THE IMPACT OF ROAD CHARGES ON EFFICIENCY, MODAL SPLIT AND CLIMATE BALANCE OF LONGER AND HEAVIER TRUCKS

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ABSTRACT

In May 2008 the Community of European Railways and Infrastructure Companies (CER) commissioned a study on the long-term impacts of extra long and extra heavy vehicles (LHVs) on climate gas emissions. The study has contributed to the ongoing debate at European and Member State level on relaxing current weight and size limits and the entailed impacts on modal split particularly in combined road-rail transport[1], on safety and on the environment including global warming. In this paper we review the results of current studies and field test experiences. We describe in detail the approach and the key findings of the CER study, saying that in the medium run modal split effects will counter-balance the higher environmental efficiency of LHVs and that there is a considerable risk that this negative climate balance persists in the long run. We further supplement the extend of the assessment by running two additional scenarios on alternative road pricing schemes. These were defined by the additional investments required on the Trans-European Road Network to safely accommodate LHVs and by the external costs of road haulage. We find that pricing measures are well suitable for preventing form negative side effects of increasing truck weight and size limits.

Keywords: Intermodal freight transport, modal split, efficiency, climate change

[1] The term „combined transport“ (CT) is used synonymously with „intermodal transport“ throughout this paper

1 INTRODUCTION

1.1 Background

Currently, weight and size limits of road vehicles are laid down in Directive 96/53/EC of the European Commission (EC). According to this regulation, standard heavy goods vehicles (HGVs) may have a maximum weight of 40 t and a maximum length of 16.25 m. For access and final haul in combined transport (CT) the maximum weight might be up to 44 t. Since 2006 there has been a discussion on increasing general size limits to 25.25m and to lift weight restrictions to 60t in the EU. While there is a great variety of names used for these longer and possibly heavier trucks (mega-liner, mega-trucks, euro-combis, eco-combis, etc.) we use the more neutral expression of "long and heavy vehicles" (LHVs) in this paper. For reasons of simplicity we use the expression LHV also for goods vehicles with excessive length, but with a gross weight according to current legal provisions.

In May 2008 the Community of European Railways and Infrastructure Companies (CER) commissioned a study of the long-term impacts of extra long and extra heavy vehicles (LHVs) on climate gas emissions. The CER study was carried out by the Fraunhofer-Society, TRT (Milan) and NESTEAR (Gentilly) with the objective of supplementing a parallel work for the European Commission on economic impacts of introducing LHVs in the EU by TML et al. (2009). Moreover, a number of studies from Member States (Germany, UK, and Austria) and NGOs have been issued and a number of Member States have undertaken road trials of these modular truck combinations. As these studies and experiences contradict each other in some major respects, the European Commission issued a second impact assessment in December 2009, lead by the Transport Research Laboratory (London) taking into account the newly available evidence.

Alongside this, signals from the Member States have been conflicting. While the field trials in the Netherlands and long term experiences of allowing vehicles up to 60t and 25.25m in Scandinavia were rather positive in the sense that market distortions through modal shift effects did not occur or were of very limited order, nevertheless, Germany and the UK have issued detailed theoretical studies on the subject (Kessel and Partner 2007, TRL 2008). As both studies reported negative impacts on rail market shares, the countries postponed the increase of truck weight and size limits.

The consultation process at the EC is a rather lengthy and formal procedure. In late 2008 an economic and technical impact assessment was put out to tender. As soon as first results were available in July 2009, the EC held a public hearing to give stake-holders a forum to express their positions and concerns. According to the spirit of the consultation procedure, these statements then enter the final decision process and are considered in the tendered study. For this reason, the CER study was carried out between May and July 2008. In order to base the second impact study on as wide a knowledge base as possible, it is accompanied by a peer group composed of the authors of the previous studies.

1.2 Objectives

The first purpose of the paper is to present the findings of the above mentioned study by Doll et al. (2008). So far, the findings have only been published in German to the research community (Doll et al., 2009). An aspect which has not been looked at with sufficient attention so far is the question of suitable road user charges for LHVs. Such charges may impact on cost efficiency, modal split and the social benefit of the concept. This paper will shed some light on the issue by extending the findings of the previously mentioned study (Doll et al., 2008) towards new evidence on the impact of road pricing on LHV market shares and the consequent CO2 balance in European freight transport.
The Commission study (TRL et al., 2009) concluded that the overall environmental balance of introducing LHVs would be positive, but it also pointed out that the additional infrastructure investments required to make roads fit for heavier and bigger trucks constitute a major obstacle for instant EU-wide implementation. This paper takes up this point and estimates the costs of additional infrastructure measures to be taken, e.g. for smoothing curvatures, widening lanes and strengthening bridges on the Trans-European road network. Building on earlier work on EU-wide road infrastructure costs carried out for the Commission within the IMPACT study (van Essen et al., 2008), alternative sets of road user charges for LHVs are derived.
In a final step the paper will re-estimate the long-term CO_2 balance of an EU-wide introduction of LHVs using the assessment model developed for the CER study (Doll et al., 2009). By applying several pricing and market condition scenarios the question shall be answered, which price level is required to protect rail freight markets from massive modal shifts when LHVs are permitted on the Trans-European road network.

2 OVERVIEW OF AVAILABLE EVIDENCE

There are a number of studies available on the topic of LHVs, their cost efficiency, safety, environment and modal split impacts. These are summarised below:

2.1 Studies on the Subject

The German Federal Environment Agency (UBA 2007) issued an overview of potential economic impacts of LHVs in 2007. They question the environmental and cost efficiency as the fuel consumption rate per ton loading are equal or worse to that of standard HGVs when LGVs are loaded below 80 %. The authors conclude, that even when fully loaded the specific CO_2-emissions per ton of cargo of a LHV by far exceed the ton-specific emissions of rail freight transport. By calling on modal shifts the authors assume that three LHVs would simply replace three 40 t / 16.75 m HGVs. Accordingly, road space and in particular space at rest areas will be more crowded.
On behalf of the German “Kombiverkehr” and the International Union for Combined Road-Rail Transport Companies (UIRR) TIM Consult has conducted a study on the impacts of long and heavy vehicles on combined transport (TIM 2006). The study concludes that LHVs are not appropriate for use in combined transport chains, but would replace them partially as the

cost advantage of combined transport is currently very limited. Balancing road transport efficiency gains against modal shift effects, the study estimates that lorry trips in road haulage would increase by 24 %.

The study by Kessel and Partner (2007) on behalf of the German Ministry for Transport, Building and Urban Development (BMVBS) has looked at the transport-related impacts of innovative vehicle designs. On the basis of eight combined transport chains investigated, the study concludes that LHVs do not contribute to cost savings in access or final haul within combined transport chains. Across all market segments, pure cost efficiency effects will cause a direct reduction in combined transport demand of 14.3 %. When considering the deterioration of combined transport service quality due to less frequent departures or consequentially omitted direct services, an overall impact of the introduction of LHVs on combined transport volumes of 32.3 % is forecasted.

The study by the Transport Research Laboratory (TRL) and the Herriot-Watt University was prepared for the UK Department of Transport in 2008 (TRL 2008). Although the study concludes that overall effects of LHVs are likely to be positive due to the saving in vehicle kilometres, the warning concerning likely investment needs in road infrastructures and the adverse environmental impacts due to modal shift effects are strong. The results are subject to a great deal of uncertainty as similar sudden extensions on vehicle dimensions and possibly weights have not been observed before.

The Commission study issued by Transport & Mobility Leuven (TML et al. 2009) has taken a broader look at the economic impacts associated with the introduction of longer and heavier vehicles. The study has investigated several scenarios of LHV weights and dimensions and of national acceptance of the concept across the EU. Transport impacts have been assessed by TML's TREMOVE model, while environmental, safety and infrastructure related aspects have been researched by additional studies. The TML report was subject to some criticism in particular because there was no specific consideration of different logistics markets and safety aspects have been denied on a very weak statistical basis. The overall conclusion of the study on the impact of LHVs in Europe was positive, but some concerns on the considerable additional investments into the road network were raised.

To tie up the results obtained by the various studies so far, the Institute for Prospective Technological Studies (IPTS) of the EC's Joined Research Centre (JRC) conducted a meta-study in early 2009 (Christidis and Leduc, 2009). The study translated the range of parameters, primarily price elasticity values, applied by TML et al. (2008), TRL (2008) and Fraunhofer et al. (2009) into probability distributions. The assessment of the EU-wide introduction of LHVs was finally found to have more positive than negative impacts in terms of transport efficiency, safety and environmental issues.

2.2 Country Experience

Sweden and Finland first introduced a restriction on vehicle lengths to 24m in 1968 due to road safety reasons. Attempts to adopt maximum vehicle lengths to the European standard of 18m in 1973 were rejected as studies did not show any significant safety improvement. A minor increase in vehicle length to 25.25m in 1979 showed no impact on safety or infrastructure requirements since the road network was traditionally designed to accommodate these long vehicle combinations. In parallel, the Scandinavian countries have

increased rail productivity by allowing higher axle loads and longer trains. Moreover, logistics are traditionally operated in a co-operative environment in these countries. The sum of these factors has prevented major adverse modal split effects (CEDR 2007).
In 1999 a long term field trial with LHVs first restricted to 50t and 22m was started in the Netherlands. The limits were increased successively to 60t and 25.25m. 155 vehicles in 71 carrier companies participated in the field test. It was planned for these vehicles to be operated in intermodal transportation feeding and discharging intermodal terminals and the applicants had to fulfil certain safety restrictions.
No security impeachment was reported in the Netherlands. Traffic jams were reported to have fallen by 0.7 to 1.4%. Carbon dioxide (CO_2) emissions fell by 11% for heavy duty and 22% for volume critical transports. Hauliers who have participated in the field trial have reported a potential for cost saving of 25% on average. Substantial modal shift was not observed due to the limited size of the country (Aarts and Feddes, 2008).
A number of German federal states have carried out field trials on the use of extra long vehicles with a maximum gross weight of 40t. Commonly these tests have been designed as special permissions for selected forwarders or hauliers on pre-defined routes. In 2008 all trials were terminated and no resumption is planned. The applicants reported a 25% saving in fuel consumption per ton of payload and a 20% reduction in overall operating costs (IVH, 2007).
Currently Denmark is undertaking field trials with permitted routes going into Sweden and Germany. Surprisingly, no activity is undertaken by France and Spain. It can be suspected that the strong positions of the French railways (SNCF) and of the labour unions play a key role here.
Across all field trials, industries are reporting positively on the concept. However informal information from the sector indicates that the pressure on drivers of extra long truck-trailer combinations is enormous, such that several of them have left their jobs during the trials.

2.3 Practice versus Theory

Table 1 compiles the results of the selected theoretical studies and field tests in terms of demand reactions of road haulage and of rail and inland waterway (IWW) transport as a consequence of introducing LHVs. The figures suggest that the market reactions assumed by theoretical studies cannot be confirmed by field applications. For a proper interpretation two aspects need to be recalled: first, the German and Dutch trials are geographically heavily restricted, and second, Sweden, as well as Finland, follow a strong policy supporting railway productivity. Contrasting this, the theoretical studies show a picture of a liberal introduction of LHVs across the Union or entire countries.

Table 1: Price elasticities reported by different studies

Area	Source	Market	LHVs 60t min.	LHVs 60t max.	LHVs 40t min.	LHVs 40t max.
OBSERVATIONS						
Sweden	CERDR08	Overall	0.0%		0.0%	
Netherlands	CERDR08	Road	0.05%	0.1%		
		Rail total	-1.4%	-2.7%		
		IWW	-0.2%	-0.3%		
MODEL STUDIES						
Europe	TML 09	Rail total	-3.8%			
		IWW total	-2.9%			
Netherlands	UBA07	Rail total	-5.0%			
UK	TRL08	Rail total	-8.0%	-18.0%	2.5%	5.5%
		Rail bulk	-5.0%	-10.0%	0.0%	0.0%
		CT maritime nat.	-22.0%	-54.0%	11.0%	27.0%
		CT cont. nat.				
Germany	K+P06, TIM07	CT total	-14.3%	-55.0%		
		CT cont. nat.	-18.2%	-44.0%	-16.1%	
		CT cont. int.	17.0%	19.6%	-16.1%	
		CT maritime nat.	-16.2%	-27.0%	-12.9%	
		CT maritime int.	-12.3%	-18.0%	-10.4%	

CT = combined rail-road transport; LHV = longer and heavier freight vehicle
Source: Fraunhofer-ISI based on different studies

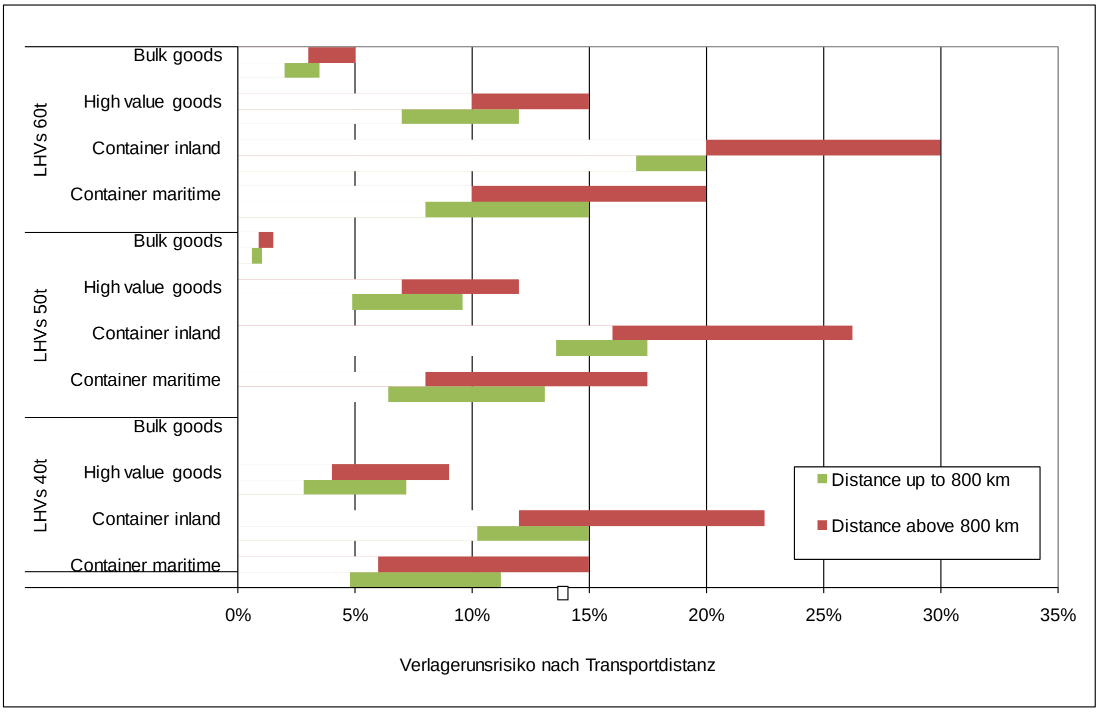
3 THE FRAUNHOFER-STUDY IN DETAIL

Methodology and results of the study carried out by Fraunhofer, TRT and NESTEAR for the Community of European Railways and Infrastructure Companies (CER) will be briefly presented here, as the elaborations in the following sections are directly based on this work.

3.1 Methodology

The study was carried out within a very short period, from May to July 2008. It was organised in five steps: (1) literature overview, (2) case study analysis, (3) network model analysis, (4) system dynamics modelling and (5) final conclusions. The results of the literature overview have been broadly discussed above. External studies were mainly used to collect information on market typologies and possible road and rail side reaction patterns when introducing LHVs. Out of the modelled and observed demand shifts towards longer and heavier trucks we have developed a set of ranges for potential shifts by commodity class and distance band as depicted in Source: Doll et al. (2009). LHV = Longer and heavier road freight vehicle; container maritime = all container shipments beginning or ending their haul in Europe at a seaport; container inland: all other container shipments.

Figure 1. The literature sources did not facilitate the narrowing of these wide ranges.



Source: Doll et al. (2009). LHV = Longer and heavier road freight vehicle; container maritime = all container shipments beginning or ending their haul in Europe at a seaport; container inland: all other container shipments.

Figure 1: Ranges or shares of railway market volumes potentially shifting to LHVs by LHV permissible gross weight, commodity type and distance band.

In addition to the literature review, two case studies were carried out: (1) alpine transit traffic and the increase of the Swiss ton limit since 2001 and (2) port hinterland traffic from Rotterdam to Poland. The main conclusion was that increased truck sizes and high road user charges can only limit truck traffic growth for a certain time. In the medium term, growth rates will continue as they do on the Swiss Alpine crossings. From Poland we learned that small and medium sized trucking companies and bad road conditions form a barrier to introducing LHVs in large scale. Both will be overcome in the new member states thanks to investments in the Trans-European transport net-works (TEN-T) and market liberalisation pushed forward by the European Union.

By designing and implementing a simple system dynamics model the study has created a tool for long term analysis. The model has divided the European freight market into four commodity sections with specific handling characteristics, two distance bands (c.f. Figure 1) and in three modes (HGV, LHV, rail). For the market entry of LHVs it was assumed that adaptation processes in the logistics sectors have to take place, such that a certain delay between the legal permission and the full market penetration occurs. This delay is longer for rail where more complex logistics processes have to be refined.

In a simple way the model has integrated capacity with transport cost related demand reactions. It is essential to model capacity effects as they diverge for road and rail. In the case of declining rail demand, particularly concerning combined transport relations, the costs for service and infrastructure maintenance increases by transport unit. Beyond a certain point, operating costs can no longer be covered, and the connection has to be closed completely, forcing the remaining rail volume to shift to road. In road transport such "vicious circle" reaction pattern does not take place.

Market reactions are described by price elasticities and by commodity-specific modal shift potentials. The latter are particularly important as the decision on organising the transport of many voluminous goods, such as electronics, is determined by shipment conditions, vehicle sizes or quality, rather than by the price alone. From field tests it becomes evident that it is just the increase of the loading volume of trucks, without altering maximum weight, that is of interest for several industry branches.

Figure 2 presents the model structure of the System Dynamics tool. A desirable feature of System Dynamics is the possibility of simulating complexity brought about by feed-back impacts and in the context of this study there are some relevant feed-back loop to be considered in order to provide a full picture of the introduction of LHVs. One loop (bold black arrows in the figure) links road demand to road congestion to competitiveness of road transport to mode shift back to road demand. The other loop (bold red arrows in the figure) starts from rail demand to rail utilisation to mode shift back to rail demand. As mentioned above, the arrows in the figure correspond to elasticity parameters in the model, so that the final outcome of the system depend on the size of such elasticities. For more details on model structure and parameters see Doll et al, (2008).

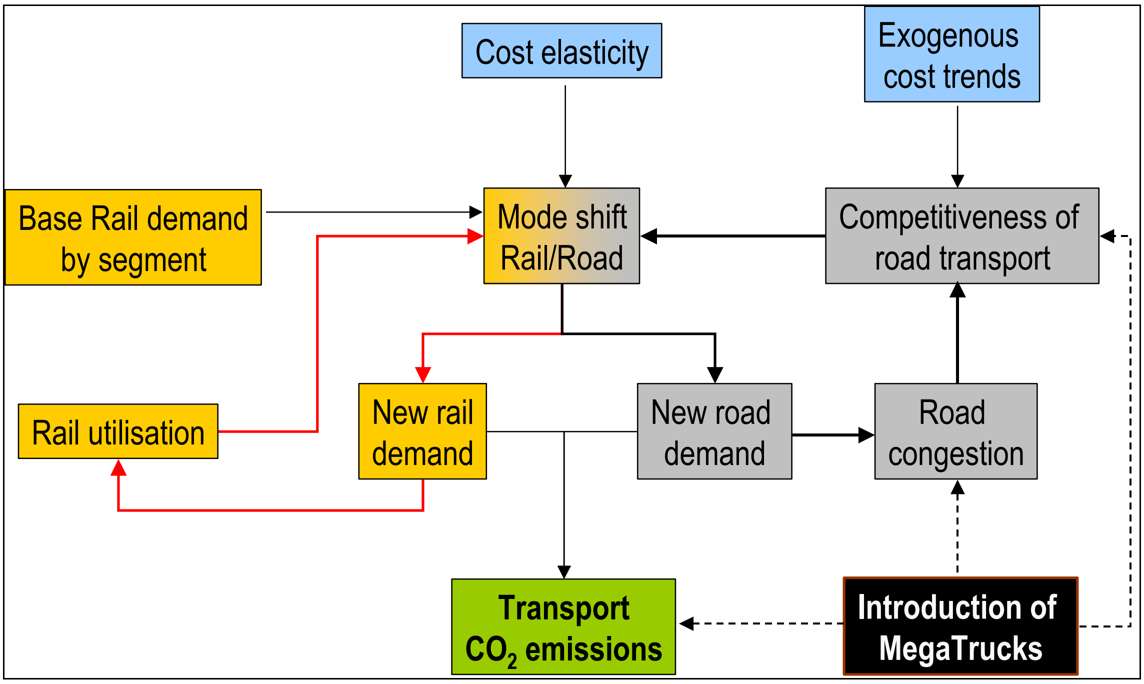


Figure 2: Architecture of the system dynamics model

Source: TRT

In parallel to the system dynamics model application the study has run the LOGIS model by NESTEAR with several LHV scenarios. The LOGIS model consists of roughly 2000 door-to-door freight relations, mainly of high value goods. By linking European road and railway networks the model is capable of modelling combined transport flows.

The LOGIS model was run on a network and with cost data estimated for 2020. Besides the three modes the markets are segmented into 16 commodity types. LHVs were represented as transport services on the TEN road network. Figure 3 depicts the LHV network implemented in the LOGIS model. Driving off these motorway-like routes requires splitting LHVs into two units. This assumed regulation was modelled by defining “splitting costs” between €75 and €100 per change from and to secondary roads to the TEN network.

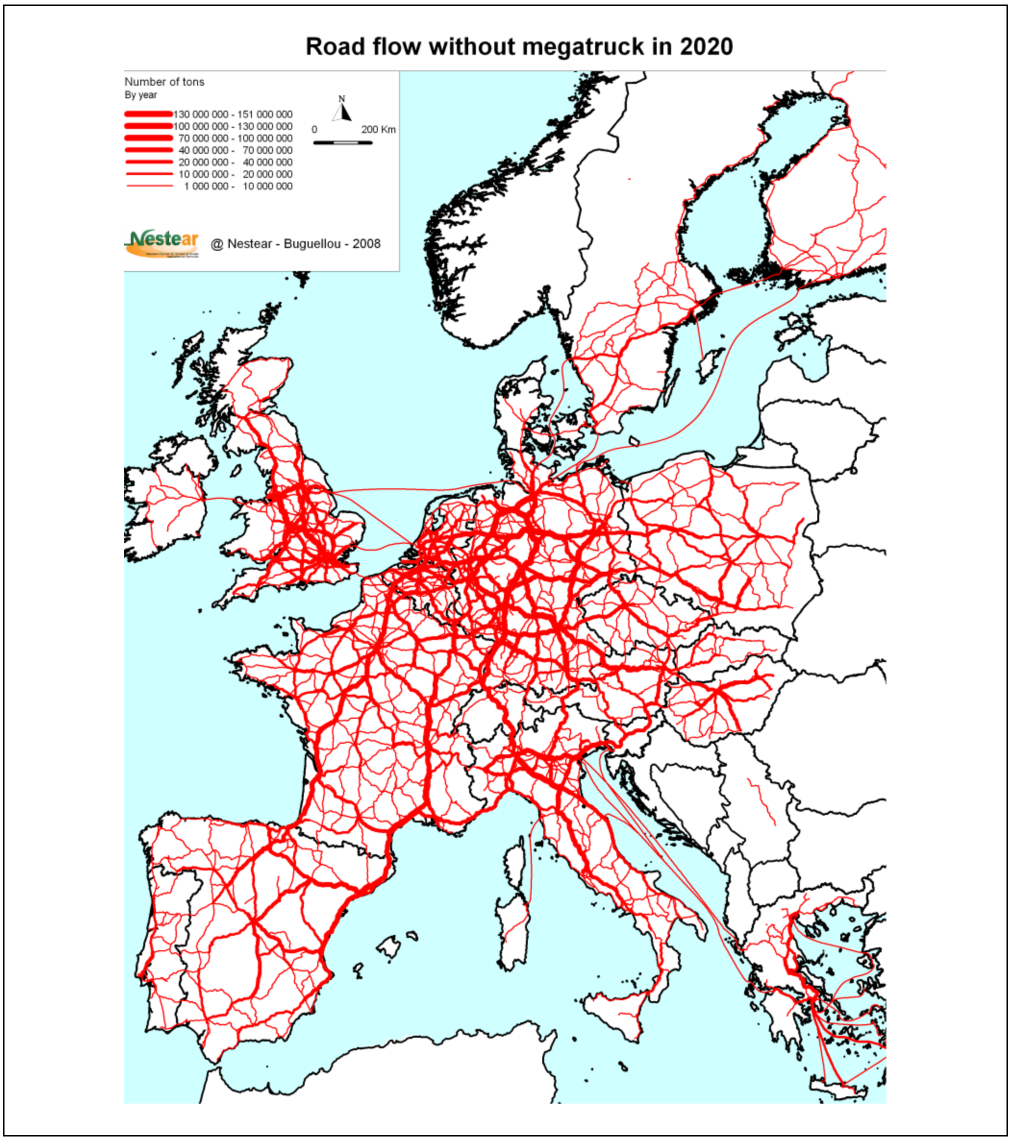


Figure 3: Road network of the LOGIS model

Source: NESTEAR

3.2 System Dynamics Model Findings for CO2 Emissions

The study finds strong evidence that the introduction of LHVs will most likely result in a medium-term negative climate gas balance: in most scenarios, negative impacts in the medium term are much stronger than initial positive effects. Thus, the authors reject the consideration of longer and heavier road freight vehicles as a suitable element of climate protection policy. The model outputs suggest that there are three phases of the impact of LHVs:

1. The road sector accepts LHVs rather quickly, resulting in a decrease of CO_2 emissions due to efficiency gains on the road. Within a time horizon of three to six years an annual decline of 0.5Mt is expected.
2. If LHVs are established in road haulage, modal shift will take place in the rail sector. With a high degree of certainty modal shift effects will counter-balance CO_2 reduction targets. Within five to 20 years an additional emission of 2Mt CO_2 per annum is expected due to the introduction of 60t LHVs.
3. If demand for road freight transport keeps on growing faster than rail demand, in the long run efficiency gains in the road sector might partly compensate for the additional CO_2 emissions due to modal shift. But this will only happen with 60t LHVs and within a time frame of 15 to 30 years.

Reducing the maximum gross weight of LHVs from 60t to 50t will increase their likely adverse climate impacts due to lower efficiency gains in the road sector. How-ever, modal shift will only be slightly affected as most goods that have a potential for modal shift are volume critical. These results of the System Dynamics model are very strong.

Figure 4 and Figure 5 present the results for the introduction of LHVs with a maximum gross weight of 60 t and 50 t across Europe. The development is expressed in probabilities until the year 2025. The probabilistic approach has been chosen as many of the model input parameters could only be expressed in ranges rather than in deterministic values. The model output graphs thus express a bundle of possible developments of the CO2 balance of European freight transport after the introduction of LHVs, where the central line of the graph indicates its most likely slope. The vertical axes of the figures indicate the annual net CO2 balance for the European Union's surface freight transport in Mt of CO2-eqivalents. A first look at the results reveals, that both LHV configurations are not favourable in terms of climate gas mitigation, but among these 50 t vehicles are the least preferable solution.

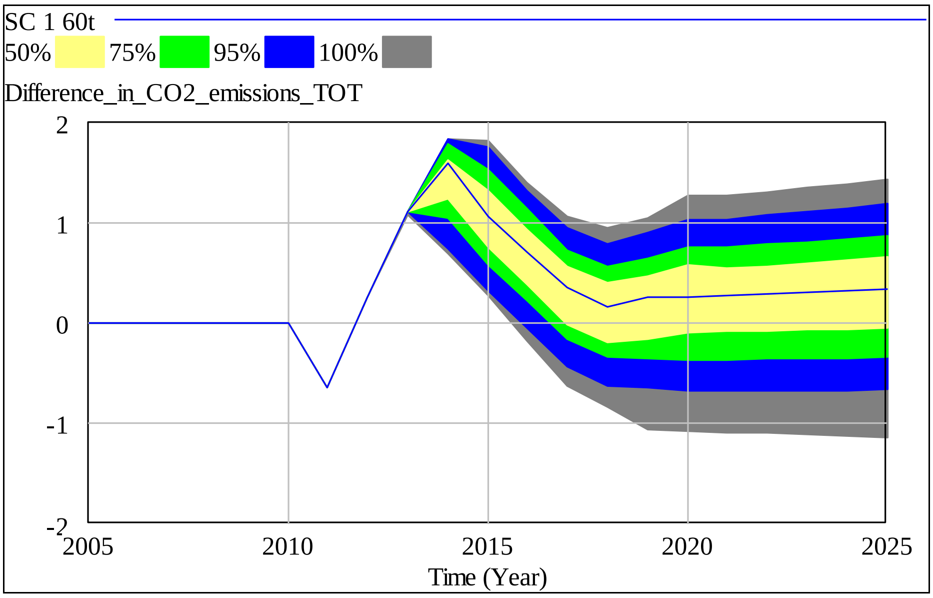


Figure 4: Probability distribution of CO_2 balance with: 60 t LHVs

Source: TRT

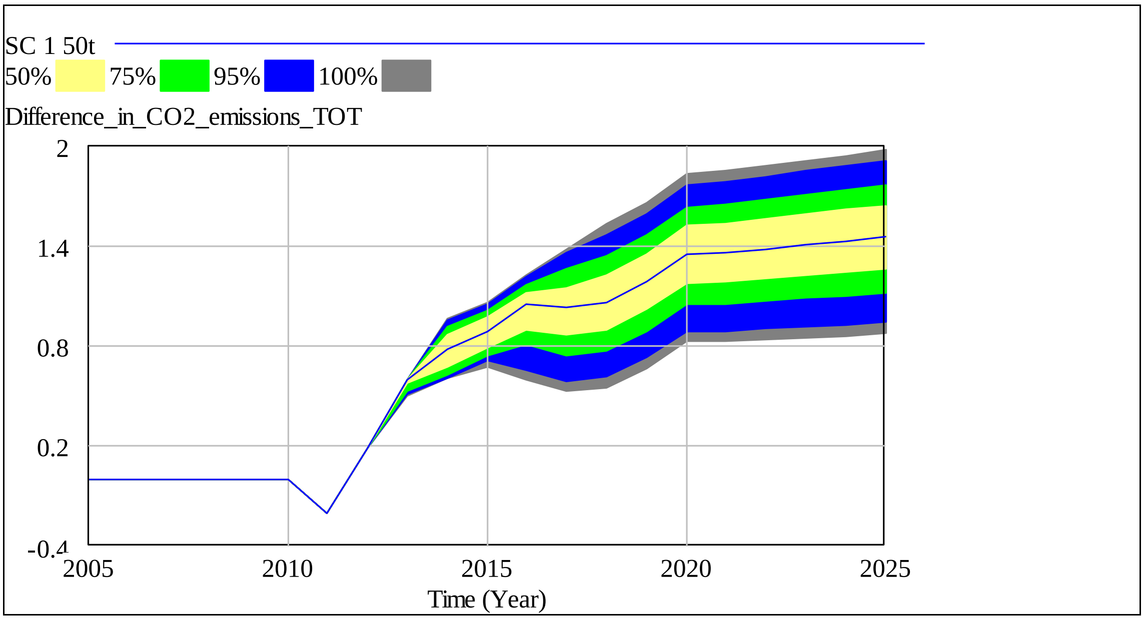


Figure 5: Probability distribution of CO_2 balance with:50 t LHVs

Source: TRT

3.3 Network Model Results

The results of the LOGIS model are presented in 7 hypotheses, distinguishing between the cost advantage of LHVs against standard HGVs and by splitting costs from and to the motorways. The main results comparing standard 40t HGVs, LHVs and rail in combined transport (CT) are presented in Table 2.

According to these figures LHVs could gain a market share of up to 40%, while the modal share of CT could drop from 10% to 1.6 %. These dramatic results, however, have to be considered against the background of the model's commodity structure. The LOGIS model focuses on high quality goods markets and thus shows particularly vulnerable market segments. The overall effect on the entire market will be smaller. Nevertheless it is concluded that the opening of new combined transport services will become more difficult with the introduction of LHVs as they might hinder the reaching of critical volumes.

Table 2: Summary results LOGIS model, road-CT competition

Cases considered	**Absolute demand (1000 million tkm)**				**Market share at tkm**		
cost per t of LHV vs. HGV / TEN splitting costs per trip	**Classic HGV**	**LHV**	**Rail in combined transport**	**TOTAL**	**Classic HGV**	**LHV**	**Rail in combined transport**
Without LHVs	1 369	0	144	1 513	90	0	10
-20% / 100€	1 247	187	75	1 509	83	12,4	4,9
-20% / 75€	1 121	330	61	1 512	74	21,8	4,0
-25% / 100€	1 146	313	56	1 514	76	20,6	3,7
-25% / 75€	978	500	41	1 518	64	32,9	2,7
-30% / 100€	1 038	442	39	1 519	68	29,1	2,6
-30% / 75€	871	628	25	1 524	57	41,2	1,6

Source: NESTEAR

Further interesting results of the LOGIS model are that above 1000 km transport distance, virtually all classical HGV trips will be replaced by LHVs. Their total market share on the road, related to ton kilometres, will then be around 20%. This conforms to expectations formulated during the German trials.

4 CONSIDERING ROAD USER CHARGES

4.1 Methodological Issues

In the original scenario setting of the system dynamics model in Doll et al. 2009, very general assumptions on infrastructure charges to be paid by different kinds of lorries were taken; in the reference case, i.e. without the presence of LHVs, an average charge level of 15€/100 vehicle kilometres was assumed. This value reflects a broad average of the charges levied in the big European Member States, namely France, Spain, Portugal, Italy, Germany and Hungary. As a consequence of the on-going process of harmonising tax and charge levels in Europe, the extreme cases at the upper charge level (Austria and Switzerland) and at the lower end including Benelux, Scandinavia, Greece and countries without charging systems, are not considered in full detail.

Deriving road infrastructure costs for LHVs requires an examination of the various components of infrastructure costs, their driving factors and the development of these drivers with vehicle weights and dimensions. Infrastructure cost components can be coarsely classified into capital costs, including annual depreciation and interest costs for long life assets such as new investments, replacement or major repair activities, and running costs. Running costs consist of smaller repair and routine maintenance measures, operation, green cutting, winter maintenance, traffic police and the charging system. A review of European national and community-wide road accounting systems carried out in Doll and van Essen (2008) lists three basic drivers for these cost elements:

1. Equivalent Standard Axle Loadings (ESAL) describe the damage potential a particular vehicle has in relation to a standard vehicle. Trials with various vehicle and pavement configurations, e.g. the AASHTO road test from the US, have found that the road damage increases with the 3rd to the 4th power of axle loadings. This factor is attached to all short-term maintenance and stability relevant cost components, including bridges and other engineering works. Related to a 40t HGV with 5 axles we receive ESAL factors between 0.48 for 50t, 7 axle LHVs and 0.82 for 60t, 8 axle trucks. This implies that where no additional investments are undertaken, the maintenance-dependent infrastructure damage costs of LHVs are essentially below those of today's heavy trucks. According to the compilation in Doll and van Essen (2008), ESAL-factors are applied to 18% of HGV motorway costs in order to estimate appropriate charge levels for LHVs.
2. Passenger car equivalents (PCE) describe the occupation of road space, and thus the number and width of lanes required by certain vehicles in relation to a standard vehicle. This factor takes account of the size of the vehicle, its manoeuvrability, required safety distance and engine power. We consider the latter being adopted to the vehicles' gross weight and thus set the PCE factor for LHVs simply in proportion to its length. Related to standard 16.25m HGVs this is roughly a factor 1.5. This is applied to 50% of infrastructure costs of HGVs.
3. Simple vehicle kilometres (vkm) are applied to those cost categories which are neither depend on damage to road structures, nor to the dimensioning of the road space. These include administration and general operation and amount to 31% of HGV-related motorway costs.

Although these cost drivers, in particularly the ESAL factors, change with truck settings, for the simplicity of the approach we assume they are equal for all LHV types.

4.2 Computing Charge Levels

In the variants computed hereinafter we assume an equal charge level for 50 t and 60 t vehicles in three variants:

- The base variant is set by the charge level of 20 €/100 vkm according to the assumptions taken by Doll et al. (2009).
- Variant 1 describes the full consideration of all the additional investments needed to prepare the Trans-European road network for accommodating LHVs. According to TML et al. (2008) the main cost drivers here are the strengthening of bridges, the widening of curves and the adaptation of rest and parking facilities alongside motorways. The selected tariffs amount to 30 €/100 vkm.
- Variant 2 finally assumes the additional consideration of external costs in the charge level. Without going into detail here we assume a surcharge for uncovered accident, air pollution, greenhouse gas emission and noise costs of 20 €/100 vkm. This leads to a final charge level in variant 2 of 50 €/100 vkm.

This selection of charge levels is based on the following principles: In the cautious approach underlying the base scenario we assume minor additional investments, e.g. for additional bridge or surface rehabilitation, corresponding to 3 €/100vkm.

According to TML et al. (2009) the estimated additional investments required for the TEN network amount to €0.8 billion for major maintenance activities and €3.1 billion for large scale bridge strengthening and replacement programs. Assuming an average depreciation period of 40 years and a social interest rate of 3% we arrive at annual capital costs of €123 million. From the output of the LOGIS model we can estimate a number of 1.12 billion vehicle kilometres of LHVs, which would finally lead to additional infrastructure costs of €11/100vkm for 60t LHVs and, due to their lower market penetration, of €15/100vkm for 50t trucks. Given that we have €3/100vkm for additional in-vestments, in the case of full charge levels (variant 1) we apply an additional charge for LHVs of €10/100vkm.

External environmental costs are considered in the extended charge scenario (variant 2) by adding 20 €/100 vkm to all LHV weight classes. This cost factor covers the external costs of accidents, air pollution, climate gas emissions and noise.

Both, the moderate charge level applied in Doll et al. (2009) and the extended level including full additional investment requirements are presented in Table 3.

Table 3: Derivation of infrastructure charge levels for LHVs

Vehicle category	**Standard HGV**	**Longer and heavier vehicles (LHVs)**		
Max. gross weight (t)	40	40	50	60
No. of axles	5	7	8	8
Max axle load (t)	11.5	11.5	11.5	11.5
Length (m)	16.75	25.25	25.25	25.25
Av. load per axle	8.0	5.7	6.3	7.5
ESAL -factor	1.00	0.36	0.48	0.82
PCE-factor	1.00	1.51	1.51	1.51
Static infrastructure cost index	1.00	1.14	1.16	1.22
Additional rehabilitation (€/100 vkm)	0.0	3.0	3.0	3.0
Cautious charge level (€/100 vkm)	15.0	20.1	20.4	21.3
Applied by Doll et al., 2009 (€/100 vkm)	15.0	20.1	20.4	21.3
Additional rehabilitation (€/100 vkm)	0.0	10.0	10.0	10.0
Full charge level (€/100 vkm)	15.0	30.1	30.4	31.3
Variant 1, this study (€/100 vkm)	15.0	-	30.0	30.0
Additional external costs (€/100 vkm)	0.0	20.0	20.0	20.0
Extended charge level (€/100 vkm)	15.0	50.1	50.4	51.3
Variant 2, this study (€/100 vkm)	15.0	-	50.0	50.0

Source: Fraunhofer-ISI, 2010

For information, the table also shows the figures for 40t / 25.25m LHVs, although they are not considered in the subsequent computation.

4.3 Results

The additional pricing scenarios have been applied to the case of 50 t LHVs only, as they represent the more harmful truck concept from the perspective of climate protection. Table 4 presents the results for transport volumes in ton kilometres (tkm) and CO_2-emissions in mega-tons (Mt) of CO_2-equivalents. The figures are given in total numbers for the year 2025 and cumulated from 2005 to 2025 and as difference to the base case taken from Doll et al. (2009).

Table 4: System-Dynamics model results for 50 t LHVs and various pricing regimes

	Reference "No LHVs"	**Base variant "Cautious charging"**		**Variant 1 "full charge"**		**Variant 2 "extended charge"**	
Perspective	Abs.	Abs.	Diff.	Abs.	Diff.	Abs.	Diff.
Tolls (€/100 vkm)	15	20	20	30	30	50	50
Freight demand in relevant markets in 2025 (million tkm)							
Rail incl. CT	2198,8	2088,2	-110,6	2130,0	-68,8	3316,6	1117,7
Road incl. LHVs	23583,6	23702,6	119,0	23652,0	68,5	22465,9	-1117,7
Total	25782,4	25790,8	8,4	25782,1	-0,4	25782,4	0,0
Cumulated freight demand in relevant markets until 2025 (million tkm)							
Rail incl. CT	39100,9	37881,2	-1219,7	38447,9	-653,0	48651,1	9550,3
Road incl. LHVs	422136,2	423430,4	1294,2	422788,9	652,7	412585,9	-9550,3
Total	461237,0	461311,5	74,5	461236,8	-0,2	461237,0	0,0
CO_2 emissions relevant markets in 2025 (Mt)							
Rail incl. CT	52,8	50,6	-2,2	51,4	-1,3	71,6	18,8
Road incl. LHVs	1726,9	1730,2	3,3	1726,4	-0,5	1631,8	-95,1
Total	1779,7	1780,8	1,2	1777,8	-1,8	1703,4	-76,3
Cumulated CO_2 emissions relevant markets until 2025 (Mt)							
Rail incl. CT	938,4	914,3	-24,1	925,5	-12,9	1108,2	169,8
Road incl. LHVs	30738,5	30821,8	83,3	30726,8	-11,6	29923,3	-815,2
Total	31676,9	31736,1	59,2	31652,3	-24,5	31031,4	-645,4

The results from Table 4 show impressively that the impact of setting the prices according to full infrastructure and external costs could be. For the vast majority of freight market segments the internalisation of external costs can prevent from massive modal shifts due to one-sided productivity increases of road haulage against rail transport. In the case of road tolls of 60 €/100 vkm there could even be a massive counter-effect. In this case the model estimates a modal shift from road to rail of 1.1 billion tkm from road to rail.

Also about the direction of the market reactions shown by the system dynamics model we must be cautious as concerns the absolute values. The model was designed to combine and visualise the various effects entailed by a general increase of truck weight and size limits. The assessment of pricing impacts was a part, but not in the foreground its specification.

5 CONCLUSIONS

The application of the system dynamics model to alternative levels of road user charges for LHVs with a maximum gross weight of 50 t suggests that accompanying market mechanisms help in easing the negative impacts of their general introduction on the railways' market shares. While charging for the current costs of infrastructure provision and maintenance does not seem to sufficiently compensate for the productivity increases of bigger trucks, the inclusion of the necessary preparation of the road network to accommodate these vehicles appears to be a fair solution for both modes.

In case of such a "full" allocation of infrastructure costs the model finds a slight counter-effect of modal split towards the railways. However, the absolute dimension of the model reaction needs to be considered with care as on the other hand the positive impacts of improved road standards on road haulage are not taken into account by the modelling framework.

From a sustainability point of view the result for the "extended" pricing variant (Variant 2 with a charge level of 50 €/100 vkm) is most favourable. In this case rail will gain substantial shares in the relevant market segments compared to road. Given the above mentioned insecurities with the absolute model results, this pricing scheme seems at least to be suitable to prevent massive market distortions by introducing LHVs in Europe.

The model results strongly suggest to take into account external cost elements. A concept for externality charges is contained in the Commission proposal to the revision of the European road infrastructure charging directive (Eurovignette-Directive DIR 2006/38/EC). For the design of applicable road user charges, however, the level of external cost elements needs to be looked at in more detail. Elaborations in the framework of the IMPACT study on behalf of the EC have recommended the internalisation of air pollution, noise and possibly congestion costs via road user charges, while climate and accident related costs may be better implemented by other instruments.

There are certainly other options to combat market distortions from permitting LHVs on European roads. Examples are local driving bans, motorway access control or specific vehicle and personnel requirements. But we have reason to assume that road transport lobbyists will put pressure on policy to weaken these restrictions when economic conditions for the sector get unfavourable. In contrast, in the case of road user charges there are good reasons for assuming that, once introduced, the public has a strong interest in maintaining the revenue flows.

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