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An ex-ante analysis of transport impacts of a distance-based heavy goods vehicle charge in the Netherlands

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ABSTRACT

In 2017, the newly installed Dutch government announced in its coalition agreement to introduce a distance-based heavy goods vehicle charge, similar to the charges levied in other European countries. To study the possible transport impacts, we applied available models and methods in preparation for the introduction of this truck charge in the Netherlands in 2023, in order to present decision information to the government on different aspects of the charge. In this paper we present the analysis of different implementation scenarios for a distance-based truck charge. Different behavioural responses can be expected in terms of freight transport demand, mode choice, logistic efficiency, and route choice. Many studies however lack sufficient detail to properly describe the impact of road charges for HGV on OD flows and freight traffic. In our contribution we explore the bandwidth of impacts of different pricing schemes, using strategic transport models for freight demand and traffic assignment, with detailed modal split and route choice models, ensuring a proper representation of generalsed transport costs. We explain how we use available transport models in an overarching analytical framework to make a comprehensive impact assessment of the different responses, and to decompose the impacts on the different responses. Final impacts are quantified in terms of freight demand (spatial pattern of transport flows), modal split and traffic flows (route choice, and congestion).

Depending on the pricing scenario the tonne kilometres decrease by 0.4%–4.8% on average. The modal shift impacts are stronger on longer transport distances: this is explained both by the larger impact of a distance-based charge on these routes, and by higher substitution possibilities to barge or rail. The results indicate that the overall impacts of the introduction of the different charging alternatives are moderate. However, the network impacts at local level can be substantial due to the impact of re-routing of truck trips to avoid charge.

1. Introduction

In 2017, the newly installed Dutch government announced in its coalition agreement that in 2023 in would introduce a distance-based heavy goods vehicle charge (HGVC), similar to the charges levied in neighbouring countries. In the preparation of the draft bill, the ministry of transport is evaluating different policy configurations for the charging network and the tariffs. The key question that should be answered is what will be the impacts of the charge? This can be measured ex-post in countries where a form of heavy goods vehicle charge has been already implemented, or it can be simulated using a transport demand model. Ex-ante studies predict impacts for all steps of the traditional Four-Step models: on the trip generation as a result of an enhanced logistic and transport efficiency, on trip distribution/distribution of transfer points/origins and destinations of freight transport, on mode choice of freight transport and on route choice through the road network. Studies that collect ex-post evidence of impacts after introduction of the charge are scarce and are often inconclusive: exact impact measurement is difficult because the impacts of the charge that was introduced always coincided with other relevant developments, such as changes in taxation policies,

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economic growth or changes in fuel price.

To study the possible transport impacts of the policy options that are considered for The Netherlands, we applied detailed freight transport and traffic assignment models in preparation for the introduction of this truck charge in 2023. Francke and Tillema (2018) describe how different behavioural responses can be expected: on freight transport demand, mode choice, logistic efficiency and route choice. In a recent review of empirical studies, Gomez and Vassallo (2020) emphasise the need for more detailed analyses to properly study the impact of road charges for HGV. In our contribution, we explore the bandwidth of impacts of different pricing schemes, using strategic transport demand models, with detailed modal split and route choice models, ensuring a proper representation of generalized transport costs. In particular for the context of the NL the analysis of modal split impacts is crucial since given the availability of a dense network of waterways and rail connections, there might be more substitution towards rail or barge transport. The analysis also incorporates route choice on a detailed road traffic network, to be able to study the impacts of traffic diversion.

In this paper we present the analysis of different implementation scenarios for a distance-based truck charge that vary with the level of the charging fee and the road network on which the HGVC applies. In order to support informed decision making, the likely impacts from different configurations of the HGVC are required: a bandwidth of likely impacts of realistic policy schemes is presented. The usage of the transport demand models allow a decomposition of the impacts on trade patterns, modal split, vehicle type use, and route choice. In this article, we explain how we use available transport models in a broad analytical framework to make a comprehensive impact assessment of the different responses, and to decompose the impacts on the different responses. Final impacts are quantified in terms of freight demand (spatial pattern of transport flows), transport efficiency, modal split and traffic flows (route choice and congestion).

2. Literature review

Heavy goods vehicles (HGVs) are responsible for approximately 25% of the CO2 emissions from road transport (T&E, 2016). Vehicle charging is an important instrument for policy makers, with the prime objective to charge the users of transport infrastructures. The concept to charge users of transport infrastructures was first introduced in Europe in the Green Paper on fair and efficient pricing (European Commission, 1995) and the White Paper on Infrastructure charging (European Commission, 1998). This led to the introduction of the Eurovignette, a fixed charge for HGVs. However, distance-based road charging systems, where users are charged by the kilometres driven, create a bigger incentive to improve logistic efficiency and to reduce the externalities from HGVs. These measures ensure that vehicles are charged according to actual road use and the pollution they generate. The advantage of the latter measure over vignettes is that it is usage based while the latter purchases access based on time, such as a year. In 1999 the road charging Directive 1999/62/CE was approved (European Parliament and the Council of the EU, 1999). This directive promotes the harmonisation of distance-based tolls in specified sections of the non-privatised network, particularly focused on heavy goods vehicles (HGVs). It is based upon the principle that the user pays and allows for charging trucks based upon characteristics such as the mileage driven and allows for differentiation based upon vehicle categories, emissions and so on. standards, etc.

Since then, a number of countries have introduced or are introducing a form of distance-based charging for HGVs. Often these measures are aimed at modal shift to rail or inland waterways, cleaner vehicles or more logistic efficiency. Switzerland introduced an electronically collected, distance dependent road toll for heavy goods traffic, the LSVA system, in 2001. All freight vehicles with a maximum total laden weight of 3.5t or greater are subject to this fee on the public road network of the Swiss Confederation and the Principality of Lichtenstein. The main reason for this measure was the high heavy traffic levels that Switzerland has to bear given its geographical position in Europe and the Alpine zone. Germany introduced the Lkw-Maut in 2005 (Doll et al., 2006). It replaced the Eurovignette- System and was designed as a toll for freight vehicles based on the number of kilometers driven, number of axles and the emissions category for heavy trucks, at that time of more than 12 tons. Other countries like Austria, the Czech Republic, Belgium and Poland have introduced a form of distance-based road charging as well. Some countries, such as Spain, France and Portugal were already applying concession tolls in parts of their networks to fund the construction and maintenance of highways. Hence there was much less need to implement new tolling policies: in France an attempt to introduce a heavy vehicle charge was not successful.

It is difficult to measure the impacts of the introduction of these distance-based charges. Vierth and Schleussner (2012) made an ex-post analysis of the impacts of the German Maut: there were relatively more trucks in the clean Euro classes IV and V and a relatively larger number of kilometers were driven in those vehicles. But the shift to cleaner vehicles could not only be attributed to the Maut, because the policy was accompanied by a compensation program for the purchase of trucks in Euro Class V. Broaddus and Gertz (2008) concluded that road traffic reduction and modal shift to rail was achieved only to a minor extent. Doll and Schaffer (2007) found that there were neither undesirable price effects nor positive effects on employment related to the Maut. In a recent overview Gomez and Vassallo (2020) concluded that the findings of analyses on the effects of these measures on road freight demand and on competing modes are generally similar across reports: effects in modal share are relatively small after the implementation of HGVs tolling. Some effects were found on truck demand, especially on motorways. Hence, these authors conclude that road freight demand follows a rather inelastic behaviour, related to lack of alternatives. This implies that truck tolling could be seen as an efficient tool to collect funds for the public budget without greatly affecting the current modal share. Current toll rates are showing a limited effect on demand.

To get more insight into the expected impacts of possible policy alternatives, many studies make use of strategic transport models or elasticities. Kleist and Doll (2005) and Doll and Link (2007) use the ASTRA model to analyse the economic impacts of an HGV charge. Raha et al. (2003a, 2003b) apply the SCENES model to study the impact of a road pricing measure in which the external costs caused by trucks are internalized. Safirova et al. (2007) uses the LUSTRE model for a case study in the US. Christidis and Brons (2009) use Transtools to study the impacts of charging policies on European corridors. Vassallo and López (2010) use input-output tables to estimate the effect of charging heavy goods vehicles in Spain. In Significance and Delft (2010) and T&E (2010) price elasticities are used to analyse the impacts of a HGV charge in Europe. In general, strategic freight models, or elasticities are common tools to provide a quantitative forecasts and make impact assessment of policies.

The heavy goods vehicle charge for the Netherlands will also include a differentiation in the charging fees across emission (EURO) classes and maximum permitted mass. Because of lack of detail in the modelling framework, impacts of a differentiated charge on vehicle type choice could not be simulated. However, recent empirical studies that analysed the impact of an emission based differentiation of the charge, showed that it will not lead to significant shifts in vehicle type choice or shipment size (de Bok et al., 2020).

Gomez and Vassallo (2020) formulate a number of challenges for future research. One of these is that a greater level of detail should be introduced in the analysis when describing freight traffic: analysing OD flows is required instead of studying freight demand at the macro (national) level. They argue that this would help to explore in greater detail the route choice effects in cross-border traffic of implementation of these policies in neighbouring countries. In addition, effects of these policies on traffic diversion over networks may require additional detailed attention to specific parts of the networks. Additional focus points for study are the effects on spatial interaction and effects on modes for passenger transport, such as traffic delays, modal split in passenger transport and so on. It is this gap in knowledge that this paper attempts to address, by using an analytical framework of multi modal transport models, and a detailed traffic assignment including the interaction with passenger transport, to make a comprehensive analysis of transport impacts of a distance-based HGV charge.

3. Introduction of distance-based truck charges in the Netherlands

3.1. Introducing a heavy goods vehicle charge in the Netherlands

The Dutch government agreed on introducing a Heavy Goods Vehicle Charge (HGVC), similar to neighbouring countries of the Netherlands. The main goal of the charge is for domestic and foreign HGVs to pay according to use. This could reduce harmful emissions, by limiting the increase in the volume of goods transported by road and to increase the modal shares of inland waterways and rail. The kilometers travelled by each HGV on the charging network will be registered by an on-board unit. The tariff amount depends on the maximum permitted mass and emission class of the HGV.

By introducing the charge, the government makes domestic and foreign HGVs pay for the use of roads by a variable tax instead of a flat tax. The vehicle tax on HGVs will be lowered at the same time. The net revenue of the charge will return to the sector as an incentive for innovation and sustainability. The charge will thus contribute to achieve a smart and sustainable transport system.

Requirements for the charging system are to implement in time, a reliable charging system that is cost-efficient, manageable, flexible and user-friendly. The system should lead to as few undesirable effects as possible on road safety and the international competitive position of The Netherlands.

3.2. Different scenarios for the heavy goods vehicle charge

In our study we examined the effects of different levels of the charging fee and different configurations on where the HGVC applies (which road type?). The result of the studies are the basis for the government to decide on the charging fee and charging network in the draft bill.

In all policy alternatives the charge applies to vehicles intended for the transport of goods with a maximum permitted mass exceeding 3500 kg, as in other European countries (except for Germany). Charges include trailer-towing vehicles with a maximum permitted mass of less than 3500 kg. In addition a limited number of vehicle categories will be excluded from the charge, for example vehicles used by branches of the armed forces, police and fire departments or vehicles that are exclusively used for refuse collection, drain suction or street cleaning.

Initially in this study the charge is implemented on the entire road network (TWN) and the average charge is varied. The charge will have some variation across vehicle types and Euro class, but this distinction cannot be made in the freight- and traffic assignment model. Therefore we applied an average distance charge. The maximum average charging fee is € 0.29 per kilometer; the medium average charging fee is € 0.15 per kilometer and the lowest mean tariff applied is € 0.05 per kilometer. The average fee was chosen to correspond to the average level of the fee in other European countries.

In addition, network alternatives were studied in which the charging fee is only applied to the highways (ASW). The choice of the charging network in these alternatives is similar to the network that is applied in Belgium. Again three different tariffs are applied: the maximum average charging fee is € 0.29; the medium average charging fee is € 0.15 and the low average charging fee is € 0.05. These network alternatives showed that many heavy vehicle goods vehicles will re-route to the secondary road network (ASW+). To limit these rerouting impacts, in an additional variant a selection of high level secondary roads are added to the charging network, with a tariff of € 0.15 per kilometer. This study focusses on the 7 alternatives as presented in Table 1.

The 7 alternatives were calculated, analysed and published (Muconsult, 4Cast, Significance; 2018). The Dutch Minister of Infrastructure and Water management decided on the charging network alternative Highways (ASW), with in addition a specific set of secondary roads to prevent negative effects of the rerouting of heavy vehicles. To configure the selection high level secondary roads to the charging network, a series of interactive workshops were organised with representatives of the national, regional and local road authorities and the transport sector. Here, traffic assignment results were shared and discussed in order to optimize the configuration of the charging network to limit the negative effects of the rerouting of heavy goods vehicles. This process leads to an extensively motivated proposal for the charging network to the Ministry.

4. Analytical modelling framework

To provide insight into the impacts of the different policy scenarios, the impacts are studied in an approach that takes into account the different responses that can be expected in the transport sector. The analytical approach is designed to fit with the conceptual framework developed by the KiM Netherlands Institute for Transport Policy Analysis (Francke & Tillema, 2018). This framework distinguishes possible responses by different agents. Carriers can change their route choice and avoid a road charge. Alternatively, they can optimize the logistic efficiency, by improving the load per vehicle, reduce empty running or change to a more cost-efficient vehicle type. Even shipment size or frequency of deliveries can change, but this decision is taken not only by the carrier but predominantly by the shipper. Shippers have the possibility to choose a different transport mode or logistic chain. This may include a change in distribution channel. And finally, the receivers of the goods can decide to buy their products from a production location with lower transport costs (producer selection or sourcing choice).

Some of these responses can be estimated in conventional strategic freight models, but there is not one tool available that predicts all these impacts together. Therefore we use a combination of available transport models and methods in a broad analytical framework to make a comprehensive impact assessment. This combined approach also allows us to investigate the impacts of the choices that are made at different levels of the transport sector.

A conventional strategic model for freight transport for the Netherlands, called 'BasGoed', is used to simulate impacts on freight transport demand (producer selection) and mode choice. An elasticity is used to predict the impact of increased transport costs on logistic efficiency. And finally, route choice is simulated in the National Transport Model 'LMS'. Fig. 1 describes the building blocks of the approach. The freight transport model uses the transport time and distances under the road charge conditions as input to calculate the generalized transport costs. This is simulated iteratively to incorporate the impact of the changes in route choice on the freight demand. Each building block in this framework is described in the next paragraphs.

4.1. Strategic freight transport model BasGoed

BasGoed was developed over the past years as a model for freight

Table 1
Overview of analysed charging alternatives in this study.

	High rate	Medium rate	Low Rate
Total network (TWN)	€ 0.42	€ 0.15	€ 0.05
Highway network (ASW)	€ 0.29	€ 0.15	€ 0.15
Highway network + main secondary roads (ASW+)		€ 0.15	

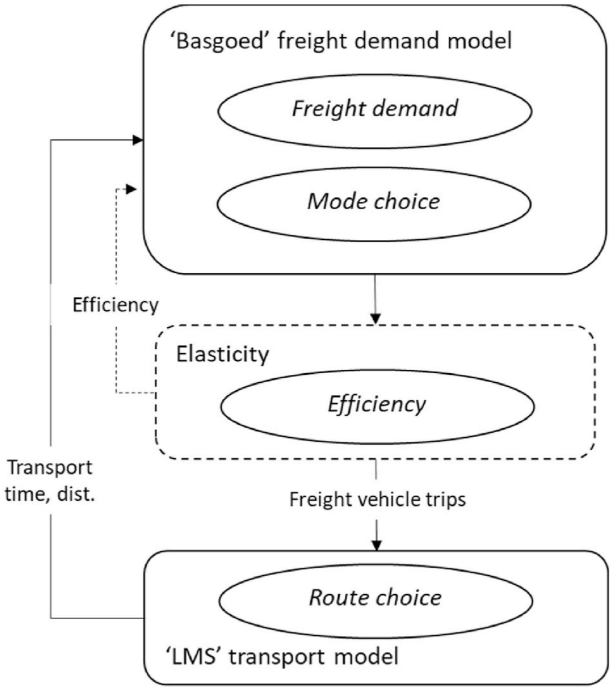

Fig. 1. Analytical framework applied in this study.

transport in the Netherlands, satisfying the basic needs for policy making, based on available knowledge and transport data. The design principles were described in Tavasszy et al. (2010) and the empirical specifications are provided in De Jong et al. (2011). The model uses available transport statistics for The Netherlands, scenarios for economic development and detailed infrastructure networks that describe the accessibility of Dutch regions and the hinterland, as inputs. It has a modular structure following the generic four-step modelling approach (see Ortúzar & Willumsen, 2011), including an additional module for maritime freight forecasts:

1. Economy Module: this module generates freight transport demand, depicting the relation between economy and transport as well as the generation of the yearly volumes (weight) of freight produced and consumed;
2. Distribution Module: predicts the freight transport flows between these regions;
3. Modal Split Module: predicts the market shares of each transport mode (road, rail and inland waterways), resulting in the freight transport flows between regions by mode;
4. Vehicle module: converts the road freight forecasts from tons into vehicle forecasts for network assignment.
5. Maritime Module: predicts a forecast of maritime freight transport flows to and from the deep sea ports in The Netherlands.

The economic module of BasGoed is based on the original SMILE + module for freight generation (see Bovenkerk, 2005; Tavasszy et al., 1998). This module follows the input-output framework and translates economic growth scenarios by industry sector into regional forecasts for the production and consumption of commodities (domestic and import/export). The geographical level of detail comprises 40 regions within The Netherlands (NUTS3) and 37 in the rest of the world. Input to this module are scenarios for the distribution of employment and population by region and international trade scenarios. International trade flows which have no origin or destination in the Netherlands are not directly related to the I/O framework of The Netherlands, but these flows could transit through The Netherlands, e.g. from the UK to Germany. These transit tables are calculated by the economic module based on the calculated export to the corresponding regions.

The second step of the model is the distribution model that generates origin-destination-commodity (OD-commodity) flows in tons, based on a double constrained gravity model. In the next step, the modal split model, the market share of road, rail and inland waterways is predicted for each OD-pair using a multinomial logit choice model. Both models, the distribution- and modal split models, use transport costs and times between regions as input. The logsum of generalized transport costs over all modes (road, rail and IWW) are used as the generalized transport costs in the distribution model. This means that the increase in road freight transport cost, will also lead to an increase in the generalized transport costs summed over all modes (road-, rail and inland waterway). Therefore, the road vehicle charge will not only affect the modal split, but also the generalized transport costs between regions and the spatial distribution of freight transport. This will lead to trade patterns with shorter average transport distances. For the derivation of the distribution and modal split modules see De Jong et al. (2011). The commodity classification used is NSTR-level1 (10 commodity groups).

The vehicle module converts the road freight forecasts into a vehicle forecast. Exogenous models are used for the assignment of freight traffic flows to infrastructure networks. For road freight traffic assignment the National Model System from the Dutch Highway and Waterway Authority (Rijkswaterstaat) is used. For rail the Nemo model is used, which is owned by the Dutch railway infrastructure provider ProRail. Finally, for inland waterways the BIVAS waterway network simulation model is used, which is owned by the Dutch Highway and Waterway Authority (Rijkswaterstaat). For prediction purposes, BasGoed uses a growth factor method (or pivot point method) in which the calculated growth factors are applied to the observed vehicle, ship- and train matrices which serve as input for the detailed assignment models.

4.2. *Transport efficiency impacts*

Transport efficiency impacts of the HGVC are responses from the shippers and carriers to improve the load factor of vehicles, by improving consolidation of shipments or optimizing shipment size. There is no empirical logistic model for the freight sector in the Netherlands, that is able to simulate these decisions under different policy scenarios. As an alternative we applied an elasticity for transport efficiency from literature. In a literature review, Significance and Delft (2010) provide an overview of price elasticities for road freight transport. The heavy goods vehicle charge in The Netherlands is designed as a distance-based vehicle charge, so we used the elasticity of vehicle kilometer costs. Significance and Delft (2010) distinguish three effects in the total impacts: changes in mode (−0.3), changes in transport demand (−0.3) and changes in transport efficiency (−0.3).

In our framework we use the elasticity of vehicle kilometer costs on transport efficiency of −0.3, which implies that vehicle kilometres decrease with increasing vehicle kilometer costs. The demand and mode choice effects are simulated with BasGoed, as explained before. There is no possibility to distinguish the transport efficiency effects into specific responses, e.g. consolidation or optimization in shipment size choice.

4.3. *Route choice*

The impacts at the network level were determined using the National Model System (LMS) from the Dutch Highway and Waterway Authority (Rijkswaterstaat). The LMS is a disaggregate multi-modal traffic model focusing on passenger traffic but also including road freight, that is used in the Netherlands for making long term mobility forecast.

One of the components of the LMS is a specially designed quasi-dynamic multi-user assignment, which assigns cars (in user classes: commuting, business and other) and freight vehicles iteratively onto the network. Within each iteration the car and freight trips are loaded onto the shortest path and the flows are mixed with the results of former iterations. The criterion for finding the shortest path is based on generalized costs which is composed of the total travel time (free flow, delay and queuing) and travel cost. The travel cost consists of the costs for fuel and toll. The costs for fuel per kilometer is higher for freight vehicles than for cars and higher on the non-highways than on the highways. The higher cost on the non-highways makes it less attractive for both cars and freight vehicles to divert from the main to the more local roads.

For studying the impacts on the network level, for each variant, the external freight matrices of the LMS were split into trips excluded from the charge (maximum permitted mass of less than 3.500 kg) and freight trips that will be charged. The number of user classes in the multi-user traffic assignment was extended to take account of the difference in route choice between charged and non-charged freight trips. The charge was added as an extra toll cost on the sections that are part of the road network on which the HGVC applies.

5. Results

We first present the overall impacts of the heavy goods vehicle charge alternatives. Next, we discuss the magnitude of different responses behind these impacts: demand, mode choice, transport efficiency and route choice.

5.1. Overall impact

The following Table shows the overall impacts of the policy alternatives that are studied. Alternatives vary by charging level (5, 15 or 29 € ct/km) and location: full network (TWN), dedicated highway charge (ASW), and a charge on highways and high level secondary roads (ASW+). The impacts are predicted in a business as usual reference case (BAU) for 2030, under two demographic and macro-economic scenarios: High, with strong economic growth, and Low with moderate economic growth.

The introduction of a kilometer charge on the entire network (TWN) leads to a reduction of 0.2%–2.1% tons lifted by road transport, depending on the level of the charge. As the total freight tonnes lifted remain constant, the reduction of tonnes lifted in road freight transport is the result of a modal shift from road transport to rail or inland waterway transport. The tonne-kilometres reduce by 0.6%–4.8%. The impacts on tonne-kilometres are larger than the impacts on tons lifted because the increase in transport costs also leads to decrease in average transport distance and a stronger reduction on tonnes lifted can be seen on longer distances. In the scenarios where the charge is introduced on highways only (ASW), the tons lifted by road transport decrease by 0.1%–1.2%. The tonne-kilometres decrease by 0.4%–3.2%. When the charging network is extended from highways to high level secondary roads, the impacts of the medium charge of 15 cents per kilometer, increase slightly from 0.6% to 0.7%.

The total impact on vehicle kilometres for HGV, after logistic efficiency and route choice impacts, varies between 1.2% in the scenario with a charge of 5 cents per kilometer on highways, and 11.6% in the alternative with 29 cent per kilometer on the entire network. The T&E (2010) study reports an expected reduction of road freight vehicle kilometres by 15% from a 15 cent charge on the European network. In our study we found a much smaller impact of 4.5% in the most similar scenario: TWN, 15 ct per kilometer. The most important explanation for this, is that here we study the impacts of a charge on the Dutch network only. Most HGV vehicle kilometres are produced on long haul transport, of which a large part is not affected by the Dutch charge; the T&E (2010) study calculated the impact of an introduction of a distance-based charge on the entire network across all EU member states.

The different charging network alternatives do not have a dominant impact on the tonnes lifted and tonne kms. If the decrease in freight demand of the medium charge of 15 ct/km are compared for the entire network (TWN), the highway alternative (ASW), or the extended highway alternative (ASW+), the results are in a similar range: 0.7%, 0.6% and 0.7% respectively for tonnes lifted, and 1.9%, 1.8% and 1.9% for tonnes-kilometres. This can be explained by the fact that most of the impacts on modal shift and reduction on transport distance take place at longer transport distances: first of all because of the higher importance of distance-based costs on these transports, and secondly because of the higher substitution possibilities to alternative modes (rail or inland waterways). This will be further analysed in the following sections. Moreover, since long haul road transports mainly use the highway infrastructure, the differences in the impacts on tons lifted and tonne kms between the network alternatives are modest.

In both economic scenarios, the impacts are very similar: the reductions of road freight transport are slightly lower in the Low scenario. The reference levels in both scenarios are not far apart, however road freight volumes are smaller in the low economic scenario, and the average transport distance is smaller: 154.7 km in Low and 164.1 km in High.

5.2. Impacts on demand

The main behavioural response that we can simulate as part of freight transport demand, is the selection of a producer by the consumer. The increase in transport costs is likely to lead to a reduction of transport distances: consumers choose to source their commodities from more nearby. The overall impacts already show that the total volume of road freight transport decreases and the average transport distances decrease simultaneously. The tonne-kilometres reduce by 1.9%, while tonnes lifted only reduce by 0.7%. This can also be referred to as redistributive impacts: the pattern of freight flows changes, and becomes more concentrated. This reduction in average transport distances was also observed after the introduction of the German MAUT: before introduction the average distance travelled per tonne freight was increasing by 3% per year, and after introduction in 2005 the average transport distances decreased by 0,5% (Significance & Delft, 2010).

To better understand and verify these redistributive impacts, we analysed the freight demand between aggregate 'super-regions' where we aggregate the Netherlands to 4 parts (north, south, east and west), and the international zones to three super-regions for Germany, Belgium, and other continental destinations.

For one of the alternatives with a dedicated highway charge of 15 ct/km these redistributive impacts are visualized in Table 3. It is clearly visible that road freight demand reduces for longer transport corridors: e.g. from the North to the South region. And the reduction in transport distances also leads to a slight increase in intra-regional freight demand. This confirms that transport patterns become more concentrated when transport costs increase.

5.3. Impacts on mode choice

Substitution between transport modes is an important response that is expected to result from the heavy vehicle road charge: transport demand will shift from road to alternative modes with lower transport costs, such as rail or inland waterways. This shift depends on availability of alternative modes, and the changes in generalized costs for each mode, and is simulated in the modal split module in BasGoed (see Section 4.1).

Table 4 shows the impacts on modal split in the different highway network alternatives, in the high and low economic growth scenarios, and by each commodity type. The table shows that most substitution takes place from road transport to inland waterways: road freight transport demand decreases by 0.6% in alternative with a 15 cent charge on highways and main secondary roads (ASW+).

Most substitution takes place in favour of inland waterway transport: the total increase in freight demand for inland waterways varies between 0.4% and 3.3%. The larger shift to inland waterways can be explained by the denser network of inland waterways in The Netherlands, in comparison to the available rail connections. Previous

Table 2

Overall impacts of the heavy goods vehicle charges on road freight transport.

Policy scenario		Tonnes lifted (kTon)	Tonnekms (MTkm)	Vkms with efficiency (Mvtgkm)	HGV Vkms with route choice (kvtgkm)	Average transport distance (km)	Average vehicle kms (km)
Baseyear	2014 (abs.)	939,557	137,209	5635		146.0	45.0
High 2030	BAU (abs.)	1,119,531	183,732	6528	26,357	164.1	44.2
	5 ct TWN	−0.2%	−0.6%	−0.7%	**−1.5%**	163.4	43.9
	15 ct TWN	−0.7%	−1.9%	−2.6%	**−4.6%**	162.1	43.2
	29 ct TWN	−2.1%	−4.8%	−7.2%	**−11.6%**	159.6	41.3
	5 ct ASW	−0.2%	−0.6%	−0.6%	**−1.5%**	163.5	44.0
	15 ct ASW	−0.6%	−1.8%	−2.1%	**−4.5%**	162.2	43.3
	15 ct ASW+	−0.7%	−1.9%	−2.4%	**−4.7%**	162.2	43.2
	29 ct ASW	−1.2%	−3.2%	−4.3%	**−8.3%**	160.8	42.5
Low 2030	BAU (abs.)	975,922	151,003	5805	23,681	154.7	43.6
	5 ct TWN	−0.2%	−0.5%	−0.6%	**−1.2%**	154.3	43.4
	15 ct TWN	−0.7%	−1.7%	−2.4%	**−3.9%**	153.0	42.6
	29 ct TWN	−1.8%	−4.6%	−6.7%	**−10.1%**	150.2	40.9
	5 ct ASW	−0.1%	−0.4%	−0.5%	**−1.2%**	154.3	43.4
	15 ct ASW	−0.6%	−1.6%	−2.0%	**−4.0%**	153.2	42.8
	15 ct ASW+	−0.6%	−1.6%	−2.2%	**−4.1%**	153.1	42.7
	29 ct ASW	−1.1%	−3.0%	−3.9%	**−7.3%**	151.7	42.0

Table 3

Redistributive impacts on road freight demand between super-regions in the 15 ct ASW scenario (2030 High).

Tonnes lifted	to							Total
	North	East	West	South	Germany	BLG/LUX	Other EU	
from								
North	1.0%	−0.1%	−6.2%	−11.8%	−0.2%	−7.9%	−3.3%	−0.4%
East	−0.6%	0.3%	−1.6%	−1.7%	0.2%	−2.8%	−1.9%	−0.3%
West	−4.9%	−2.2%	0.3%	−2.3%	−4.8%	−1.4%	−2.0%	−0.6%
South	−10.6%	−1.6%	−2.1%	0.2%	−0.2%	0.7%	0.2%	−0.4%
Germany	−1.4%	−0.3%	−3.6%	−1.4%	−0.4%	−0.6%	−0.1%	−1.4%
BLG/LUX	−13.1%	−4.6%	−2.3%	0.1%	−0.5%	0.0%	−0.1%	−1.6%
Other EU	−5.9%	−3.1%	−1.6%	−1.7%	−0.3%	−0.1%	0.0%	−1.6%
Total	−0.6%	−0.5%	−0.5%	−0.6%	−1.5%	−0.7%	−1.0%	−0.6%

studies also found a relatively minor modal shift to rail (Broaddus & Gertz, 2008; Gomez & Vassallo, 2020). The analysis using the freight transport demand model show that in the Dutch context, more modal shift can be expected as a result of the availability of inland waterway network.

The largest modal shift takes place in dry- and wet bulk commodities: oil products, coals, minerals. This result can be explained because of the higher cost sensitivity of these products. The forecast takes into account the higher cost sensitivity and predicts stronger substitution for these commodity types.

5.4. *Impact on transport efficiency*

The cost increase will also have an impact on transport efficiency: in order to increase the cost efficiency of road transport the load factor of vehicles can be improved. This can be done by improving consolidation of shipments, optimizing shipment size, or by reducing empty return trips. BasGoed provides a forecast of road freight vehicle movements, taking into consideration the impacts on demand and mode choice, but without changing the transport efficiency. To simulate the impact of more efficient use of vehicles, as explained in Section 4.2, this response is simulated by applying an elasticity from literature. The efficiency elasticity is applied on the relative cost increase and vehicle kilometers predicted on each OD-pair.

The impact of transport efficiency is also presented in Table 2: the impacts on vehicle kilometers predicted by BasGoed, and on vehicle kilometres with efficiency improvements can be compared to see the added effect of logistic efficiency. In the 15 ct/km charge on the highway network (ASW), the reduction in vehicle kilometres increases from 1.4% to 2.1%. This is a significant part of the overall impact. The order of magnitude of this impact compared to the demand and modal shift impact is also comparable to the generalized results presented in Significance and Delft (2010).

The logistic efficiency assumes better use of vehicles, and less vehicle kilometres for each tonne transported. This results in a stronger decrease in vehicle kilometres and is therefore an important element for the assessment of policy impacts. The applied approach using an external elasticity to predict this additional impact also has an important limitation: it cannot be further specified what is the exact nature of this efficiency gain: e.g. improved consolidation, better planning, less empty running. To better understand the possibilities for logistic efficiency improvement, logistic choice models are required.

5.5. *Impacts on route choice*

The individual trips (outputs of Basgoed) are used as input to a traffic

Table 4
Impacts on modal split by commodity type in the highway network alternatives (Tonnes lifted, kTon).

		2014 (abs.)	High 2030					Low 2030				
			BAU (abs.)	5 ct ASW	15 ct ASW	15 ct ASW+	29 ct ASW	BAU (abs.)	5 ct ASW	15 ct ASW	15 ct ASW+	29 ct ASW
	Road											
0	Agricultural products	80,579	93,920	−0.1%	−0.3%	−0.3%	−0.6%	83,412	−0.1%	−0.3%	−0.3%	−0.6%
1	Foodstuffs	137,309	164,260	−0.2%	−0.6%	−0.6%	−1.2%	140,818	−0.2%	−0.6%	−0.6%	−1.1%
2	Solid mineral fuels	2827	3517	−1.2%	−2.5%	−2.9%	−4.6%	2911	−0.5%	−2.2%	−2.6%	−4.3%
3	Petroleum products	21,044	27,658	−1.1%	−4.5%	−5.3%	−8.7%	21,347	−0.9%	−3.9%	−4.6%	−7.4%
4	Ores and metal waste	6304	7660	−0.9%	−3.2%	−3.6%	−6.2%	6540	−0.8%	−2.9%	−3.3%	−5.7%
5	Metal products	25,832	33,814	−0.1%	−0.5%	−0.5%	−1.0%	30,189	−0.1%	−0.5%	−0.5%	−0.9%
6	Minerals, building materials	170,102	184,669	−0.5%	−1.8%	−2.0%	−3.5%	156,914	−0.4%	−1.6%	−1.8%	−3.1%
7	Fertilizers	39,864	46,567	0.0%	−0.2%	−0.2%	−0.4%	38,719	0.0%	−0.2%	−0.2%	−0.3%
8	Chemicals	88,083	108,033	−0.1%	−0.4%	−0.3%	−0.7%	87,738	−0.1%	−0.3%	−0.3%	−0.6%
9	Machinery, other	367,613	449,432	0.0%	0.0%	0.0%	−0.1%	407,335	0.0%	−0.1%	−0.1%	−0.2%
	Total	939,557	1,119,531	−0.2%	−0.6%	−0.7%	−1.2%	975,922	−0.1%	−0.6%	−0.6%	−1.1%
	Rail	–	–					–				
0	Agricultural products	283	385	0.6%	3.2%	3.7%	7.4%	333	0.6%	2.7%	3.2%	5.6%
1	Foodstuffs	227	372	1.3%	5.4%	6.3%	11.5%	345	1.9%	8.3%	9.3%	17.2%
2	Solid mineral fuels	9020	14,192	0.1%	0.2%	0.2%	0.3%	12,413	0.0%	0.1%	0.2%	0.3%
3	Petroleum products	1331	1871	0.4%	1.5%	1.8%	2.9%	1561	0.3%	1.0%	1.3%	1.9%
4	Ores and metal waste	6355	6140	0.1%	0.4%	0.4%	0.6%	6208	0.0%	0.0%	0.0%	0.1%
5	Metal products	2716	4077	0.3%	1.3%	1.6%	2.7%	3722	0.2%	1.2%	1.5%	2.4%
6	Minerals, building materials	972	1595	−1.1%	−3.1%	−2.9%	−4.7%	1288	−1.2%	−3.6%	−3.5%	−5.4%
7	Fertilizers	295	404	−0.3%	−0.1%	0.8%	−0.3%	306	−0.9%	−0.1%	0.8%	0.1%
8	Chemicals	3341	4578	0.1%	2.0%	2.5%	2.5%	3875	0.1%	0.9%	1.4%	2.0%
9	Machinery, other	16,860	24,571	−0.1%	0.0%	0.1%	0.2%	21,268	−0.2%	0.3%	0.4%	0.9%
	Total	41,399	58,183	0.0%	0.3%	0.5%	0.7%	51,319	0.0%	0.3%	0.5%	0.8%
	Inland waterway	–	–					–				
0	Agricultural products	13,915	16,334	0.5%	1.5%	1.5%	3.5%	15,278	0.5%	1.7%	1.7%	3.3%
1	Foodstuffs	19,766	22,165	1.3%	4.3%	4.2%	8.9%	22,750	1.0%	3.5%	3.4%	6.7%
2	Solid mineral fuels	32,081	43,105	0.1%	0.1%	0.2%	0.3%	38,461	0.0%	0.1%	0.1%	0.2%
3	Petroleum products	45,690	50,218	0.6%	2.4%	2.8%	4.7%	42,347	0.5%	1.9%	2.3%	3.7%
4	Ores and metal waste	35,674	33,549	0.2%	0.7%	0.8%	1.3%	33,596	0.1%	0.6%	0.6%	1.1%
5	Metal products	11,210	16,619	0.2%	0.6%	0.6%	1.4%	15,646	0.2%	0.6%	0.6%	1.2%
6	Minerals, building materials	91,267	88,774	1.0%	3.7%	4.1%	7.4%	86,622	0.8%	2.9%	3.3%	5.6%
7	Fertilizers	6463	7588	0.3%	1.0%	0.9%	2.2%	6745	0.3%	1.0%	0.9%	1.9%
8	Chemicals	42,968	55,053	0.2%	0.6%	0.5%	1.2%	47,432	0.2%	0.5%	0.5%	1.0%
9	Machinery, other	51,331	70,802	0.1%	0.3%	0.3%	0.6%	63,220	0.1%	0.4%	0.3%	0.8%
	Total	350,367	404,204	0.5%	1.7%	1.8%	3.3%	372,096	0.4%	1.4%	1.5%	2.7%

assignment in the LMS (National Transport Model), to analyse possible additional impacts from re-routing decision. Fig. 2 shows the impact on the traffic flow in the 15 ct/km network charge, relative to the reference scenario. Overall, the intensities decrease (green), but in some parts of the network large shifts can be observed. For instance for the heavy transport corridor between the ports of Rotterdam and Antwerp, the model predicts that many road transports will shift from the western A4 route to the A16 a bit more to the East, a larger part of which is on Belgium territory, and will be less affected by the Dutch heavy vehicle charge.

Route choice has a big impact on the vehicle kilometres in the network. In Table 5 the impact on HGV vehicle kilometres is distinguished for the highway network, and the secondary and tertiary road. This shows the impact of the decision of the charging network. With no additional configuration of the charging network, a charge on the highway network only will lead to rerouting impacts of HGVs from the highway network and rerouting to the auxiliary network to avoid charge: in the medium charge of 15 ct/km (ASW) the vehicle kilometres driven on the highway decrease by 12.0% but the vehicle kilometres on the auxiliary network increase with 13.4% (in the High scenario). This is highly unwanted, because this might lead to large negative impacts on local emissions, safety, and accessibility. This corresponds to findings in other countries: in Germany and Austria because of re-routing strong increases of freight traffic occurred in some sections on secondary road network (TRT, 2008). To avoid these re-routing impacts a selection of secondary roads were added to the configuration of the charging network, the so called ASW + alternative. Calculations show that most of the unwanted rerouting impacts can be avoided: in the extended highway network alternative with a medium charge of 15 ct/km (ASW+) the vehicle kilometres driven on the highway decrease by 8.5% and the increase of vehicle kilometres on the auxiliary network is much less severe: 4.1%. This shows the importance of configuring the charging network to avoid unwanted increased truck volumes on secondary roads, with negative impacts on congestion, local emissions and safety.

The results as presented have been used as input for decision making on the charging network. Road authorities of secondary roads were consulted, with the objective to prevent negative effects of rerouting. These road authorities were consulted for their specific knowledge of their network, economic situation and the environment. Also the transport sector was consulted. Conclusion is that the rerouting effect that is calculated is the top of the bandwidth. In addition, the Ministry will implement a monitoring and evaluation program, to monitor rerouting effects on specific routes and can change the charging network if necessary, to prevent negative effects on the environment or road safety.

6. Conclusion and discussion

The presented quantitative impact study of different scenario and policy combinations provides a bandwidth of possible impacts of distance based HGV charge in The Netherlands. The results predict a moderate overall impact of the HGV charge which is in line with

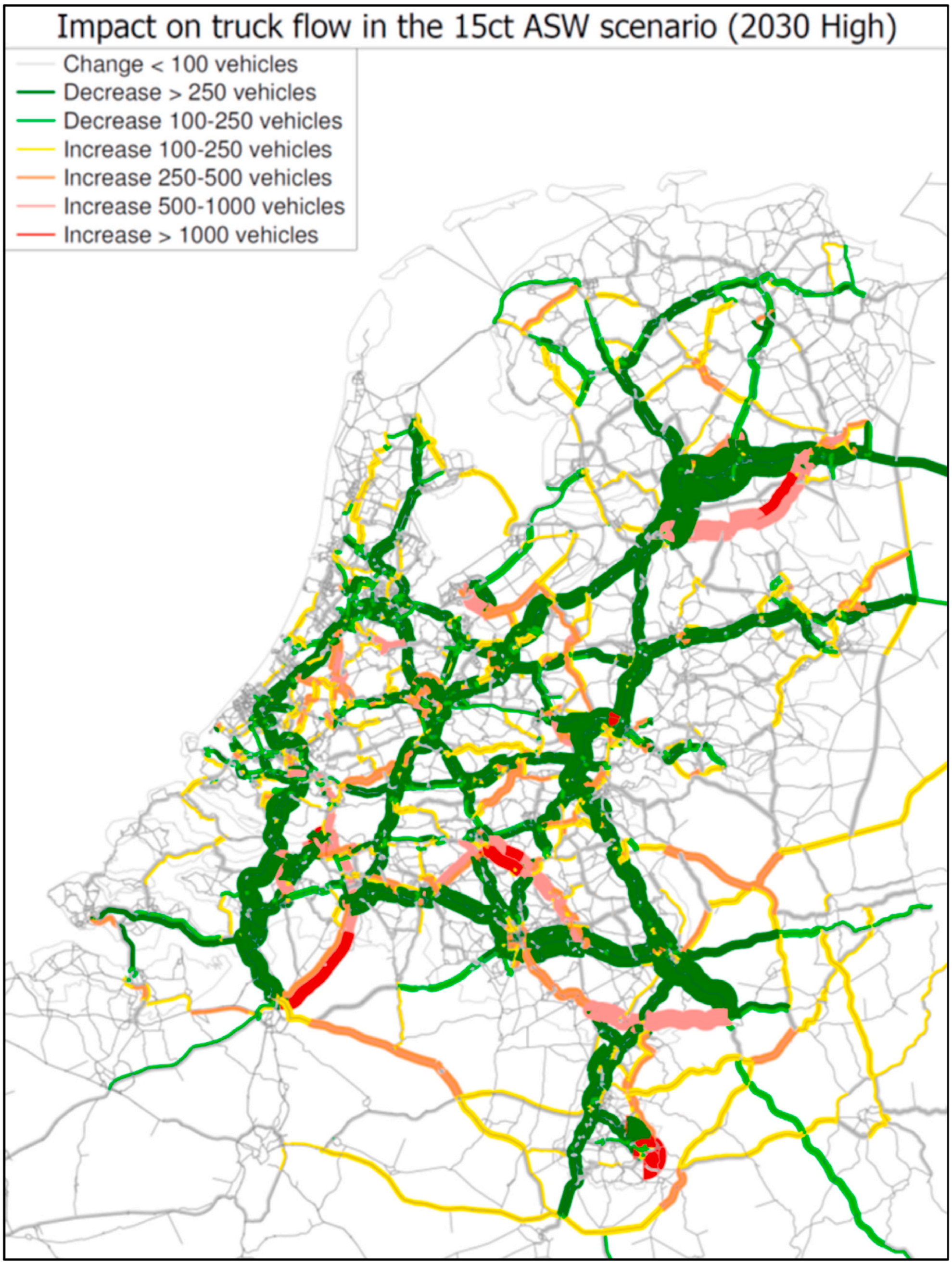

Fig. 2. Impact on truck flow on the Dutch road network in the 15 ct ASW scenario (2030 High).

previous studies in the European context (Gomez & Vassallo, 2020). Depending on the pricing scenario the tonne kilometres decrease by 0.4% and 4.8% on average. The total impact on vehicle kilometres for HGV, after logistic efficiency and route choice impacts, varies between 1.2% in the scenario with a charge of 5 cents per kilometer on highways, and 11.6% in the alternative with 29 cent per kilometer on the entire network.

The modal shift from road to rail is modest, as can be expected based om previous studies (Broaddus & Gertz, 2008; Gomez & Vassallo, 2020), but more substitution is predicted between road and inland waterway transport. This is the result of the availability of a relatively well-developed inland waterway network in The Netherlands. Most modal shift will take place in dry- and wet bulk commodities: oil products, coals, minerals. These products are more cost sensitive, and therefore more likely to shift to more cost-efficient alternatives.

The detailed traffic assignment results show significant shifts from the highway network to secondary roads in the highway charging alternatives. Such an impact is known from studies looking at the introduction of highway charging in Austria and Germany (TRT, 2008). These impacts of re-routing and increasing HGV traffic intensities in some parts of the secondary road networks might lead to large negative impacts on local emissions, safety and accessibility.

It is confirmed that highway charging possibly leads to substantial negative local externalities. It is recommended for policy making to design the charging network configuration using detailed network analysis of the expected shifts in HGV traffic flow. In the presented case study for Dutch distance-based HGV charge, the impacts on secondary roads were mitigated by developing an extended highway charging alternative where a specific selection of main secondary roads was added to the network scenario. The selection of additional secondary roads was done in workshops with relevant representatives of regional and local authorities; the results from the traffic assignment were used as

Table 5
Route choice impact on highway and auxiliary network (1000 vehicle kilometres).

		Total	Highway network	Auxiliary network
High 2030	BAU (abs.)	26,357	18,599	7758
	5 ct TWN	−1.5%	−2.4%	0.7%
	15 ct TWN	−4.6%	−7.2%	1.6%
	29 ct TWN	−11.6%	−18.0%	3.9%
	5 ct ASW	−1.5%	−3.7%	3.8%
	15 ct ASW	−4.5%	−12.0%	13.4%
	15 ct ASW+	−4.7%	−8.5%	4.1%
	29 ct ASW	−8.3%	−23.4%	28.0%
Low 2030	BAU (abs.)	23,681	16,495	7186
	5 ct TWN	−1%	−2.1%	0.6%
	15 ct TWN	−4%	−6.3%	1.5%
	29 ct TWN	−10%	−16.3%	4.1%
	5 ct ASW	−1%	−3.4%	3.7%
	15 ct ASW	−4%	−11.5%	13.2%
	15 ct ASW+	−4%	−7.8%	4.2%
	29 ct ASW	−7%	−22.2%	27.0%

an important input in this process.

A strategic freight model can provide a quantitative forecast, based on theoretical sound models and valid base data. This article has presented how models are used to provide a systematic, evidence-based estimate of impacts of different policy configurations. These varied by the level of the charging fee, and the location of the charge (entire network, or part). In policy studies, the scope of the model needs to be clear and appropriately addressed. Effects that are out-of-scope should be carefully defined and where possible quantified based on other sources. Impacts of the distance = -based truck charge on transport efficiency were predicted using elasticities for the logistic efficiency effect from previous empirical studies.

The analysis of simulated results shows different impacts for transport corridors and commodity type. Thus it is confirmed that pricing policy studies require proper detail in analysis (Gomez & Vassallo, 2020). In our approach we applied strategic transport models to have sufficient detail in modelling the transport cost changes at origin-destination pairs. Even though we had to apply a simple elasticity for transport efficiency, by applying it at the level of origin-destination pairs, it provides a more accurate prediction and is better capable of capturing the heterogeneity and dynamics underlying the changes in logistic efficiency. To further understand the impact on logistic efficiency future research could focus on the development of econometric models for logistic decisions.

Author statement

Michiel de Bok: Conceptualization, Methodology, Formal analysis, Writing - Original Draft, Writing - Review & Editing; **Gerard de Jong:** Methodology, Writing - Original Draft, Writing - Review & Editing; **Bart Wesseling:** Data curation, Formal analysis, Writing - Review & Editing; **Henk Meurs:** Methodology, Writing - Original Draft, Writing - Review & Editing; **Peter van Bekkum:** Project administration, Writing - Original Draft, Writing - Review & Editing; **Peter Mijjer:** Formal analysis, Visualisation, Writing - Review & Editing; **Dick Bakker:** Formal analysis, Visualisation, Writing - Review & Editing; **Teun Veger:** Project administration; Supervision; Writing - Review & Editing.

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