External costs as competitiveness factors for freight transport – a state of the art

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ABSTRACT: *External costs have been a key issue in the last years of transport research. In Europe, this trend is in line with the political willingness to internalize externalities in transport pricing policies. This paper has two purposes. It first identifies the recent work achieved in the field of external costs of road and intermodal freight transport, where each paper is assessed in terms of its perspective (academic or project-oriented), its objective (prescription, application, projection), the type of externality (air pollution, climate change, noise, accidents, congestion) and the type of cost (marginal, average, total) that is considered. The literature review reveals a gap in the development of generic mathematical functions for external costs of transport. The second objective of the paper is thus to highlight the usefulness of such functions by identifying the main parameters that influence freight transport competitiveness in terms of external costs, and by determining which of these parameters should be incorporated in further research works.*

Keywords: freight transport; externality; transport competitiveness; road transport; intermodal transport

1. Introduction

Freight transport provides societal benefits but also generates costs. The sum of the private and external costs of transport corresponds to the total or social cost of transport (Pigou, 1920). Private (or operational or internal) costs refer to the costs that an economic agent has to support in order to perform his activities. External costs are side effects of transport and, “without policy intervention they are not taken into account by the transport users” (Maibach et al., 2008).

The objective of the European Union is to integrate external costs in transport pricing policies (European Commission, 2008). Internalizing external costs allows pricing at the right social cost, leading to an efficient allocation of resources. European authorities also aim at limiting the total amount of external costs and therefore encourage the transfer of freight flows from road to more environmentally friendly modes of transport (European Commission, 2011). Road transport is thus in competition with intermodal transport, in order to ensure this modal transfer.

In the recent years, external costs have become a key issue in transport studies. The broad variety of costs valuation methods, types and uses has led to the development of an extensive literature.

The aim of this paper is twofold: it first provides a literature review on external costs of freight transport, for the last 15 years, identifying for each paper its perspective (academic or project-oriented), its objective (prescription, application, projection), the type of externality (air pollution, climate change, noise, accidents, congestion) and the type of cost (marginal, average, total) that is considered. The second part of the paper aims at showing the practical interest of generic mathematical functions of external costs, for identifying the most important parameters that influence the competitiveness of road and intermodal freight transport. A sensitivity analysis of the external cost functions found in the literature review is therefore proposed. A reference situation is compared to a worst-case and best-case scenario, for different parameters such as pre- and post-haulage distances, terminal locations, load and density of the goods. On the basis of this analysis, the main future research directions are identified.

Section 2 describes the basic concepts and methodology related to transport external costs. Section 3 provides a literature review of the different studies dealing with external costs in freight transport. The main parameters that influence the competitiveness of freight transport in terms of external costs are identified in section 4. Discussion of the results is performed in section 5. Conclusions are finally drawn in the last section.

2. External Costs: Methodology

It is now acknowledged that transport generates negative effects on society. External costs consist in five main categories: global warming, air pollution, noise, accidents and congestion.

External costs are not easy to evaluate and to monetise. Indeed it is difficult to measure physically the damage because the scope of the externality is not totally known, the effect is uncertain and can vary a lot from an individual to another, and externalities happen with different time horizons. Moreover, for the majority of externalities, there are no markets on which they can be exchanged at a commercial value (Nayes and Arnold, 2010).

Dealing with costs requires distinguishing between marginal and average costs. In transport, marginal cost refers to the additional cost provoked by the transport of one additional unit. Average cost refers to the total transport costs divided by the number of units transported. In the literature, this differentiation has led to the development of two main methodologies: the bottom-up and the top-down approach.

The bottom-up strategy consists in starting the evaluation from the lowest level, i.e. the micro level. The analysis is based on the definition of the external effects of a particular element and how it affects its environment. This approach focuses on determining the marginal external cost. This method provides precise and detailed information on which specific parameters impact negative externalities. Nevertheless, since it focuses on very specific cases, it might be difficult to translate the obtained results into policy measures (Van Essen et al., 2007).

The top-down strategy relates to a macro vision and consists in evaluating the external effects of a wider system, for example a country or a sector. This leads to the definition of average costs, which makes it difficult to extract the marginal cost value (Maibach et al., 2008). The total externalities are then divided by a cost unit in order to obtain the external effects of specific items. This approach has the advantage to be simpler than the bottom-up methodology but leads to less precise values.

External costs thus deal with two main steps: determination and valuation of the impact. When there is no market price, different methods of evaluation exist: damage cost (Bickel et al., 2005, 2006a, Schmid et al., 2001), avoidance cost (Bickel et al., 2005, Schmid et al., 2001) or opportunity (or willingness-to-pay) cost method (Bickel et al., 2005, 2006a, OECD, 2005, Ortúzar et al., 2000, Schmid et al., 2001). The damage cost method consists in defining the real damages caused by the external costs. The avoidance cost method is based on scenarios and determines which costs are generated for avoiding a specific amount of externalities in the future. Finally, the opportunity cost method identifies the external cost value as the price that should be paid to an economic agent, who suffers from the externalities, in order to accept to support the external effect. The latter can be obtained through stated preference methods.

3. Literature Review

Several kinds of papers related to the identification and computation of external costs of road and intermodal transport can be found in the literature. They differ in terms of their perspective (academic or project-oriented), the type of externality (air pollution, climate change, noise, accidents, congestion) and the type of cost (marginal, average, total) that they consider. A differentiation of these papers can also be performed based on their objective. Some papers focus on the development of the methods and tools to be used to determine the scope and value of external costs. Their aim is thus to prescribe the right methodology (prescription). Another objective is to practically use and combine these methods for determining specific numerical values of external costs. This second objective thus consists in applying concretely the methodology on external costs (application). Finally other papers aim at formally generalising the modelling of external costs, for instance for forecast purpose (projection).

Based on Forkenbrock (1999), for the external costs assessment of intercity freight trucks, Forkenbrock (2001) compares the average external costs of rail and truck freight transport in the United States. Externalities of four types of trains are analysed. The main result of the study reveals that, since rail transport private costs are much lower than the road ones, external costs for rail represent a higher proportion of rail private costs than what road external costs do compared to their respective private costs.

Sansom et al. (2001) compute the external costs of rail and road transport in Great-Britain. For both rail and road transport two applications of the model are developed. The first one determines the marginal and fully allocated cost for the average road vehicle (disaggregate unit costs are weighted by relative vehicles-kilometres by area, road type, vehicle type and time period). The second one provides a value of the marginal and fully allocated cost by vehicle type, by road type, by time period and by area.

Mayeres et al. (2001) determine the marginal external costs of transport for Belgium. For freight transport, they provide values of externalities for various transport means. They conclude that large inland ships and electric trains are the best options in terms of external costs. This statement is even truer when the population density increases.

The RECORDIT study (Schmid et al., 2001) focuses on short-run marginal external costs on a road and intermodal route of three main European corridors. The intermodal solution consists either in a combination of rail and road or in a combination of rail, road and waterway. The results show that external costs of the intermodal route are between two and three times lower than road-only external costs. However the difference in values between both solutions depends mainly on the length of the pre- and post-haulage (PPH) travels by road. Rail transport generates the lowest external costs and inland waterways transport causes relative high external costs because of air pollution.

INFRAS/IWW (2004) estimates the external costs of transport for 17 countries in Europe (EU-15 states, Switzerland and Norway). The authors compute the total, average and marginal costs for road, rail, inland waterways and air transport.

As part of the Clean Air for Europe (CAFE) Programme, AEA Technology Environment (2005) assesses the marginal external costs per tonne of emission of PM2.5, NH3, SO2, NOx and Volatile Organic Compounds (VOCs) from each EU-25 Member State (excluding Cyprus). Four scenarios are considered, which thus leads to four different evaluations of the same pollutant costs.

The HEATCO project (Odgaard et al., 2005) aims at developing harmonised approaches for transport costing and project assessment. The authors compare the scope and assessment methods of several projects undertaken for evaluating externalities in European countries. The comparison is based on three main criteria i.e. the elements considered under a specific category, the valuation method and the obtained values. Bickel et al. (2006a) provide recommendations on computation methods for environmental (air pollution, noise, and global warming) and congestion costs.

The External Costs of Energy (ExternE) methodology (Bickel et al., 2005) deals with external costs evaluation. It is not specifically focused on transport but is relevant for this specific sector. The methodology contains five main stages: (i) definition of the activity to be assessed and of the background scenario, (ii) definition of the important impact categories and externalities, (iii) estimation of the impacts or effects of the activity in physical units, (iv) monetization of the impacts and finally (v) assessment of uncertainties, and sensitivity analysis. The Impact Pathway Approach (IPA), one of the most important contributions within the ExternE project, consists in a bottom-up approach focused on air pollution external costs.

Bickel et al. (2006a) provide cost factors for road transport emissions (global warming and air pollution), for noise exposure and for congestion (value of travel time saving) per country. The focus is on European states. Bickel et al. (2006b) develop the practical application of the HEATCO methodology. Four specific transport links are taken as case studies respectively in Italy, United Kingdom, Greece and Denmark.

Bickel et al. (2006c) determine the total environmental costs of 18 countries in Europe for road, rail and air transport. Marginal costs for a number of specific routes and locations are also determined. The authors conclude that if Europe charges only on transport costs and ignores environmental costs, road and air transport are favoured compared to rail transport.

Very few studies focus on general external cost functions formulations. To the best of our knowledge, only Janic (2007, 2008) determines generic cost functions for rail and road transport. No comparative study has been found for inland waterways transport.

Janic (2007) compares intermodal transport using rail with road transport. He develops external cost functions. The author applies his model to the European case study and concludes that internalizing external costs leads to an increased breakeven distance between road and intermodal, compared to the situation in which only operational costs are considered. Internalization of external costs would thus reduce intermodal competiveness. It calls into question the European willingness of internalization policy for shifting goods from road to more environmentally friendly modes of transport.

Janic (2008) compares the performance of Conventional Intermodal Freight Trains (CIFTs) and Long Intermodal Freight Trains (LIFTs). The author concludes that, when full costs are considered, the use of LIFTs instead of CIFTs shortens the breakeven distance between intermodal transport and road transport from 1000 to 700 km.

Maibach et al. (2008) identify in a comprehensive manner the different approaches and default values used for estimating external costs in the literature. The costs of European countries are analysed. The authors compare average and marginal costs from the content and implementation perspective. Best-practice valuation methods are highlighted and detailed for each cost component. Numerical information is provided at two levels i.e. input and output levels. The input values refer to specific data that can be used for determining the external costs values. The output values are estimated default unit values of external costs for different traffic situations. For each type of cost, a comparative analysis of the covered elements and results values of different studies is provided.

Van Essen et al. (2008) realise an analysis of internalization approaches and assess the impact of each of them. The objective is to evaluate these internalization processes in order to determine how to organise the European infrastructure pricing policy. The main conclusion states that current tax and charge structure fails to reflect marginal costs, especially for road transport. The authors recommend internalizing external costs through a kilometre based charge. Carbon content based fuel taxes or emission trading are emphasised for climate change cost while road pricing schemes can be used for mitigating the accidents costs.

Delucchi and McCubbin (2010) provide a review of the different methods and issues for computing the external costs of each mode of transport in the USA. Based on this review, they summarize the existing external costs values of congestion delays, accidents, air pollution, climate change, noise and water pollution.

Janic and Vleugel (2012) develop a method for identifying and analysing potential savings in externalities achieved by substituting road transport with rail in the CREAM freight corridor which connects the Benelux countries and Turkey/Greece. The externalities are valuated thanks to average cost values provided in Maibach et al. (2008). It results that, on the CREAM freight corridor, moving goods by trains would lead to external costs that represent only one third of the costs generated when using trucks.

Michiels et al. (2012) apply the IPA for determining the marginal health costs of PM2.5 and NOx emissions. They expect the health external costs to differ broadly from one European country to another and thus focus on the case study of Belgium. The effects are split into domestic (inside Belgium) and foreign (outside Belgium) costs. The authors provide 2007 values for specific conditions of road transport (urban, motorway and rural) in the domestic market.

Cravioto et al. (2013) identify average and total external costs of road transport in Mexico. The authors focus on passenger and freight transport and thus compare externalities of cars, buses and trucks. They conclude that transport by car generates the highest total external costs, followed by transport by trucks and by buses. The authors also provide a comparison of their results with other international regions on the basis of different criteria: total external costs, average external costs, external costs per capita and external costs as a percentage of gross domestic product. Most of the comparisons result in external cost levels in Mexico below those of developed regions but slightly above developing ones.

Based on the methodology of Maibach et al. (2008), Pérez-Martínez and Vassallo-Magro (2013) determine the evolution over time between 1993 and 2007 of the marginal external costs of road and rail freight transport in Spain. They conclude that, even if the external costs of road transport decrease by 44% and those of rail transport increase by 12% over this period, external costs of rail remain eight times lower than those of road in 2005.

In 2014, Ricardo-AEA issues an update of the "Handbook on estimation of external costs in the transport sector". The objective is to highlight the new developments that appeared in research and policy since the initial report of Maibach et al. (2008).

van Lier (2014) proposes an external cost calculator framework for transport. He focuses on marginal external costs and proposes applications of this framework to different case studies of passenger and freight transport. The external cost calculation framework is developed on the basis of four methodologies, i.e. geographic information system based model, discrete event simulation, life cycle assessment and survey methods.

Besides external costs computations, some studies focus more on internalization policies (e.g. Beuthe et al., 2002, Macharis et al., 2010, Moliner et al., 2013, Agarwal et al., 2015, Austin, 2015). Optimisation objectives can also be attributed to external costs of transport (e.g. Musso and Rotengatter, 2013, Zhang et al., 2013). External cost papers can focus on a specific cost type, a particular mode, multimodal transport or a defined transport entity such as a port or a terminal.

The literature on external costs of road and intermodal freight transport does not only rely on academic production but is also considerably based on project-related papers. This shows the practical interest in tackling the issue of internalization of external costs of transport. The main objective of most of the papers is to determine the specific external costs values for different modes of transport. Indeed, more than 70% of the reviewed literature focuses on concrete evaluations of external costs, or on the impact on several internalization policies. Research on external costs of transport is therefore not only of theoretical scientific interest but has concrete applications in the real world. A smaller fraction of the analysed papers concentrates on the methods that exist and that are appropriate to correctly evaluate the external costs of transport. This small amount of reference literature is not very surprising since these documents summarise all the current knowledge and best practices in the field. They are used by a lot of application papers in order to choose the correct methodology. Finally, only two papers define external costs functions that combine mathematically the different parameters that influence externalities. The lack of research in this specific area is damageable, since sensitivity analyses of these functions allow explicitly identifying the key parameters that ensure transport competitiveness, when external costs are internalised.

In the following section, we look more deeply at the mathematical external costs functions found in the literature and propose a sensitivity analysis of different parameters of these functions, in order to determine the main factors which influence the competitiveness of road and intermodal transport, in terms of external costs.

Table 1. Summary of the main external costs characteristics studied in the literature

Author	Air pollution	Climate change	Noise	Accidents	Congestion	Costs: Average (A) Marginal (M) Total (T)	Perspective: Academic Project-based	Objective Prescription Application Projection
Forkenbrock (1999)	X	X	X	X		A	Academic	Application
Forkenbrock (2001)	X	X	X	X		A	Academic	Application
Sansom (2001)	X	X	X		X	A, M	Project-based	Application
Mayeres (2001)	X	X		X	X	M	Project-based	Application
RECORDIT (2001)	X	X	X	X	X	M	Project-based	Application
Beuthe et al. (2002)	X	X	X	X	X	M	Academic	Application
INFRAS/IWW (2004)	X	X	X	X	X	A, M, T	Project-based	Application
CAFE (2005)	X					M	Project-based	Application
HEATCO (Odgaard et al., 2005)	X	X	X		X	A, M, T	Project-based	Prescription
ExternE (Bickel et al., 2005)	X	X		X		M	Project-based	Prescription
HEATCO (Bickel et al., 2006a, 2006b)	X	X	X		X	A	Project-based	Application
Bickel et al. - UNITE(2006c)	X	X	X			M, T	Project-based	Application
Janic (2007)	X		X	X	X	A	Academic	Projection
Janic (2008)	X		X	X	X	A	Academic	Projection
Maibach et al. (2008)	X	X	X	X	X	A, M	Project-based	Application
Van Essen et al. (2008)	X	X	X	X	X	M	Project-based	Prescription
Delucchi and McCubbin (2010)	X	X	X	X	X	M	Academic	Prescription
Macharis et al. (2010)	X	X	X	X	X	M	Academic	Application
Janic and Vleugel (2012)	X	X	X	X	X	A	Academic	Application
Michiels et al. (2012)	X					M	Academic	Application
Cravioto et al. (2013)	X	X	X	X	X	A, T	Academic	Application
Moliner et al. (2013)			X			A	Academic	Application
Pérez-Martínez and Vassallo-Magro (2013)	X	X		X		M	Academic	Application
Ricardo-AEA (2014)	X	X	X	X	X	A, M	Project-based	Application
van Lier (2014)	X	X	X	X	X	M	Academic	Prescription
Agarwal et al. (2015)	X	X			X	M	Academic	Application
Austin (2015)	X	X		X	X	A, M	Project-based	Application

4. External Costs as Competitiveness Factors

The previous literature review shows that papers rarely focus on the development of generic mathematical functions that allow for determining the value of external costs. However, the use of these functions is very helpful to define the main parameters that ensure the competitiveness of transportation modes. This section aims at highlighting the interest of such functions in the identification of competitiveness factors of road and intermodal transport. A sensitivity analysis of the functions of Janic (2007, 2008) is provided in order to emphasise the key elements that have to be tackled in further research in the field. Best-case and worst-case scenarios are compared to the reference scenario, in order to determine the key issues that influence transport competitiveness.

A common tool to evaluate the competitiveness of transportation modes is to compare their breakeven distance, i.e. the distance at which two modes of transport have the same cost. Below and above this breakeven distance, one mode is more advantageous than the other one.

According to Kim and Van Wee (2011), the elements that influence the breakeven distance of intermodal freight transport for operational costs can be classified into two categories: geometric and cost factors. These two categories are also valid for external costs. However, based on the sensitivity analysis of the generic costs functions of Janic (2007, 2008), we also identify a third category called weight factors. This class includes the load factor of the vehicle and the density of the transported goods. Finally, by reconsidering the classical hypothesis that demand for flows decreases with the distance, we highlight the importance of the management of flows on the breakeven distance. Flow management factors are thus grouped in a fourth category which tackles the issues of freight consolidation and transport reliability and flexibility. The analysis first focuses on geometric factors of intermodal transport and thus deals with PPH distances issues and terminal location scenarios. The effects of the weight (load and density) factors are then analysed. We finally highlight the importance of freight consolidation and of the reliability and flexibility of transport services (flow management factors) in terms of external costs.

4.1. Reference Scenario

We use the cost functions of Janic (2007, 2008) for analysing the factors that influence transport external costs. The reference scenario reflects the main hypotheses assumed by Janic (2007, 2008) for the European case-study. Door-to-door transport costs by road are determined thanks to internal and external cost functions for long-haul travels. Intermodal transport costs are constituted by internal and external (i) PPH costs by road, (ii) transshipment costs at the intermodal terminals and (iii) long-haul costs by rail.

For rail transport, we use the cost function of Janic (2008) but slightly modify the term which represents the transshipment external costs. This term is multiplied by a factor two for considering the transshipment that happens both at the origin and destination terminal. The rail internal cost function for one train is provided by

$$(4.60n_l + 0.144n_w + 0.3)s + 12.98(n_l + n_w) + 5.6q + 0.0019Ws + \sum_{l=1}^{L}\left[0.227 * \frac{10^{-6}v_l^2}{\ln(d_l)} + 0.000774\right]Ws + 33n_d\left(t_{dp} + \frac{s}{v} + D\right), \quad (1)$$

and the rail external cost function by

$$0.000128Ws + 2 * 0.0549q + \sum_{l=1}^{L}\left[1.889 * \frac{10^{-7}v_l^2}{\ln(d_t)} + 0.00064\right]Ws + 0Ws + 5.6s\overline{D}_m. \quad (2)$$

The internal cost function (1) is constituted by six terms: the unit cost of depreciation and maintenance of the rolling stock and monitoring of the train, the unit cost of assembling/decomposing the train at both ends of the corridor, the unit transshipment cost at the intermodal terminals, the unit cost of using the rail infrastructure, the unit cost of the energy consumption along the line with L segments and finally the unit cost of the train's driver.

The external cost function (2) is composed of five principal terms: the unit cost of noise, the unit external cost of transshipment at the intermodal terminals, the cost of air pollution due to the energy consumption, the cost of traffic accidents and finally the unit external cost of congestion. This last term is omitted because we assume an uncongested rail network.

q stands for the net weight of the goods transported and is equal to 702 tonnes. W is the gross weight of the train and is equal to 1606 tonnes since the empty train is estimated at 724 tonnes and the train loading at 882 tonnes. We assume an average weight of 12 tonnes transported in one 20' container (Black et al., 2003 and Janic, 2007, 2008).

One train consists in 26 flatcars. Each flatcar contains three 20 foot load units. Each unit weighs 14.3 tonnes, i.e. 12 tonnes of freight and 2.3 tonnes of tare. A load factor of 0.75 is assumed (Black et al., 2003). The load factor is defined as the ratio of the average load to total vehicle freight capacity (EEA, 2010). The load factor represents the utilization of the available capacity in terms of weight.

Road external costs are split into short-haul (assumed average PPH distance of 50 km) and long-haul (road-only) travels (Janic, 2007). A load factor λ of 0.85 and 0.60 is respectively used for long-haul and short-haul journeys (Black et al., 2003). The internal and external cost functions are non-linear with the distance travelled and are expressed in €/t.km. We assume that a full truck contains two 20 foot load units. Cost functions of Janic (2007) are provided by vehicle.km. The cost per t.km is obtained by dividing the coefficient of the cost function by a factor 14.4 (2*12*0.60) for short-haul transport and by a factor 20.4 (2*12*0.85) for long-haul transport. These amounts correspond to the number of tonnes effectively transported by a truck over short- or long-haul transport. For long-haul travels, the internal cost function is $0.2676\mathrm{d}^{-0,278}/(\mathrm{t.km})$ and the external cost function is $0.4843\mathrm{d}^{-0,624}/(\mathrm{t.km})$. For short-haul travels, the internal cost function is $0.3791\mathrm{d}^{-0,278}/(\mathrm{t.km})$ and the external cost function is $0.6861\mathrm{d}^{-0,624}/(\mathrm{t.km})$. These cost formulations imply that an increase in the handled quantities does not lead to economies of scale and therefore does not result in reduced average road costs per t.km.

Full costs of transport refer to the sum of internal and external costs. The remaining parameters of the internal and external costs functions used in this section are detailed in table 2.

Table 2. Parameters and reference values of the internal and external cost functions

Parameter	Definition	Value	Unit
n_l	Number of locomotives per train	1	locomotive
n_w	Number of flat wagons	26	flat wagon
s	Long-haul distance	25-1600	km
q	Net weight of the goods transported	702	tonne
W	Gross weight of the train	1606	tonne
l	Number of segments between origin and destination terminal	1	segment
v_l	Train commercial speed on segment l	60	km/h
d_l	Distance of segment l	25-1600	km
n_d	Number of drivers	1	driver
t_{dp}	Driver's preparation and finishing time before and after the trip	1	hour
v	Train commercial speed along a given line	60	km/h
D	Anticipated delay of a train running between two intermodal terminals	1	hour

Road and intermodal using rail transport are compared based on the assumption that the distance between two intermodal terminals on rail (s) is equal to the door-to-door distance by road (d). For comparing fairly intermodal and road transport, an additional PPH distance must thus be added to the total kilometres travelled using intermodal transport. For instance, a travel of 500 km by road is thus compared with a long-haul travel by rail of 500 km and a PPH of 50 km each. This assumption reflects an average situation for which the additional kilometre that must be performed when using intermodal transport are taken into account.

Costs and breakeven distances are computed for distances comprised between 25 and 1600 km, distances for which the cost functions of Janic (2007) are valid. The breakeven distance has to be understood as the road distance (d) at which intermodal transport becomes more interesting than road transport.

According to the reference values of the cost functions of Janic (2007, 2008), the breakeven distance between road and intermodal transport for internal costs (925 km) is lower than the breakeven distance for full costs (1100 km). In addition, there is a convergence of the internal and full costs, both for road and intermodal transport, meaning that unit external costs decrease with the distance. PPH distances of intermodal transport are assumed to be 50 km. The values of PPH external costs thus remain the same, whatever the distance travelled. However, if the long-haul distance increases, these PPH road external costs can be split into more kilometres. For intermodal transport, it therefore leads to decreasing external costs with the distance travelled. The decrease of road transport external costs along with the distance is linked to the definition of the cost function, which reflects economies of distance (figure 1).

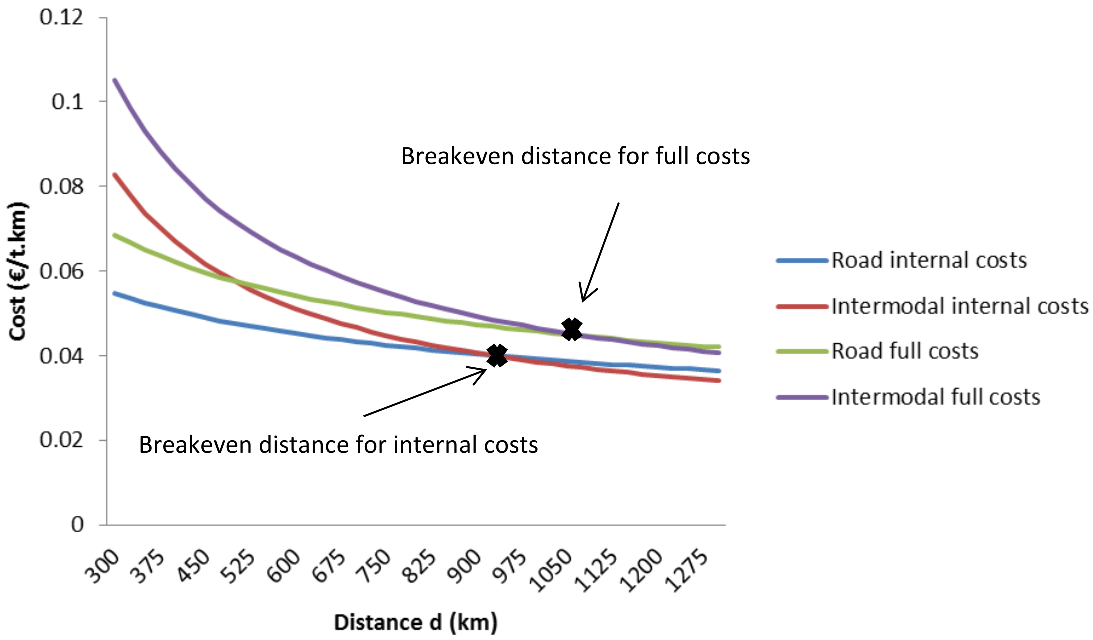

Figure 1. Evolution of internal and full costs with the distance travelled, for road and intermodal using rail transport – Reference scenario

4.2. Geometric Factors

This chapter analyses the effects on the breakeven distance of PPH distances and several location scenarios. The focus is therefore on drayage external costs. Intermodal drayage costs are generated during the road operations of the PPH travels by truck (Caris et al., 2013). Drayage external costs thus refer to the externalities that are generated during the road travel between the pick-up at the origin node and the delivery at the first intermodal terminal, or between the pick-up at the second intermodal terminal and the delivery to the destination node.

4.2.1. PPH distances.

Considering a PPH distance of 50 km refers to the basic scenario of Janic (2008) and thus to an average European situation. However in some countries, the part of intermodal transport is higher than the average European one and PPH distances are thus smaller.

This is in particular the case in Belgium (Eurostat, 2013) where the modal share in t.km of road transport is 66.3% (75.5% for Europe), the modal share of inland waterways is 18.5% (6.2% for Europe) and the modal share of rail is 15.2% (18.4% for Europe). Verhetsel et al. (2013) study the impact of accessibility on the location of logistics centres in Flanders. They observe that most of the 235 main logistics sites are located within 10 km of a rail and inland waterways terminal.

In this sensitivity analysis, we study the impact on the breakeven distance of PPH distances of 50 km (reference scenario), 10 km, 5 km (Verhetsel et al., 2013) and 0 km. The latter case consists in comparing road versus rail-only transport, which represents the possibility of door-to-door travels by rail, thanks to private sidings. Table 3 summarises the values of the breakeven distances for internal and full costs of the different scenarios.

Table 3. Breakeven distances for internal and full costs

	Breakeven distance for internal costs (km)	Breakeven distance for full costs (km)
Road vs. intermodal with PPH= 50	925	1100
Road vs. intermodal with PPH= 10	300	300
Road vs. intermodal with PPH= 5	225	200
Road vs. intermodal with PPH= 0	No cost convergence	No cost convergence

With a PPH of 50 km, the breakeven distance increases between internal and full costs consideration. This means that intermodal transport becomes less quickly attractive if external costs are taken into account. In the contrary, a shorter PPH distance leads to an identical (for PPH = 10 km) or decreased (for PPH = 5 km) breakeven distance from internal to full costs consideration. This tends to show that intermodal transport is more rapidly competitive if external costs are internalized. The comparison between rail-only (intermodal with PPH= 0) and road transport leads to no breakeven distance, since the costs of rail are always lower than the ones of road, both for internal and full costs. The results of this sensitivity analysis show the importance of the proportion of PPH costs in total costs of intermodal transport. The difference in trend between internal and full costs breakeven distances is explained by external costs variations between intermodal and road transport. If the PPH distances increase, road external costs of these PPH travels increase considerably the total full costs of intermodal transport, leading to a longer breakeven distance between road and intermodal transport. External costs of road transport are higher than external costs of rail transport. If the PPH distances of intermodal transport become too long, then the long haul travel by rail cannot compensate anymore for the higher external costs of the PPH costs by road. This means that the internalization of external costs leads to a longer breakeven distance for full costs than for internal costs. In order to allow rail transport to compensate for the negative impacts of road transport in terms of externalities, PPH distances must thus be reduced as much as possible.

Figure 2 shows the different external costs of transport, according to the considered scenario. The external costs of rail-only transport are always lower than the external costs of road transport (on an identical distance). For a PPH distance of 5 km, intermodal transport external costs are lower than road transport external costs around a distance of 125 km, against 300 km for a PPH distance of 10 km. When considering a PPH distance of 50 km, the external costs of intermodal transport are always higher than the ones of road transport. However intermodal external costs decrease more quickly with the distance travelled than road external costs.

The results of this analysis confirm that the PPH operations are very important for the competitiveness of intermodal to road transport. Indeed it comes out of the results that small PPH distances lead to lower external costs for intermodal than for road transport. In the case of small PPH and with the internalization of external costs, intermodal transport becomes more rapidly competitive in terms of distance than when only internal costs are taken into account. On the other hand, for longer PPH distances, external costs internalization leads to a lower competitiveness of intermodal transport, i.e. to a higher breakeven distance than when only internal costs are considered.

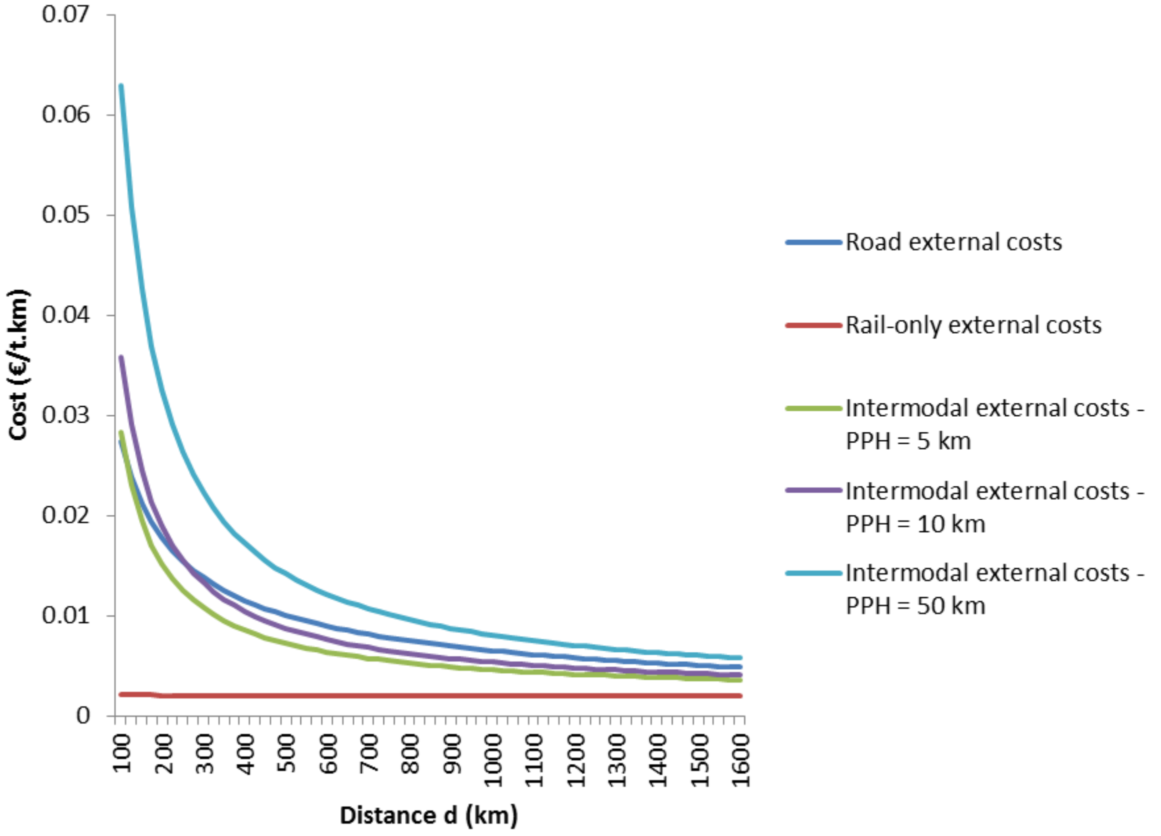

Figure 2. Comparison of road and intermodal external costs with different PPH

4.2.2. Location scenarios.

Until now we considered that the rail distance was equivalent to the door-to-door distance by road (i.e. between the origin and the destination nodes). Figure 3 illustrates the two extreme situations under the alignment condition. The origin A and destination B represent the best-case scenario for intermodal transport whereas the origin C and destination D represent the worst-case scenario for intermodal transport. T1 and T2 stand for the origin and destination terminals.

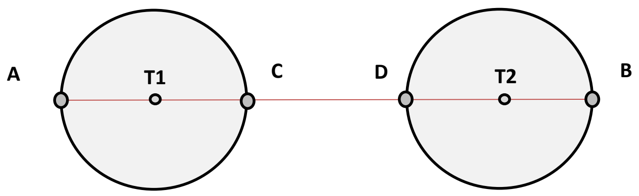

Figure 3. Location of origin and destination nodes in relation to origin and destination terminals

It is first to notice that the circle determined around a terminal by a specific average PPH distance must not be mixed up with the terminal market area. In our example this circle represents the potential origin/destination nodes that can be served by the terminal. In the contrary the rail market area is defined as the set of all the points around the terminal for which intermodal transport using rail is less expensive than road-only transport. The shape of the terminal market area is part of the family of Descartes' ovals (Niérat, 1997). The border of the market area represents all the points for which road and intermodal using rail transport have the same cost. Limbourg and Jourquin (2010) discuss the shape of this market area around intermodal terminals.

In the reference scenario, a comparison is made between road and intermodal using rail transport, based on the hypothesis that the long-haul transport by rail is equal to the door-to-door transport by road (s=d). In the best-case scenario for intermodal transport, the transport distance by rail is determined as $s = d - 2 * p$, where p stands for the PPH distance. In the worst-case scenario for intermodal transport, the transport distance by rail is defined as $s = d + 2 * p$. This instance is very simple since it assumes that the road and rail network are equivalent in terms of pathway, which is generally not the case.

Table 4. Sensitivity analysis of the breakeven distance for internal and full costs to the location scenario

Scenario	Breakeven distance for internal costs (km)	Breakeven distance for full costs (km)
Reference scenario: s = d	925	1100
Best-case scenario: s = d-2p	750	875
Worst-case scenario: s = d+2p	1150	1375

The relation between the door-to-door distance by road and the long-haul distance by rail impacts the competitiveness of intermodal transport (table 4). Both internal and external costs are affected by the relation between rail distance and door-to-door distance by road. The breakeven distances for internal and full costs are thus both modified. However the variation of the breakeven, in relation to the reference scenario, is a little bit higher for full costs than for internal costs. Indeed, for the best-case scenario, the variation is -18.9% for internal costs against -20.4% for full costs. For the worst-case scenario, a variation of +24.3% is observed for internal costs against +25% for full costs.

The location scenario, and therefore the distances on which road and intermodal using rail transport are compared, also impacts the external costs of transport and the full costs breakeven, but to a lesser extent than the PPH distances. These results confirm the importance of drayage operations for external costs generation and therefore transport competitiveness.

4.3. Weight Factors

This section focuses on how the competitiveness of transport is affected by the load and density aspects.

4.3.1. Load factors.

The load factor has been defined as the percentage of the available capacity of the vehicle that is effectively used. The load factor influences externalities of transport (Maibach et al., 2008) and therefore impacts the competitiveness of transport modes when external costs are internalised. The load factor of rail transport is varied in order to analyse its effects on external costs and breakeven distances. The best-case scenario for intermodal transport refers to a load factor of 1, meaning that the full capacity of the train is used. The worst-case scenario is determined using a load factor of 0.5 (EEA, 2010). Table 5 provides the different breakeven distances.

Table 5. Sensitivity analysis of the breakeven distance for internal and full costs to the rail load factor

Scenario	Breakeven distance for internal costs (km)	Breakeven distance for full costs (km)
Reference scenario: λ_{rail} = 0.75	925	1100
Best-case scenario: λ_{rail} = 1	675	750
Worst-case scenario: λ_{rail} = 0.5	No cost convergence	No cost convergence

The results show that the internal and external breakeven distances are sensitive to the rail load factor. As expected, an increased load factor for rail favours intermodal transport competitiveness. The comparison of the reference and best-case scenario shows that the breakeven distance for full costs decreases more (-31.82%) than the breakeven distance for internal costs (-27.02%). Again, external costs seem even more sensitive than internal costs to the load factor. When considering a load factor of 0.5, no breakeven distance is found between intermodal and road freight transport since road transport is always cheaper. The load factor of rail transport is therefore an important element in the decision of using intermodal transport, both from the economic and sustainable point of view.

A half loaded train is thus not sufficient for achieving intermodal competitiveness. A deeper analysis determines that, under the reference scenario hypotheses, a minimum rail load factor of 67% is required for intermodal transport to become competitive from the full costs point of view. This rail load factor decreases to 63% for achieving intermodal competitiveness from the internal costs point of view.

4.3.2. Density factors.

The reference scenario assumes that a 20' container contains on average 12 tonnes of freight. This hypothesis stands for average density goods. However the weight can vary depending on the heaviness or lightness of goods (Black et al., 2013). We analyse the effect on transport competitiveness of such a density modification. We assume that heavy goods have to be transported, meaning that an average load of 22 tonnes is considered. This corresponds to the maximum load of a 20' container according the ISO standards. As expected, the breakeven distances for both internal and full costs decrease respectively to 550 and 625 km. The breakeven variation is again more important for internal (-40.5%) than for full (-43.3%) costs, meaning that external costs are more sensitive than internal costs to density. Nevertheless, the variation of external costs is not sufficient for reducing the breakeven for full costs to a distance lower than the breakeven for internal costs.

4.4. Flow Management Factors

The hypothesis of Janic (2007), stating that demand flows generally decrease while the distance increases, is in particular supported by the transport gravity generation model (Ortúzar and Willumsen, 2011, Rodrigue et al., 2006). However, consolidation of flows is one technique that allows for generating higher demand on long distances. Consolidation is a critical issue for transport actors and bundling strategies can be classified into five basic bundling types (Kreutzberger, 2010). For barge transport, bundling can be achieved through cooperation between inland terminals, which leads to aggregate flows generation (Caris et al., 2012, Konings et al., 2013). The use of freight corridors allows avoiding flow reductions over longer distances. Increased distances between origin and destination nodes are thus not necessarily synonym of reduced intermodal competitiveness.

Transport reliability must also be considered for comparing different modes of transport in a fair way. Reliability refers to transit/lead time variability (Dullaert and Zamparini, 2013). Reliability has effects on external costs and thus impacts the transport mode competitiveness. Indeed the unreliability of a mode of transport, especially in the case of intermodal transport, can lead to the missing of the connection with the following mode in the chain. This situation generates increased external costs that result, for instance, from the additional storage or handling operations that are required.

Transport flexibility is another element that influences the external costs of transport. This notion is related to the concept of synchromodal transport. The idea is for the shipper to let the freedom to the logistics service provider (LSP) to choose the transport modes during the travel (DINALOG, 2013). The LSP is thus able to dynamically select the best way of traveling according to the current traffic, time, weather, service level, environmental or costs conditions (SteadieSeifi et al., 2014, Verweij, 2011). The main challenges are related to the coordination and optimal use of modalities. If this improved connection between modes is achieved, it allows for more sustainability because it helps in reducing the number of operations and the storage time that are responsible for external costs (e.g. noise or pollutants). Synchromodality thus refers to the efficient use of intermodal transport. The design of such a transport system has recently been studied by Fan (2013).

5. Discussion

Based on the literature review and on the analysis in the last section, we discuss the use of externalities, marginal or average costs for integrating external effects. The cost functions studied in the previous section only refer to road and intermodal rail transport. However, intermodal inland waterways transport is also recognized for its benefits in terms of externalities. We thus give some insights for further research topics on this particular mode.

The literature review shows that external costs of transport are not only of academic but also of real-life and project-based interests. Most of the papers deal with the topic of concretely evaluating the external costs values of specific modes of transport, or the impact of different internalization policies in the competitiveness of modes. Very few studies focus on the identification of generic mathematical functions that define average costs of transport. However, these functions have been proven to be very useful to identify the main competitiveness factors in terms of external costs.

The analysis in the previous section deals with average costs estimations. Nevertheless, even if identifying the competitiveness of one mode of transport based on average costs is relatively easy and provides general recommendations, the use of average costs may lead to a lot of variations. External costs can appear in various situations such as different means of transport, vehicle technologies, road types, time periods, traffic conditions, geographical zones characteristics, population densities and standards of living. Some of these elements are related to the externality itself. A higher slope means for instance higher fuel consumption (Demir, 2012) and thus more emissions of pollutants. Other elements are linked to the valuation aspects. For instance an additional decibel in an already noisy environment will be valued less than in a very calm area (Bickel et al., 2006). The particular circumstances of the external costs generation cannot thus be totally reflected in average costs.

The choice for the type of considered costs must therefore carefully be achieved. For general strategic issues, i.e. for the identification of the main factors that influence the competitiveness of road transport, we recommend the use of average external costs functions.

However, if the focus is on a specific case-study (papers grouped under the “application” category), the marginal cost approach seems more appropriate to identify the external costs values. Indeed, this method provides more reliable results for a well-defined problem in terms of geographical area or vehicle type. The scope of the external costs analysis can focus on the emissions related to the use of the transport mode (tank-to-wheel analysis), on the production phase (well-to-tank analysis) or on both aspects (well-to-wheel analysis, e.g. Hoffrichter et al., 2012). For the geographical issue, we suggest the definition of a specific corridor on which comparisons of different modes of transport can be achieved.

Instead of focusing on costs, one can also consider the externality itself, in non-monetary units. Under this situation, it is easy to compare different modes of transport for a same type of external effect. For instance carbon dioxide emissions can simply be evaluated since they are virtually proportional to fuel consumptions (Kirby et al., 2000). However the use of the externality unit instead of its cost may lead to difficulties in comparing two different types of externality (e.g. noise and air pollution).

Externalities, average costs functions and marginal costs values should thus be used in a complementary way, depending on the specific issue that is addressed. Average costs functions better suit the objectives of identifying strategic competitive factors, while marginal costs values are more appropriate for application to specific case studies. The use of externalities in non-monetary units allows for less variation in the estimation, although it suffers from the difficulty to compare external costs of different units.

Also, the determination of external cost values or functions is generally an iterative procedure, based on related earlier studies. However, in order to account for the evolution of technologies (e.g. EURO norms for trucks), there is an important need for actualising these values and functions with up-to-date data.

Finally, several studies deal with external costs of inland waterways transport (see for instance Beuthe et al., 2002, Brons and Christidis, 2012 in the framework of the European Marco Polo project, Caris et al., 2013, Ricci and Black, 2005 or van Lier and Macharis, 2010). The above analysis has been developed for the evaluation of road and intermodal using rail transport costs. In the literature, we did not find any similar cost functions to those provided by Janic (2007, 2008) for inland waterways transport. However, it has been showed for intermodal rail transport that these generic functions considerably help in identifying the main competitiveness factors of a specific mode. Some of the results obtained for rail transport should also be valid for inland waterways transport, such as results related to drayage distances and location scenarios. Further research work should nevertheless be performed in this direction, in order to confirm these statements.

6. Conclusions

This paper focuses on the identification of external costs as competitive factors of freight transport. After a review of the basic methodology and definitions related to the topic, an analysis of the recent literature is provided. Very few papers in this field focus on the development of generic mathematical functions of external costs. However, the latter are very useful to strategically identify the main factors that influence the competitiveness of transport in terms of external costs. For illustrating the usefulness of such functions, a sensitivity analysis of the parameters of the functions developed by Janic (2007, 2008) is provided in the context of the internalization of transport external costs.

The analysis of the functions of Janic (2007, 2008) highlights the importance of drayage operations external costs. Indeed, the PPH distances and location scenarios clearly influence the competitiveness of transport, when external costs are internalized. The load and density factors also impact transport competitiveness but to a lesser extent. Furthermore, the way in which flows are managed also influences the amount of generated externalities, and thus the competitiveness of different transportation modes.

Further research topics on freight transport and environmental effects clearly have to consider the decisions related to the location of intermodal terminals. Indeed, depending on the commercial density of their surrounding areas, terminal locations determine the level of consolidation and thus the load factor. Furthermore, terminal locations also define the PPH distances of the companies that they disserve. These factors have been identified as competitiveness attributes for intermodal transport full costs. Location decision problems have thus to integrate environmental issues and focus on both rail and inland waterways transport.

The use of generic mathematical functions dealing with average costs is useful for identifying the strategic competitiveness factors of freight transport. Nevertheless, this method should be considered in a complementary way with other approaches, such as the use of marginal costs. This solution is more appropriate for representing a particular case-study with all its specificities. In order to avoid errors in the monetisation of costs, externalities themselves can also be directly taken into account. External cost values and functions require regular updates along time to account for the quick evolution of technologies.

Finally few articles deal with the definition of generic functions for external costs computation. In this paper, the usefulness of such kinds of functions has been practically shown for road and intermodal rail transport. No formulation was found in the literature to determine the external costs of inland waterways transport. Some research should also be performed in that direction.

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