	1 189.0	5 371.1	398.1	10 710.5	
true=3	change	-166.9	-46.3	0.6	-7.6	-27.0	-33.1	-40.3	-41.7	-611.8	-28.6	-1 002.7	-9.4
	Esal-km*	2 117.1	1 047.9	22.2	44.3	278.2	409.4	705.7	1 310.6	6 882.8	487.5	13 305.7	
true=4	change	-217.6	-56.1	0.5	-9.6	-32.8	-39.7	-45.0	-46.0	-783.9	-35.0	-1 265.1	-9.5
	Esal-km*	2 836.7	1 304.8	20.0	57.6	345.6	506.7	810.5	1 526.4	8 914.2	610.3	16 932.8	
true=5	change	-291.5	-69.9	0.5	-12.5	-40.7	-49.2	-51.7	-53.5	-1 015.3	-43.8	-1 627.6	-9.6

* millions

If the same kind of computation is performed for all the five scenarios, the results could be displayed in a matrix, as in Table 4.5. In the table, the columns represent the power relation chosen when the charge was designed and the rows the true relation. Again, focusing for example on the column where the fourth power relation was used for the charge, we see that the deviation from the true relation resulted in a deviation of -0.6, -0.3, -0.1 and +0.1% of annual road wear costs. These figures could also be found in the right hand column in Table 4.4 by subtracting –8.9, -9.2, -9.4 and –9.6 from the true fourth power result of –9.5. Making the same computations for all the other scenarios shows that the deviation from the optimal change in road wear costs ranges from –0.8% to +0.2% of annual road wear costs. A positive figure means actual road wear is reduced more than the optimal, a negative that actual road wear is reduced less than the optimal. Hence, if the true relation between truck characteristics and road wear lies somewhere between the first and the fifth power, the deviation from the optimal incurred by designing the charge according to a false power ranges between –15.1 and 3.8 million SEK, as long as the charge is designed according to one of the five powers.

Table 4.5 - Cost of being wrong, percentage of annual road wear costs*

		Charge designed according to exponent:				
		1	2	3	4	5
True exponent:	1	..	-0.2	-0.3	-0.6	-0.8
	2	0.1	..	-0.1	-0.3	-0.5
	3	0.1	0.1	..	-0.1	-0.2
	4	0.2	0.2	0.1	..	-0.1
	5	0.2	0.2	0.2	0.1	..

* a positive figure means actual road wear is reduced more than the optimal, a negative that actual road wear is reduced less than the optimal

ii. The Results of the 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, especially 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 while some key parameters are simultaneously perturbed, very much like a Monte Carlo simulation. The key elasticities in the study are the substitution elasticities within the trucking nests and between the trucking nests. These are shown in Table 4.6[49].

The parameter values are perturbed simultaneously and the model is then solved 1000 times[50]. The resulting t-values are shown in Table 4.1 above. The results do overall appear to be statistically significant at a 5% level of statistical significance[51]. Hence, the results seem to be robust with regard to the key parameters of the study.

Table 4.6 – Some key elasticities

Elasticity of substitution	Point estimate	Range	Distribution
- between input of 'local' trucks	0.2	(0.0 , 0.4)	uniform
- between input of 'regional' trucks	0.4	(0.0 , 0.8)	uniform
- between input of 'long-distance' trucks	0.6	(0.0 , 1.2)	uniform
- between the nests	0.25	(0.0 , 0.5)	uniform

[49] For the source of these estimates, see Appendix F.
[50] Following Harrison and Kriström (1997) and Hill (1998), the sample size, i.e. the number of times the model is solved is set to 1000. For more on this, see Harrison et al. (1993).
[51] Note that not all distributions are assumed to be normal, so that the critical t-values are valid only asymptotically.

5. Concluding Remarks

In this study, an axle-weight-distance related kilometer charge has been differentiated for ten different truck categories according to their contribution to road wear and deformation. The AASHO Fourth Power Rule, set to cover the annual road wear and maintenance costs in Sweden, determines the money cost of this contribution on the margin. The charge has also been designed by varying the power, from the first through the fifth power. The different charges have then been simulated in a CGE model.

The results tells us to expect a decrease in activity in the most damaging truck categories, while when the higher powers are used to design the charges, the charge actually might lead to significant increases in the activity of the least damaging truck category (assumed to be used only locally). This last is an effect only possible in a CGE model.

The decrease in road wear ranges from 155 when the first power is used to 181 million SEK when the fifth power is used. This could be compared to the total road wear cost of 1889 million SEK that was used to determine the level of the charges. Most of the decrease in road wear in the model appears to be a result of the decrease in the general trucking activity and only to a lesser extent a result of shifts towards less damaging truck categories. The decrease in the overall number of vehicle kilometers performed ranges between 8.0% when the first power is used and 8.7% when the second power is used. Moreover, the "extra" decrease in the overall number of esal-kilometers performed increases as a higher power is used to design the charge.

The effect on the government budget does not vary much with the choice of power used to design the charge. However, only between 56% and 63% of the tax revenue expected to be raised, based on a static calculation, was actually raised in the model. That is, only 56-63% of 1889 million SEK actually flowed into the government's accounts after the adjustment to the newly imposed charges.

These results were based on the assumption that the people designing the charge, thereby choosing a power rule, made the right choice. By studying the effects of designing the charge according to one power relation, while the true one was another of the five at hand, the model results told us that the cost of being wrong appears to be modest. Choosing the wrong power leads to a deviation from the effects when one was right of between –0.8% and +0.2% of the annual road wear costs.

We have also seen that the results imply that we could expect a somewhat different outcome if a weight-distance charge was used, as compared to an axle-weight charge. The trucking activity and road wear costs would be reduced to a lesser extent by the weight-distance charge compared to the axle-weight charge. The positive fiscal effect on the government budget is 120 million SEK less with the weight-distance charge. If this figure is compared to the reduced road wear costs of 155 million SEK in this scenario, the difference could be considered significant. This then has to be weighed against other practical advantages of the weight-distance charge, for example that less information is needed and that it imposes less of a burden to collect the charges. However, the present model provides no answer to this.

Furthermore, the results presented here appear to be robust with regard to the choice of some key parameters. However, it is perhaps also appropriate to raise some uncertainties regarding these results. The results are of course highly dependent on the design of the charge, the choice of model used for the simulations, the model structure itself, etc. A degree of caution is therefore called for when inferring the consequences of these results in the real world. In conclusion, a few words about future work. Since the model simulation of this study would seem to indicate that the choice of power is of only minor importance, I suggest that more effort needs to be put into (i) finding a monetary measure of road wear, (ii) finding a charging technology that satisfies relevant minimum cost and maximum convenience criteria, both for the trucking business and the collection of the charges, and (iii) finding ways to compensate the trucking businesses financially for their increased costs, for example by lowering some other tax they are forced to pay today.

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Appendices

Appendix A – TSA Sweden 1995

Appendix B – Calibration of the Labor Supply Function

Appendix C – Truck Data

Appendix D – The Reduction of the Existing Annual Vehicle Registration Tax and the Eurovignette Charge

Appendix E – Nested Production Structure

Appendix F – Elasticities

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Use matrix expanded with new commodities

	AGRI	FORE	MING	INDU	PULP	PETR	CHEM	META	ENGI	ELGW	CONT	RAIL	LAND	SHIP	AIR_	FORW	POST	SERV	REAL	PUBL	TIIN
AGRI	487	0	0	22648	0	0	54	0	3	0	16	0	0	30	0	0	0	442	82	438	24200
FORE	18	699	2	12722	9303	0	33	6	31	861	88	0	0	0	0	0	0	0	30	2	23795
MING	76	0	729	587	320	253	206	1866	170	310	681	0	0	0	0	0	0	22	101	468	5789
INDU	4618	117	132	30987	4884	7	938	747	5635	78	10871	58	607	820	63	322	223	7750	204	6403	75464
PULP	78	92	66	3121	28916	19	1798	548	6744	469	1026	84	972	236	83	506	2411	15578	264	7439	70450
PETR'	482	201	79	615	362	293	479	185	461	482	427	12	5	416	0	5	1	228	140	255	5130
CHEM	801	42	324	2020	1886	65	6214	722	13071	253	970	40	487	208	32	162	175	1595	480	2967	32514
META	0	0	4	217	43	18	133	16994	18188	1	933	0	0	0	0	0	0	190	0	115	36836
ENGI	1769	1223	1205	5481	2278	222	1577	4576	47807	1262	16852	1870	1021	821	1116	377	538	5481	728	9291	105495
ELGW	846	98	571	3081	4268	393	1939	2032	5353	1732	273	586	169	29	35	75	437	4843	10435	7209	44404
CONT	1720	364	249	1030	801	180	531	574	1650	8205	1066	2314	703	40	35	202	1591	3862	32643	13596	71356
RAIP	0	0	0	0	5	0	2	2	53	2	15	0	20	0	0	0	19	246	3	484	851
RAIF	0	0	98	499	329	3	122	118	539	0	0	1310	1564	0	0	0	129	2174	0	188	7073
BUSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2023	2023
BUSF	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	41	1166	0	0	1208
TRUK	210	0	822	4877	4429	40	1716	696	5261	0	4357	481	7770	0	0	0	0	9568	0	2049	42276
TAXI	6	6	2	48	53	0	64	15	286	38	40	19	153	14	34	57	81	791	13	3284	5004
PARK	0	0	1	10	29	0	25	17	106	0	31	0	30	0	2	23	0	795	3	85	1157
SHPA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	0	15	35
SHFR	0	0	87	677	329	64	109	145	675	0	0	0	0	1948	0	0	7	246	0	0	4287
ROUT	0	0	0	0	0	0	0	0	0	0	0	0	0	275	0	0	0	70	0	0	345
STOR	0	0	17	226	46	0	41	58	332	0	0	0	0	0	0	58	0	868	0	0	1646
HARB	0	0	55	328	74	1	76	62	430	0	0	0	0	147	0	0	0	654	0	0	1827

Continued on the next page

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Use matrix expanded with new commodities (continued)

	AGRI	FORE	MING	INDU	PULP	PETR	CHEM	META	ENGI	ELGW	CONT	RAIL	LAND	SHIP	AIR_	FORW	POST	SERV	REAL	PUBL	TIIN
AIRP	24	36	11	266	228	9	183	70	1284	146	244	47	568	0	0	1165	341	3378	66	3267	11333
AIRF	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1920	247	227	997	0	0	3392
TRAV	5	5	0	43	40	0	40	7	221	17	53	86	131	42	177	49	53	702	13	0	1684
CHAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FFOR	12	0	177	1330	334	6	320	316	1881	0	0	23	559	37	5	6	0	738	0	0	5744
POST	133	58	35	823	1752	21	952	268	4166	271	416	84	1099	172	127	529	640	10716	324	7879	30465
SERV'	3516	756	1245	15152	13434	332	10297	9587	51303	2182	13273	528	11434	1294	733	2764	8223	84221	12226	42554	285054
REAL	0	0	33	624	308	18	344	158	1191	0	142	38	417	64	48	206	1774	14573	0	25548	45486
PUBL	188	69	23	1102	178	64	594	113	1390	27	839	19	41	0	30	66	101	7756	315	9566	22481
DIHV	19	12	24	67	5	15	11	2	31	39	109	50	855	1	18	43	9	191	35	68	1604
DITR	12	8	15	42	3	9	7	1	19	24	68	31	529	0	11	27	5	117	22	42	992
PET_	57	39	2	43	40	16	54	2	283	64	388	2	338	1	301	19	17	1524	39	169	3396
TIIN	15077	3825	6008	108666	74677	2048	28859	39889	168564	16463	53178	7682	29472	6595	4770	6908	17043	181502	58166	145404	974796

AGRI=Agriculture and fishing, FORE=Forestry, MING=Mining, INDU=Other industries, PULP=Pulp and Paper mills, PETR=Petroleum refineries, CHEM=Chemical industries, META=Basic metal industries, ENGI=Engineering, ELGW=Electricity, gas and water, CONT=Construction, RAIP=Railway passenger , RAIG=Railway freight, BUSP=Bus passenger, BUSF=Bus freight, TRUK=Trucking, TAXI=Taxi, PARK=Car parking/Car leasing, SHPA=Shipping passenger, SHFR=Shipping freight, ROUT=Route services, STOR=Stowage services, HARB=Harbor services, AIRP=Air passenger, AIRF=Air freight, TRAV=Travel agencies, CHAT=Private international charter flights, FFOR=Freight forwarding, POST=Postal services, SERV=Services, REAL=Real estate, PUBL=Public service, TIIN=Total intermediate input

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Value added matrix

	AGRI	FORE	MING	INDU	PULP	PETR	CHEM	META	ENGI	ELGW	CONT	RAIL	LAND	SHIP	AIR_	FORW	POST	SERV	REAL	PUBL	TIIN
IMPO	2578	620	1094	25682	16035	16245	29747	17133	1E+05	6999	26693	386	1656	13014	4922	4826	4126	33041	642	21181	4E+05
PTAX	1111	334	180	1373	1145	37	730	600	2184	1363	1427	220	2435	428	545	159	926	11167	15639	3886	45889
PSUB	0	0	0	-1037	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1037
WAGE	3486	2923	2071	24816	22106	717	12792	7491	83708	6362	42624	2866	15680	2875	3561	8853	12458	2E+05	10412	225426	7E+05
WTAX	1313	1113	774	9630	8781	319	5523	2971	32778	2473	15581	1148	5495	993	818	2926	4841	63942	3554	80231	2E+05
CAPI	11870	17112	2096	23449	37956	3441	19645	13960	41097	37702	15325	1814	14017	3070	4050	1745	16433	2E+05	2E+05	18820	6E+05
CTAX	782	158	85	1012	844	28	837	284	3353	424	1836	124	1070	108	135	369	525	12550	15669	6188	46381
CSUB	-5962	-37	-94	-252	-1123	-1	-88	-46	-5091	-1070	-87	-2802	-6753	-490	-189	-1	-225	-7182	####	0	####
SOUT	30255	26048	12214	2E+05	160421	22834	98045	82282	5E+05	70716	2E+05	11438	63072	26593	18612	25785	56127	6E+05	3E+05	501136	3E+06

IMPO=imports, PTAX=specific product taxes, PSUB=specific product subsidies, WAGE=wage payments, WTAX=taxes on wages (excluding income tax), CAPI=capital payments (profit), CTAX=corporate tax (excluding capital income tax) and SOUT=sector/industry output.

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Final demand matrix expanded with new commodities

	CONS	PUBL	INVE	EXPO	TOUT
AGRI	5488	0	-1511	1953	30130
FORE	171	0	2252	637	26855
MING	3	0	1063	5161	12016
INDU	60049	0	-3356	49342	181499
PULP	9264	0	2374	66802	148890
PETR'	2233	0	-1604	11439	17198
CHEM	6240	0	-4371	64346	98729
META	5	0	801	39426	77068
ENGI	13663	0	55130	295880	470168
ELGW	26318	0	9	1334	72065
CONT	0	0	85723	0	157079
RAIP	2199	0	0	158	3208
RAIF	123	0	0	504	7700
BUSP	7475	0	0	1406	10904
BUSF	0	0	0	0	1208
TRUK	336	0	0	1809	44421
TAXI	1696	0	0	0	6700
PARK	359	0	0	0	1516
SHPA	2330	0	0	1993	4358
SHFR	0	0	0	17948	22235
ROUT	0	0	0	705	1050
STOR	0	0	0	0	1646
HARB	353	0	0	497	2677
AIRP	3940	0	-1	2659	17931
AIRF	0	0	0	1100	4492
TRAV	486	0	0	1717	3887
CHAT	5458	0	0	0	5458
FFOR	0	0	0	1672	7416
POST	14986	0	3	1768	47222
SERV'	185804	0	123148	71420	665426
REAL	229113	0	1	0	274600
PUBL	28636	449386	141	492	501136
DIHV	0	0	0	0	1604
DITR	0	0	0	0	992
PET_	8232	0	0	0	11628
TIIN	614960	449386	259802	642168	2941112

AGRI=Agriculture and fishing, FORE=Forestry, MING=Mining, INDU=Other industries, PULP=Pulp and Paper mills, PETR=Petroleum refineries, CHEM=Chemical industries, META=Basic metal industries, ENGI=Engineering, ELGW=Electricity, gas and water, CONT=Construction, RAIP=Railway passenger , RAIG=Railway freight, BUSP=Bus passenger, BUSF=Bus freight, TRUK=Trucking, TAXI=Taxi, PARK=Car parking/Car leasing, SHPA=Shipping passenger, SHFR=Shipping freight, ROUT=Route services, STOR=Stowage services, HARB=Harbor services, AIRP=Air passenger, AIRF=Air freight, TRAV=Travel agencies, CHAT=Private international charter flights, FFOR=Freight forwarding, POST=Postal services, SERV=Services, REAL=Real estate, PUBL=Public service, DIHV=diesel used for heavy trucks, DITR=other diesel used for transport, PET_=petrol used for transport, TIIN=Total intermediate input, CONS=Private consumption, PUBL=Public consumption, INVE=Investments, EXPO=Exports, TOUT=Total commodity output

Appendix B – Calibration of the Labor Supply Function

Here an algebraic calibration of the labor supply function is made, including many of the steps Ballard (1999) leaves out in his article. Ballard starts by defining the time-endowment ratio as:

$$\Phi = E / H \tag{1}$$

where E is the consumer's endowment of time, and H is the amount of labor that is supplied in the benchmark. H is given by the benchmark input-output matrix and is net of any taxes. Adopting the following utility function, defined over leisure, *l*, and consumption, C:

$$U = \left[\beta^{\frac{1}{\varepsilon}} l^{\frac{\varepsilon-1}{\varepsilon}} + (1-\beta)^{\frac{1}{\varepsilon}} C^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{2}$$

where β is a weighting parameter (the benchmark value share for leisure demand), and ε is the elasticity of substitution. The budget constraint is:

$$WE + Y = Wl + PC \tag{3}$$

where *W* is the net-of-tax wage rate, *E* is the time endowment, *P* is the price of one unit of aggregate consumption, and *Y* is non-labor income. The time endowment is *E=H + l*. The leisure demand function derived from utility maximization is:

$$l = \frac{\beta I}{W^{\varepsilon}\left[\beta W^{1-\varepsilon} + (1-\beta)P^{1-\varepsilon}\right]} \tag{4}$$

where *I = WE+Y* is the consumer's 'full income'. The uncompensated leisure demand elasticity is:

$$\eta' = \frac{\partial l}{\partial W}\frac{W}{l} = \frac{\beta E W}{W^{\varepsilon}\Delta l} - \frac{\beta(1-\varepsilon)W}{W^{\varepsilon}\Delta} - \varepsilon \tag{5}$$

where $\Delta = \beta W^{1-\varepsilon} + (1-\beta)P^{1-\varepsilon}$. The uncompensated labor supply elasticity can be expressed in terms of leisure:

$$\eta = \frac{\partial H}{\partial W}\frac{W}{H} = \frac{\partial(E-l)}{\partial W}\frac{W}{(E-l)} = -\frac{\partial l}{\partial W}\frac{W}{(E-l)} \tag{6}$$

since $\delta E / \delta W = 0$. (2) and (3) can be combined to derive an expression for the leisure demand elasticity in terms of the uncompensated labor supply elasticity and the time endowment parameter:

$$\eta' = -\eta\frac{(E-l)}{l} = -\eta\left(\frac{1}{\Phi - 1}\right) \tag{7}$$

Ballard lets the reader verify the calibration from here, but for the sake of clarity the rest of the calibration is included as well. Hence, by noting that all price levels equal unity in the benchmark, (5) collapses into:

$$\eta' = \frac{\beta E}{l} - \beta(1-\varepsilon) - \varepsilon = \frac{\beta E}{l} - \beta + \varepsilon(\beta - 1) = \beta\left(\frac{E}{l} - 1\right) + \varepsilon(\beta - 1) = \beta\left(\frac{1}{\Phi - 1}\right) + \varepsilon(\beta - 1) \qquad (5)'$$

since

$$\frac{E}{l} - 1 = \frac{E}{E-H} - \frac{E-H}{E-H} = \frac{H}{E-H} \qquad (8)$$

and

$$\frac{E-H}{H} = \frac{E}{H} - \frac{H}{H} = \Phi - 1 \qquad (9)$$

so that

$$\frac{E}{l} - 1 = \frac{1}{\Phi - 1} \qquad (10)$$

Solving for ε gives:

$$\varepsilon = \frac{\eta'}{(\beta-1)} - \frac{\beta}{(\beta-1)}\left(\frac{1}{\Phi-1}\right) = -\frac{\eta}{(\beta-1)}\left(\frac{1}{\Phi-1}\right) - \frac{\beta}{(\beta-1)}\left(\frac{1}{\Phi-1}\right) = -\frac{(\beta+\eta)}{(\beta-1)}\left(\frac{1}{\Phi-1}\right) = \frac{(\beta+\eta)}{(1-\beta)}\left(\frac{1}{\Phi-1}\right) \qquad (11)$$

and solving for time-endowment ratio:

$$\Phi = \frac{(\beta + \eta)}{\varepsilon(1-\beta)} + 1 \qquad (12)$$

Assigning a value for the time-endowment ratio gives the weighting parameter. Setting the time endowment ratio to, for example, 1.25, the full income becomes $I=1.25*WH+Y$ and $Wl=0.25WH$. Assuming the benchmark labor supply net of tax is $10*(1-0.46)=6.4$, benchmark non-labor income net of tax is $10*(1-0.25)=7.5$. This gives $I=1.25*6.4+7.5=15.5$ and $\beta = Wl/(Wl+PC)=0.103$ (the bmk total consumption equals $WH+Y$ and, thus, the denominator equals the full income). Next, assuming the uncompensated labor supply elasticity is for example 0.1, the elasticity of substitution becomes $\varepsilon=0.906$. Thus, picking values for the labor supply elasticity and the time endowment ratio will help control the labor supply function in the way Ballard advocates. And, as mentioned above, omitting to do this can seriously affect the results, for example with respect to. the welfare measure.[52]

[52] The actual calibration is done within the GAMS computational program.

References:

Ballard CL, (1999), 'How many Hours are a Simulated Day? The Effects of Time Endowment on the Results of Tax-Policy Simulation Models', Paper prepared for the 'Using OLG Models for Policy Analysis' Workshop, Copenhagen, Denmark, August 13-14, 1999.

Appendix C – Truck Data

Table C1 - Truck category data

Category	L2	L3	L4	LS21	LS22	LS23	LS32	LS33	LS34	LS44	Total
Truck weight, ton	18	24	24	18	18	18	24	24	24	24	
Trailer weight				10	18	22	16	16	36	36	
Vehicle km, millions[a]	498.9	325.2	18.5	6.8	38.7	62.5	139.5	338.8	738.2	66.7	2234.0
ESALS per unit	4.243	3.222	1.201	6.486	7.186	6.552	5.059	3.868	9.323	7.302	
ESAL-km, millions	2117.1	1047.9	22.2	443.5	278.2	409.4	705.7	1310.6	6882.7	487.5	13305.7

Source: a. T30 SM 9603; Table 19. L2=2 axles, L3=3 axles, L4=4 axles, L21=2-axle truck with 1-axle trailer, etc. The combinations of axles are shown in Table C2.

Table C2 – Weight distribution and esals (the rectangles are supposed to represent the axle configurations of the trucks and trailers respectively)

L2

18	4.24
O	O
37	63
6.6	11.4
14.5	25.2
0.8	1.4
0.418	3.83

L3

24	3.22
O	OO
26	74
6.3	17.7
13.8	39.1
0.77	1.3
0.345	2.88

L4

24	1.201
O	OOO
27	73
6.4	17.6
14.2	38.7
0.79	0.95
0.385	0.816

LS21

18	4.24	10	2.242
O	O	O	
37	63	100	
6.6	11.4	10	
14.5	25.2	22	
0.8	1.4	1.22	
0.418	3.83	2.24	

LS22

18	4.24	18	2.94
O	O	O	O
37	63	50	50
6.6	11.4	9	9
14.5	25.2	19.8	19.8
0.8	1.4	1.1	1.1
0.418	3.83	1.47	1.47

LS23

18	4.243	22	2.309
O	O	O	OO
37	63	41	59
6.6	11.4	9	13
14.5	25.2	19.9	28.6
0.8	1.4	1.1	0.95
0.418	3.825	1.48	0.82

LS32

24	3.22	16	1.837
O	OO	O	O
26	74	50	50
6.3	17.7	8	8
13.8	39.1	17.6	17.6
0.77	1.3	0.98	0.98
0.345	2.88	0.92	0.92

LS33

24	3.22	16	0.65
O	OO	O	OO
26	74	41	59
6.3	17.7	6.6	9.4
13.8	39.1	14.4	20.8
0.77	1.3	0.8	0.69
0.345	2.88	0.42	0.23

LS34

24	3.222	36	6.101
O	OO	OO	OO
26	74	50	50
6.3	17.7	18	18
13.8	39.1	39.6	39.6
0.77	1.3	1.32	1.32
0.345	2.878	3.05	3.05

LS44

24	1.2	36	6.101
O	OOO	OO	OO
27	73	50	50
6.4	17.6	18	18
14.2	38.7	39.6	39.6
0.79	0.95	1.32	1.32
0.385	0.82	3.05	3.05

LEGEND

	Category		
Total weight	18	4.24	Total unit esals
	O	O	Axle configuration
	37	63	Weight distribution, %
	6.6	11.4	Weight distribution, ton
	14.5	25.2	Weight distribution, 1000 pounds (kip)
	0.8	1.4	Relative standard load of 18 kip
	0.42	3.83	Esals, i.e. raised to four

Sources: Mainly my own figures. The weight distribution data stems mainly from AASHTO (1993). These figures are the ones used, but they lay no claim to being scientifically correct.

References:

AASHTO (1993), 'Guide for Design of Pavement Structures', American Association of State Highway and Transportation Officials, Washington D.C. 1993.

Statistics Sweden, T30 SM 9603

Appendix D – The Reduction of the Existing Annual Vehicle Registration Tax and the Eurovignette Charge

There is no clear figure available of what a joint reduction of the annual vehicle registration tax and the Eurovignette charge to the minimum level set by the EU might mean. Here the computations made to reach such a figure are outlined[53].

Data on the vehicle registration tax payments for 1995 for each industry are available from Statistics Sweden. The tax payments are subtracted from the general tax payments in the Value Added matrix, thereby keeping the total tax payments unchanged and the matrix consistent.

In 1995 there was no Eurovignette system in Sweden, but by estimating how much of the vehicle registration tax payments for 1995 would have consisted of EV charge payments, had it been in place in 1995, that particular problem was circumvented. This was possible since when the Eurovignette charge was introduced, the vehicle registration tax was lowered by the same amount. There were no figures available on what the lowering of the tax and the charge to the EU minimum level meant in terms of percentage decrease in the corresponding payments. This was solved in the following way. Table D1 shows the tax revenue from the vehicle registration tax and the Eurovignette charge in 1995 and 1998. In 1998 the Eurovignette charge was about 7.6%of the total revenue from vehicle registration tax and the Eurovignette charge. This figure is shown at the bottom right of the table.

Table D1 - Tax revenue 1995 and 1998, mSEK

	Tax on vehicles			Total	share
1995**	Vehicle reg.			4049	
	- *whereof*	Trucks		1089	
		- *whereof*	*Producers*	*874*	
			Households	*216*	
1998	Vehicle reg./EV charge*			6608	
	- *whereof*	Vehicle reg.**		6103	92.40%
		EV charge***		505	7.60%

Sources: *RSV 'Fakta om punktskatter' (1998), **RSV 'Årsbok'(1998), ***Implied by * and **.

Next, in Table D2 we can see that the 1999 Eurovignette charge was 750 Euro for lighter trucks and 1250 for heavier. If 15000 and 38000 vehicles paid the lower and the higher charge respectively, revenue amounting to 58.75 million Euro would be raised. The EU minimum level is set to 535 Euro per truck and this would render a revenue of 28.355 million Euro. So, the fraction of the EU minimum level revenue to the 1999 Eurovignette

[53] The reduction of these taxes/charges was suggested by Gunnar Eriksson at the Swedish Ministry for Industry, Employment and Communications (Näringsdepartementet), by telephone, on 4/17/00.

charges revenue is about 48.3%. But this is still not the figure we are looking for.

Table D2 – The EV charge and EU minimum level

EV charge 1999	EV charge* Euro	Vehicles**	Revenue mEuro	EU min* Euro	Revenue*** mEuro	EU min/ EV charge
<12 ton	750	15000	11.25	535	8.025	
>12 ton	1250	38000	47.5	535	20.33	
Total		53000	58.75		28.355	0.483

Source: SIKA (2000). * Annual charge, **In use 1999, *** Imputed

The figure on how much to lower the tax/charge is obtained by combining the data in Table D1 with that in Table D2. The result is shown in Table D3 (and it certainly requires some explanation). Here we have taken the 1995 total vehicle registration tax payments of 4049 million SEK and assumed that the same fraction would be Eurovignette charge revenue as it was in 1999. This means that the fictional Eurovignette charge for 1995 would be 308 million SEK and that the rest is normal vehicle registration tax. So these fictional Eurovignette charge payments, the remaining 566 million SEK for the producers and the 216 million SEK for the households, would together add up to the original figure of 1089 million SEK for 1995. Finally, to find what we were after, the 566 million SEK in vehicle registration tax payments by producers is abolished, the vehicle registration tax for the households is left unchanged at 216 million SEK, but the 308 million SEK in Eurovignette charges is lowered to the EU minimum by using the fraction from Table 12, i.e. 0.483. The result is that we now have to lower the 1995 vehicle registration tax payments by about 83.2% to reach the EU minimum, leaving households' vehicle registration tax unchanged.

Table D3 – Computation of the EUMIN parameter

			mSEK	Counter-factual	EUMIN
Total vehicle reg.			4049		
- *whereof* EV charge (7.6%)			308		
	- *whereof producers*		*308*		
Vehicle reg. (92.4%)			3741		
	- *whereof trucks*		*1089*		
		- *whereof* Producers	566	0	
		EV charge	308	149*	0.168**
		Households	216	216	1***

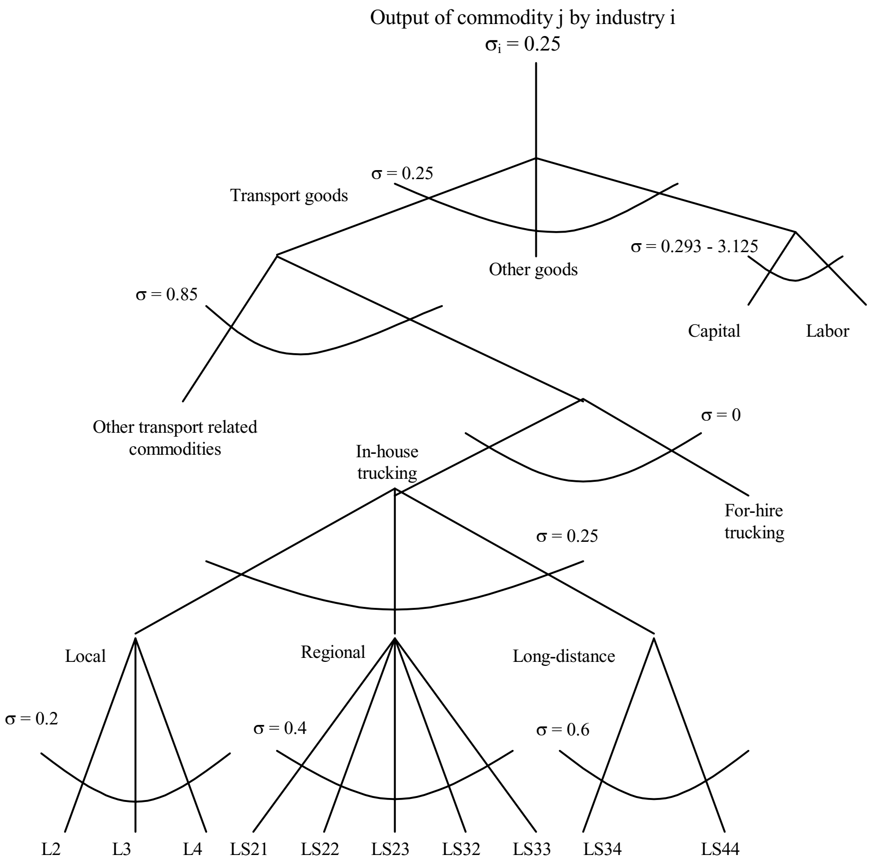
*0.483x308=149, **149/(566+308)=0.168, ***216/216=1

References:

SIKA (2000), 'Effekter av alternativ till Eurovinjettsystemet' (Effects of alternatives to the Eurovignette system), Report 2000:4, Statens institut for kommunikationsanalys, Stockholm, Sweden.

Eriksson, Gunnar, The Swedish Ministry for Industry, Employment and Communications (Näringsdepartementet), personal communication, 4/17/00.

Appendix E – Nested Production Structure



Appendix F – Elasticities

Appendix E illustrated the elasticities in the nesting structure. The output of any particular sector is an aggregate of a transport composite good, a composite of other goods, and the value added composite. The value added composite consists of the labor and capital inputs. The transport composite good is an aggregate of the railway, shipping and air transport goods together with a road transport composite. The road transport composite is an aggregate of the land transport good and the internal trucking composite. Finally, the internal trucking composite is an aggregate of the local, regional and long-distance composites. Starting at the bottom and moving up the nesting structure, we will start by explaining how the substitution elasticities used in the trucking nests, i.e. 0.2, 0.4 and 0.6 for the local, regional and long-distance nests respectively, were reached.

Finding estimates for these elasticities turned out to be almost impossible, so rough guesstimates have had to be made. Fortunately, something similar to the km-charge proposed in this study was in use in Sweden up to 1993, when it was abolished when Sweden became a member of the EU. If it would be possible to compare what had happened to the use of different truck categories after that, one could perhaps get some general guidance. After having had to order the data material specifically for 1993, since there was no data available for that year, some simple figures for the elasticities were computed. These are shown in Table F1. One crucial assumption for calculating these numbers is to find figures for diesel consumption of the different trucks. These are based to a large extent on NGM and Hammarström and Yahya (1999). Next, the cost level per vehicle kilometer (vkt) had to be estimated, to see how the costs had changed from 1993 to 1995. For 1993 the costs consisted of the fuel cost (at a certain price per liter) and the cost of the then existing kilometer tax. Data on how much each truck category had to pay in km-tax was available in published tables[54]. The 1995 fuel cost is deflated with the consumer price index. Hence, the change in cost per vkt and truck category was computed. This together with the changes in the use of the truck categories made it possible to find something like own price elasticities. These are reported at the bottom of the figure on the row labeled 'w.r.t own category'. But since the nested structure implies that the substitution takes place primarily within a particular nest, an idea to use something similar occurred, focusing instead on the change in vkt for each category in relation to the total number of km within the nest. This is shown on the row labeled "% change in vkt as part of 'nest'". Combining

[54] It turned out that the old km-tax was differentiated in a 'smoother' way than 'my' km-charge. This can be explained by the more refined analysis of the cost structure that was performed in the sixties. However, it is not evident that that particular analysis was the correct way to design the charge.

these figures with the price changes gave the last row of the table, labeled ”w.r.t ‘nest’”.

Looking at these figures it was concluded that they where all between zero and one, and had a tendency to be lowest in the local nest, followed by the regional and long-distance nests. Even if it is not totally clear from the table, it is an appealing result from a theoretical perspective. A higher elasticity means that at a given price change there will be a larger substitution to other modes. And long-distance trucking certainly has more options with regard to changing mode than the local trucker. So, it was decided to use the value in Appendix E. Although these figures are not very accurate statistically, they could provide some guidance for other studies. The uncertainty of these figures will be handled in the systematic sensitivity analysis.

Table F1 – Elasticities w.r.t. trucking

	LOCAL			REGIONAL					LONG-DISTANCE	
	L2	L3	L4	LS21	LS22	LS23	LS32	LS33	LS34	LS44
Diesel consumption, l/km[a]	0.4	0.45	0.45	0.52	0.52	0.52	0.5	0.5	0.55	0.55
Costs[b]										
1993										
Fuel cost/vkt at 6.018kr/l	2.41	2.71	2.71	3.13	3.13	3.13	3.01	3.01	3.31	3.31
Km tax'/vkt truck	0.58	0.53	0.47	0.58	0.58	0.58	0.53	0.53	0.53	0.47
Km tax'/vkt trailer				0.24	0.36	0.30	0.30	0.20	0.47	0.47
Cost/vkt	2.99	3.24	3.18	3.95	4.07	4.01	3.84	3.74	4.31	4.25
1995										
Nominal cost/vkt at 6.6025kr/l	2.72	3.06	3.06	3.54	3.54	3.54	3.40	3.40	3.74	3.74
Real/vkt at CPI=1.048	2.60	2.92	2.92	3.38	3.38	3.38	3.25	3.25	3.57	3.57
Distance										
1993[c] 000's km	480742	309925	11839	7930	34953	42478	139410	305999	625204	106355
1995[d] 000's km	498915	325237	18521	6838	38721	62475	139494	338826	738239	66752
Changes										
in vkt	18173	15312	6682	-1092	3768	19997	84	32827	113035	-39603
% change in cost/vkt	-13.1	-9.8	-8.1	-14.5	-17.0	-15.8	-15.4	-13.2	-17.2	-16.0
% change in vkt within own category	3.8	4.9	56.4	-13.8	10.8	47.1	0.1	10.7	18.1	-37.2
% change in vkt as part of 'nest'	2.3	1.9	0.8	-0.2	0.7	3.8	0.0	6.2	15.5	-5.4
"Own-price elasticity"										
w.r.t. own category	-0.3	-0.5	-7.0	0.9	-0.6	-3.0	0.0	-0.8	-1.1	2.3
w.r.t. 'nest'	-0.2	-0.2	-0.1	0.0	0.0	-0.2	0.0	-0.5	-0.9	0.3

Sources: a. NGM and Hammarström and Yahya (1999), b. Price changes from SPI (www.spi.se), CPI from Statistics Sweden, km tax tables from RSV (The National Tax Board - personal communication with Lena Mellberg), where the tables are found in Supplement 2 to the law SFS 1992:883. c. Special order from Statistics Sweden in Örebro to fill in missing data in T30 SM 9403 Table 19. d. T30 SM 9603; Table 19.

There are some substitution possibilities between the three trucking nests, but it was chosen to let it stop at something close to a Leontief ‘fix share’ structure. In the road transport composite the trucking composite is modeled as a Leontief fixed share with the land transport good. The next nest requires some deeper analysis. There are a number of econometric studies providing estimates of the elasticities of substitution between modes of transport but unfortunately few of them deal with freight transport. Oum et al. (1991) summarize some studies and these helped me to come up with a value.

Table F2 shows how this was done. By looking at the point estimates of the truck freight elasticities and the rail freight elasticities reported in Oum et al. (1991), an average for each category could be calculated quite simply. Next, the average of these two figures was calculated and resulted in the figure 0.85. Not very scientific perhaps, but this estimate will be subjected to systematic sensitivity analysis where the estimate varies uniformly over the range of the original Oum et al (1991) estimates. In this way the figure to some extent is validated.

Turning back to Appendix E, we see on the right hand side in the value added composite that each sector has a specific value for the elasticity of substitution between capital and labor. These figures originally come from Harrison et al. (1993) but can be found in the GAMS code of the Harrison and Kriström (1997) model. Finally, at the top level of the production nest, the transport composite, other goods and the value added composite are modeled as something close to the Leontief 'fixed' share structure.

Table F2 – Elasticities w.r.t. freight. Various estimates of elasticities for aggregate commodities

TRUCK FREIGHT	RAIL FREIGHT
1.34	1.52
0.93	0.25-0-35
0.69	0.34-1.06
	0.83
	0.09-0.29
	0.60
Average: 0.99	Average: 0.69
Range: 0.69-1.34	Range: 0.09-1.52
Average: 0.85	
Range: 0.09-1.52	

Source: Oum et al. (1991), Table 6-7.

Most of the elasticities in the model will be subjected to a systematic sensitivity analysis according to Harrison and Vinod (1992). For these, a distribution and a standard deviation will also be specified in addition to the point estimate. These are found, together with some other elasticities not yet mentioned, in Table F3.

Table F3 – Some key elasticities used in the model

Description	Value	std. [d]	distrib.
Production			
Elasticity of substitution between intermediate inputs and the composite of primary factors	0.25	(0.0,0.5)	uniform
Elasticity of substitution between labor 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		

Sources: 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 labor supply elasticity of 0.1 in the benchmark data. This estimate is perturbed in a uniform (0.05,0.15) distribution. The uncompensated labor supply elasticity is used, as opposed to the compensated labor 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 e.g. Wikström (1996).

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Interview
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