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The efficient use of infrastructure – is Sweden pricing traffic on its roads, railways, waters and airways at marginal costs?

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Abstract

This review summarizes recent information about the marginal costs for using Sweden's infrastructure and the relationship between the sum of marginal costs and charges for each mode. It is demonstrated that the tax on petrol used by private cars is higher than the marginal costs for emissions, accident risk and road wear and tear. The diesel tax is, on the other hand, not sufficient for internalization of heavy vehicles' externalities. Neither trains nor aircraft or ships pay for their marginal costs. For railways, this confirms previous observations that Swedish track user charges are low in an international context. Except for a low level of charges, several examples are given of the strong motives for differentiation of charges in time and geography. The rapid technical development makes the cost motive for not differentiating the charges increasingly irrelevant.

Keywords: Marginal cost pricing; roads; railways; waterway infrastructure; air infrastructure

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KTH VETENSKAP OCH KONST

1. Introduction

The Swedish government has commissioned VTI[1] to review current knowledge of the social marginal costs[2] for using the country's national infrastructure, i.e. roads, railways, airports and sea infrastructure. Based on research and reviews reported in several background papers, the purpose of this paper is to provide a condensed version of the study to an international audience. This also includes a comparison of marginal costs and the current level of taxes and charges. Using the Swedish acronym for the projects, results reported are collectively referred to as SAMKOST.[3]

The focus on costs for using publicly available infrastructure means that terminals built for handling people or commodities (railway stations, rail and truck freight terminals, ports and airport terminals) is not part of the analysis. Another delimitation emanates from that data is primarily available about the provision of state assets. Roads handled by local communities and non-state railways are therefore not part of the analysis. There is a huge and diverse literature of relevance for the parameter estimates. The reader is referred to the background papers for a comprehensive reference list.

One result of the study is that the current tax on petrol is higher than the marginal cost for private cars' road use. Explanations include that (i) much traffic in a country with a small and concentrated population relative to its size uses rural roads with small environmental consequences, (ii) accident risks have steadily declined over a sequence of year and (iii) the road network has excess capacity which – in combination with the use of road congestion charges in Stockholm and Gothenburg – means that road congestion is not a problem.

The social marginal costs of all other infrastructure use are higher than the taxes or charges that are levied. The explanation for under charging of heavy road vehicles is that the diesel tax is not able to capture the differential wear and tear costs of vehicles with different weight per axle. Both freight and passenger trains' use of railway infrastructure is also priced below marginal costs. The quality of airstrips and sea lanes is not affected by use. Since both modes have excess capacity, environmental externalities are the most important marginal costs of shipping and flights. Due to international treaties, neither aircraft nor shipping pay taxes for their fuel use. Even though the public-sector agencies responsible for the provision of infrastructure services to aircraft and ships are instructed to charge users the full financial

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[1] VTI, *Väg- och Transportforskningsinstitutet*, the Swedish National Road and Transport Research Institute in English, is a government-owned research institute.
[2] Social marginal costs comprise cost for the (private or corporate) user (the use of vehicle propellant, etc.), costs for infrastructure wear and tear when using the infrastructure and external costs for the environment etc. The first component is already internalised and focus is on the latter two components of the concept. To simplify, marginal cost is often used as a shorthand.
[3] After the domestic publication of the reports, our institute has been given an extended mission with focus on air and sea transport. This is subsequently referred to as SAMKOST 3.

costs for this, the level of start-and-landing charges and fairway dues are well below the externality costs.

The cost estimates for Sweden are benchmarked against the common EU framework, most recently summarized in Ricardo-AEA (2014).[4] The need to compile information from background reports with different dating and with costs denoted in different currencies provides a challenge for both SAMKOST and Ricardo-AEA. The reader should be aware of that the subsequent review of cost estimates (sections 2-4) make use of different price levels. The motive is to benchmark single marginal cost estimates in SAMKOST against relevant values from other sources. In section 5, and in the concluding section 6 where costs and charges are combined, costs have been inflated to 2015. In view of a generally low rate of inflation during the last few years, price level differences may be less important than the estimation approach or the type of data used in the original analysis.

2. Environmental externalities

The Impact Pathway Approach (IPA) provides the methodological framework for the analysis. This bottom-up-approach was originally developed for estimating environmental benefits and costs[5] and comprises four steps:

1. Identification of the primary effect of different types of vehicles and vessels using the four types of infrastructure.
2. Review of the pathway taken by the primary effect to establish how people are exposed.
3. Quantifying the causal consequences for welfare parameters.
4. Economic valuation per unit of each consequence of the primary effects.

For economists, the step 1 effects are the externalities from using a common infrastructure: emissions, noise, risks, the users' impact on the infrastructure surface and the consequences for other users' time. Externalities are typically generic across countries. For instance, fuel use of a certain car, train, airplane or ship generates the same consequences (amount of emissions, noise) irrespective of where it is used.

The pathway taken by the primary effect – step 2 – differs across externalities. The pathway of emissions describes where different compounds are released relative to where humans are located. The final deposition of the harmful components may be affected by the prevalent wind direction, the type of landscape (city centre or suburb, hilly or flat, etc.) and

[4] A more recent comparison of marginal costs and taxation of road traffic is Santos (2017). That paper is, however, based on values dating back to 2008. Since Ricardo-AEA (2014) use results that include 2010, this is a better source for benchmarking. Ljungberg (2016) provides a recent review of the situation in Sweden. The results in that paper are to a substantial degree based on the results reported by SAMKOST.

[5] IPA was developed as part of ExternE which is the acronym for "External Costs of Energy", a series of projects running from early 1990s till 2005. http://www.externe.info/externe_d7/

it varies greatly across countries. The third step concerns the number of people exposed to the primary effect and the expected impact on health and the eco system. Epidemiological research and WHO recommendations that are continuously updated from international sources provides the basis for identifying which emissions that have negative health effects. Moreover, if a negative effect doesn't affect anyone, it is irrelevant for the assessment, an obvious example being noise in uninhabited surroundings.

The final step of the IPA is to establish a price tag for the welfare consequences of traffic. Not only may the number of people exposed to negative health effects differ across countries (the third step), but so may also the economic value of lives or life-years-lost. It is well known that both the level of income and the preferences of people in different countries may call for different parameter values in this respect.

This model provides the platform for the review of three types of environmental consequences from infrastructure use; the emission of green-house gases (2.1), of other emissions (2.2) and the noise emitted by vehicles in the different modes of transport (2.3).

2.1 Green-house gases

All use of fossil and non-fossil fuel in combustion engines release carbon into the atmosphere and contributes to global warming. The benefits of climate change mitigation, i.e. the mirror image of the social cost of carbon dioxide ($SCCO_2$), is the reduction of costs for the damage caused by emitting one additional unit of carbon dioxide (CO_2). Since the first estimates of the $SCCO_2$ were made more than 25 years ago, hundreds of evaluations that seek to estimate the chain from emissions to atmospheric concentration to temperature change, to damages and costs have been produced. But despite increasingly sophisticated models, there are still shortcomings to tackle and omitted factors to consider there is still no scientific consensus on *the* value of $SCCO_2$.

In the absence of a commonly accepted value, Sweden's climate policy framework is used as a point of departure for establishing the social cost for carbon emissions. For members of the European Union, the target set in Council of the European Union (2009) is that, relative to the 1990 emissions, the member states' release of carbon in the atmosphere shall be reduced by 20 percent to year 2020 and by at least 80 percent to year 2050.

The targets have been broken up in two parts. The first is a system with trading of emission permits for the energy intensive industries, the *EU Emission Trading System* (EU ETS). Secondly, a cap on emissions from the non-trading sector has been established for the Union as an aggregate as well as for each member country; road transport is included in this second category. The Union has, however, delegated the choice of mechanism to use for reducing emissions in the non-trading sector to each member country. A tax on carbon emitted from burning fossil fuels is Sweden's primary means for emission reduction in the transport sector. A recent parliamentary decision has established a scheme for annual escalation of this tax and the 2015 tax level is SEK 1.15 per kg CO_2. In the wake of a universally agreed carbon cost, this tax is used as a proxy for the $SCCO_2$. The logic is that policy makers have committed themselves to meet the emission target set by the EC. If the level of Sweden's carbon tax is insufficient it would be necessary to increase the tax or to introduce other policy instruments.

Since the price of fossil fuel used by cars and lorries includes this tax, road users – by definition – fully internalize this externality. Neither shipping nor aviation pays any surcharges on fuel. Flights within the Union is, however, part of EU ETS, meaning that European flying pay for (most of, cf. section 5.4) their $SCCO_2$. This is not so for long distance flights that are exempted from the mechanism. Since most trains run on electricity, and since electricity generation is part of the EU ETS, trains (indirectly) pay for their $SCCO_2$.

Ricardo-ENEA (2014, p. 56) suggests a range of values between €48 and €168, with a central value €90 per ton CO_2 equivalent at price level 2010. Using this central value, and with about eight percent higher prices in 2015 than in 2010, this corresponds to about €97 per ton. With the (approximate) exchange rate SEK9.50/€1 this represents a cost of SEK 0.92 per kilo, while Sweden's tax on CO_2 was SEK 1.15 in 2015. Sweden and SAMKOST consequently uses a higher (and automatically rising) valuation of $SCCO_2$ than our European peers.

2.2 Air pollution other than CO_2[6]

The IPA approach is used for establishing the social costs for emissions other than CO_2 when motor fuel is burned. The health consequences of emissions increase with local exposure to emissions; concentrations may be high if roads are used by many vehicles and/or if population density is high. Emissions are also spread over long distances and may be transformed to secondary chemical compounds that contribute to regional background concentration of pollutants. These background levels may affect both health (trough Secondary Inorganic Aerosols and ozone) and the eco system.

Sweden is at the periphery of Europe and is therefore not much affected by emissions from the continent. Therefore, regional background concentrations are generally low and so is also the impact of secondary emissions. Estimates of the impact of emissions on eco systems is based on the concept of critical loads which means that nature can accommodate deposition up to a certain threshold. On the other hand, the impact on human health is estimated without thresholds.

Different modes of transport emit pollutants in different localities. Roads in cities may expose a substantial number of people to emissions while road traffic outside conurbations primarily affects background concentrations. Moreover, many national roads are bypasses at

[6] This section is based on Nerhagen (2016).

a distance from residential areas and city centers. In addition, although the use of diesel today is gradually increasing, most Swedish cars use petrol which has lower impact than diesel on the total emissions of nitrogen oxides (subsequently NOx); cf. further Nerhagen (2017). These aspects influence the extent of population exposure and social costs.

Table 1 benchmarks these results against the recommendations made by RICARDO-ENEA (2014, table 15), and demonstrates that emission costs for Sweden is below the EU average. For a more specific comparison, the cost of $PM_{2.5}$ from cars is estimated to be SEK 1620/kg; the European estimate in Table 1 suggests the cost to be SEK_{2010}/kg 1974 for the highest population density. The value in SAMKOST for NOx is SEK_{2010}/kg 70 while it is SEK_{2010}/kg 52 for Sweden in **Fel! Hittar inte referenskälla.**. Differences are obviously not very large.

Table 1: Marginal cost for impact of NOx and PM emissions (SEK_{2010}/kg). Source: RICARDO-ENEA (2014, table 15).

	Population density, inh./m^2	**1500**	**300**	**< 150**
Sweden	**$PM_{2.5}$**	1974	502	146
	NOx	52	52	52
EU Average	**$PM_{2.5}$**	2701	702	281
	NOx	106	106	106

The marginal cost per vehicle kilometer has been derived by multiplying the unit marginal costs by average emission factors for conurbations with different population density and adding the regional background costs.

This assessment is based on emission and pathway estimations reported in SMHI (2016). Records of the precise route taken by all vessels calling at Swedish ports provided the starting point for the analysis. To handle regional differences, three sea basins were modelled. *Figure 1* illustrates the nature of this analysis for one of the basins. The figure shows where emissions are deposited, demonstrating that not only Sweden but also other countries are affected by the pollution. As a complement, an assessment has been made of current concentrations. This provides the point of departure for understanding whether, and by how much critical thresholds are affected and the subsequent costs because of this.

Table 2 indicates that it first and foremost is heavy vehicles that emit harmful pollutants. Emission factors for the average Swedish type of lorry (weight, axles and Euro class) are based on modelling by the Traffic Administration. Table 2 as well as Table 4 in the next section reports costs for a detailed taxonomy which is relevant for Sweden, rather than for the more aggregate European conurbation sizes in Table 1.

This assessment is based on emission and pathway estimations reported in SMHI (2016).[7] Records of the precise route taken by all vessels calling at Swedish ports provided the starting point for the analysis. To handle regional differences, three sea basins were modelled. *Figure 1* illustrates the nature of this analysis for one of the basins. The figure shows where emissions are deposited, demonstrating that not only Sweden but also other countries are affected by the pollution. As a complement, an assessment has been made of current concentrations. This provides the point of departure for understanding whether, and by how much critical thresholds are affected and the subsequent costs because of this.

Table 2. Marginal costs for emissions from light and heavy vehicles using state roads. SEK_{2012} per vehicle km.

	Regio-nal cost	**Costs in conurbations with different population density**				**Total cost (local + regional impact),**			
		Size of conurbation*				**Size of conurbation***			
		1	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Cars									
NOx	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
PM	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Total	0.01	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03
Lorries									
Nox	0.16	0.03	0.03	0.03	0.02	0.19	0.19	0.19	0.18
PM	0.01	0.11	0.11	0.10	0.10	0.12	0.11	0.11	0.11
Total	0.17	0.13	0.13	0.13	0.12	0.31	0.30	0.30	0.29

* 1 - < 400; 2 – 400-1000; 3 – 1000-2000; 4 >4000 inhabitants per m^2

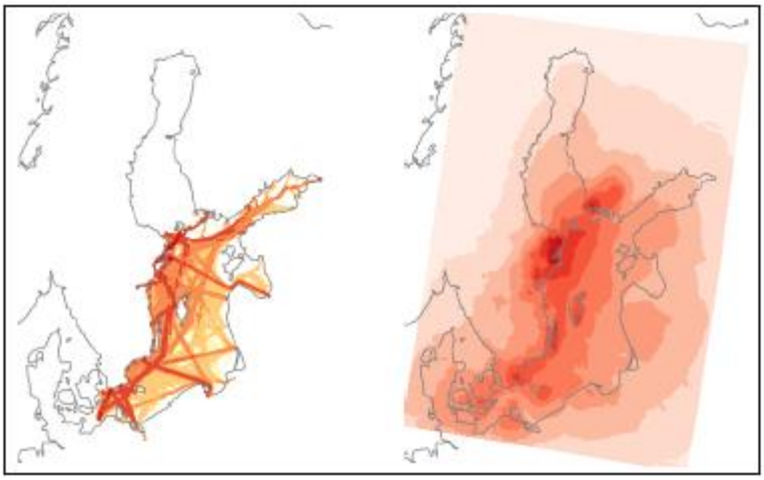

Figure 1. Emissions from ships calling on Swedish ports in the Southern basin (left panel) and modelled concentrations (right panel). Source: SMHI (2016).

Using the same accident cost as reported in section 3, *Table 3* summarises the costs for exposure to nitrates. It is not clear how this cost can be compared to recommendations in

[7] Swedish Meteorological and Hydrological Institute, SMHI, has developed several models that facilitate the analysis of how emissions from different sources are disseminated.

RICARDO-ENEA (2014, Table 16). That report covers all European sea territories, giving a 2010 cost that is much higher value that reported in *Table 3*. Since the RICARDO-ENEA (2014) costs for sea traffic also includes other emissions than NOx, it is not possible to make a systematic comparison. However, other analyses within the SAMKOST project establishes that population density plays an important role also for the cost estimates from sea traffic.

Table 3. Estimation of marginal costs for NOx emissions from shipping, SEK_{2010}/ton

Basin	Emission (ton)	Total exposure (µg/m3)	Cost (NOx)
North	5 600	16 897	2 669
South	53 000	288 545	4 817
West	19 300	87 838	4 026
Total/average	77 900	393 800	4 467

2.3 Noise[8]

Noise caused by traffic represents a cost to society, both because of its direct impact on those working or living in an affected area as well as the long-term impact on health from noise exposure. The IPA model used when addressing noise externalities, accounts for that the inconvenience from noise is affected by the distance from, as well as barriers between, the source of noise and a building. Since noise may affect the attraction and the sale value of properties, hedonic price approaches are often used for estimating the social costs for noise. This means that the two last steps of the IPA chain are merged. The understanding is that values derived from hedonic pricing primarily relates to the direct effects from noise, while the long-term consequences for health may not be reflected in price differentials.

With access to information about number and type (heavy or light) of vehicles using some 100 000 road sections within conurbations, the Cnossos-EU model (Kephalopoulos et al, 2012) is used as a starting point for estimating noise emissions from different types of road vehicles. To handle the consequences of different pathways taken by noise, distinctions are made between ground quality (hard or soft soil), settlement density and Euclidian distance of buildings from a road. Further, the conurbations are classified into four population density categories referring to the number of inhabitants per km^2.

*Table 3*4 demonstrates that the marginal cost of road noise is more than 10 times higher for a lorry with trailer compared to a passenger car. Number of exposed individuals, as measured through conurbation population density, is about 20 times higher for conurbations with the highest population density compared to conurbations with the lowest population density. Even though the disturbance from a marginal dB is highest during nights, the marginal cost is highest during evenings. The reason is that the traffic volume is so low during nights so that many road sections have too low noise level to be considered as a nuisance in the basic value functions.

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[8] This section is based on Swärdh & Genell (2016)

Table 4. Marginal costs for noise from road vehicles separated for conurbation density, time of day, and type of vehicle. SEK₂₀₁₄ per vehicle km

	Population density*											
Vehicle type	**1**			**2**			**3**			**4**		
	D	E	N	D	E	N	D	E	N	D	E	N
Passenger car	0.13	0.25	0.34	0.07	0.19	0.18	0.02	0.05	0.05	0.00	0.01	0.01
Lorry, no trailer	0.65	1.04	1.37	0.35	0.95	0.94	0.08	0.28	0.25	0.02	0.09	0.07
Lorry with trailer	1.58	3.22	3.27	0.93	2.16	2.65	0.21	0.71	0.67	0.05	0.26	0.16

* 1: >2000 inhabitants per m^2; 2: 1000-2000; 3: 400-10001; 4: < 400 Note: D = day; E = evening; N = night.

Differences in the way in which conurbations and vehicle types are defined makes comparisons with RICARDO-AEA (2014) results difficult. The two sources still seem to recommend values of the same magnitude and when the conurbation population density coincides, the marginal costs are similar. A further aspect is that Sweden has large rural parts and many conurbations with low population density. Since marginal noise disturbances for roads outside conurbations (fewer than 400 inhabitants per m^2) are set to zero, the marginal cost for rural areas in Ricardo-AEA (2014) is higher than in SAMKOST.

To assess the marginal noise costs for railways, detailed information about tracks and traffic is combined with information about population density in 250 m squares. This makes it possible to assess the number of individuals exposed at different distances from the source. As the rail network is much smaller than the road network, the marginal costs can handle the specific feature of each rail section. This is exemplified in

Table 5 that provides examples of four sections where the cost of one section (no. 401) is very high while the cost for using another (327) is very low. The difference stems from that the first passes through a densely populated area while traffic on the second inflicts disturbances for few people only.

Since countries use different types of railway vehicles it is even more difficult to compare SAMKOST and Ricardo-AEA (2014) recommendations than it is for road noise. An aggravating circumstance is also that track section values derive from actual number of exposed individuals rather than on broad categories, as in Ricardo-AEA (2014). The national average in

Table 5 (SEK 4.22) is much higher than corresponding value (SEK 0.61) in Ricardo-AEA (2014). At least a substantial part of the difference is due to a higher valuation function for rail noise disturbances used in SAMKOST, compared to the valuation function used in Ricardo-AEA (2014).

Table 5. Marginal costs for railway noise separated for section of track and type of vehicle. SEK per train km, price level 2014.

Track section	Freight train (500 m, 90 km/h)	Passenger train (39 m, 120 km/h)
327	0.96	0.01
401	143.0	1.59
637	4.06	0.04
919	3.15	0.03
National average	4.22	0.05

SAMKOST uses a model developed by WSP, a consultancy, for estimating the marginal cost for noise emanating from air services. Costs are based on the size of the population around eight airports and the cost level is also affected by the type of aircraft used as well as the frequency of landing and take-off (LTO) cycles at the airports. The same detailed information about people living at different distance from the air strips as for rail noise is used. This facilitates the estimation of costs for each airport based on its actual characteristics.

The hedonic value of air noise is based on the valuation for road noise plus a disturbance-correcting factor for air noise. In addition, a monetary cost for the health effects because of increased mortality is added using the generic Value of Statistical Life estimates described in section 4. *Table 6* reports the marginal cost estimates and the current LTO charge at national-owned airports. While Arlanda, Sweden's largest airport is situated some 40 km north of Stockholm, Bromma airport, the second airport of Stockholm, is just 7 km from the city center and its approaches pass over central parts of Stockholm.

Table 6. Marginal costs, LTO charges and degree of internalization of costs at six Swedish airports, SEK per LTO-cycle. Price level 2015.

	Marginal cost	Charge	Internalisation (%)
Bromma	6 241	289	5
Arlanda	114	273	239
Landvetter	90	272	303
Malmö	44	207	468
Umeå	179	257	143
Visby	49	71	146
Average	959	220	23

International comparisons of marginal costs for noise are difficult to make. One reason is that the use of hedonic techniques generates highly situation-specific property values. Moreover, the location of an airport relative to population is important; this is illustrated by the extreme differences in the Swedish costs, and that the cost at Bromma most probably resembles the situation at airports like Berlin/Tegel.

2.3 Summary

Both Sweden and our Nordic neighbours face several and more severe consequences of emissions from combustion engines than other countries. Because of several inland ice cycles, the soil layers are thin and with low calcium content. The impact of NOx and SO2 on acidification is therefore high, meaning that precipitation of aluminum and heavy metals (especially mercury) in lakes, streams and in the long term on groundwater is high. In addition, a lot of the Nordic flora and fauna live on the border with its spread and is sensitive for that reason. At some places, the cold climate results in inversion problems wintertime, meaning that not only Oslo (in Norway) may be heavily contaminated but also some Swedish cities.

The Nordic countries, however, also have qualities that balance these concerns. Sweden's area is large relative to its population (10 million) and only nine cities have more than 100 000 inhabitants. With low population density, relatively few individuals are affected by road traffic externalities and the number of vehicles on many roads is low compared to peers in other parts of Europe. Moreover, problems with inversion are relevant only for some places during few days per year, having a low impact on the average marginal costs. Taken together, the social marginal costs for emissions are therefore surprisingly low.

Geographical differentiation is the obvious keyword for emissions to the air as when the marginal costs from road, rail and air noise is estimated. There is no single marginal cost of a given type of traffic but the dependence of location, vehicle type and time of day is the focal point. In rural parts of Sweden, the marginal noise costs are negligible. In conurbations, there are marginal costs of traffic noise to be considered, but despite the comparatively high absolute value of traffic noise costs compared to European peers, the marginal costs are relatively moderate. The reason is that population density in Sweden's conurbation are low in an international perspective.

3. External costs for road traffic accidents[9]

Traffic in all modes of transport is associated with a larger or smaller degree of risk for being involved in accidents. The external cost of accident risks is related to whether drivers only account for their own accident risk but not the marginal increase in risk they inflict on others. More specifically, when a driver decides to drive an additional kilometer, the accident risk of all exisiting vehicles on the road increases marginally – this is the social marginal increase in accident risk. However, the driver's own risk of being involved in an accident is determined by the existing number of vehicles on the road (the average risk). Thus, if a driver only considers the average risk when deciding to drive the extra kilometer, the external accident costs depend on the relation between the marginal increase in risk and the average risk. If drivers are myopic in this sense, the marginal accident cost may be higher for society at large than for the individual vehicle user and the number of accidents is too large.

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[9] This section is based on Isacsson & Liss (2016). Since the number of casualties is higher on roads than on other parts of the transportation infrastructure, this secion focuses on road accidents.

To estimate the external costs for road accidents, it is necessary (1) to establish the link between traffic flow (number of cars and lorries on the road) and risk; (2) to identify which types of costs that come with traffic accidents; (3) to value these costs and (4) to allocate costs to vehicles involved in the accident. The last point is important for handling the distinction between light and heavy vehicles and in analyses of safety enhancing measures that increase the safety of pedestrians, bicycles and other less protected travelers.

Two sources are used in the empirical analysis; the National Road Database, inter alia providing information about some 400 000 segments of national roads and their attributes (Annual Daily Traffic and share of heavy vehicles, road width, road crossings, speed limits etc.), and Strada, a database recording the number of individuals and number and types of vehicles involved in accidents as well as their consequences. These sources are combined by linking the geographic coordinates of each accident to the closest road segment in the National Road Database. Table 7 and Table 8 provide information on the annual number of fatalities and number of individuals experiencing severe and light injuries in accidents for each year in the sample used in the analyses.

Table 7: No. of fatalities and injuries in accidents involving light vehicles

Year (20-)	04	05	06	07	08	09	10	11	12
Fatalities	274	255	252	253	237	241	164	183	180
Severe injuries	1855	1793	1725	1681	1776	1948	1544	1570	1574
Light injuries	8647	8571	8697	9069	9918	11406	10667	9944	10452
10th of M vkm	4720	4779	4947	5094	5047	5072	5022	5115	5112

Note: From 2010, suicides have been deleted from the number of fatalities.

Table 8: No. of fatalities and injuries in accidents involving heavy vehicles

Year (20-)	04	05	06	07	08	09	10	11	12
Fatalities	50	44	87	62	62	53	46	53	50
Severe injuries	177	167	196	156	139	163	213	137	181
Light injuries	728	850	1027	871	857	917	1168	1002	969
10th of M vkm	535	570	606	642	643	620	661	680	679

Note: From 2010, suicides have been deleted from the number of fatalities.

The (expected) social costs of accidents comprises both direct and indirect consequences. Hospital care, rehabilitation as well as costs on property is part of the former while indirect costs relate to production lost if an individual is killed or injured in an accident. Importantly, the indirect cost includes also a measure of drivers' willingness-to-pay for avoiding the risk of suffering accidents.

Table 9 shows that the Swedish values for serious accident values are slightly higher than the European average while the slight consequences have a lower value.[10]

Table 9: Accident costs, million SEK_{2010}. Sources: Sweden Trafikverket (2014); Europe Ricardo-AEA (2014), table 10.

	Fatality	**Severe injury**	**Slight injury**
Sweden	23.7	4.4	0.2
Europe (at SEK10/€1)	18.7	2.4	1.9

Table 9, thus, summarizes two of the above four ingredients needed for estimating the marginal cost of traffic accidents. The remaining two ingredients pertain to the empirical relationship between the number of fatalities and injuries and traffic flows and how the related costs are divided between the parties involved in the accidents. Several models have been estimated to assess the marginal costs and the stability of the marginal cost estimates, in particular to consider the consequences for the estimates of external accident costs of light and heavy vehicles separately.

A general observation from the empirical exercise is that the results pertaining to heavy vehicles are sensitive to the treatment of traffic flows for light and heavy vehicles across the various models. The estimates reported in the first column of **Fel! Hittar inte referenskälla.** are derived from three separeate models of the number of fatalities, severe injuries and light injuries by road segment. In these models traffic flows of both light and heavy vehicles are included even though light (heavy) vehicles are not involved in all accidents. The results indicate that the marginal external cost of traffic is close to zero for light and heavy vehicles. Since it may be argued that the flow of light (heavy) vehicles is a kind of 'bad control' (cf. Angrist and Pischke, 2009, pp. 64-68) in accidents that do not involve light (heavy) vehicles, separate models for accidents involving light vehicles only and heavy vehicles only have been estimated. Thus. in the models of accidents that did not involve heavy vehicles, only the flow of light vehicles is included and vice versa for heavy vehicles.

The results in the second column indicate that the marginal external cost of accidents pertaining to light vehicles still is close to zero. However, the marginal external cost of heavy vehicles' accidents is now 0.24 SEK. This indicates that heterogeneity in the accidents may relevant to the estimated marginal external costs, and separate models have therefore also been estimated for different types of accidents, where "type" refers to the other party involved in the accident.

[10] The Swedish values will be revised and increased in the spring 2018. The revision is motivated by the results in Olofsson et al. (2016). This will of course increase the estimated external costs of traffic accidents.

Table 10: Representative results of the external marginal cost of traffic accidents SEK_{2012}/vkm.

	Including flows of both[a]	Separate flows[b]	Separate flows and by type of accident[c]
Light vehicles	-0.03	0.03	0.00
Heavy vehicles	0.01	0.24	0.26

Notes: Where possible separate models have been estimated for fatalities, severe injuries and light injuries. All models include control variables for maximum speed limit, road width and yearly dummy variables. (a) All underlying models include flows of both light and heavy vehicles, (b) All underlying models only include flows of light (heavy) vehicles if the vehicles involved in the accident does not include heavy (light) vehicles. (c) All underlying models only include flows of light (heavy) vehicles if the vehicles involved in the accident does not include heavy (light) vehicles and separate models have been estimated for type of accident defined in terms of the other party involved in the accident.

The results in the third column of Table 10 are closer to the values in column 2. The conclusion is therefor that, at the best of our understanding, cars' marginal accident cost is naught while it is higher for heavy vehicles; the concluding estimate SEK 0.25 per vehicle km. Both values indicate a lower marginal cost than in previous analyses of Swedish data that dates to the 1990s. Tables 7 and 8 shows that and the number of road accidents has subsequently been steadily falling; during the same period, traffic has increased. Except for lower risks, the focus both in the industry and in the transport administration has been on reducing the number of traffic accident casualties, resulting in roads that on average are much safer today than they were 20 years ago. Thus, even though individuals still only internalize some of the expected marginal costs of traffic accidents, safer vehicles and roads have most likely reduced the impact of the 'non-internalizing behaviour'. Note, however, that the results pertain to the national road network. Many roads in conurbations are administered by local authorities. On these roads accidents between pedestrians and cyclists on the one hand and cars and lorries on the other may be more frequent and the external costs may hence be higher on these roads.

A comparison with estimates in RICARDO-AEA (2014, table 12) shows that marginal costs for most cars and heavy vehicles in Sweden are slightly higher than the European average. The SAMKOST result for cars sticks out, while the cost for heavy vehicles is approximately double the value given in the EU report. Part of the latter result may be related to the higher Swedish accident cost reported in *Table 9*. It is, however, difficult to discern how the European results have handled heterogeneity issues in their analyses.

4. Infrastructure wear and tear

The assessment of marginal costs for infrastructure use seeks to understand if and how resources spent by infrastructure agencies on day-to-day maintenance and on renewals are affected by traffic. One of the challenges for this analysis is to disentangle the quality deterioration because of time per se and the significance of usage for quality and maintenance to retain an acceptable road or track standard.

Johansson & Nilsson (2004) provides a first analysis of marginal costs for day-to-day railway maintenance costs. They use a standard regression approach to understand how the allocation of resources for maintenance of track sections is affected inter alia by traffic. The seminal contribution to the analysis of renewal costs, i.e. the link between traffic and the timing of renewals, is Small et al (1987). That book summarizes research to that date with respect to renewal of road infrastructure, but the analytical approach generalizes across modes of transport. The point of departure is that asset quality (*Q*) deteriorates as a function of time (*t*) and traffic (*x*); $Q = f(t, x)$. When quality has deteriorated to some trigger value Q^L, a renewal activity is implemented at cost *C*. The marginal cost is the derivative of the present value cost (*PVC*) of an infinite series of renewals with respect to traffic. Using these two approaches for deriving the effect of traffic on both current maintenance and on renewals, the estimates of marginal wear and tear costs for using railways and roads are presented in 4.1 and 4.2, respectively. While the use of railways and roads reduces asset quality, this is not so in shipping and in aviation.

4.1 Railway infrastructure[11]

Maintenance: Sweden's national railway network is separated into some 250 track units. *Table 11* summarizes information about annual spending on day-to-day maintenance, about traffic as well as about technical qualities of each track unit.

Table 11. Descriptive statistics for track sections for the 1999-2014 period (2819 obs.); day-to-day maintenance

Variable	Median	Mean	Std. Dev.	Min	Max
Maintenance cost, million SEK*	8.4	12.6	15.3	0	277.5
Hourly wage, SEK*	156	157	12	129	187
Iron and Steel, price index	113	100	31	52	141
Ton density (ton per track km)	5	8	9	0	66
Track length, km	56	69	51	4	291
Switch length, km	1	2	2	0	14
Snow, mm precipitation when temp. <0 C°	98	112	64	2	344
Dummy when tendered in competition	0	0.5	0.5	0	1

* Costs are inflated to the 2014 price level using the consumer price index (CPI).

With access to considerably more data than previous studies, Odolinski & Nilsson (2017) have derived new marginal cost estimates presented in *Table 12*. While the static estimate of elasticity is 0.17, the addition of a dynamic component to the model increases the elasticity to 0.39. The dynamic aspect refers to a causal link from traffic not only on current

[11] This section is based on Odolinski (2016b), Odolinski & Nilsson (2017) Smith et al. (2016) and Yarmukhamedov et al. (2017).

but also on future activities; traffic variations one year is observed to have consequences also for maintenance in subsequent years. One reason may be that the response taken by the Infrastructure Manger (IM) is insufficient in so far as the intervention "today", due to a traffic increase, makes it necessary to perform additional maintenance in the subsequent year(s) to get back to the equilibrium level of maintenance. Both the static and the dynamic cost estimate are demonstrated to be within the range of benchmark values in this literature.

Table 12. Elasticities and marginal costs per ton km for two models

Model	Method	Cost elasticity (std. err)	Marginal cost, SEK
Static	Fixed eff.	0.17 (0.04)	0.007
Dynamic	System GMM	0.39 (0.17)	0.012

Renewal: Yarmukhamedov et al. (2017) analyze the link between traffic and timing of track renewals. *Table 13* summarizes some of the information used in the model estimation. Contrary to previous analyses of Swedish data, information is now available not only about sections of tracks between stations but also sections comprising station areas only. Another difference is that previous analyses have addressed only renewal of tracks, while the table shows that information is now available about costs for all spending on renewal – tracks, signaling, electricity and telecom – (first row) as well as for spending on tracks only (second row). Not only renewal of tracks but also of power supply and signaling equipment is demonstrated to be linked to the volume of traffic.

Table 13. Descriptive statistics for track and station sections for the 1999-2014 period; renewal

	Track sections N = 2653		Station sections N = 317		|t-test|
	Mean	SD	Mean	SD	
Total reinvestment costs, million SEK*	7.4	26.7	8.2	20.4	0.05
Track reinvestment cost, million SEK*	4.0	20.8	1.2	3.5	2.39
Section length, km	72	52	26	25	15.79
Tonnage density (thousand gross tons per route)	7	8	13	12	12.12
Number of switches	85	69	190	161	21.06
Switch age, years	21	10	20	8	1.86
Rail weight, kg	51	5	51	3	2.07
Rail age, years	21	11	19	8	3.18
Number of trains, thousand	16	19	30	35	11.28

* Costs are inflated to the 2014 price level using the consumer price index (CPI).

Table 14 summarizes the results of the analysis. The first row is based on analyzing only costs for spending on tracks and superstructure while the second row also includes costs for renewal of electricity, signaling and telecommunication systems. While the elasticity is not much affected by this distinction, the estimate of marginal cost is. This is relevant since, with this approach, the marginal cost is calculated using eq. $MC_{ik} = \gamma_{ik}\widehat{AC}_i$

(1) where γ_{ik} is the cost elasticity for track section *i* with respect to tonnage density *(k)* and $\widehat{AC}$ is the predicted average renewal cost per gross ton km.

$$MC_{ik} = \gamma_{ik}\widehat{AC}_i \qquad (1)$$

The marginal cost reported in *Table 14* is higher than previous estimates; cf. RICARDO-ENEA (2014), table 48. Except for being based on a substantially longer time-period than the previous papers and comprising more track sections, the new results also verifies that not only renewal of tracks-and-structures but also of electricity and signalling installations is affected by traffic.

Table 14. Marginal costs (SEK_{2014} per ton km) for railway infrastructure renewal using two different cost definitions based on data for 1999-2014.

	Elasticity (standard error)	Marginal cost
Track superstructure reinvestment cost	0.55 (0.12)	0.015
Total reinvestment cost	0.53 (0.08)	0.034

4.2 Road infrastructure[12]

Maintenance: An important difference between roads and railways affecting the results of the analysis is related to accounting practices. The annual spending on railway maintenance is reported for each of the 250-something well delimited sections of tracks. *Table 11* demonstrates that a lot of information is available about each track section's technical qualities, traffic etc. For railways, it is therefore straightforward to regress costs against explanatory variables, including traffic, and derive a measure of the marginal cost in the way described above.

The annual spending on on-going maintenance of roads is allocated to each of 100-something maintenance districts. The complicating aspect for the analysis is that each district comprises many kilometers of roads with differing traffic, quality, width etc. While it is straightforward to calculate district averages for all these parameters, the average values more than anything hides the heterogeneity across districts.

Table 15 reports marginal cost estimates using this information, indicating that the marginal cost for gravel road maintenance and operation is 0.07 SEK per vehicle kilometer. For paved roads, there is no marginal cost since the cost elasticity estimate is not statistically significant. For winter road operations, the marginal cost is 0.009 SEK per vehicle kilometer.

[12] This section is based on Nilsson et al. (2017) and Yarmukhamedov & Swärdh *(2016).*

The weighted marginal cost estimate[13] is 0.0001 SEK for gravel road maintenance and operation and very close to zero for winter road operations. However, due to the possible traffic volume measurement accuracy issues, the constant marginal cost estimate is used for further reference.

Table 15. Marginal costs, SEK_{2014} per vehicle kilometer.

	Cost elasticity	Average cost	Marginal cost
Paved road operation and maint.	Non-significant	0.011	Non-significant
Gravel road operation and maint.	0.161	0.428	0.069
Winter road operations	0.281	0.032	0.009

Note: Average cost is based on vehicle kilometers of all vehicles for all cost types.

Renewals: To estimate the impact of traffic on surface renewals, it is necessary to be precise in the treatment of road traffic. Conventional wisdom holds heavy vehicles to be more important for road quality deterioration than passenger cars. This is illustrated by eq. (2) where W_{ia} is the weight (tons) on axle $a = 1, \dots, A$ which is divided by 10 for normalization to Newton. Weight per axle is raised to the power σ to represent the fact that road wear of vehicle of class $i = 1, \dots, I$ increases exponentially. μ_i is therefore a number that represents each vehicle's wear of the road.

$$\mu_i = \sum_{a=1}^{A} \left(\frac{W_{ia}}{10}\right)^{\sigma} \qquad (2)$$

The value of σ in eq. (2) is of immense importance for the translation from weight per axle to road wear. The conventional wisdom is that $\sigma = 4$, commonly referred to as the fourth power rule, meaning that an increase from 8 to 10 tones per vehicle axle does not increase wear of vehicle type μ_i by (10/8=) 25 percent, but by ($(10/8)^4$=) 144 percent. This inter alia points to the irrelevance of vehicles below 5 tonne for road quality deterioration. Since passenger cars typically weigh less than two tonnes, they do not inflict costs for quality deterioration for this reason.

One input for estimating the marginal cost concerns the spending on road surface rehabilitation. The Swedish Transport Administration (*Trafikverket*) tenders both maintenance and reinvestment activities and 285 resurfacing contracts tendered during 2012 and 2013 have been made available for deriving an estimate of resurfacing costs (*C*). The estimate of national average cost is SEK 87 per m^2.

[13] A weighted marginal cost estimate accounts for both differences in traffic and average costs across maintenance districts $MC^W = \sum MC_{it} \frac{Vehicle-km_{it}}{\sum_{it} Vehicle-km_{it}}$ The weighted marginal cost allocates larger weights to the heavily trafficked MDUs.

In contrast to the situation for maintenance, background information about road renewals is much better in terms of geographic detail and timing. With access to information about 250 000 road sections, it is possible to draw conclusions about the longevity for different types of pavement. The analysis also demonstrates that not only heavy traffic but also time per se reduces road quality. Moreover, and contrary to the previous discussion, also cars (light vehicles) affect the timing of resurfacing activities and consequently the life length of pavements. The statistically significant value of the car coefficient can be rationalized by Swedish drivers using studded tires, indicating the possibility of a structural difference between countries that have and don't have severe winter conditions.

Table 16 summarizes the results of the analysis demonstrating an average marginal cost for heavy vehicles to be SEK 0.32 per ESAL km and SEK 0.03 per car km. The concluding summary of road usage costs in section 6.1 has converted the ESAL cost to a cost estimate for specific lorries, assuming different combinations of gross weight and number of axles.

Table 16. Marginal and average cost. SEK_{2013} per ESAL kilometer and per car kilometer.

	ESAL		Car	
	Marginal	Average	Marginal	Average
	Cost		Cost	
Average	**0.32**	**3.78**	**0.03**	**0.27**
EU average*	**0.39**		**0.05**	

*The average refers to a 14-ton vehicle with 2 axles, price level 2010. Cf. RICARDO-ENEA (2014), table 51.

It is not obvious how results from RICARDO-ENEA (2014) compares to the present study. The primary uncertainty is that their results seem to be based on average variable infrastructure costs while the present analysis is based on a detailed analysis of marginal costs. Moreover, the distinction between costs for day-to-day maintenance and for renewal is not clear in the referenced study.

5. Marginal costs vs. Charges

Separately accounting for each of the four types of infrastructure, this section summarizes information about marginal costs in sections 5.1-5.4. This also includes information about costs for which background details have not yet been specified. In addition, each section compares the sum of marginal costs to the current level of taxes and charges in the respective modes. In doing so, costs must be compared to all taxes and charges that affect behaviour at the margin rather. While the tax on the content of CO_2 is explicitly levied for internalization purposes, charges on landing and take-off at airports as well as levies for using naval lanes are implemented for completely fiscal purposes. Since all types of charges affect the propensity to drive, fly or to use naval services, they are interpreted to have the internalization property.

Since 2011, state road and railway infrastructure is handled by the National Transport Administration (*Trafikverket*). *Sjöfartsverket*, the Swedish Maritime Administration, is a governmental agency with responsibility for delivering what corresponds to maritime infrastructure. *Luftfartsverket*, Air Navigation Services of Sweden, a state-owned enterprise, is responsible for providing air navigation services. In addition, Swedavia is the corporatized owner of the largest state airports.

5.1 Roads

Table 17

The marginal cost of road wear & tear is a major component in the summary for heavy vehicles. So is also the cost for CO_2 emissions. On this account, it should be emphasized that the last row comprises two components of tax on fuel referred to as the energy and the carbon tax, respectively. Section 2.1 described how the cost for CO_2 emissions in **Fel! Ogiltig självreferens i bokmärke.** is directly offset by the level of this tax. The approach currently used for providing a proxy for the social cost of carbon implies that an increase of the carbon tax would be exactly offset by the same increase of the social cost of carbon emissions. If the purpose is to consider the degree of taxation relative to costs for road use, the comparison concerns all other external costs relative to what is labelled the energy tax. At the same time, this approach for deriving the $SCCO_2$ price-tag also provides an input for valuing this emission from other modes of transport and indeed from any (non-trading) sector of the economy.

Table 17 summarizes the marginal costs for traffic using state roads. Costs for both noise and emissions are local, but are still included in these types of summaries. No estimations have so far been done for costs in cities, but the different cost estimates in the project can be further developed to account for how much higher the cost is in conurbations of different sizes.

The analysis of emission externalities shows that the gradual sharpening of the EURO classification has resulted in that heavy vehicles with most stringent standards (EURO VI) have low emissions of particles and NOx. The scientific understanding of the toxicity of exhaust from combustion engines is improving over time and one consequence may be that risks that were previously unknown will become part of future marginal cost estimates. At the same time, road vehicles may in the future be using propellants with zero emissions. But even if emissions from fuel use would disappear, netither noise nor wear and tear from heavy vehicles would not.

The reduction of the number of road accidents as well as increased focus on traffic safety provides the background for the low external accident costs of cars on state roads. The same phenomenon is present also for heavy vehicles, but the statistical robustness of our results gives reasons for concern. Our interpretation of the overall results for heavy vehicles, is that there is still a non-negligible external marginal accident cost related to heavy vehicles on state roads.

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Table 17. Average marginal costs for use of state roads relative to fuel taxes. SEK_{2015} per vehicle km.

	Car	**Lorry***	**Lorry w. trailer ****
	Petrol	**Diesel**	
Wear and tear	0.04	0.41	1.69
-Thereof day-to-day maintenance	0.01	0.02	0.02
-Thereof reinvestment	0.03	0.39	1.67
Accidents	0.00	0.25	0.25
Emissions (lorry EURO-class IV)	0.02	0.14	0.22
Noise	0.02	0.06	0.15
CO_2	0.21	0.24	1.28
Congestion	0	0	0
Total marginal costs	**0.29**	**1.10**	**3.59**
Fuel tax	**0.47**	**0.38**	**2.00**
Thereof CO_2 tax	0.21	0.24	1.28

* 0.83 ESAL; could be a lorry with total weight 14 tons and 2 axles

** Lorry w. 3 axles, trailer w. four axles, total weight 62 ton.

Taken together, previous national studies have made a similar observation as ours: Cars are not underpriced while heavy vehicles are. Since the above calculations were made, the tax on diesel has increased. This further increases the “over taxation” of diesel cars (cars in

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Table 17 use petrol) while it narrows the gap between marginal costs and taxation for heavy vehicles.

A tax on motor fuel is not able to differentiate charges to account for the fact that the axle weight of heavy vehicles may be deleterious for road surface quality. A recent committee proposal to introduce a weight-distance tax (SOU 2017:11) – which would be able to address this deficiency – has been shelved by the government for unclear reasons. That study, however, illustrates the potential for implementing very detailed road user charges, not only handling wear and tear differences but also charging more when noisy and emitting vehicles get closer to cities.

5.2 Railways

Electrified traction accounts for 95 percent of the total number of train kilometres operated. For this reason, *Table 18* doesn't account for environmental costs from diesel engine emissions.

Collisions between, or derailing of trains are rare. In addition, road and railway traffic has been vertically separated on railway lines with much traffic and high speed. The accident externality is therefore linked to collisions between trains and road vehicles, pedestrians etc. at grade crossings. This means that the marginal costs for accident risk is a local nuisance, concentrated to the secondary network. Both noise and the two accident cost entries in Table 18 have been calculated for an average train service. SAMKOST 3 will consider in further detail the regional split of this and other localized marginal costs.

Similarly, congestion is a highly local phenomenon. Unlike accident risk, it primarily relates to the most used parts of the railway network and refers to the demand for departure slots that cannot be satisfied or that trains are forced to leave their origin at inferior departure times. No approach for estimating the significance of this externality is, however, available.

Table 18. Marginal costs for use of railway infrastructure. SEK 2015.

		Passenger trains	Freight trains
Day-to-day maintenance	Per gross ton km	0.012	0.012
Reinvestment	Per gross ton km	0.034	0.034
Accidents. train-car	Per train km	0.92	0.92
Accidents; train-pedestrians (excl. suicide)	Per train km	0.49	0.49
Noise	Per train km	2.38	4.22
Congestion		+	+

The analytical understanding of how costs for railway maintenance is affected by traffic has gradually improved over the last 20 years. The accumulation of facts summarised in section 4.2 indicates a substantially higher marginal cost level than in the first studies. Two observations of this nature linger behind the first two rows in *Table 18*. First, there seems to be a dynamic component of marginal costs for day-to-day maintenance, meaning that the marginal gross ton-km increase maintenance cost both “today” and “tomorrow”; secondly, not only reinvestment in tracks but also in signaling and electricity supply is at least partly driven by traffic. Both observations imply higher estimates of these costs than previous studies.

This presumption is however confounded by the charge per train kilometer which is imposed at three different levels. The low level refers to parts of the network that are little used and the high level applies to sections with much traffic. This would therefore signal another dimension of capacity shortage. Another complication when trying to account for the differentiation becomes apparent when observing that the train kilometre charge until 2014 was levied to account for accident costs. While noise disturbances may be higher on highly used sections of the network, the opposite is true for accident costs.

Table 19 summarizes track user charges in 2015, excluding surcharges on diesel traction vehicles. Starting from the bottom, the peak charge is levied for using tracks in Stockholm, Göteborg and Malmö during morning and afternoon weekday peaks. Since little is known about the costs for congestion, a first proxy would be to assume these charges reflect congestion costs.

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differentiation becomes apparent when observing that the train kilometre charge until 2014 was levied to account for accident costs.[14] While noise disturbances may be higher on highly used sections of the network, the opposite is true for accident costs.

Table 19. Track user charges in 2015. SEK[15]

	Passenger trains	Freight trains
Track use charge; per gross ton km	0.014	0.005
Train charge, per train km; high	6.00	6.00
Medium	2.30	2.30
Base	1.90	1.90
Peak charge in three cities, per passage	416	416

The final component of the scheme is levied per gross ton km and was originally set to account for the wear and tear of vehicles on tracks. There is no analytical evidence of different wear and tear cost for passenger and freight trains. Instead, the differentiation originates in a previous administrative charge levied on passenger trains only; this component is now subsumed in this charging component. In comparison with the two components of costs for maintenance reported in *Table 18*, the level of the track use charge is well below current cost estimates.

For a passenger train weighing 300 ton and a freight train weighing 600 ton, *Table 20* illustrates the implications of current levels of charging relative to costs. It is obvious that track user charges are well below marginal costs for using the railway network. Since there are some indications of scarcity in that not all trains are given slots at current levels of track user charges, the difference may even be larger than indicated by *Table 20*.

An important difference of marginal cost pricing for the use of road and railways is that it would be technically straightforward to calculate the marginal cost of each train departure and to levy charges accordingly. This is so since before a train departs, information specifying origin and destination and route (a list of which track sections that the train will use), as well as the weight and composition of the train (type of propulsion, number and weight of cars, etc.) must be submitted to the train control. Corresponding disaggregate pricing of road use would require higher administrative costs.

Table 20. Marginal costs and track user charge for a passenger and freight train. SEK/ train km.

	Train weight, ton	Charge			Marginal cost
		Base	Medium	High	

[14] The elimination of accidents as a basis for the charge was implemented in accordance with EU Directive 2012/34/EU. The directive states that charging for environmental or accident costs shall be allowed only if such charging is applied to road freight transport in accordance with Union law.

[15] The scheme of track user charges also includes an earmarked charge for the use of the Öresund bridge. This charge is levied as part of the agreement between Sweden and Denmark for building and financing the bridge. It has minor allocation consequences for use of the domestic railway network

Passenger	300	6.10	6.50	10.20	17.59
Freight	600	4.90	5.30	9.00	33.23

5.3 Shipping

Costs for providing port infrastructure for loading and unloading are not considered to be part of the costs for providing national infrastructure services. The Maritime Administration's responsibility includes making Swedish waters available and safe for shipping and the provision of maritime traffic information; pilotage and ice breaking services; hydrographic, maritime and aeronautical Search and Rescue services. The agency receives an annual allocation from the national budget but is instructed to cover the costs for service delivery to commercial traffic by charging users. Revenue from charging of pilotage services and the use of fairways accounts for about 60 percent of the agency's total costs. Icebreaking services is cross-subsidised from the fairway dues.

The need to recover the costs for providing services to commercial traffic makes the Maritime Administration (as well as the state representatives in the aviation sector, see the next section) different from roads and railways. Decisions about changes in the level of taxation of petrol and diesel are made by the parliament, and it is also the parliament that is responsible for the annual allocation of funds for maintenance of, and investment in both roads and railways. The Maritime Administration therefore has some discretion over the charging structure that the Transport Administration does not have. Moreover, the focus on cost recovery eliminates any link between the fairway dues and pilotage fees on the one hand and shipping's marginal external costs on the other hand.

The institutional framework for decisions in different parts of Sweden's infrastructure sector obviously differs, in particular with respect to charging principles. Except for this domestic aspect of institutional design, much shipping and flights have international destinations and the possibility for national governments to tax bunker oil (and kerosene for flights) is severely restricted.

The tradition to estimate marginal costs for shipping (and for aviation, cf. next section) is less established than for estimating marginal costs for using roads and railways. Moreover, several data problems are of a different nature compared to estimating costs for road and railway use. One consequence is that the practice has come to be to account for costs and charges for shipping (and aeronautical services) as an aggregate rather than per vessel km. Furthermore, the tradition is to handle costs for pilotage and icebreaking as parts of the marginal costs for using infrastructure, i.e. Swedish waters. Since some countries have decentralised the provision of these services, SAMKOST 3 will provide a benchmark for considering whether this difference in institutional structure affect the conclusions with respect to cost internalisation.

Icebreaking costs in *Table 21* differ between a low and a high level due to different assumptions about the relevant marginal costs for these services. The entry for pilotage is based on the average costs for this service. Moreover, since accident statistics don't account for if injuries are minor or severe, while the Swedish CBA guidelines recommend different unit values for the severity of accident consequences, a low and a high estimate for accident costs is provided in *Table 21*. The estimates furthermore assume that any accident-related costs for vessels and cargo are internalised via insurances while all costs related to killed and injured people are external costs. SAMKOST 3 will consider the relevance of accidents at sea for marginal cost estimation in more detail, in particular to ascertain that principles are applied consistently across modes. Since hardly no environmental accidents (oil spills etc.) were registered in Swedish waters during the last 30 years, these risks have not been accounted for.

Table 21. The marginal costs for shipping using Sweden's territorial waters. Million SEK_{2014}.

	Low	**High**
Pilotage	171	171
Icebreaking	113	188
Accidents	85	207
Air pollution, regional effects	477	572
CO_2	1 240	1 240
Total	2 086	2 378

The estimation of emission costs is based on coefficients of CO_2, NOx and other compounds (cf. section 2) emitted from the use of an estimated 370 000 tonnes Marine Gas Oil (MGO) on Swedish waters. The lower level of the estimate in **Fel! Hittar inte referenskälla.** refers to the regional health impacts of secondary PM and another 20% are added in the high-cost alternative to account for costs related to acidification, eutrophication and ozone. An important observation from results reported in *Table 22* is that the consequences for the environment of using MGO account for about 75 percent of the industry's total costs.

To recap, SAMKOST's purpose is to compare charges that affect ship-owner behaviour with the (marginal) costs for providing these services. *Table 22* indicates that current charges account for about two thirds of costs.

Table 22. Aggregate marginal costs relative to shipping charges for using Sweden's naval waters, SEK_{2014}.

	Low	High
Marginal costs	2 086	2 378
Pilotage and fairway charges	1 400	1 400
Internalization	67%	59%

5.4 Aviation

Air Navigation Services of Sweden handles landings and take-offs at 20 national airports and operates two control centers for national services, for international departures and arrivals as well as for flights passing over Swedish territory. It covers all costs by charging airlines. In addition, Swedavia operates airports under a commercial platform. A substantial revenue share derives from commercial activities at or around airports (car parking, licensing of airport terminal sales etc.). In addition, charges are levied per passenger (safety controls etc.), for terminal services (luggage etc.), for airplane parking as well as for take-offs and landings. Only the latter component is relevant for comparison with the marginal costs for infrastructure use. The rest of Swedavia's costs refers to services at terminals that are not part of the provision of infrastructure.

The assessment in SAMKOST is that take-offs and landings at airports do not generate costs for runway wear and tear. Moreover, there is no shortage of slots using the country's runways. The combination of these two observations makes aviation and shipping similar from the perspective of marginal cost estimation.

In the same way as for other modes of transport, there is a risk for accidents linked to use of airports and flight routes. Aviation is, however, the mode of transport that has pursued safety aspects to its extreme. Official data shows that there have been three accidents during the last 10 years, none of which had any injuries or casualties. Almost 20 years ago, a Swedish flight crashed at Milan's Linate airport with 110 fatalities. While this accident did not appear at an airport under domestic jurisdiction, it demonstrates the long-run, latent risk for severe accidents. For SAMKOST, the conjecture is however that there is no reason to account for accident risks.

The major source of marginal costs related to air traffic are externalities from fuel use and from noise at airports. To estimate the former costs, the point of departure in the background study has been to establish how much fuel that airlines use. Since some information necessary for this calculation is classified, a proxy has been constructed based on (a) the number of airline movements at the country's airports and (b) flight distance for both domestic and international flights. In addition, (c) different types of aircraft with different specific fuel consumption are assumed for short- and long-distance flights. Assumptions have been calibrated against the information that is publicly available.

The allocation of specific types of planes to different routes has facilitated the estimation of CO_2, NOx, SOx and particle emissions. Furthermore, a distinction between CO_2 emissions during the landing and take-off (LTO) and the under-way phases of flights is made. This is based on information from the air pollutant emission inventory guidebook for 2016 published by the European Environment Agency. *Table 23* demonstrates results for the cost of CO_2 emissions.

Table 23. Climate costs for different types of airplanes for domestic, European and other international flights. SEK_{2015} for an average flight of the respective categories.

	CO_2	High altitude effect	Total
Domestic	0 (5 867)	1 979	1 979
European	0 (16 490)	11 958	11 958
Overseas	73 021	66 437	139 458
Overall average	4 140	10 156	14 296

Section 2.1 established that aviation is part of EU-ETS. Consequently, all emissions of climate gases from flights have been internalized and the costs for emissions is zero in Europe. As demonstrated by *Table 23*, this is not the end of the story. There seems to be a common understanding that emissions from other greenhouse gases than CO_2 (i.e. water vapor, soot and nitrogen oxides) at high altitudes generate a greater climate impact than at the ground level. The assumption here is that high-altitude emissions are 1.7 times as harmful as emissions at the ground level. This is therefore a cost which is not handled by the emission trading scheme.

Information about flight distances is also an input for estimating the costs for the health impact of air pollution. Due to resource constraints, it has not been feasible to calibrate an IPA model for estimating the social costs for these emissions in the same way as for naval services. A numerical example of the possible level of these costs is, however, included in *Table 24*. The table also includes an entry for the costs of the average noise costs at a Swedish airport, described in section 3.

Table 24. Marginal costs for example types of flights and fees paid per flight. SEK

	Costs					Fees
	Runway Wear	Climate	Other emissions	Noise	Total	
Domestic	-	1 979	1 394	959	4 331	3 912–5 175
Europe	-	11 958	9 031	959	21 948	4 589–6 145
Overseas	-	139 458	19 353	959	159 769	9 336–13 786

The final step in the analysis concerns a comparison of marginal costs with the charges that airlines pay. The charges levied by Air Navigation Services of Sweden and Swedavia have been reviewed to distinguish between charges related to provision of terminal services (which are not relevant) and charges for using infrastructure. The interval in *Table 24* reflects an uncertainty about whether some of the charges should be conceived of as levied for passenger handling, for providing terminal services or for using runways.

The results reported in this table has more shortcomings than the corresponding results for roads and railways. This includes crude assumptions in the estimation of several cost components, the necessity to use only a few types of airplanes and the interpretation of which charges that are relevant for affecting behavior of the airlines. Moreover, the international comparison does not include en-route charges that flights to and from Sweden must pay when passing over other countries. With these caveats in mind, the results indicate that domestic flights may (on average) be paying their way for the marginal costs they generate; this is not so for international flights.

6. Conclusions

The purpose of marginal cost analysis is to provide a platform for implementing a welfare enhancing policy for pricing infrastructure use. This line of work is not rocket science, not least since we as researchers must use the information that happens to be available rather than the ideal data set. SAMKOST's prime conclusions are however reasonably robust. The first is that the taxation of petrol used by cars is higher than the level of marginal costs of using national roads. This does not necessarily violate the overall efficiency objective since the low price-elasticity of fuel makes it an appropriate candidate for generating tax revenue, i.e. for Ramsey pricing. Secondly, all other infrastructure users pay less than their marginal costs.

It may seem surprising that the marginal costs for accident risk and environmental impact of road traffic is lower than suggested byprevious assessments. Our work however illustrates the fact that the marginal cost estimates emanate from both the level of unit costs and from the underlying causal relationship. The low level of accident costs is, for instance, due to that the number of severe road accidents have fallen for a long time. In the same way, the improving quality of both fuel (no longer emitting lead or Sulphur) and engines has reduced emissions dramatically. The most recent EURO VI heavy vehicles for instance discharge almost no NOx and particles.

Considering today's debate over a deteriorating climate, it may still seem odd to conclude that private cars pay more than their marginal costs. Our conclusion goes back to the assumption that, in the absence of an internationally accepted measure of the $SCCO_2$, Sweden's tax on the carbon content of petrol and diesel can be used as a proxy. As part of the country's commitment to reduce emissions, the explicit purpose of this tax is to internalize $SCCO_2$. There is no guarantee that the level of the carbon tax will suffice for meeting Sweden's undertaking for emission reduction. It is still convenient to use the tax as a proxy for costs since the tax must increase faster than the established trajectory for tax increases if this is not sufficient for meeting the set target. Moreover, it is straightforward to use the same proxy for emissions from modes of transport – air and sea – that currently do not pay this tax.

Technically,

The marginal cost of road wear & tear is a major component in the summary for heavy vehicles. So is also the cost for CO_2 emissions. On this account, it should be emphasized that the last row comprises two components of tax on fuel referred to as the energy and the carbon tax, respectively. Section 2.1 described how the cost for CO_2 emissions in **Fel! Ogiltig självreferens i bokmärke.** is directly offset by the level of this tax. The approach currently used for providing a proxy for the social cost of carbon implies that an increase of the carbon tax would be exactly offset by the same increase of the social cost of carbon emissions. If the purpose is to consider the degree of taxation relative to costs for road use, the comparison concerns all other external costs relative to what is labelled the energy tax. At the same time, this approach for deriving the $SCCO_2$ price-tag also provides an input for valuing this emission from other modes of transport and indeed from any (non-trading) sector of the economy.

Table 17 illustrates that this assumption eliminates the $SSCO_2$ component from the comparison of taxes with marginal costs: The carbon tax by our definition internalizes the $SSCO_2$. This observation notwithstanding, it has also been established that the Swedish tax/$SSCO_2$ value is higher than the European benchmark value. The claim that cars pay their way is therefore not a result of an artificially low estimate of the climate cost.

The difference between track user charges and marginal costs in the railways sector is larger than indicated by previous work. This is primarily due to that information about costs for maintenance of, and reinvestment in railway infrastructure gradually is improving and now refers to a 15-year panel over track units. More and better data provide new modelling possibilities and insights, in this case indicating that marginal costs are higher than previously believed.

State-of-the art knowledge about the costs of shipping and air transport is less good than for roads and railways. With reservation for several shortcomings regarding the underlying causal relationships and the cost estimates, our best estimate is however that neither shippers nor airlines pay for their social marginal costs. An important reason is the international agreement to exempt bunker oil and kerosene from national taxation. Charges paid by the respective industries for using sea lanes, air corridors and scarce landing capacity are primarily implemented to recover financial costs and, except for the level of these charges, the link to externalities is, at best, weak.

Shortly before the SAMKOST report was finalized, it became clear that emissions from international services had been handled in different ways for flights and sea transport. The rule-of-thumb used for estimating airlines' costs means that all emissions from a flight from a Swedish to an international airport are accounted for as a cost of the trip; in contrast, the return leg is assumed to be a responsibility of the other country. On the other hand, the costs for emissions from international shipping are accounted for only while ships are on Swedish waters. An important task for future research (SAMKOST 3) is obviously to eliminate this difference.

It is, moreover, important to point to that several taxes and charges used today are unable to address different sources of cost level variations, for instance with respect to noise and many emissions from combustion engines. But the technical development is fast and it is now feasible to implement more disaggregate pricing schemes than was possible just a few years ago. The use of congestion charges in Stockholm clearly illustrates how a high price for using roads during peak has diverted traffic to other time of the day or increased the use of public transport, and indeed has eliminated some trips. Stockholm is now a better functioning city than before the implementation of the charging system.

Except for that train operators are charged below marginal costs, levies are not sufficiently differentiated; some vehicles wear down infrastructure quality faster than others do; the current difference between peak and off-peak capacity charges is small; and there is no means for differentiating for noise from different types of rolling stock and at different locations. Overall, the ambition to save the railways from what has been seen to be malign (high) charging levels and inappropriate differentiation of charges may have been harmful for the ability of the industry to renew itself. This is in stark contrast to the pressure in the road industry understood in its widest sense: The concerns over road accident fatalities and over harmful emissions from fossil fuels have put extensive pressure on car manufacturers, on the provider of road infrastructure and indeed on users themselves by way of speed limits, surveillance cameras, etc. Externalities from road use is therefore rapidly shrinking. This demonstrates the long-term benefits of using charges and other types of incentives for making traffic in all modes of transport sustainable.

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