How will electrification and increased use of new fuels affect the effectiveness of freight modal shift policies?

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Abstract

The objective of this paper is to determine how policy instruments targeting a modal shift of long-haul freight transport from road to rail or shipping might affect the distribution of freight tonne-kilometers across the different modes of transport in Sweden. The analysis is conducted in two steps. First, possible developments of freight tonne-kilometers until 2030 and 2040 are compared to base figures for 2017. This is done by developing a set of alternative forecast models where different assumptions and scenarios prevail and analyzing these using Sweden's national freight transport model SAMGODS. Second, the effects of two hypothetical modal shift policy instruments – a wear and tear tax for road traffic and an ecobonus scheme to promote shipping by rail and sea – are analysed with respect to modal split in the base year of 2017 and for the forecast year 2040. The analysis involves the aggregation of calculated modal shares across each of the SAMGODS model's vehicle/ship types – i.e., six road freight vehicles, eleven freight train variants and 22 ship types. Given the conditions that are assumed in the forecasts, the amount of freight tonne- kilometers is calculated to increase by between 31% and 53 % between 2017 and 2040. The increase is generally largest for maritime transport, followed by road transport and smallest for rail transport. The concept developed in this paper can be useful in studying impacts of different types of technology shifts and policy packages.

Keywords

Freight transport, modal split, transport work, forecast models, policy analysis

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1. Introduction

In seeking to achieve a target of a 60% reduction in greenhouse gas emissions (GHG emissions) by 2050, one of the goals of EU transport policy is that 30% of long-distance road freight (over 300 km) should shift to rail or waterborne transport by 2030 and more than 50% by 2050 (European Commission, 2011)., Sweden does not have any quantitative targets for freight modal switches, but the National Freight Transport Strategy has been established to achieve transport policy goals, strengthen the competitiveness of business, and promote a transfer of freight from road to rail and shipping (Government Offices of Sweden, 2018). This intention to promote a freight modal transfer has been operationalised in a 'roadmap' produced by the Swedish Transport Administration (2020a) which recognises, however, that in connection with infrastructure planning, "…road transport will continue to be important for maintaining accessibility throughout the country and for transporting goods where shipping or rail is not an option" (Swedish Transport Administration, 2020b. p.30).

Sweden's freight transport sector can contribute to national climate objectives through improved transport and/or energy efficiency, switching to less environmentally damaging energy carriers, switching to less environmentally damaging modes of transport and, ultimately, through a reduction in freight transport demand. Within the analysis conducted herein, the emphasis is on the transfer of freight away from road and towards rail and shipping. The underpinning assumption is that rail and waterborne transport can perform the same transport work as road, with lower energy consumption and/or lower emissions to air.

Within both the wider EU and at national level within Sweden, policy instruments are being implemented to streamline truck transport and/or to reduce their emissions to air. An example within Sweden is the plan to increase the proportion of state roads that allow trucks up to a maximum total weight of 74 tonnes, instead of a maximum of 64 tonnes (Swedish Transport Administration, 2020c). An example at EU level is the regulation that reduces the maximum CO2 emissions from new heavy vehicles by 15% by 2025 and by 30% by 2030, compared to a reference period of 1 July 2019 - 30 June 2020 (EU, 2019).

Sweden's overarching climate target is to achieve zero net emissions of GHG emissions by 2045; the specific goal within the transport sector implies that GHG emissions from domestic transport shall be reduced by at least 70 % between 2010 and 2030 (excluding aviation which is included in the European Union Emissions Trading System), Government Offices of Sweden (2021). Policy targets and instruments, both at the national and the EU-level, influence technical development, choice of energy carriers, investments in infrastructure, transport costs for the different modes etc.

The objectives of the paper are twofold; the primary objective is to derive and analyse freight transport forecasts for 2030 and 2040 based on different assumptions regarding the development of efficiencies, electrification and fuel changes for the different modes, the permission of trucks with a maximum total weight of 74 tonnes on major Swedish roads and the development of freight transport demand. Within the context of todays' situation and the forecasts 2040, the secondary objective is to identify how policy instruments that aim to promote the transfer of freight from road to rail and shipping affect the distribution of transport work over the various available modes of freight transport. The scope is constrained to analysing solely those freight movements originating in or destined for Sweden.

The paper is structured as follows. Section 2 presents a review of the literature on the impact of policy instruments on freight mode choice and modal shares. Section 3 provides a detailed description of the methodology applied within this study, as well as of the assumptions and input data which drive the various forecast models that are implemented and evaluated. The results derived from applying Sweden's national freight transport model (SAMGODS) to calculate effects on transport work and its distribution across the various modes of freight transport for a base-case year of 2017 and the forecasts to 2030 and 2040 are presented in section 4. The potential effects of implementing two specific, hypothetical policy instruments to promote a transfer from road to rail and shipping today and in 2040 are evaluated in section 5 and conclusions are drawn in section 6.

2. Literature Review

Although overshadowed by the surfeit of studies on passenger mode choice, the issue of freight mode choice has received fairly significant coverage in the literature. The most popular foci of research in the field are evidenced in a number of review papers in relation to:

- the modelling approaches deployed (Tavasszy et al., 2012; Comi et al., 2013; De Jong et al., 2013; Tavasszy and De Jong, 2013; Ratrout et al., 2014; Engebrethsen and Dauzère-Pérès, 2019; Izadi et al., 2020; Tavasszy et al., 2020, Merkel et al. (2021), encompassing more specific analyses of elasticities (De Jong et al., 2010; Beuthe et al., 2014) and the value of time in freight transport (Feo-Valero et al., 2011; Shams et al., 2017).
- the behavioural analysis of freight mode choice decisions (Samimi et al., 2011; Li and Hensher, 2012; Stockhammer et al., 2021), with a more recent emphasis on decision contexts where intermodal options are available (Agamez-Arias and Moyano-Fuentes, 2017; SteadieSeifi et al., 2014; Ertem et al., 2017).
- the implications for the environment and sustainability (Bask and Rajahonka, 2017; Demir et al., 2014; Demir et al., 2015; Marchet et al., 2014).

Despite the plethora of work conducted in these broad areas of freight mode choice, there are relatively few papers, however, which specifically address or investigate the potential or, even actual, impact of policies for promoting the modal transfer of freight. Only a few merit further attention within the context of the work conducted herein.

Blauwens et al. (2006) applied the inventory-theoretic framework to evaluate the effectiveness of three policy measures aimed at triggering a modal shift in the freight transport market in Belgium. The policies evaluated were as follows: i) The introduction of road pricing such that the costs of road freight transport would be increased by 5%, 10% and 20%, ii) a decrease in the lead-times of combined rail/road transport and combined barge/road transport by half a day by increasing the opening hours of terminals and other relevant infrastructure, iii) a decrease in the transportation costs of rail transport through deregulation by 5%, 10% and 20%. It was concluded that:

- Both rail/road transport and barge/road transport benefit from an increase in the transportation costs of road transport, but the impact is clearly the biggest on rail/road transport.
- A decrease in the lead-time of combined rail/road transport by half one day results in a doubling of its market share from 17% to 33%, while road reduces its market share from 37% to 26%. The impact on barge/road transport's market share is limited.
- Cutting the average lead-time of barge/road transport by half a day increases its market share by roughly 10%, with both road and rail/road transport losing about 5% each in market share.
- When the lead-times of both forms of combined transport are improved by half a day, the share of direct road transport drops significantly from about 37% to about 24%, with rail/road transport being the main beneficiary of this.'

As might be expected, the market share of combined rail/road transport increases when the transportation costs of rail transport are decreased. For a 5% reduction in costs, market share is captured almost exclusively from road. For the 10% and 20% reductions, however, the increase in market share is mainly captured from barge/road transport.

Feo et al. (2011) found that a combination of road pricing and an ecobonus scheme applicable to maritime transport were the most effective policy measures in terms of prompting a modal shift. Both policy instruments are aimed at providing the transport system with an authentic framework for competition between modes by incorporating external costs directly into the price payable for the use of each mode. These authors found that policies aimed at improving the transit time of the maritime mode yielded negligible benefits in terms of modal transfer.

Nealer et al. (2012) examine the accumulated energy and emissions associated with freight transport that is embodied in final products and services in the US and compares the modelled results under scenarios where different potential modal shift policies are applied. They conclude that policy instruments that are specifically aimed at promoting modal shift are relatively ineffectual in the shorter term, in comparison to policies that lead more directly to greater efficiency in road freight transport. In either case, the authors attest that such policy instruments are best targeted at specific sectors, rather than being generally applicable to all.

Brogan et al. (2013) evaluate a number of alternative policy instruments which might provoke a freight modal switch within the US. Their main findings for each of a range of potential policy instruments can be summarised as follows:

- *Increasing fuel Taxes or GHG pricing* – The price of diesel would have to nearly double to increase rail tonnage by the equivalent of about 1%.
- *Road pricing* – The potential for modal transfers from road to rail is low, because only a small fraction of truck trips would be long enough with high enough tolls to encourage diversion. A switch to non-tolled roads would be more likely.
- *Reducing truck driver hours of service* – Hours of service could be reduced further, which would increase trucking costs, especially for long distances. Without a strong safety justification, reducing hours of service any further is politically difficult and is unlikely to prompt any significant modal transfer.
- *Changing truck Size and weight limits* – Increasing allowable truck sizes and weights on Interstates and major state roads would divert freight from rail to truck. The authors estimate that allowing a nationwide increase in truck size and weight, permitting 100,000-pound trucks on all Interstate routes (a 25% increase in maximum weight) might result in 5% of rail tonnage shifting to road.
- *Re-regulating rail freight rates and services* – Re-regulation would reduce prices for some shippers, but also reduce railroad profitability and access to capital for railway refurbishment and expansion.
- *Investing in rail freight corridors and service improvements* – A radical increase in public investment in rail could reduce prices and improve services, allowing rail to capture more freight from road. The authors

estimate that a major program to expand capacity and improve service to levels to make freight rail more competitive with road could increase rail tonnage by 10-20% in the US.

Pinchasik et al. (2020) developed model simulations of transport and modal distribution effects under several scenarios where policy instruments for modal shift were strengthened, expanded, combined, and harmonized across borders within the Nordic region. They concluded that a Norwegian ecobonus scheme for rail delivers a greater modal shift away from road than does a similar ecobonus scheme for shipping.[1] Harmonizing policies across the Nordic countries of Norway, Sweden and Denmark was found to be beneficial in strengthening the modal shift effects of policy instruments, but the overall effect was not that significant. The authors conclude that policy instruments that seek to prompt freight modal shift should not exclusively be regarded as an element of environmental strategy, since their impact is small in this respect. They may, however, contribute positively to other policy objectives. Given the nature of the scenarios tested in Pinchasik et al. (2020), the geographical scope of its analysis and how recently the work was done, this work provides the most appropriate comparator for the analysis conducted herein with respect to the implementation of freight modal shift policies within the Swedish context.

3. Methodology

The analysis of the effects of a) various assumptions about the development of vehicles and energy carriers etc. and b) policies that aim to promote the transfer of freight from road to rail and shipping is undertaken in two steps:

1. The level and distribution of transport work associated with the different modes of transport under different forecasts (FAST ELECTRIFICATION and SLOW ELECTRIFICATION) for 2030 and 2040 are derived and compared with the base 2017. For the SLOW ELECTRIFICATION forecast 2040 two alternatives are studied, one allowing for trucks with a maximum total weight of 74 tonnes on major roads and the other assuming a slower growth of freight transport demand.
2. The effects of two policy instruments (an ecobonus scheme for shipping and a wear and tear tax for road transports), on the level of transport work for various modes of transport, are tested both in the base year setting and in the main forecasts for 2040 (FAST ELECTRIFICATION and SLOW ELECTRIFICATION).

The focus is on changes in transport work as opposed to other dependent variables such as tonnage or number of transports. The Swedish Transport Administration's national freight transport model (SAMGODS) is used to calculate the impacts in step 1 and 2. In general, the concept introduced in this paper will be useful in studying the effects of technology shifts, changes in freight transport demand, upcoming policy packages etc. on the operating costs for vehicles, transport work and modal split.

3.1 Overview of SAMGODS – The Swedish National Freight Transport Model

SAMGODS is a model that has been developed for system-wide traffic analysis and to produce forecasts of future freight traffic. It is particularly suitable for studies of infrastructure investments, policy instruments or changes in the business environment that are sufficiently extensive to affect the balance between modes of transport. The SAMGODS model searches for optimal transport chain solutions to solve the need for transport between Swedish municipalities and regions abroad, as cost-effectively as possible.

The demand for freight transport is calculated on the basis of data on: the production and consumption of goods, as contained within national accounts; international trade in merchandise goods; Input-output tables and; employment statistics. The functions underpinning the distribution of demand between production and consumption nodes, have been estimated with the help of information from, among other things, goods flow surveys. The price level utilized in the model corresponds to that which pertained in 2017, with transport demand in the model calculated as the volume of goods in tonnes required for transport between all the zones in the model. This involves demand matrices for 16 product groups based on EUROSTAT's standard goods classification for transport statistics. For the latter, information on economic growth from the latest available long-term study

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[1] The annual budget is assumed to be about EURO 13 million in both schemes.

produced by the Swedish Ministry of Finance is used. The method for creating demand matrices is described in Edwards et.al. (2019).

The SAMGODS model's logistics module calculates optimal shipment sizes, shipment frequencies, transport chains, selection of terminals and the like. The choice is affected by the possibility of groupage in terminals. The logistics module thus creates origin/destination (O/D) flows (start and finish point flows) for vehicles based on Producer/Consumer (P/C) flows between companies (the relationship between production volumes and demand volumes). The proportion of transport work (tonne-kilometers) produced by different types of vehicles and ships is affected by the distribution of freight transport demand by product group, as the available product groups have different average product values per unit weight and different proportions handled as bulk transport. The transport arrangements associated with freight movements or flows are then determined so that transport and logistics costs are minimized. The logistic optimization is described in de Jong, G. C. and Baak, J. (2020). The fundamental principles behind the method can be found in Ben-Akiva, M. and de Jong, G. C. (2013) and de Jong, G. C. and Ben-Akiva, M. (2007). Limitations in the railway capacity are handled via a special module which, in the event of congestion on certain sections, seeks alternative transport arrangements that relieve these congested sections of the railway at the least possible alternative cost. A description of the railway capacity module is given in Edwards, H. (2019).

In the network module of the SAMGODS model, the routes that provide the lowest time and distance costs for the vehicles are calculated. The network module is used both in calculating the level of service for different vehicles and in assigning the resulting O/D flows on to the network.

The SAMGODS model calculates tonne-kilometers, vehicle kilometers and transport costs per consignment, as well as the volumes associated with each network link and O/D municipal pair. The model's base year is calibrated so that, given a certain set of input demand matrices, the model produces estimates of transport work, throughput in ports and flows on selected routes that match available transport statistics.

The SAMGODS model operates using 6 variants of trucks, 11 freight train configurations and a total of 22 different ships. A central part of what governs the outcome of the model's calculation is how these vehicle variants are costed, both per kilometer driven and in terms of cost per hour driven. These costs are calculated via: average fuel consumption; the cost of different fuels; driver salaries and other personnel costs; vehicle purchase prices; operating and maintenance costs; taxes and fees and more. Costs related to loading, unloading and transfers are also included.

All operating costs used for the standard base-case for 2017 are described in Swedish Transport Administration (2020f). For the purposes of this paper, however, a range of alternative base-case and forecast cost estimates have been produced using our own calculations for each available vehicle/ship category. The model calculations then follow the approach used by the Swedish Transport Administration when calculating costs for the base-case of 2017 and the forecast year of 2040. The following section presents an overview of the vehicles included in the models and which costs are used in the calibrated base-case, which should represent the situation as in 2017.

3.2 Vehicle settings in the base year 2017

The truck variants available within the SAMGODS model, together with their operating costs for the base-case year of 2017 are described in Table 1.

Table 1: Truck variants used in the SAMGODS model and their standard operating costs for 2017

Type of traffic	**Truck variant**	**Load Capacity (Tonnes)**	**Cost per km (€)[2]**	**Cost per hr (€)**
Neighbourhood traffic	Light trucks with a maximum total weight of 3,5 tons; two axles	2	0.27	30
Local distribution	truck with a total weight between 3,5 and 15 tons; two axles	9	0.48	33
Regional distribution	Truck with a total weight between 16 and 24 tons; three axles	15	0.64	35
Remote distribution	Truck with a total weight between 25 and 40 tons; 3 + 4 axles	28	0.68	34
Heavy transport	Truck with a total weight between 41 and 60 tons; 3 + 4 axles (Allowed in Sweden and Finland)	47	0.79	36
Extra heavy transport	Truck with a total weight between 41 and 74 tons; 4 + 5 axles (Allowed in Sweden and Finland)	60	0.87	36

Notes: The Neighbourhood traffic type does not capture all light truck traffic under 3,5 tonnes in the statistics, for example mail and parcel distribution, Source: Swedish Transport Administration (2020f)

The train types included in the SAMGODS model are reported in Table 2,

Table 2: Train variants used in the SAMGODS model and their standard operating costs for 2017

Type of train[4]	**Gross weight (Tonnes)**	**Length (Metres)**	**Maximum load capacity (Tonnes)[2]**	**Cost per train km (€)**	**Track fees (€)**	**Cost per train hr (€)**
Feeder train	893	271	488	0.84	1.15	363
Combi train, short	1,116	340	610	1.26	1.30	382
Combi train, long	1,329	405	726	1.45	1.46	400
System train, short (MAL[3] 22,5)	1,756	327	959	1.68	1.77	387
System train, long (MAL 22,5)	2,091	390	1 142	1.99	2.02	407
System train, short (MAL 25)	2,010	327	1,098	1.95	1.96	396
System train, heavy (MAL 30)	10,980	750	6,000	10.48	8.50	674
Wagonload, short	1,311	380	716	1.31	1.45	393
Wagonload, medium	1,560	452	852	1.51	1.64	413
Wagonload, long[1]				1.60	1.74	440
Wagonload, extra large[1]		750	1,480	2.61	2.83	718

Notes: (1) Information on gross weight and length is lacking in Swedish Transport Administration (2020f). (2) Maximum load capacities include an average allowance for empty wagons, (3) MAL = Maximum Axle Load, (4) In the base-case year of 2017, the 'Combi train, long', 'System train, long (MAL 22,5)', 'Wagonload, long' and the 'Wagonload, extra-large' are not available for use; on certain routes, the extant plans for expanding track capacity in the future will mean that the model needs to allow for these longer and heavier trains in the forecasts for 2040, Source: Swedish Transport Administration (2020f)

The ship types included in the model are reported in Table 3.

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[2] The average exchange in 2017 of 9.6 SEK/€ is used throughout the paper to convert from Swedish crowns to Euros.

Table 3: Fuel consumption, distance cost within and outside SECA[3] and time cost for the ship types in the SAMGODS model base year 2017

Type	Size (DWT[1,2])	Fuel Consumption (Kg/Km)	Cost Outside SECA (€/Km)	Cost Within SECA (€/Km)	Cost per Hour (€)
Container vessels	5,300	10.70	4.0	4.6	270
Container vessels	16,000	23.91	9.0	10.2	500
Container vessels	27,200	35.72	13.4	15.2	690
Container vessels	100,000	98.31	37.0	41.8	1,627
Tankers. bulk and dry cargo vessels	1,000	2.54	1.0	1.1	134
Tankers. bulk and dry cargo vessels	2,500	5.03	1.9	2.1	188
Tankers. bulk and dry cargo vessels	3,500	6.04	2.3	2.6	215
Tankers. bulk and dry cargo vessels	5,000	7.43	2.8	3.2	249
Tankers. bulk and dry cargo vessels	10,000	12.49	4.7	5.3	338
Tankers. bulk and dry cargo vessels	20,000	19.47	7.3	8.3	417
Tankers. bulk and dry cargo vessels.	40,000	29.84	11.2	12.7	543
Tankers. bulk and dry cargo vessels	80,000	45.83	17.3	19.5	777
Tankers. bulk and dry cargo vessels	100,000	50.74	19.1	21.6	838
Tankers. bulk and dry cargo vessels	250,000	86.74	32.7	36.9	1,199
Roro vessels	3,600	12.65	4.8	5.4	290
Roro vessels	6,300	18.50	7.0	7.9	379
Roro vessels	10,000	25.21	9.5	10.7	481
Ferry (ropax)	2,500	17.94	6.8	7.6	555
Ferry (ropax)	5,000	32.45	12.2	13.8	1,096
Ferry (ropax)	7,500	41.76	15.7	17.8	1,725
Ferry (train)	5,000	26.26	9.9	11.2	785
Inland shipping vessels	1,750	6.96	0.0	3.0	129

Notes: (1) DWT stands for "Deadweight tonnage" or "deadweight" and is a measure of a ship's maximum load capacity. i.e., the weight of cargo. fuel. storage. crew and passengers when unloaded to the minimum permitted freeboard. (2) The stated size (in DWT) corresponds to the assumed cargo capacity in tonnes. except for the larger passenger ferries (5.000 and 7.500 DWT) where the freight cargo capacity is set at 3.000 and 5.000 tonnes respectively. (3) The fact that different costs per kilometer within and outside the North European SECA (Sulphur Emission Control Area) reflects the fact that the rules for the sulphur content of marine fuels differs within and outside the SECA. which gives different fuel prices (4) Fairway dues and pilot fees are also included in the model, but not specified in the table. Source: Swedish Transport Administration (2020f).

The costs for loading. unloading and transhipment/transfer are also handled by the SAMGODS model and are described in Swedish Transport Administration (2020f). These vary by 16 different product groups, as previously shown in Table 1. Since the costs for loading, unloading and transhipment are assumed to be unchanged in the freight transport forecast these are not explicitly reported.

3.3 Assumptions used in forecasts for 2030 and 2040

The following sections describe the assumptions and estimations undertaken to create the alternative freight transport forecasts used in this analysis.

3.3.1 Changes in streamlining of vehicles and energy carriers

The alternative freight transport forecasts we develop for analysis are assumed to have either a positive or negative impact on the costs of freight transport. Figure 1 presents a schematic of the different factors which are taken into account in these forecasts and how these affect the transport costs for the different modes of freight transport.

Figure 1: Overview of considered factors that either increase or decrease transport costs for road. rail and shipping

Road		**Rail**		**Shipping**		
Electric Drive	↓	Lower electricity consumption	↓	Electric Drive	↓	
Lower electricity and	↓	Increased track charges	↑	Lower electricity and fuel consumption	↓	
Other fuel mix	↑	Investment in higher rail capacity (infrastructure)	↓	Use of alternative fuels	↓	↑
		Investments to allow for longer trains (infrastructure)	↓	Tighter sulphur requirements	↑	
				Cost of investing in LNG	↑	

For road traffic an increased use of electric power and streamlining of vehicles will results in lower costs per kilometer while an increased mix of biofuels will increase the cost for transports using internal combustion engines. Except for LNG operation, the same is estimated for shipping. For shipping LNG operation is estimated to be cheaper per ship-kilometer in 2030 and 2040 than using LSMGO (Low Sulfur Marine Gas Oil) while the use of biofuels or carbon-free fuels is assumed to result in higher costs per kilometer. In addition, it is assumed that the stricter sulphur requirements outside the SECA area from 2020 will lead to higher costs for shipping. It is also assumed that investment in LNG operation and investments in catalysts to meet future requirements for reduced emissions of nitrogen oxides both lead to higher capital costs mainly affecting vehicle cost per hour used.

For rail traffic the possibility of efficiencies that result in lower electricity consumption is taken into account but also that track charges will gradually increase in line with the plans of the Swedish Transport Administration. The modelling also accounts for the decided investments included in the national transport plan that provide increased track capacity and the opportunity to be able to use longer trains for certain sections of the rail network. These infrastructure measures have a relatively large positive impact on the ability of rail to compete with other modes of freight transport.

Assumptions and calculations are presented in more detail below for each of the modes.

In the FAST ELECTRIFICATION forecast for 2040 the same efficiency improvement in fuel consumption for road transports is assumed as in the Swedish Transport Administration's forecast for 2040 (Swedish Transport Administration, 2020d); for 2030 half of that efficiency is assumed to have been achieved. In the SLOW ELECTRIFICATION forecast only half of these efficiency improvements are assumed to have been achieved for both 2030 and 2040. All these model assumptions yield net fuel consumption figures as shown in Table 4.

Table 4: Assumed fuel consumption (diesel) in the model forecasts (litres/km)

	BASE	**FAST ELECTRIFICATION**		**SLOW ELECTRIFICATION**	
Type of truck	**2017**	**2030**	**2040**	**2030**	**2040**
Neighborhood traffic	0.072	0.061	0.049	0.067	0.061
Local distribution	0.164	0.137	0.110	0.152	0.139
Regional distribution	0.222	0.183	0.143	0.205	0.189
Remote distribution	0.271	0.224	0.177	0.251	0.230
Heavy transport	0.352	0.291	0.230	0.326	0.299
Extra heavy transport	0.394	0.326	0.257	0.364	0.335

With respect to the electrification of truck traffic, the same development is assumed in FAST ELECTRIFICATION as in Swedish Transport Administration (2020d). For the FAST ELECTRIFICATION forecast for 2030 the proportion of kilometers operated with electricity has been set in accordance with the data provided in Swedish Transport

Administration (2020a). In the SLOW ELECTRIFICATION forecast, it is assumed that only one-third of this level of electrification is achieved in each year (see Table 5). It is important to point out that these simplifying assumptions concerning the electrification of truck traffic are necessary for the purpose of model estimation but it does mean that the issue is not addressed as rigorously as in for example. Börjesson (2021), the Swedish Transport Administration (2021a) and the Swedish Transport Administration (2021b) where the interaction between diesel-powered and electric trucks, geographical differences in infrastructure and range problems are all analysed. For the purposes of the analysis herein, therefore, it is simply assumed that the introduction of electric trucks will drive down the average cost per kilometer for the trucks included in the SAMGODS model.

Table 5: Proportion of kilometers driven under electric power in the different forecasts.

	FAST ELECTRIFICATION		**SLOW ELECTRIFICATION**	
Type of truck	**2030**	**2040**	**2030**	**2040**
Neighborhood traffic	0.50	0.68	0.17	0.23
Local distribution	0.50	0.85	0.17	0.28
Regional distribution	0.50	0.85	0.17	0.28
Remote distribution	0.14	0.36	0.05	0.12
Heavy transport	0.02	0.19	0.01	0.06
Extra heavy transport	0.02	0.19	0.01	0.06

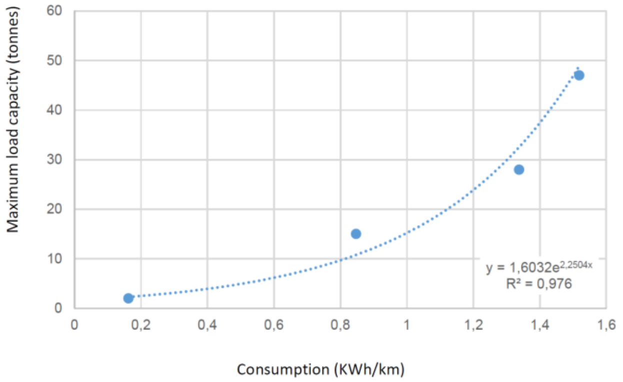
As shown in Table 6 both FAST ELECTRIFICATION and SLOW ELECTRIFICATION forecasts assume that the electricity consumption will reduce over time. The FAST ELECTRIFICATION forecast for 2040 assumes that electricity consumption falls at the same rate as diesel consumption but is calculated on the basis of a slightly higher electricity consumption in 2017 than stated in Swedish Transport Administration (2020f); 1.54 kWh/km instead of 1.34 kWh/km for a 40-tonne truck. For the FAST ELECTRIFICATION forecast for 2030 it is assumed that half of the efficiency gains by 2040 will be achieved. The SLOW ELECTRIFICATION forecast assumes that the streamlining of electric vehicles will be relatively rapid until 2030 but that the possibilities for streamlining will then decrease until 2040.

Table 6: Electricity consumption for trucks in the forecasts FAST ELECTRIFICATION and SLOWELECTRIFICATION *(KWh/km)*

	FAST ELECTRIFICATION		**SLOW ELECTRIFICATION**	
Type of truck	**2030**	**2040**	**2030**	**2040**
Neighborhood traffic	0.152	0.127	0.162	0.159
Local distribution	0.738	0.593	0.767	0.751
Regional distribution	0.802	0.628	0.847	0.829
Remote distribution	1.274	1.006	1.337	1.309
Heavy transport	1.446	1.142	1.518	1.486
Extra heavy transport	1.532	1.211	1.610	1.576

Since Information on electricity consumption for “Extra heavy transport”. i.e., trucks with a permissible total weight of 74 tonnes, is lacking in Swedish Transport Administration (2020f) a consumption figure has been calculated using the relationship between maximum load capacity and consumption, as shown in Figure 2. The relationship has also been used for the alternative forecasts that are derived within this analysis and for revising the electricity consumption of trucks engaged in local distribution, which in Swedish Transport Administration (2020f) has been set equal to the consumption of trucks engaged in regional distribution.

Figure 2: The Relationship between the maximum load capacity of trucks and the specified energy consumption during electric operation



Source: Swedish Transport Administration (2020f)

As shown in Table 7 other distance costs are linked to depreciation, maintenance and tyre wear and tear.

Table 7: Cost per kilometer for trucks in the 2017 base-case (€/km)

Type of truck	Fuel cost	Depreciation	Maintenance & repair	Tyres	Total
Neighborhood traffic	0.07	0.11	0.03	0.05	0.27
Local distribution	0.16	0.18	0.11	0.03	0.48
Regional distribution	0.22	0.22	0.13	0.07	0.64
Remote distribution	0.27	0.19	0.12	0.10	0.68
Heavy transport	0.35	0.20	0.11	0.12	0.79
Extra heavy transport	0.40	0.21	0.12	0.14	0.87

Source: Swedish Transport Administration (2020f)

The purchase price of trucks in real terms is not assumed to change over the period of analysis nor do the costs for service and repair or for tyres. Even though the purchase price of an electric vehicle is currently higher than for a corresponding diesel-powered vehicle it is expected to decline rapidly in the future to equate to an equivalent diesel-powered vehicle by 2030 (Holmgren et al., 2021). Swedish Transport Administration (2020d) assumes, therefore, that the investment cost for electric vehicles is the same as for traditional diesel-powered trucks; the same assumption is applied in forecasts FAST ELECTRIFICATION and SLOW ELECTRIFICATION. Estimated distance costs per hour as well as loading, unloading and reloading costs are assumed to be virtually unchanged until 2040. In the analysis we do, however, consider that the cost per kilometer of using trucks changes due to electrification and changes in fuel prices.

Assumptions on fuel prices that are used for the forecasts FAST ELECTRIFICATION and SLOW ELECTRIFICATION in 2030 and 2040 are shown in Table 8. The fuel mix in 2040 has been assumed to be the same as in Swedish Transport Administration (2020d), i.e., 7% FAME and 63% HVO. For the forecasts for 2030 the mix has been set at 6% FAME and 40% HVO which corresponds to a linear development between the mix in 2017 and the assumed mix in 2040. Taxes are expected to develop in the same way as in the Swedish Transport Administration's forecast (2% real annual revaluation from 2017). The product price of diesel is based on estimated production and distribution costs (Holmgren et al. 2021). Prices for HVO and FAME (in the 2017 price level) are expected to increase until 2030 and then remain stagnant between 2030 and 2040.

Table 8: Assumptions about the price of diesel in the forecast for 2030 and 2040 (€/l in 2017 prices)

Diesel (5% FAME. 18% HVO)	**2017 (€/l)**	**2030 (€/l)**	**2040 (€/l)**
Product price	0.54	0.75	0.79
Energy tax	0.21	0.29	0.37
Carbon dioxide tax	0.26	0.30	0.34
Total	1.00	1.34	1.51

Note: 2017 prices exclude VAT. Source: Swedish Transport Administration (2020f), and Holmgren (2021).

The prices of electricity for the road transport sector in the FAST ELECTRIFICATION and SLOW ELECTRIFICATION forecasts are shown in Table 9. For the base year 2017, the share of electricity is set at zero, so no price is required. An additional cost for charging infrastructure has been added and allowed to vary between the truck variants used in SAMGODS depending on different assumptions about the balance between depot and fast charging. The additional cost for depot charging is estimated to be lower than for fast charging (based on Holmgren (2021)). For neighbourhood, local and regional traffic depot charging is assumed to cover 90 % of kilometers driven on electricity. For long-distance traffic and heavy transport 70 % of the kilometers driven have been judged to be manageable with depot charging. The price for electric operation is expected to be lower in 2040 compared with 2030 since the cost of charging infrastructure is expected to be lower in 2040.

Table 9: Assumed price of electricity for truck traffic in forecasts for 2030 and 2040 (€/kWh in 2017 prices).

	2030	**2040**
Product cost	0.0729	0.0729
Energy tax	0.0351	0.0351
Charging Infrastructure		
- Neighborhood. local and regional	0.0224	0.0191
- Remote and heavy transport	0.0255	0.0218
Totals		
- Neighborhood. local and regional	0.1304	0.1270
- Remote and heavy transport	0.1335	0.1298

Notes: The product cost is based on Bokinge et al. (2020) with a supplement for network cost according to Holmgren (2021) and with an underlying cost in €/kWh for depot and for fast charging according to data in Holmgren (2021).

This then gives the final costs per kilometer for forecasts FAST ELECTRIFICATION and SLOWELECTRIFICATION as shown in Table 10.

Table 10: Distance costs for trucks in the MOSEL forecasts (€/km at 2017 prices)

	FAST ELECTRIFICATION		**SLOW ELECTRIFICATION**	
Type of truck	**2030**	**2040**	**2030**	**2040**
Neighborhood traffic	0.25	0.23	0.28	0.28
Local distribution	0.46	0.42	0.51	0.50
Regional distribution	0.59	0.51	0.66	0.65
Remote distribution	0.69	0.63	0.74	0.73
Heavy transport	0.82	0.74	0.87	0.87
Extra heavy transport	0.91	0.82	0.96	0.96

As shown in Table 11, these model assumptions yield quite large differences in the development of distance costs as compared to the 2017 base-case. In the FAST ELECTRIFICATION forecast the high proportion of electric operation and the streamlining of trucks has resulted in a sharp fall in operating costs for truck traffic. It can also be seen that the SLOW ELECTRIFICATION forecasts yield approximately the same outcome in 2040 as in 2030. This is explained by the fact that the savings which accrue from increased electrification are offset by higher fuel prices because of an increased blending of biofuels.

Table 11: Changes in distance cost for trucks compared with the 2017 base-case in the various forecasts (%)

	FAST ELECTRIFICATION		**SLOW ELECTRIFICATION**	
Type of truck	**2030**	**2040**	**2030**	**2040**
Neighborhood traffic	-7.6	-13.7	2.2	1.5
Local distribution	-5.1	-14.1	4.5	3.3
Regional distribution	-7.5	-19.3	3.9	1.7
Remote distribution	1.5	-8.0	8.4	7.9
Heavy transport	4.2	-5.7	10.4	10.3
Extra heavy transport	4.2	-6.0	10.4	10.2

According to the Swedish Transport Administration (2020g), the future energy use of rail transport is expected to be reduced by about 10 %. However, no assessment is made of when such efficiency can be achieved. The Swedish Transport Administration's forecast for 2040 (Swedish Transport Administration. 2020d) assumes no streamlining of rail traffic and a similar assumption is embodied within the SLOW ELECTRIFICATION forecasts. In the FAST ELECTRIFICATION forecasts, on the other hand, it is assumed that electricity consumption for rail traffic is reduced by 5 % by 2030 and 10 % by 2040.

The electricity price for rail traffic is assumed to be stable over time (at fixed prices). Bokinge et al. (2020) uses a product price of € 400 per MWh and estimates that it will be fixed until 2040. In addition, there is an electricity network cost which, according to the Swedish Transport Administration's Electricity Price Report (Swedish Transport Administration, 2020h) will be fixed at 0.011 € per kWh over the next five years. Since the network costs for road traffic are assumed to be at approximately the same level until 2040, the same is assumed to apply to rail traffic. In the forecasts FAST ELECTRIFICATION and SLOW ELECTRIFICATION, the costs per kWh consumed are therefore assumed to remain at the same level as in the base 2017. Overall, this gives costs per vehicle-kilometer as shown in Table 12. The cost per kilometer represents about 15 % of the total operating cost per kilometer.

Table 12: Cost per train kilometer for the different train types (€/train-km at the 2017 price level)

	BASE	**FAST ELECTRIFICATION**		**SLOW ELECTRIFICATION**	
Type of train	**2017**	**2030**	**2040**	**2030**	**2040**
Feeder train	0.84	0.80	0.76	0.84	0.84
Combi train – short	1.26	1.20	1.14	1.26	1.26
Combi train – long	1.45	1.38	1.30	1.45	1.45
System train – short (STAX 22.5)	1.68	1.59	1.51	1.68	1.68
System train – long (STAX 22.5)	1.99	1.89	1.79	1.99	1.99
System train – short (STAX 25)	1.95	1.85	1.75	1.95	1.95
System train – heavy (STAX 30)*	10.48	9.96	9.43	10.48	10.48
Wagonload – short	1.31	1.25	1.18	1.31	1.31
Wagonload – medium	1.51	1.44	1.36	1.51	1.51
Wagonload – long	1.60	1.52	1.45	1.60	1.60
Wagonload – extra large	2.61	2.48	2.35	2.61	2.61

Note: System train – heavy is used to transport iron ore from LKAB in Kiruna to Narvik (Norway) and Luleå.

For all forecasts, the track fees (as shown in Table 13) have followed those specified for 2040 in Swedish Transport Administration (2020f). The track fees for the 2030 forecasts were derived by interpolation from the data for 2017 and 2040.

Table 13: Track fees (€ /train-km at the 2017 price level)

Type of train	2017	2030	2040
Feeder train	1.15	1.50	1.85
Combi train – short	1.30	1.76	2.23
Combi train – long	1.46	2.01	2.58
System train – short (STAX 22.5)	1.77	2.51	3.29
System train – long (STAX 22.5)	2.02	2.51	2.97
System train – short (STAX 25)	1.96	2.81	3.72
System train – heavy (STAX 30)*	8.50	13.26	18.68
Wagonload – short	1.45	1.99	2.55
Wagonload – medium	1.64	2.28	2.97
Wagonload – long	1.74	2.43	3.14
Wagonload – extra large	2.83	3.36	3.84

Note: System train – heavy is used to transport iron ore from LKAB in Kiruna to Narvik (Norway) and Luleå.

The changes in distance cost, as compared to the 2017 base-case, are summarised in Table 14. The increased distance cost is mainly due to higher track fees.

Table 14: Changes in distance cost for different types of trains compared with the 2017 base-case in the various forecasts (%)

	FAST ELECTRIFICATION		SLOW ELECTRIFICATION	
Type of train	**2030**	**2040**	**2030**	**2040**
Feeder train	15,6	31,2	17,6	35,2
Combi train – short	15,6	31,6	18,0	36,3
Combi train – long	16,5	33,3	18,9	38,5
System train – short (STAX 22.5)	18,8	39,1	21,4	44,1
System train – long (STAX 22.5)	9,7	18,7	12,2	23,7
System train – short (STAX 25)	19,2	39,9	21,7	45,0
System train – heavy (STAX 30)	22,3	48,1	25,1	53,6
Wagonload – short	17,4	35,1	19,6	39,9
Wagonload – medium	18,1	37,5	20,3	42,2
Wagonload – long	18,3	37,4	20,7	41,9
Wagonload – extra large	7,4	13,8	9,7	18,6

The capacity improvements that the Swedish Transport Administration (2020d) have included in their forecast for 2040 are also used in the forecasts FAST ELECTRIFICATION and SLOW ELECTRIFICATION. For the sake of simplicity. it has been assumed that these capacity improvements can also be realized for the forecast for 2030. This means that the possibility of longer trains is encompassed within the forecasts. These capacity improvements have a major impact on the competitiveness of the rail mode. In the SAMGODS model, this is handled via a capacity module that is based on the specified maximum freight train passages per section and seeks alternative solutions with the lowest alternative cost in cases where the capacity ceiling is reached. In all forecasts the time costs and costs for loading, unloading, and reloading are assumed to be unchanged from 2017. The costs of investing in and owning trains are thereby assumed to remain unchanged at fixed prices.

The forecasts FAST ELECTRIFICATION and SLOW ELECTRIFICATION assume that the fuel consumption of the different ships analysed can be reduced over time in accordance with Table 15.The data on possible efficiencies in shipping are taken from the IMO's 4th greenhouse gas study (IMO, 2020). The IMO's assessment to 2030 is in line with the estimate of energy efficiency in the Swedish Transport Administration (2020g); i.e., that the potential for efficiency improvements is approximately as great for shipping as for heavy trucks (see Table 4). This means an efficiency improvement of 18% over the period 2017-2030. This is in good agreement with the final figure that emerges if, as suggested by Tattini and Teter (2020), a current annual efficiency improvement of 1.5% is assumed (i.e., 17.8%) or if it is assumed that the efficiency achieved so far (historically) is 1.6% annually.

Table 15: Assessment of fuel efficiency gains in shipping (at fleet level)

Ship type	**2030**	**2040**
Bulk ships	16%	25%
Tankers	16%	25%
Container vessels	17%	23%
Other unit load vessels	11%	15%
Passenger ships	9%	12%
Total	10%	15%

Source: IMO (2020). Annex K.

An increase in operating cost also comes from the requirement for lower sulphur content in marine fuels outside the SECA areas as from 2020. When setting up the forecasts there was no priced fuel fraction that met the requirements for lower sulphur content outside SECA, so instead a calculation based on a mixture of IFO 380 and LSMGO has been used.[3]

In the forecasts it is assumed that 14 % of the kilometers driven with smaller ships that make many calls will use LNG in 2030. By 2040, the proportion of kilometers driven with LNG will increase further, and alternative fuels will be used. Possible candidates among these may be ammonia or methanol but other alternatives are also possible. By 2040, it is also assumed that 10 % of kilometers driven by ferries will be able to take place with electric operation. Assumptions made are based on data from Trosvik et al. (2020) and are reported in Table 16.

Table 16: Assumed share of kilometers with alternative fuels in the 2030 and 2040 FAST and SLOW ELECTRIFICATION forecasts (%)

		2030		**2040**			
Ship type	**Size (DWT)**	**MGO**	**LNG**	**MGO**	**LNG**	**Alternative Fuels**	**Electricity**
Container vessels	5,300	86	14	47	28	25	
Container vessels	16,000	100		47	28	25	
Container vessels	27,200	100		47	43	10	
Container vessels	100,000	100		100			
Tankers. bulk and dry cargo vessels	1,000	86	14	47	28	25	
Tankers. bulk and dry cargo vessels	2,500	86	14	47	28	25	
Tankers. bulk and dry cargo vessels	3,500	86	14	47	28	25	
Tankers. bulk and dry cargo vessels	5,000	86	14	47	28	25	
Tankers. bulk and dry cargo vessels	10,000	100		47	28	25	
Tankers. bulk and dry cargo vessels	20,000	100		47	43	10	
Tankers. bulk and dry cargo vessels	40,000	100		47	43	10	
Tankers. bulk and dry cargo vessels	80,000	100		47	43	10	
Tankers. bulk and dry cargo vessels	100,000	100		100			
Tankers. bulk and dry cargo vessels	250,000	100		100			
Ro-Ro vessels	3,600	86	14	47	28	25	
Ro-Ro vessels	6,300	86	14	47	28	25	
Ro-Ro vessels	10,000	86	14	47	28	25	
RoPax ferries	2,500	86	14	47	23	20	10
RoPax ferries	5,000	86	14	47	23	20	10
RoPax ferries	7,500	86	14	47	23	20	10
Train ferries	5,000	86	14	47	23	20	10
Inland waterway vessels	1,750	86	14	47	28	25	

Table 17 shows the fuel consumption under the various fuel alternatives. The starting point has been the consumption per kilometer for MGO as given in Swedish Transport Administration (2020f). These figures are then used as the basis for deriving the consumption of other fuels. For methanol the same energy consumption has been assumed as for MGO while for LNG 15% higher energy consumption has been assumed. Consumption depends on which engine technology is chosen and for LNG the assumption is conservative.

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[3] IFO - Intermediate Fuel Oil, LSMGO - Low-sulfur (<0.1%) Marine Gas Oil.

Fuel prices are reported in Table 18. Future prices are based on the assessment made in World Economic Outlook 2019, scenario Sustainable development.

Table 17: Assumed average consumption per kilometer for different fuel alternatives MGO, LNG, MDO (Kg/km) and electricity (MWh/km)

	Size	**2017**	**2030**		**2040**			
Ship type	**(DWT)**	**MGO**	**MGO**	**LNG**	**MGO**	**LNG**	**'Alternatives'**	**Electricity**
Container vessels	5,300	10.7	8.88	8.82	8.24	8.18	17.73	
Container vessels	16,000	23.91	19.85	19.71	18.41	18.29	39.61	
Container vessels	27,200	35.72	29.65	29.45	27.50	27.32	59.18	
Container vessels	100,000	98.31	81.60	81.05	75.70	75.19	162.87	
Tankers. bulk and dry cargo vessels	1,000	2.54	2.13	2.12	1.94	1.93	4.18	
Tankers. bulk and dry cargo vessels	2,500	5.03	4.23	4.20	3.85	3.82	8.28	
Tankers. bulk and dry cargo vessels	3,500	6.04	5.07	5.04	4.62	4.59	9.94	
Tankers. bulk and dry cargo vessels	5,000	7.43	6.24	6.20	5.88	5.65	12.23	
Tankers. bulk and dry cargo vessels	10,000	12.49	10.49	10.421	9.55	9.49	20.56	
Tankers. bulk and dry cargo vessels	20,000	19.47	16.35	16.25	14.89	14.79	32.05	
Tankers. bulk and dry cargo vessels	40,000	29.84	25.07	24.90	22.83	22.67	49.11	
Tankers. bulk and dry cargo vessels	80,000	45.83	38.50	38.24	35.06	34.83	75.43	
Tankers. bulk and dry cargo vessels	100,000	50.74	42.62	42.34	38.82	38.56	83.51	
Tankers. bulk and dry cargo vessels	250,000	86.74	72.86	72.37	66.36	65.91	142.77	
Ro-Ro vessels	3,600	12.65	11.26	11.18	10.75	10.68	23.13	
Ro-Ro vessels	6,300	18.50	16.47	16.25	15.73	15.62	33.83	
Ro-Ro vessels	10,000	25.21	22.44	22.29	21.43	21.29	46.10	
RoPax ferries	2,500	17.94	16.33	16.22	15.79	15.68	33.97	0.11
RoPax ferries	5,000	32.45	29.53	29.33	28.56	28.36	61.44	0.20
RoPax ferries	7,500	41.76	38.00	37.75	36.75	36.50	79.07	0.25
Train ferries	5,000	26.26	23.90	23.74	23.11	22.95	49.72	0.16
Inland waterway vessels	1,750	6.96	5.85	5.81	5.32	5.29	11.46	

Source: Swedish Transport Administration (2020f) and IMO (2020).

Table 18: Fuel prices used in forecasts for 2030 and 2040, price of MGO (€ per kg)[1] and price of electricity (€-cent per kWh) at 2017 price levels)

Fuel	**2017**	**2030**	**2040**
MGO	425	477	466
VLSFO[2]		429	419
LNG		314	314
Biomethanol		387	348
Electricity (öre/kWh)		130	127

Notes: (1) Conversion from price per MWh to price per kg has been done with information on the energy content and density of the various fuels according to Swedish Energy Agency (2019) and Drivkraft Sverige (2019). (2) VLSFO (very low sulphur fuel oil) is the fuel variant that has been developed for use outside SECA from 2020 and thus meets the IMO's stricter requirements for low sulphur content. Source: Swedish Transport Administration (2020f) and Holmgren (2020) based on IEA (2019).

With the assumptions and base data as described above, this yield costs per kilometer as shown in Table 19.

Table 19: Cost per km for ship at 2017 price levels (€/ km)

		Inside SECA			Outside SECA		
Ship type	**Size (DWT)**	**2017**	**2030**	**2040**	**2017**	**2030**	**2040**
Container vessels	5,300	4.55	4.03	4.06	4.03	3.81	3.45
Container vessels	16,000	10.17	9.47	9.08	9.00	8.52	7.72
Container vessels	27,200	15.18	14.15	11.76	13.45	12.73	11.52
Container vessels	100,000	41.79	38.94	35.24	37.02	35.04	31.72
Tankers. bulk and dry cargo vessels	1,000	1.07	0.97	0.96	0.96	0.92	0.81
Tankers. bulk and dry cargo vessels	2,500	2.05	1.92	1.90	1.90	1.81	1.61
Tankers. bulk and dry cargo vessels	3,500	2.57	2.30	2.28	2.27	2.18	1.94
Tankers. bulk and dry cargo vessels	5,000	3.16	2.83	2.80	2.80	2.68	2.39
Tankers. bulk and dry cargo vessels	10,000	5.31	5.01	4.71	4.70	4.51	4.00
Tankers. bulk and dry cargo vessels	20,000	8.28	7.80	6.36	7.33	7.02	6.24
Tankers. bulk and dry cargo vessels	40,000	12.69	11.96	9.76	11.24	10.77	9.56
Tankers. bulk and dry cargo vessels	80,000	19.48	18.38	14.99	17.26	16.53	14.69
Tankers. bulk and dry cargo vessels	100,000	21.57	20.34	18.07	19.10	18.30	16.26
Tankers. bulk and dry cargo vessels	250,000	36.86	34.77	30.90	32.67	31.29	27.80
Ro-Ro vessels	3,600	5.38	5.11	5.30	4.76	4.83	4.51
Ro-Ro vessels	6,300	7.86	7.48	7.76	6.97	7.07	6.59
Ro-Ro vessels	10,000	10.72	10.19	10.57	9.49	9.64	8.98
RoPax ferries	2,500	7.64	7.42	8.32			
RoPax ferries	5,000	13.79	13.41	15.06			
RoPax ferries	7,500	17.75	17.25	19.39			
Train ferries	5,000	11.16	10.85	12.19			
Inland waterway vessels	1,750	2.96	2.66	2.63			

Source: Swedish Transport Administration (2020f), Holmgren (2020) based on IEA (2019) and IMO (2020).

Changes in distance cost are summarized in Table 20. For most ship types distance cost is calculated to be lower in 2030 and 2040. The exceptions are RoPax ferris within SECA 2040, where an assumed higher share of alternative fuels will drive up costs, and Ro-Ro vessels outside SECA 2030 where efficiency gains will not be able to offset increased fuel prices due to lower sulphur content.

For shipping, an additional cost has been added for ships that use alternative fuels. Mainly because in many cases it may be relevant to rebuild existing ships to be able to use alternative fuels. Based on calculations in Holmgren (2020), which itself is based on cost estimates from Taljegård et al. (2014), the cost of the propulsion system for an LNG ship is approximately 58% higher than for a conventional ship. For the sake of simplicity, the same supplement, except for Methanol, is adopted for all types of alternative fuels. Because methanol can be used in existing engines the equivalent additional cost mark-up, according to Taljegård et.al. (2014), is only 6%. Due to uncertainties concerning the capital cost and presumed reductions in maintenance cost for ferries that are assumed to use electricity by 2040 the time cost, in fixed prices, has been left unchanged. The resulting costs per hour for each ships category are summarised in Table 21.

Table 20: Changes in distance cost for different ship types compared with the 2017 base-case in the 2030 and 2040 FAST and SLOW ELECTRIFICATION forecasts (%)

		Inside SECA		**Outside SECA**	
Ship type	**Size (DWT)**	**2030**	**2040**	**2030**	**2040**
Container vessels	5,300	-11.4	-10.8	-5.4	-14.5
Container vessels	16,000	-6.9	-10.7	-5.3	-14.2
Container vessels	27,200	-6.8	-22.5	-5.3	-14.3
Container vessels	100,000	-6.8	-15.7	-5.3	-14.3
Tankers. bulk and dry cargo vessels	1,000	-9.7	-10.7	-4.3	-15.2
Tankers. bulk and dry cargo vessels	2,500	-6.6	-7.6	-4.4	-14.8
Tankers. bulk and dry cargo vessels	3,500	-10.5	-11.3	-4.1	-14.7
Tankers. bulk and dry cargo vessels	5,000	-10.2	-11.2	-4.5	-14.9
Tankers. bulk and dry cargo vessels	10,000	-5.7	-11.4	-4.0	-14.9
Tankers. bulk and dry cargo vessels	20,000	-5.8	-23.1	-4.3	-14.9
Tankers. bulk and dry cargo vessels	40,000	-5.7	-23.1	-4.2	-14.9
Tankers. bulk and dry cargo vessels	80,000	-5.7	-23.0	-4.2	-14.9
Tankers. bulk and dry cargo vessels	100,000	-5.7	-16.2	-4.2	-14.9
Tankers. bulk and dry cargo vessels	250,000	-5.7	-16.2	-4.2	-14.9
Ro-Ro vessels	3,600	-4.8	-1.4	1.5	-5.3
Ro-Ro vessels	6,300	-4.9	-1.3	1.5	-5.4
Ro-Ro vessels	10,000	-5.0	-1.4	1.5	-5.4
RoPax ferries	2,500	-2.9	9.0		
RoPax ferries	5,000	-2.8	9.2		
RoPax ferries	7,500	-2.8	9.2		
Train ferries	5,000	-2.7	9.2		
Inland waterway vessels	1,750	-10.2	-11.3		

Table 21: Cost per hour when using ships in different categories IN 2017, 2030 AND 2040 at 2017 price level (€/hr)

Ship type	**Size (DWT)**	**2017**	**2030**	**2040**
Container vessels	5300	270	279	288
Container vessels	16000	500	500	543
Container vessels	27200	690	690	792
Container vessels	100000	1,627	1,627	1,627
Tankers. bulk and dry cargo vessels	1000	134	137	139
Tankers. bulk and dry cargo vessels	2500	188	193	198
Tankers. bulk and dry cargo vessels	3500	215	221	226
Tankers. bulk and dry cargo vessels	5000	249	256	264
Tankers. bulk and dry cargo vessels	10000	338	338	360
Tankers. bulk and dry cargo vessels	20000	417	417	464
Tankers. bulk and dry cargo vessels	40000	543	543	613
Tankers. bulk and dry cargo vessels	80000	777	777	888
Tankers. bulk and dry cargo vessels	100000	838	838	838
Tankers. bulk and dry cargo vessels	250000	1,199	1,199	1,199
Ro-Ro vessels	3600	290	302	313
Ro-Ro vessels	6300	379	397	414
Ro-Ro vessels	10000	481	505	529
RoPax ferries	2500	555	577	592
RoPax ferries	5000	1,096	1,157	1,197
RoPax ferries	7500	1,725	1,833	1,902
Train ferries	5000	785	820	843
Inland waterway vessels	1750	129	131	133

Source: Swedish Transport Administration (2020f) and Taljegard et al. (2014).

3.3.2. Future freight transport demand

The Swedish Transport Administration's forecast of freight transport demand for 2040 (Swedish Transport Administration. 2020f) is based on predicted economic growth. as specified in the latest available long-term government study of Sweden's economy (SOU 2019).[4] For the 2040-forecasts FAST ELECTRIFICTION AND SLOW ELECTRIFICATION, the same freight transport demand is used and the 2030-forecasts assume the same annual growth rate. Especially imports are expected to grow sharply (see Table 22).

Table 22 Freight transport demand in the SAMGODS model (million tonnes).

	2017	**2040**	**Increase (%)**
Domestic	259	356	37.5
Imports	73	121	65.8
Exports	90	125	38.9
Transit	8	14	75
Total	430	616	43.3

Source: Swedish Transport Administration (2020d).

According to an evaluation undertaken by the Swedish Transport Administration (see Edwards et al. 2019). imports are expected to increase by almost 66 % (by weight) between 2017 and 2040. In absolute terms, coal, oil and natural gas imports are expected to increase the most, but also imports of metal products, chemicals, wood products and roundwood, i.e., goods where shipping has a large share of transport, are expected to increase sharply. When it comes to exports it is primarily international demand for pulp, paper and stationery that is expected to increase the most, but demand for ore and refined petroleum products exports also stand out.

4. Resulting forecasts

4.1 Impacts on the amount of transport work per mode

This section presents the results obtained from applying four forecast models, which are summarised as follows:

- FAST ELECTRIFICTION – which presupposes efficiencies and fuel changes for all modes and 35 % lower electricity consumption for electric trucks.
- SLOW ELECTRIFICATION – which presupposes the same efficiencies and fuel changes for all modes of transport as in FAST ELECTRIFICATION, but a slower phasing-in of electricity and a lower degree of efficiencies.
- SLOW ELECTRIFICATION + 74 tonnes – a variant of SLOW ELECTRIFICATION that allows trucks with a maximum total weight of 74 tonnes on European roads and major national roads in Sweden and Finland.
- SLOW ELECTRIFICATION + 50% lower demand – a variant of SLOW ELECTRIFICATION that assumes 50% lower growth in freight transport demand than in other forecasts.

The results which emerge from applying these forecasting models relate to changes in freight transport work per type of traffic and total transport work as compared with the outcomes for the SAMGODS model's base-case year of 2017. As shown in Table 23 under all forecasts transport work on Swedish territory is calculated to increase sharply between 2017 and 2040. Growth is generally highest for maritime transport (up to about 71 %), second largest for road transport (up to about 56 %) and least for rail transport (up to 49 %).

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[4] For the purposes of the SAMGODS model. industry-wide economic growth is translated into freight volumes in tonnes that are produced in. and demanded for. each of the zones included in the model. This is done separately for the 16 product groups with which the model works. The process by which the production/consumption matrices (PC matrices) are produced is described in Edwards et al. (2019).

Table 23: Estimated change in transport work per mode on Swedish territory between the base 2017 and the forecasts for 2030 and 2040 (%)

	2030			2040		
	Road	Rail	Shipping	Road	Rail	Shipping
FAST ELECTRIFICATION	23.4	28.6	51.6	51.6	42.0	63.2
SLOW ELECTRIFICATION	19.9	39.9	42.5	42.5	48.5	71.7
SLOW ELECTRIFICATION, 74 tonnes trucks				51.4	36.3	67.6
SLOW ELECTRIFICATION, 50% demand increase				21.2	37.0	41.3

Note: When interpreting the various modal shares of total transport work it should be recognised that any change in transport arrangements will affect the total transport work. In particular, the distances travelled by ships is sensitive because there can be quite large shifts in the choice of port within the SAMGODS model. Since the distance from the port to the border of the Swedish territory varies a lot between different ports, this can affect the calculated distances operated by ship which, of course, is pivotal to the calculation of tonne-kms by ship on Swedish territory.

The higher tonne-kilometer growth for the rail mode in the SLOW ELECTRIFICATION forecast than in the FAST ELECTRIFICATION forecast 2030 and 2040 illustrates how the speed of the electrification process for road and shipping affects the development of the rail mode. The result indicates also that there is a potential for making better use of the railway infrastructure. Among other things, as Kågeson (2019) points out, it is difficult to determine how crowded it is (and will be) on the track and to what extent it is possible to increase freight transport work by rail by making better use of existing track capacity. For example, the track charges and the capacity allocation process could be developed so that they provide greater incentives to make better use of the existing track capacity, particularly on the most congested parts of the rail network.

The fact that transport work for shipping is rising more than by road and rail is explained by the high growth in international trade that is assumed in the freight transport demand matrices. An important explanation for shipping's increased share of transport work (see Table 25) is, therefore, the expected growth in demand for international transport (particularly bulk transport) that is usually transported by sea and not because shipping's competitiveness vis-à-vis the other modes of transport has improved.

Transport work on the road is calculated to increase the most in the FAST ELECTRIFICATION forecast and, with the exception of the forecast where the demand growth is halved, least in SLOW ELECTRIFICATION. Opening up the possibility of using 74-tonne trucks in the SLOW ELECTRIFICATION forecast gives almost the same outcome for road transport work as in the FAST ELECTRIFICATION forecast. It is also noteworthy that the introduction of 74-tonne trucks has a large effect on the rail transport work, with growth remaining at around 36 % compared with 48 % under the standard SLOW ELECTRIFICATION forecast. i.e., approximately the same outcome as obtained by halving freight transport demand in 2040.

The (main) SLOW ELECTRIFICATION forecast yields the most favourable outcomes for shipping and rail. This is because it is assumed that the streamlining and electrification of road traffic will not go as far as in the FAST ELECTRIFICATION forecast. Another notable outcome is that reducing freight transport demand by 50% in 2040 will, in principle, halve the growth of transport work by road and sea, but only a smaller reduction in the estimated transport work of rail in 2040 is found. One explanation for this is the less obvious capacity problems in the railway network in this case.

4.2. Impacts on different vehicle and ship categories

If we break down the modal share forecasts into specific vehicle and ship categories, it appears in the FAST ELECTRIFICATION forecast that the volume of transport work undertaken by smaller trucks, for local and regional distribution, increases more than the transport work for larger trucks (see Table 24). The explanation lies in the high degree of electrification assumed for smaller vehicles in this forecast. This means that the cost per kilometer for these vehicles will fall to 2040. In the FAST ELECTRIFICATION forecast, the cost per kilometer also falls for heavier trucks, but not as much. Edwards et al. (2019) estimated large growth in foreign trade in general, and for bulk goods in particular, which has an impact on freight transport demand. This explains why the transport work forecasts for large tankers, bulk and dry cargo vessels is expected to increase most in all forecasts. Within these larger ship segments, there is often no realistic choice between different types of traffic and ships. In the FAST

ELECTRIFICATION forecast, where road transport is expected to increase sharply, freight transport via Ro-Pax ferries is also estimated to increase by a relatively large amount. This is because increased truck traffic increases the demand for transport by ferries. With the exception of transport to and from Norway and northern Finland, as well as transport via the Oresund Bridge to Denmark, Sweden’s international traffic is dependent on ferries.

The (main) SLOW ELECTRIFICATION forecast, yields the largest increase in transport work for rail and sea. In shipping, this forecast gives the largest increases for all segments except for ferries. The SLOW ELECTRIFICATION forecast that assumes that trucks of 74 tonnes are allowed, however, involves a slower phasing-in of electricity and a lower degree of streamlining of vehicles (as in the main SLOW ELECTRIFICATION forecast), but with truckloads of up to 74 tonnes allowed on major national roads in Sweden. Under this forecast, the estimated increase in transport work becomes more concentrated in the heaviest truck segment and, as previously mentioned, significantly lower growth is obtained in transport work by rail.

For shipping, allowing trucks of 74 tonnes results in a relatively sharp reduction in transport work for Ro-Ro ships and a marginally lower level of transport work for container ships and ferries. As expected, however, the transport work carried out by larger container ships and tankers, bulk and dry cargo ships is expected to increase (see Table 24). Allowing larger trucks enables larger shipment sizes and lower shipment frequencies, which favours an approach that can benefit from economies of scale. While inland waterways are not specifically addressed within the modelling, a comparison between the SLOW ELECTRIFICATION forecast and the forecast, SLOW ELECTRIFICATION + trucks of 74 tonnes, suggests that the introduction of heavier trucks will reduce the possibility of gaining profitability in the design of inland waterways.

In the forecast with only 50% of freight transport demand in 2040, the most significant result is that lower levels of growth in freight transport demand will primarily affect the transport work undertaken by trucks involved in long-distance distribution and larger tankers, bulk and dry cargo ships. i.e., the vehicles that handle a large part of Swedish exports and imports.

Table 24: Estimated change in transport work between the base 2017 and the respective forecast for 2030 and 2040 (%)

	2030		**2040**			
	FAST ELECTRIFICATION	**SLOW ELECTRIFICATION**	**FAST ELECTRIFICATION**	**SLOW ELECTRIFICATION**	**SLOW ELECTRIFICATION + trucks of 74 tonnes**	**SLOW ELECTRIFICATION +50% demand**
Road: Local and Regional Distribution	45.2	22.8	81.0	39.3	22.8	27.2
Road: Inter-regional distribution	22.0	14.9	58.1	41.4	12.2	16.9
Heavy transport	22.9	21.4	47.9	42.8	66.1	22.3
Road: Rail	28.6	39.9	42.0	48.5	36.3	37.0
Sea: Container vessels	23.9	27.8	24.8	42.6	26.6	27.1
Sea: Tankers & Bulk cargo vessels <10.000 dwt	43.2	44.6	54.5	67.6	66.3	44.4
Sea: Tankers & Bulk cargo vessels >10.000 dwt	62.3	64.7	131.8	134.9	139.2	67.4
Sea: Ro-Ro	13.4	13.5	8.9	14.5	0.4	7.9
Sea: RoPax	26.2	14.2	57.3	37.1	23.2	15.6
Sea: Railway ferries	-10.6	-8.2	18.8	27.1	17.5	3.3

4.3 Impacts on modal split

Compared with the modal distribution pertaining in 2017, shipping's share of total transport work in 2030 and 2040 will increase in almost all the forecasts produced (see Table 25). The largest (1.8 percentage points) is the increase under the SLOW ELECTRIFICATION forecast. The share of rail is expected to increase the most (2.4 percentage points) under the SLOW ELECTRIFICATION + 50% lower demand forecast. In the SLOW ELECTRIFICATION + 50% lower demand forecast, the share of shipping is estimated to be 0.4 percentage points higher than in 2017 and the share of road transport 2.8 percentage points lower.

Table 25: Distribution of transport work in the various model forecasts for 2040 (percentage of transport work)

	2017			2030			2040		
	Road	**Rail**	**Shipping**	**Road**	**Rail**	**Shipping**	**Road**	**Rail**	**Shipping**
Base	47.7	19.3	33.0						
FAST ELECTRIFICATION.				47.9	19.1	32.9	47.9	19.1	32.9
SLOW ELECTRIFICATION				45.2	20.1	34.8	45.2	20.1	34.8
SLOW ELECTRIFICATION + trucks of 74 tonnes							47.8	18.4	33.8
SLOW ELECTRIFICATION + 50% demand							44.9	21.7	33.4

The overall picture is that there are unlikely to be any really significant changes in the distribution of transport work across the various modes of transport. The forecast that makes the biggest difference compared to 2017 is the (main) SLOW ELECTRIFICATION forecast. The introduction of 74-tonne trucks means that the share of rail transport falls and halving the growth in freight transport demand means that the share of road transport falls. However, these outcomes should be interpreted within the context that there are quite strong differences between the forecasts in terms of how the fuel costs for different vehicles are assumed to change by 2040. These results correspond to the finding that, historically, freight modal shares in Sweden have been fairly stable (Takman et al. 2020).

5. Testing the impact of policy instruments for modal transfer

An analysis is now conducted on how the introduction of policy instruments that have the objective of prompting a transfer of freight from road to rail and shipping affect the distribution of freight transport work on the various modes of transport. Similar studies have previously been conducted by Pinchasik et al. (2020) and by Vierth et al. (2019). However, these studies refer to a given year and do not consider how the conditions under which the policy instruments are implemented change over time. Two hypothetical policy instruments are tested, one that reduces transhipment costs for all 16 product groups in all ports and railway terminals (excluding marshalling yards) in Sweden (Ecobonus+), and a ‘wear and tear’ tax for trucks in Sweden. In this way, the effects of a policy instrument that “pulls” freight transport to rail and shipping and a policy instrument that “pushes” freight transport away from road are investigated.

The same types of policy instrument have been analyzed using the Norwegian national freight transport model in Pinchasik et al. (2020), but bulk transports were excluded from the analysis of the ecobonus system. The study by Pinchasik et al. (2020) also examines the effects of railway investments that allow the operation of longer trains in 2030. This is not tested within the FAST ELECTRIFICATION or SLOW ELECTRIFICATION forecasts because railway investments required to be able to operate longer trains are already included in the forecasts for 2030 and 2040. Pinchasik et al. (2020) also examine the effects of a) combining the above-mentioned instruments and b) implementing the instruments also in Denmark and Sweden.

5.1 Specification of the Ecobonus+ policy instrument

This hypothetical policy instrument could be considered an expanded Ecobonus system that favours multimodal rail and sea transport or some form of investment support for more efficient loading and unloading in all of Sweden's more than 250 ports and railway terminals. Ecobonus+ is assumed to provide 30 % lower transhipment costs per loaded/unloaded tonne in all ports and railway terminals in Sweden that are represented in the SAMGODS model. This specification is thus much broader than the current actual ecobonus system which, in the Swedish system, can at most give a reduction of 30 % of the operating costs for a maritime transport scheme or a maximum of 10 % of the cost of purchasing equipment for transhipment to provide the maritime transport scheme (Swedish Parliament, 2018; Swedish Transport Administration, 2020i). Today's ecobonus system is referred to as 'Environmental Compensation' and is provided for measures that lead to goods being moved from road transport on the Swedish road network to sea transport. The compensation is based on the transport work that the transferred goods would have generated if it had instead been transported by truck in Sweden. For the years 2020 to 2022, € 50 million per year has been set aside as the budget for this support tool.

5.2 Specification of the 'Wear and Tear' tax policy instrument

The second hypothetical policy instrument to be tested is a 'Wear and Tear' tax which means that trucks driving on the Swedish road network must pay a tax per kilometer driven, corresponding to the cost of the wear and tear caused. In itself, this is not a direct means of securing a modal transfer but, instead, is a way of getting truck traffic to pay its external costs. The 'Wear and Tear' tax has been set on the basis of the Road Wear Tax Committee's report (SOU 2017) and has been adapted for use in SAMGODS model in accordance with Johansson & Johansson (2018). Furthermore, the 'Wear and Tear' tax has been calculated for the forecast year 2040 at the 2017 price level using Sweden's consumer price index. This results in the tax per truck type presented in Table 26. The smallest trucks in the model are assumed not to cause any wear.

Table 26: 'Wear and Tear' taxes used in testing at 2017 price level €/vehicle-kilometer)

Type of truck	Wear and Tear tax
Neighborhood traffic	0.00
Local distribution	0.01
Regional distribution	0.03
Remote distribution	0.09
Heavy transport	0.14

Source: SOU (2017). Johansson & Johansson (2018)

5.3 The impacts of the 'Ecobonus+' policy instrument

The introduction of an 'Ecobonus+' policy instrument which gives 30 % lower transhipment costs per loaded/unloaded tonne in all Swedish ports and railway terminals is estimated to yield the results with respect to transport work undertaken on Swedish territory as reported in Table 27.

Table 27: Estimated changes in transport work by mode 2017-2040. with 30% lower costs for loading/ unloading in ports and railway terminals (%)

	2017	2040	
	Base	**FAST ELECTRIFICATION**	**SLOW ELECTRIFICATION**
Road	-2.9	-3.0	-2.7
Rail	3.5	3.1	2.1
Shipping	4.5	3.9	3.7
Total	0.7	0.4	0.5

As a consequence of the 'Ecobonus+' policy instrument, transport work by road is estimated to decrease between 2.7% and 3.0% depending on scenario. There are small differences between the estimated effect 2017 and the estimated effect in the forecast year. Shipping is most affected, with transport work increasing between 3.7% and 4.5 %. In this case there are only larger differences between its introduction in the base year 2017 and in the different forecasts 2040. The conditions for moving goods to sea are estimated to be slightly worse in the forecasts 2040 than in 2017. In general, a more detailed analysis of the model calculations indicates that lower transhipment costs primarily benefit container and inland waterway transport. For rail transport, transport work is estimated to increase between 2.1% and 3.5% depending on scenario. The lowest increase for rail is obtained in the SLOW ELECTRIFICATION, while the outcome is forecast to be higher in FAST ELECTRIFICATION and in the base-case year of 2017. One explanation for this may be that in FAST ELECTRIFICATION it is assumed that rail traffic can be made more efficient, corresponding to 10 % lower electricity consumption in 2040. This makes the relative transport cost difference before the instrument is introduced more like the differences in the base-case year of 2017.

It is noteworthy that planned railway investments that are expected to be in place by 2040 and which will, among other things, enable the use of longer trains (a maximum of 750 m instead of the maximum of 630 m today) do not in themselves improve the conditions for moving goods from road to rail. It is also required that rail traffic keep costs at a level that meets the trend towards lower costs that are assumed for road traffic. All of the forecasts include (depending on train type) 50% to 80% higher track charges in 2040 than 2017. In all cases, passenger and freight trains share the tracks and it is not a given that investments in the railway network always lead to more freight trains.

5.4 The impacts of the 'Wear and Tear' Tax policy instrument

As is shown in Table 28,Table 28 the introduction of a tax based on the marginal cost of wear and tear results in a relatively sharp reduction in road transport work in the base-case year and all forecasts. The lowest reduction, 4.3%, is obtained under the SLOW ELECTRIFICATION forecast and the highest reduction, 5.5%, under the FAST ELECTRIFICATION forecast. This difference in outcomes is primarily due to the 'Wear and Tear' tax having a lower percentage impact in the SLOW ELECTRIFICATION forecast, where the truck cost per kilometer is slightly higher than for other forecasts, because the degree of electrification and achieved efficiency is assumed to be lower in the SLOW ELECTRIFICATION forecast.

Table 28: Estimated changes in transport work by mode 2017-2040. with the introduction of a 'Wear and Tear' Tax (%)

	2017	**2040**	
	Base	**FAST ELECTRIFICATION**	**SLOW ELECTRIFICATION**
Road	-5.2	-5.5	-4.3
Rail	5.0	4.4	3.1
Sea	4.4	4.1	3.0
Total	-0.1	-0.5	-0.3

A lower reduction in road transport work leads to a lower increase in transport work for the other modes of freight transport, but the outcome is also affected by the assumptions made regarding future transport costs for rail and sea modes. It is noteworthy, for example, that a 'Wear and Tear' tax results in greater increases in transport work for rail than for shipping. For the 'Ecobonus+' policy instrument the outcome was the opposite. In other words, it appears that maritime transport benefits more than rail transport when the costs of loading and unloading are reduced and rail transport benefits more than maritime transport when the costs of road traffic increase.

5.5 Corollary

As summarised in Table 29, the implementation of a 'Wear and Tear' tax is expected to result in a greater reduction in the share of road transport in transport work and the largest increase in the share of rail transport. For maritime transport, the instruments seem to have a similar effect. The introduction of an 'Ecobonus+' policy instrument is estimated to affect the distribution of transport work on the various modes of transport almost consistently less than the introduction of a 'Wear and Tear' tax. The overall picture is that, despite the relatively large cost changes, the results indicate that there are not very significant changes in modal split. This suggests a certain level of inertia in mode choice decisions because there are often "given solutions" for different transport arrangements.

Table 29. Distribution of transport work by mode in 2017 base-case and in model forecasts for 2040 with Ecobonus+ and Wear and Tear tax

Forecast	Road	Rail	Shipping
BASE 2017	48.4	20.7	30.9
BASE-2017 Ecobonus+	46.7	21.2	32.1
BASE-2017 Wear and Tear tax	46.0	21.7	32.3
FAST ELECTRIFICATION 2040	47.9	19.1	32.9
FAST ELECTRIFICATION 2040 Ecobonus+	46.3	19.6	34.1
FAST ELECTRIFICATION 2040 Wear and Tear tax	45.5	20.1	34.4
SLOW ELECTRIFICATION 2040	45.2	20.1	34.8
SLOW ELECTRIFICATION Ecobonus+	43.7	20.4	35.9
SLOW ELECTRIFICATION Wear and Tear tax	43.3	20.8	35.9

6. Discussion and conclusions

The aim of this paper has been to investigate how policy instruments that have the objective of promoting the transfer of freight transport from road to rail and shipping affect the distribution of transport work by the various modes of transport and how the effectiveness might change in the future. To evaluate the effects several different forecasts, that are anchored in the assumptions about future development that have mainly been sourced from Holmgren et al. (2021) for road, the Swedish Transport Administration (2020g) for railway and IMO (2020, 2021) for shipping, have been constructed. Above all, it was considered important to capture the potential impact on freight modal choice of the likely evolution of shipping operations. Two supplementary forecasts for the year 2040 have been developed whereby: (1) heavier trucks of up to 74 tonnes are permitted to drive on Sweden's and Finland's major roads and (2) the demand for freight transport only increases by half as much as in the Swedish national forecast. Something that could potentially affect the results, is that extensive technology shifts and associated changes in transport costs might change future production and demand structures. The scenarios constructed in this paper reflect the known policy environment and expected technology development at the time of writing, but the concept developed in this paper can be useful in studying impacts of other types of technology shifts and policy packages.

This approach also provides the opportunity to compare several different forecast outcomes. The paper thus reports how the transport work per mode of transport may evolve into the future given different assumptions about the phasing in of new technology and new fuels and how this affects vehicle costs within the different modes of transport. The calculations have been carried out using SAMGODS, the Swedish national freight transport model, i.e., the same model used by the Swedish Transport Administration for the official national freight transport forecasts for 2040. Policy instruments aimed at influencing freight modal choice can then be tested under the various forecasts and for the base for 2017. This makes it possible to investigate the robustness of the estimated policy instrument effects and how different future directions of development influence the ultimate effects of the policy instruments.

The forecasts FAST ELECTRIFICATION and SLOW ELECTRIFICATION assume that all modes can achieve efficiencies by 2030 and 2040. For shipping, an increased use of alternative fuels is also assumed. For road traffic, the forecast FAST ELECTRIFICATION can be seen as a "high alternative" since it assumes a more rapid transition to electric trucks than the forecast SLOW ELECTRIFICATION. In all forecasts it is assumed that the cost of truck diesel will increase due to higher shares of renewables in the fuel mix. Two extensions have been made to the forecast SLOW ELECTRIFICATION, one that includes the possibility of using heavier trucks (max. 74 tonnes instead of 64 tonnes) on Swedish and Finnish roads, and one where the growth rate of freight transport demand is halved.

The forecasts FAST ELECTRIFICATION and SLOW ELECTRIFICATION estimate that transport work will increase by 31% to 53% between 2017 and 2040; the increase is generally largest for maritime transport, second largest for road transport and smallest for rail transport. An important explanation for shipping's increased share of transport work in 2040 is the much greater demand for international and bulk transport (cargoes that are mostly carried by sea) and not because of any improvement in shipping's competitiveness vis-à-vis other modes of transport. This gives rise to an interesting avenue for further research in determining how alternative assumptions about the volume and structure of demand affect the distribution of transport work among the various modes of transport.

Two instruments to promote a change in modal choice have been analysed; the introduction of an "Ecobonus+" system that reduces transhipment costs in Swedish ports and railway terminals by 30%, and a ‘Wear and Tear’ tax for trucks on the Swedish road network of up to € 0.14 per vehicle-kilometer (depending on the size of the truck). Both instruments make it more attractive to use rail and shipping. The effects of the instruments have been studied both in the base situation (2017) and in the forecasts FAST ELECTRIFICATION and SLOW ELECTRIFICATION for 2040. Under all forecasts, both these instruments are estimated to lead to the expected effects when it comes to the transfer of transport work from road to rail and shipping. Although the implementation of these policy instruments was motivated on the basis of national climate objectives, it is important to recognise that freight transport gives rise to other non-internalized externalities and that the transfer of freight transport from road to rail and shipping can be important for other objectives; the aim of the ‘Wear and Tear’ tax for heavy trucks is, for example, to internalize infrastructure costs. The shift from road to rail and shipping also leads, *ceteris paribus,* to less congestion, lower noise and fewer traffic accidents, all of which have a positive impact on any social cost-benefit analysis.

In terms of further research possibilities, the outcomes of the analysis reported in this paper with respect to forecasts of total transport work and its modal distribution (especially when disaggregated across vehicle/ship types) could form the basis for a supplementary analysis of the environmental implications of the forecasts and what this means for the achievement of Sweden’s environmental quality objectives. It would also be both interesting and useful to investigate how alternative directions of development for trade in goods could affect both total transport work and future modal split, particularly the shipping sector’s use of Swedish ports. For instance, although this paper has applied the simple approach of testing a forecast where freight transport demand is half that of the official forecast for 2040, it would be interesting to also test specific changes in product composition and the regional distribution over the Swedish imports and exports. Finally, as suggested by Feo et al. (2011), a full social cost-benefit analysis aimed at comparing the effect that these policy options have on overall social welfare would not only further inform government policy, but would also shed greater light on the wider, less direct effects of such policy instruments, beyond the modal shift they may cause.

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