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Generalized transport costs in intermodal freight transport

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Abstract

Intermodal transport solutions, implying non-road freight transport on the long-haul, can contribute to the advance of more energy efficient transportation systems. This paper presents a model for analyzing the generalized transport cost of an intermodal transport solution. We find that the required long-haul distance required to make intermodal transport preferable increases when (1) handling costs at terminals increases, (2) total transport distance increases, (3) pre- and posthaulage costs increase, (4) distance dependent marginal generalized costs for rail increases, (5) the distance dependent marginal generalized costs for truck decreases and (6) reduced resting costs for truck drivers. The model results are discussed in light of transport of fresh aquaculture products from Norway to Continental Europe.

Keywords: Intermodal transport; transport distance; generalized transport cost; freight transport policy

1. Introduction

Intermodal transport is the movement of goods in one and the same loading unit or vehicle that successively uses two or more modes of transport without handling the goods themselves in changing modes (UN/ECE, 2001), and where most of the route is travelled by rail, inland waterway or ocean going vessel (Macharis and Bontekoning, 2004). As it is widely accepted that non-road modes are less energy intensive than road freight (Woodburn et al., 2007), a transition from road-only transport to intermodal transport can make freight transport more energy efficient.

Following ever-growing freight transport volumes and increasingly congested roads, intermodal transport has been put high on the agenda of public and private players in the transport industry (Bontekoning and Priemus, 2004. The idea behind intermodal transport is to utilize the strengths of different transport modes in one integrated transport chain (Flodén, 2007), thereby improving the

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economic performance (Rodrigue et al., 2009).

It is the goal of the transport policy within the European Union to establish a sustainable transport system (European Commission, 2009) and the successful promotion of intermodal transport has been identified as the most critical action in order to achieve this (Tsamboulas et al., 2007). Thus, intermodal transport is promoted through policies that are addressed at all political levels (Macharis et al., 2011). However, the growth in intermodal transport has not lived up to expectations (see e.g. Janic, 2007), suggesting that the implemented policies have failed.

To make intermodal transport a preferred alternative to road haulage, generalized transport costs would have to be equal or lower (van Klink and van den Berg, 1998), thus the extra costs due to pre- and post-haulage (PPH) as well as transshipments at the intermodal terminals must be offset by the lower costs of the long-haul transport (Bärthel and Woxenius, 2004). The aim of the paper is to develop a model framework for assessing the generalized transport costs in intermodal freight transport. The results from the model can be used by policy makers when aiming to improve the competitiveness of intermodal transport.

The structure of the paper is as follows. In Section 2, we review recent research on intermodal freight transport. Then, in Section 3, we develop a model on the relationship between transport distance and generalized costs which are related to intermodal transport chains in Section 4. The relevance of the model is illustrated in Section 5, using empirical data related to intermodal transport of fresh fish from Norway to central Europe. Finally, conclusions and implications are presented in Section 6.

2. Intermodal Transport

2.1. The intermodal transport chain

The introduction of the container in freight transport in the late 1950s was a major technological advance with significant economic consequences (Levinson, 2006). Being first introduced in the shipping industry, it was a major contribution to the development of intermodal transport as it made transfer of freight from one mode to another more efficient (Muller, 1995). Later, the development of intermodal transport, as an alternative to road only transport, has been supported through public policies (Rodrigue et al., 2009). An important policy contribution was the White Paper on Transport entitled *European Transport Policy for 2010: Time to Decide* (European Commission, 2001), which emphasized sustainable transport and established that increased efficiency and competitiveness of alternatives to road transport is critical to achieve this.

Intermodal transport systems consist of finely distributed distribution/collection systems, utilizing the flexibility of road transport, a roughly distributed long-haul system and terminals that connect the transport modes (Flodén, 2007). The components of the intermodal transport network are presented in the subsequent sections.

2.1.1. Pre- and post-haulage (PPH)

Road transport is often assigned to collection and distribution of goods in intermodal transport networks (Bergqvist and Behrends, 2011), allowing intermodal transport solutions to offer finely distributed distribution and collection systems with door-to-door services. Pre-haulage typically involve the provision of an empty container to the shipper and subsequent transportation of a full container to the terminal, whereas post-haulage involve the distribution of a full container from the terminal to a receiver and the return to the terminal of an empty container (Macharis and Bontekoning, 2004).

The competitiveness of intermodal transport solutions does to a large extent depend on the costs of the PPH (Kreutzberger et al., 2006). PPH accounts for between 25% and 40% of the total cost of moving an intermodal loading unit (Macharis and Bontekoning, 2004). Moreover, since PPH has a larger cost, per tonne-km, compared with its share of the total distance in the transport chain (Bergqvist and Behrends, 2011), pre- and post haulage operations becomes increasingly crucial when the long-haul distance decreases (Bärthel and Woxenius, 2004). Consequently, increased efficiency of PPH operations is crucial for the competitiveness of intermodal transport.

2.1.2. Intermodal terminals

The core of intermodal networks is the terminals where goods and logistics providers physically meet and interact (Stokland et al., 2010) and are critical to making intermodal transport networks competitive (Woxenius and Barthel, 2008). The cost of the transshipment of containers at an intermodal terminal is incurred regardless of the distance the container is to be transported (Rodrigue et al., 2009). Moreover, the high fixed cost of operating an intermodal terminal must be shared among many transshipments (Bärthel and Woxenius, 2004), suggesting considerable economies of scale.

The efficiency of an intermodal transport network depends on where the terminals are located (Limbourg and Jourquin, 2009). That trucking is eleven times as expensive, per tonne-km, than rail (Ballou, 2004), suggests that intermodal terminal ought to be located near the shipper/receiver (e.g. Hanssen and Mathisen, 2011), thereby minimizing trucking distance. However, intermodal terminals need a critical catchment area for efficient operations (Bergqvist et al., 2010).

By introducing information management systems, containerization and mechanization of loading and unloading activities, significant steps have been taken to make the terminal costs more efficient in the past few decades (Rodrigue et al., 2009). However, at least in Norway, intermodal terminals are still unable to provide seamless interconnectivity between transport modes (Stokland et al., 2010).

2.1.3. Long-haul shipment

The predominant modes of transport for the longest links in the intermodal transport chain are rail, inland waterways, short sea shipping or ocean shipping where units are consolidated and economies of scale apply (Bergqvist and Behrends, 2011). In some cases air transport is also an alternative, particularly for highly deteriorating goods where transport time is critical. The costs of transporting freight by these modes vary greatly. Estimates show that compared to transport by water, the average freight cost per tonne is 3 times as high for transport by rail, 35 times as high for transport by truck and 83 times as high for transport by air (Ballou, 2004). However, the low cost water transport is ranked as the slowest of these transport modes, while the high cost air transport is the fastest (Ballou, 2004). High value, time sensitive and fragile goods will therefore to a larger extent than low value, time indifferent and sturdy goods, be transported by air.

A decade ago, intermodal transport solutions became attractive at distances in excess of 500 km (van Klink and van den Berg, 1998). However, the break-even distance depends on the properties of the consignment and of the transport services (Janic, 2007) and has, during the last decade, fallen to 400 km (Tsamboulas, 2008). Thus, short- and medium-distance transports are still the domain of road transport (Bärthel and Woxenius, 2004). To further reduce the break-even distance, it has been proposed that freight trains should be given higher priority in the rail network (PROMOTIQ, 2000).

2.2. Factors influencing choice of transport solution

Knowledge about factors determining the choice of transport services is a key to understand the freight transport market and to design competitive transport systems (Flöden et al., 2010), and numerous studies have been conducted on transport service choices (for reviews see Meixwell and Norbis (2008), and Flöden et al.(2010)). A factor which is of great importance to transport purchasers is cost, and several studies have ranked it as the most important attribute when transport solution is chosen (e.g. Danielis and Marcucci, 2007; Punakivi and Hinkka, 2006). However, cost will often have to be traded against other quality measures.

Transport time, punctuality and frequency are important factors considered by transport purchasers. Average delivery time and delivery time reliability is often listed as the most important transportation characteristics (Ballou, 2004). However, the importance of transport time will depend on the time cost of the freight which is being transported. For example is perishable goods particularly time sensitive, with rough assessments indicating price reductions of between 20 and 25% for fresh fish which is delayed in transit by 48 hours (Lervåg et al., 2001).

The selection criteria of transportation mode are strongly dependent on the industry sector (Punakivi and Hinkka, 2006). Speed is, for example, a more important selection criterion for industries producing goods with high value/kg ratio and short life cycles, than for industries producing less time sensitive products. Consequently, pharmaceutical trade almost always goes from one continent to another by air freight, whereas road freight is the most important mode of transport for the constructional product industry (Punakivi and Hinkka, 2006).

3. Generalized Transport Costs

3.1. The model

Let us assume that a shipper of goods seeks to minimize the total costs for transport and, thereby, chooses the transport solution that gives the lowest generalized costs. The generalized costs per tonne for a purchaser of transport services, G, is defined in (1).

$$G(D) = P(D) + HT(D) \text{ where } \partial P/\partial D, \partial T/\partial D > 0 \Rightarrow \partial G/\partial D > 0 \tag{1}$$

The generalized transport cost in (1) is the sum of two elements. First, pecuniary costs, P, are related to price for the transport service. Second, time cost is the product of time cost per hour, H, and transport time, T. It is assumed that P and T, and thereby also G, are positively related to transport distance measured in kilometers (km), D, while H is independent of the transport distance.

The definition of generalized transport cost in equation (1) includes important costs relevant for the shipper of freight. From the perspective of welfare economics also external costs should be included. If all external costs are internalized in the generalized transport cost function, then private economic and welfare economic costs would be equal and the chosen transport solutions would be optimal for the society as a whole. A higher focus on environmental issues and attitude campaigns could make transport companies more aware of the costs they impose on others.

$$C = \alpha_0 + \alpha_1 X + \alpha_2 XD \textit{ where } \alpha_0, \alpha_1, \alpha_2 > 0 \tag{2}$$

It is reasonable that costs for the transport firm, C, depends on the amount transported, X, and the transport distance, D. In (2) the influence of X and D on C are represented by linear relationships which is an example of a simple cost function with the advantage of simple interpretations. However, more advanced specifications could be used to capture more of the variation in costs. Despite the weakness of treating all transport services as a homogenous product, common output measures are tonne and/or tonne kilometer (e.g. Pels and Rietveld, 2008). In (2) the parameters $\propto_1$ and α_2 represent marginal increase in costs when X and XD increase by one unit, respectively. Costs which are independent of amount and distance are given by the parameter α_0. Marginal costs, $\partial C/\partial X$, do in this simple cost function increase linearly with transport distance.

3.2. Price and transport distance

Costs are an important basis for setting prices for transport services. The setting of prices for freight transport is less standardized and regulated by the authorities than public passenger transport and market characteristics have considerable influence on prices. The degree of competition in the freight industry varies from monopoly to almost perfect competition. While a monopolist can utilize market elasticity to make extraordinary profit, e.g. measured by the price cost margin, a firm exposed to high competition must set fares closer to marginal costs (e.g. Carlton and Perloff, 2005). Three major factors indicate that perfect competition is a more suitable frame of competition than monopoly for transport of standard containers implying that fares should then according to (2) approximate $\alpha_1 + \alpha_2 D$. First, in contrast to public passenger transport where authorities often implements fare schemes, prices in freight transport are set freely in the market. Second, transport firms are usually maximizing profit. Finally, barriers for entry and exit other than investments are low. Basically, firms with available capacity on trucks or vessels can enter new markets for freight transport at will.

If we assume a high competition market, then the relationship between price (equal to marginal costs) and distance is defined in equation (3) for transport by water, truck or rail using subscripts *w*, *t* and *r*, respectively.

$$P_w = \beta_{0w} + \beta_{1w} D \text{ (water)}, \; P_t = \beta_{0t} + \beta_{1t} D \text{ (truck) and } P_r = \beta_{0r} + \beta_{1r} D \text{ (rail)} \quad (3)$$

$$\text{where } \beta_{0w}, \beta_{1w}, \beta_{0t}, \beta_{1t}, \beta_{0r}, \beta_{1r} > 0.$$

The parameter β_{0i}, where $i = \{w, t, r\}$, in (3) indicates distance independent prices for services such as loading and unloading. It is reasonable that $\beta_{0w} > \beta_{0r} > \beta_{0t}$ since terminal costs are highest for sea transport and lowest for road transport (Rodrigue et al., 2009). It follows from (3) that $\partial P_i/\partial D \geq 0$ and $\partial^2 P_i/\partial D^2 = 0$. Empirical evidence suggests that the relationship between price and distance on average is steepest for road transport and least steep for transport by sea (Ballou, 2004). This marginal increase in price with respect to distance is indicated by β_i and related to α_2 in (2). Hence, $\beta_{1t} > \beta_{1r} > \beta_{1w}$ implying that $\partial P_t/\partial D > \partial P_r/\partial D > \partial P_w/\partial D$. The parameter restrictions in (3) implies that price per kilometer decreases with distance, $\partial(P_i/D)/\partial D < 0$ for all three modes of transport. When distance moves towards infinity, then the price per kilometer, (P_i/D), approach β_{1i}.

3.3. Time costs and transport distance

The relationship between time costs, HT_i, and trip distance, D, is defined in (4) by combining time costs per hour by the time usage.

$$HT_w = \gamma_{0w} + \gamma_{1w} D \text{ (water)}, \; HT_t = \gamma_{0t} + \gamma_{1t} D \text{ (truck) and } HT_r = \gamma_{0r} + \gamma_{1r} D \text{ (rail)} \quad (4)$$

The distance independent time costs are represented by γ_{0i}, while γ_{1i} is interpreted as the increase in time costs when the transport distance increases by one kilometer. In (4) $\gamma_{0i} = H\tau_i$ and $\gamma_{1i} = H/S_i$ where τ_i and S_i are positive and represent distance independent time usage for loading and unloading the goods and the speed of the transport mode, respectively. It is reasonable to assume that $\tau_w > \tau_r > \tau_t$ and $S_w < S_t < S_r$. Since $\tau_w > \tau_r > \tau_t$ then $\gamma_{0w} > \gamma_{0r} > \gamma_{0t}$. Moreover, $\gamma_{1w} > \gamma_{1t} > \gamma_{1r}$ since $S_w < S_t < S_r$. An increase in time costs per hour, H, makes all three relationships between total time costs and trip distance to shift upward and become more steep. A higher value of H thereby increase the differences in time costs between the transport modes.

Time costs per hour, H, is equal for a given type of goods independent of transport mode and distance. It will, however, in practice be a self selection of which goods use a specific transport mode. The value of H for a commodity can be calculated by considering the value per tonne, the interest rate per hour and the deterioration costs per hour. Value, interest rate and deterioration rate are all positively related to time costs per hour.

The expressions in (4) assume that the truck has two drivers. If trucks, in contrast, have only one driver the rules for resting times must be considered. Resting regulation is a major constraint on road haulage operations (Lowe, 2005) but ensure equal competition, improved road safety and good working conditions within the European Union (European Commission, 2006). The use of one driver implies that the curve representing the time usage for vehicles increase stepwise rather than continuously with respect to transport distance. However, the cost per km will be less steep since only the salary for one driver is included. Since these two factors pull in opposite directions it is not possible to unambiguously conclude whether it is profitable to use two drivers instead of only one.

3.4. Generalized transport costs and transport distance

An expanded expression for generalized transport costs for each transport mode is derived by inserting (3) (price) and (4) (total time costs) into (1) as defined in (5).

$$G_w = \rho_{0w} + \rho_{1w}D \text{ (water)},\ G_t = \rho_{0t} + \rho_{1t}D \text{ (truck)},\ G_r = \rho_{0r} + \rho_{1r}D \text{ (rail)} \tag{5}$$

In (5) the distance independent part of generalized costs are represented by $\rho_{0i} = (\beta_{0i} + \gamma_{0i})$ where $i = \{w, t, r\}$. According to previous assumptions $\rho_{0w} > \rho_{0r} > \rho_{0t}$. The linearly increasing distance dependent elements are defined by $\rho_{1i} = (\beta_{1i} + \gamma_{1i})$ comprising both price and time costs. It has previously been defined that both distance dependent elements are higher for truck compared to that of transport by rail. Hence, the two curves will intersect since truck has a lower distance independent element than rail and thereby will have the lowest generalized costs for short distances.

It is, however, unclear how generalized costs for transports by water develop with distance compared to the other transport modes. Compared to the other transport modes it is defined that price (β_{1w}) and time cost (γ_{1w}) for transport by water increases least and most with distance, respectively. The total effect depends on the relative sizes of these parameters. If, for example, time costs are reduced (lower value of the commodity) then γ_{1i} becomes less important and the probability increases for transport by water having the least steep increase in generalized cost with respect to distance.

The threshold distance when a transport mode is preferred to another according to minimization of generalized transport cost can be derived from (5). Equation (6) presents the conditions ensuring that generalized cost for transport by truck is lower than transport by water, D_{tw}, transport by truck is lower than transport by rail, D_{tr}, and transport by rail is lower than transport by water, D_{rw}.

$$\begin{aligned} G_t < G_w &=> \rho_{0t} + \rho_{1t}D < \rho_{0w} + \rho_{1w}D => D_{tw} < \frac{\rho_{0w}-\rho_{0t}}{\rho_{1t}-\rho_{1w}} \\ G_t < G_r &=> \rho_{0t} + \rho_{1t}D < \rho_{0r} + \rho_{1r}D => D_{tr} < \frac{\rho_{0r}-\rho_{0t}}{\rho_{1t}-\rho_{1r}} \\ G_r < G_w &=> \rho_{0r} + \rho_{1r}D < \rho_{0w} + \rho_{1w}D => D_{rw} < \frac{\rho_{0w}-\rho_{0r}}{\rho_{1r}-\rho_{1w}} \end{aligned} \tag{6}$$

The distances where the curves intersect, defined by D_{tw}, D_{tr} and D_{tw}, will all be positive provided that the assumed ranking of parameters is met. All intersection distances increase with the difference between the distance independent elements and decrease with the difference between the marginal increase in price with respect to transport distance. If $\rho_{1w} < \rho_{1r} < \rho_{1t}$ then it can be expected that $D_{tr} < D_{tw} < D_{rw}$. Then transport by truck has the lowest generalized cost for distances less than D_{tr}, rail is lowest for distances between D_{tr} and D_{rw} and water is lowest for distances above D_{rw}.

4. Comparing Generalized Costs for Intermodal and Unimodal Transport Solutions

4.1. Intermodal versus unimodal freight transport

An important question is whether an intermodal transport solution is preferred to unimodal transport for a transport purchaser aiming to minimize generalized transport costs. Let us assume that a container needs to be transported from origin to destination with a total distance denoted by $\widehat{D}$. An unimodal alternative applies road transport only with the corresponding generalized costs as defined in (7).

$$G_t = \rho_{0t} + \rho_{1t}\widehat{D} \tag{7}$$

The container can alternatively first be transported by truck (pre-haulage) to the distance D_1, then by rail or water for the long-haul distance $(D_2 - D_1)$ and finally by truck to the final destination (post-haulage), $\widehat{D}$. Costs for transferring the container (handling at terminal) from truck to rail or water and back to truck are symmetric and defined by L each. Note that these handling costs comprise both pecuniary costs and time costs. The generalized transport costs for this intermodal transport solution using truck and rail, G_{Int}, is defined in (8). Moreover, in (8) the PPH costs are adjusted by $\varphi \geq 1$. This factor takes into consideration that generalized transport costs for truck may be higher per kilometer due to low speed compared to that of long-haul transport by road.

$$G_{Int} = (\rho_{0t} + \varphi\rho_{1t}D_1) + \left(L + \rho_{1r}(D_2 - D_1)\right) + (L + \varphi\rho_{1t}(\widehat{D} - D_2)) \tag{8}$$

Starting from the left in (8), the first element, $(\rho_{0t} + \varphi\rho_{1t}D_1)$, represents generalized transport costs by road from origin to the terminal at distance D_1. The second parenthesis, $\left(L + \rho_{1r}(D_2 - D_1)\right)$, represents costs for loading the container on rail and the long-haul transport by rail between terminals at D_1 and D_2. Finally, the last parenthesis, $(L + \varphi\rho_{1t}(\widehat{D} - D_2))$, represents costs for loading the container back on a truck and transport by road to the final destination.

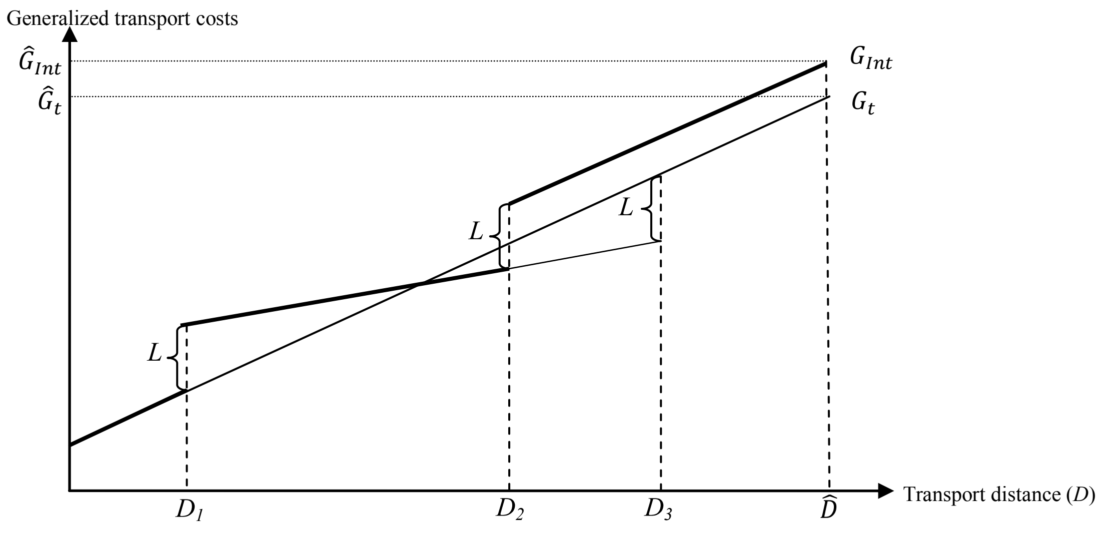

Fig. 1. Relationship between generalized transport costs and transport distance for transport by road and for intermodal transport.

The generalized transport transport costs for the total transport distance is defined for intermodal and unimodal transport solutions by $\hat{G}_{Int}$ and $\hat{G}_t$, respectively. It is assumed that marginal generalized costs with respect to distance are equal for pre- and post-haulage distances and equal to $\varphi\rho_{1t}$. It is previously defined that $\rho_{1w}, \rho_{1r} < \rho_{1t}$ meaning that generalized transport costs increase more rapidly with distance for truck compared to water and rail. In Fig. 1 unimodal transport is preferred to intermodal transport when the long-haul distance is $(D_2 - D_1)$. If, however, the long-haul distance is increased to D_3, then the generalized costs for the two alternatives becomes equal. If the long-haul distance increases further then intermodal transport will be the best alternative.

An intermodal transport solution is preferred to unimodal if (8) is lower than (7) as defined in (9).

$$G_{Int} < G_t => (D_2 - D_1) > \frac{2L + \rho_{1t}\hat{D}(\varphi - 1)}{\varphi\rho_{1t} - \rho_{1r}} \quad (9)$$

The condition for preferring intermodal transport is in (9) rephrased to demonstrate how different factors influence the required threshold distance for the long-haul distance by rail (could as well be by water). It is evident from (9) that the distance transported by truck does not influence whether intermodal transport is preferred. The derivatives of $(D_2 - D_1)$ with respect to $L, \hat{D}, \varphi$ and ρ_{1r} are positive, while the derivative with respect to ρ_{1t} is negative. This implies that the threshold transport distance by rail required to make intermodal transport preferable increases when

- the handling costs at terminals, L, increases
- the total transport distance, $\hat{D}$, increases
- the adjustment factor of pre- and posthaul costs for trucks, φ, increases
- the distance dependent marginal generalized costs for rail, ρ_{1r}, increases
- the distance dependent marginal generalized costs for truck, ρ_{1t}, decreases

In the special case when $\varphi = 1$, meaning equal costs for pre- and post-haulage and unimodal long-haul by truck, then the condition is in (9) reduced to $2L/(\rho_{1t} - \rho_{1r})$. Thus, the required long-haul distance by rail is independent of the total distance when $\varphi = 1$.

4.2. The influence of resting costs

The illustration in Fig. 1 does, however, not include the resting restrictions for truck drivers. In (10) the additional costs relating to resting regulations are included in G_t^*. For each rest the generalized cost curve G_t^* get a positive shift equal to ΔG_t. For simplicity the rests are placed at even intervals derived by dividing total travel time by truck, $\hat{D}/S_t$, by the average regulated time between each rest, N. Hence, $\hat{D}/S_t\, N$ indicates the necessary number of rests. In practice the distance between rests will vary according to speed variations at different parts of the trip and requirements for more frequent and longer rests as time lapses.

$$G_t^* = \rho_{0t} + \rho_{1t}\hat{D} + \frac{\hat{D}/S_t}{N}\Delta G_t \quad (10)$$

If resting costs for trucks are included then an intermodal transport solution will be preferred to unimodal if (8) is lower than (10) as defined in (11). The threshold distance when including resting costs is denoted $(D_2 - D_1)^*$.

$$G_{Int} < G_t^* => (D_2 - D_1)^* > \frac{2L + \rho_{1t}\hat{D}(\varphi - 1) - \frac{\hat{D}/S_t}{N}\Delta G_t}{\varphi\rho_{1t} - \rho_{1r}} \quad (11)$$

The variables $L, \hat{D}, \varphi, \rho_{1r}, \rho_{1t}$ influence $(D_2 - D_1)^*$ in the same directions as they influence $(D_2 - D_1)$. Partial differentiations of (11) show how the required long-haul distance is related to the factors comprising the additional costs related to rests for trucks. The derivative of $(D_2 - D_1)^*$ with respect to N

and ΔG_t are positive and negative, respectively, The derivative of (11) with respect to S_t is more unclear since S_t is a part of $\rho_{1t} = (\beta_{1t} + H/S_t)$. Consequently, with respect to resting regulation, the threshold long-haul distance to make intermodal transport preferable increases (i.e. intermodal transport becomes less favorable) when the resting cost, using truck only, is reduced by either longer intervals between rests, N, or lower time cost for each rest, ΔG_t.

The influence on $(D_2 - D_1)^*$ of distance dependent marginal generalized transport cost is positive with respect to rail transport (ρ_{1r}) and ambiguous with respect to truck transport (ρ_{1t}). However, if the cost adjustment factor for PPH by truck, φ, is defined as 1, then the derivative of $(D_2 - D_1)^*$ with respect to (ρ_{1t}) is negative provided that total terminal costs are higher than resting costs, i.e. $2L > \Delta G_t \widehat{D}/S_t N$.

Let us assume that a new charge is put on trucks implying that $(\rho_{1t} - \rho_{1r})$ increases. Then the required long-haul distance by rail is reduced when the difference in generalized marginal costs with respect to distance for truck and rail increases. Oppositely, if resting costs are higher than handling costs, then the required long-haul distance will increase. It can also be seen from (11) that costs related to handling and resting have higher impact on the required long-haul distance if the difference between generalized marginal costs for the two transport modes with respect to distance is small.

5. Model Results seen in the Light of Empirical Evidence – Transport of Fresh Fish

There are many examples of intermodal transport in practice. A case to illustrate challenges related to intermodality is the transport of fresh fish from Norway to central Europe (see Hanssen and Mathisen, 2011).

Fresh fish is a perishable product and its value dwindles rapidly. Time cost per hour for one container filled with fresh salmon is the sum of the hourly reduction in the value of the fish and the interest rate cost per hour for the same fish. Fresh fish has lost all its value after seven days (Lervåg et al., 2001). The rate at which fish deteriorates is influenced by factors such as packaging, and the characteristics of the transport mode used. We follow Lervåg et. al. (2001) and assume a linear reduction over time in the value of fresh fish. As one container can hold 10640 kg of fish (Nerdal, 2003) and the value of salmon is € 3.9 per kg, the total value of the salmon in a full container is € 41496 when transport begins. Since the value is assumed to dwindle linearly with time, the hourly value reduction is € 247. An interest rate of 5% per year yields an hourly interest rate cost per container of € 0.24. Hence, total time cost per hour is € 247.24.

The threshold distance for making intermodal the preferred alternative for transport of fresh salmon, assuming equal costs for pre- and post-haulage and long-haul by truck, is given by $2L/(\rho_{1t} - \rho_{1r})$ in (9).

The cost per loading operation, (L), is the sum of pecuniary cost and time cost. The pecuniary cost of each loading operation is €38 per container (Nerdal, 2003). As time cost per hour is € 247.24, and average loading time is 1h and 30 min (Nerdal, 2003), the time cost for each loading operation becomes € 370.86. Total cost per loading operation becomes € 408.86.

Marginal distance cost for truck (ρ_{1t}) is the sum of marginal pecuniary distance cost per km and marginal time cost per km. Marginal pecuniary distance cost for truck is approximately € 0.65 per km (Kim and Van Wee, 2011). Average truck speed is 61 km/hour (Nerdal, 2003). Thus, it takes 0.016 hours to transport a container one km by truck. The time cost becomes € 3.96. Total marginal generalized distance cost truck becomes € 4.61 per km.

Marginal generalized distance cost for rail (ρ_{1r}) is the sum of marginal pecuniary distance cost for rail and marginal time cost per km for rail. Marginal pecuniary distance cost for rail approximates € 0.46 per km (Kim and Van Wee, 2011). Average speed for rail is 65 km/hour (Nerdal, 2003). Thus, it takes 0.015 hours to transport a container one km by rail, and time cost is € 3.71 per hour. Total marginal generalized distance cost for rail is € 4.17 per km.

By inserting L, ρ_{1t} and ρ_{1r} into (9), assuming that costs for pre- and post-haulage and unimodal long-haul by truck is equal, i.e. that $\varphi = 1$, we find that intermodal transport becomes preferable for distances with rail in excess of 1858 km. This estimated break-even distance is considerably longer than the 400 km suggested by Tsamboulas (2008) as the break-even distance by train for making intermodal transport preferable. The particularly long break-even distance by train in our example is primarily due to the particularly high deterioration rate for fresh fish, implying high time costs.

The distance from origin in Norway to central hubs in Europe is in most cases more than 2000 km, exceeding the distance required to make intermodal transport viable alternatives. In theory, both water and rail could be used for the long-haul distance from most origins in Norway. Due to the long coast line there are available harbors close to most origins for this particular product, but sea transport is in its traditional form too slow. Currently, the only sea transports of fresh fish are carried out by trucks using ferries, but these transports are not considered intermodal since the containers are not loaded on the ship.

The rail network is well developed in Europe but covers only parts of Norway and the standard is partially poor. A further problem with the Norwegian rail network is that freight trains have lower priority than passenger trains. In the Northern Norway, where a large proportion of the fish is produced, the road standard is low. Traditionally, intermodal transport solutions have been used only domestically. According to the purchasers of transport services this is caused mainly by the lack of rail services running directly to hubs in Continental Europe (Hanssen and Mathisen, 2011). However, since 2008 intermodal transport has also been provided internationally and an increasing proportion of the fresh fish utilizes these solutions as the long-haul distance by rail, $(D_2 - D_1)$, increases. Finally, the European Greening transport package is expected to introduce a charge that will increase the price for transport by road (European Commission, 2008). This will increase the distance dependent element of G_t and reduce the long-haul distance required to make intermodality a real alternative.

6. Conclusion and Implications

In this article we have developed a framework for discussing the influence of different aspects of intermodal transport on generalized transport costs. Generally, the distance transported by truck in pre- and posthaulage, does not influence whether intermodal transport is preferred. Moreover, the long-haul distance required to make intermodal transport preferable increases when (1) handling costs at terminals increases, (2) total transport distance increases, (3) pre- and posthaulage costs increase, (4) distance dependent marginal generalized costs for the long-haul increases, (5) the distance dependent marginal generalized costs for truck decreases and (6) reduced resting costs for truck drivers.

The model is linked to the context of transport of fresh fish from Norway to Continental Europe. Much of the fish is produced in the northern parts of Norway with sufficiently long distance to the main markets to make intermodal transport viable.

The results from the model show that the following measures can be taken by policymakers to make intermodal transport solutions better alternatives relative to unimodal transport by truck: (i) Promote cross-border standardization of intermodal equipment to make terminal operations more efficient. (ii) Reduce transport costs for vehicles specially designated to pre- and posthaulage in urban areas. (iii) Give freight trains increased priority in the rail network in order to reduce the distance dependent marginal generalized costs for rail. (iv) Implement additional charges on road transport to increase the distance dependent marginal generalized costs for trucks. (v) Stricter enforcement of resting regulations, in order to increase the cost of long-haul freight transport by truck and make intermodal transport more competitive for shorter distances. These measures will if implemented, contribute to the attainment of a sustainable European transport sector based on a more energy efficient freight transport sector.

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