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Analysing the Influence of Hinterland Transportation Costs on Port Market Share: A Combined Discrete-Event and Agent-based Simulation Approach

Analyse des Einflusses von Transportkosten im Hinterland auf den Marktanteil von Häfen: Ein kombinierter ereignisdiskreter und agentenbasierter Simulationsansatz

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Abstract: Well established hinterland connections play an even more important role in the competition of ports for market shares. In this relation changing transport costs in the hinterland can shift large transport volumes between ports. However a sophisticated estimation of port market shares in dependence of hinterland transport costs that consider the economic-geographic conditions in the hinterland (transport networks, geographical distribution of transport sources/sinks) along with the port choice behaviour of decision makers has not been conducted so far. The paper at hand provides such estimation by the means of a combined discrete-event and agent-based simulation study. The impact of changing rates for intermodal transport in the maritime export of containerized freight from south-west Germany towards the ports in the Hamburg – Le Havre range is analysed. The results show an inelastic transport demand towards the northern ports (Hamburg and Bremerhaven), revealing a possible scope for intermodal operators to increase their rates.

1 Introduction

Ocean container transport is the backbone of globalization and has shown sustainable growth over the last decades (World Bank 2017). The prospect of continuing increases in container traffic does not only lead to intense competition among ocean carriers. A fierce rivalry for market shares can also be observed between ports. Especially ports that are located in the same port range (like the Hamburg – Le Havre range) and therefore share the same hinterland face a so called intra-range competition for container transhipment volumes (Notteboom and de Langen 2015).

In this case shippers, ocean carriers and freight forwarders can chose between several ports for import or export cargo flows. The competitiveness of a port is determined by a broad range of factors that all together significantly influence the port choice (Song et al. 2016). Besides the seaside connectivity (among others number of available container liner services and frequency of port calls) and the infrastructure within the port (among others terminal operations) the hinterland connections are of high relevance as well (Steven and Corsi 2012). In this relation changing rates of the land carriers (intermodal rail/road freight operators or unimodal road freight carriers) can significantly influence the competitiveness of a port since 40 % to 80 % of the overall transport chain costs in containerized transport is caused by inland costs (Notteboom and Rodrigue 2009). Considering the high price elasticity in maritime transport even moderate changes in hinterland transportation costs can shift large freight volumes between competing ports (Song et al. 2016).

Due to its importance regarding port choice an accurate calculation to which extent freight volumes relocate to other ports in dependence of changing hinterland transportation costs can provide useful insights for all actors in the maritime transport process. Land freight carriers can determine the transport demand on their hinterland connections as function of their rates and can identify possibilities for revenue growth. Port authorities and terminal operators can evaluate the impact on transshipment volumes within the port. Finally ocean carriers can quantify the effect on loading and unloading volumes in a specific port and in consequence may decide to adapt the port calls in their service routes.

Despite the relevance of hinterland transportation costs existing research has either focused on identifying decisive criteria for selecting a specific port by the means of empirical surveys (see among others Yuen et al. 2012; Nugroho et al. 2016) or analysing price and capacity decisions of ports in intra-range competition by game theoretical models (see among others Ishii et al. 2013). Regarding the hinterland connections as one decisive part in port choice (besides seaside connectivity and port infrastructure) the empirical studies of the first research stream identify transport cost and transport time as the most prominent evaluation criteria (Nugroho et al. 2016). Consequently transport times should also be considered when analysing the impact of changing transport cost since the decision makers weight both criteria and lower transport times can compensate higher cost up to a certain level (Yuen et al. 2012).

In summary such empirical studies provide a deeper understanding of the decision behavior of the actors. However for analysing the impact of changing hinterland transportation costs on the market share of a port a more comprehensive approach is required that consider geographical distribution of freight demand and the existing transport networks in the hinterland additionally to the choice behavior of shippers, carriers and freight forwarders. When the locations of transport sinks/sources in the hinterland and the respective available transport options from/to the ports are known it is possible to calculate transport times and costs in the hinterland. Those can then be evaluated by the choice behavior models for determining the chosen ports.

Game theoretical models for price and capacity decisions are the second relevant research stream regarding port competition (Lee and Song 2017). The existing approaches focus on the strategic behavior of ports in intra-range competition regarding price and capacity decisions in the ports. Due to the game theoretical approach the reactions of competing ports can be considered and market shares of the ports in the economic equilibrium can be determined. However these analytical models strongly simplify the economic-geographic conditions in the hinterland and the port choice behavior (Lee and Song 2017). They assume a uniform price for hinterland transport for each port and neglect the concrete locations of transport sources/sinks as well as the transport networks in the hinterland. Regarding choice behavior the transshipment volumes of the ports are determined by a simple cost equilibrium (Ishii et al. 2013). Therefore despite their importance regarding port choice transport times in the hinterland are not considered.

In summary the following research gap can be identified: The influence of changing hinterland transportation costs on the market share of competing ports has not been analysed so far by a comprehensive approach that considers the economic-geographic conditions of the hinterland (transport networks, geographical distribution of transport demand) and a port choice model that takes hinterland transport times into account, too. In consequence intermodal operators in the hinterland cannot estimate in how far their revenues could be increased by changing their rates. Furthermore port authorities as well as terminal operators and carriers operating in the ports cannot determine the robustness of market shares in the ports with regard to varying hinterland transport cost. However this evaluation is important for assessing the competitive position of the respective ports. The research goal of the paper at hand is therefore to determine how price sensitive decision makers react to changing hinterland costs and as a result to which amount market shares of the ports change. This question is answered for an exemplary case for the maritime export from south-west Germany (Baden-Württemberg, Hesse and Rhineland-Palatine) via the four largest ports in the Hamburg – Le Havre range (Antwerp, Bremerhaven, Hamburg and Rotterdam). The hinterland region is characterized by a high gross value added and high export quotas (Statistisches Bundesamt 2016; Statistisches Landesamt Baden-Württemberg 2016). Due to the geographical location, the well-developed hinterland connections and a wide range of container liner services the four named ports find themselves in intra-range competition for the export volumes from this region (Notteboom and de Langen 2015). The analysis determines the market share for the ports in the three federal states as well as the modal split of intermodal rail/inland waterway transport and unimodal road transport in the hinterland by the means of a combined discrete-event and agent-based simulation study.

The remainder of the paper is organized as follows: Section two describes the simulation model and the conduction of the simulation experiments. In section three the results are presented. Finally a conclusion and outlook is given in section four of the paper.

2 Simulation

A combined discrete-event and agent-based simulation model is implemented in the software AnyLogic 8.0 as a leading tool for multi-method simulation (The AnyLogic Company 2017). The model can be structured in four modules as shown in Figure 1, together with the embedded GIS-map of the model and the visualization of hinterland transport to the ports by rail, barge and truck.

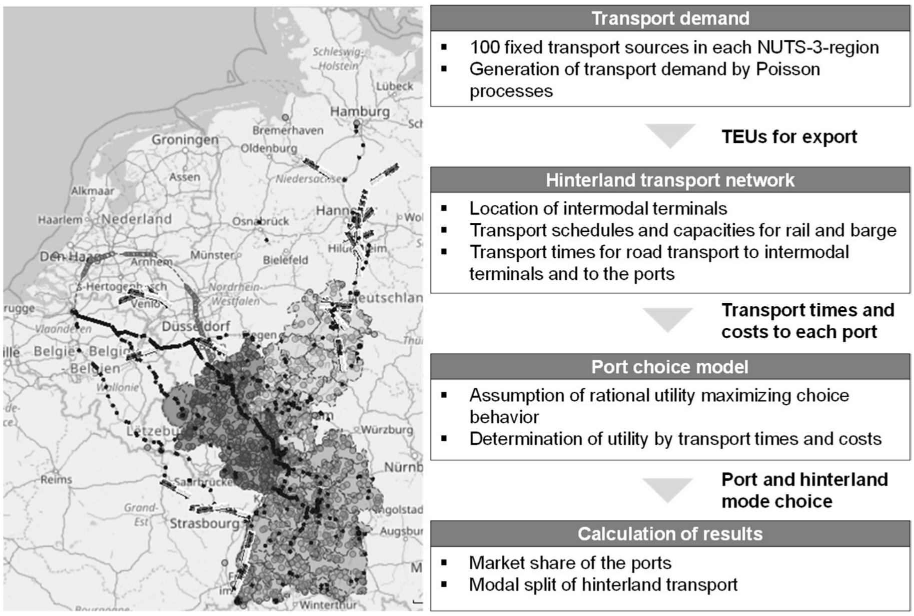

Figure 1: *GIS map with visualization of the transport processes and modules of the simulation model*

In the first module the transport demand is generated. The three federal states are further divided into their NUTS-3-regions (systematic of the European Union for territorial units; corresponds to districts and independent cities in Germany). For each NUTS-3-region the annual export volumes (in twenty-foot equivalent unit, TEU) is calculated based on statistical information for gross value added in the industry sector in each region (Statistisches Bundesamt 2016) and data for annual exported TEU from the North European Container Traffic Model (NECTM, ISL and Holocher 2015; ISL and HIS Global Gmbh 2015). By assuming that the export volume is linear in gross value added the overall transport volumes (available in NECTM) are assigned to the NUTS-3-regions in each federal state. In the simulation model a Poisson process for each NUTS-3-region is defined (rate equals exported TEU per day for the region, assuming that the annual exported TEUS are distributed evenly over the year). The created TEU are located randomly within the region.

The second module represents the hinterland transport network. The locations of intermodal terminals are implemented into the GIS-map of the simulation model (data available at SGKV 2017). The transport times for road transport from all transport sources to the intermodal terminals and to the ports are calculated by a shortest path algorithm (constant travel times and a mean velocity of 50 km/h according to Kille and Schmidt (2008) are assumed). For each source all terminals with a road distance of maximum 100 km are considered as possible transhipment point for intermodal transport (according to Ye et al. 2014). The schedules of intermodal rail and inland waterway transport are stored in the model (data available at ECORYS Nederland BV 2017 and at the websites of respective intermodal operators). Uniform capacity limits for each transport unit are assumed (1 TEU for trucks, the capacity limits for trains and barges are part of the model calibration that is described below). Regarding transport costs for road the marginal costs are set to 2.5 €/TEUkm (based on Reis 2014). For intermodal rail and inland waterway transport relation-specific rates are stored that were provided by an intermodal operator. Since the focus of the analysis is on the hinterland connections an equal seaside connectivity of the ports and equal port infrastructure is supposed so that those factors do not influence the port choice. They are therefore neglected in the model. In further model developments those criteria could be integrated. However for this first simulation neglecting the seaside and port infrastructure makes the impact of changing hinterland transport costs more transparent.

For the port choice a rational utility-maximizing decision behavior is assumed. The decision process is modelled as follows: for each created TEU all possible transport options to all four ports are evaluated regarding transport time and cost. Transport costs for road are calculated by road distance and fix marginal cost value. Transport costs for intermodal transport are the sum of road transport costs for pre-haulage to the terminal and the respective relation-specific rate (including transshipment costs and transport costs from terminal to port). The transport time is defined by the difference of date where the TEU is created to date where the TEU arrives in the port. For each transport option a utility value is calculated by adding transport costs and transport time. Transport time is weighted by the fix parameter value of time (VOT). This parameter represents the monetary value for the decision maker of a transport time reduction by one time unit. Finally the transport option with highest utility is chosen for the respective TEU.

A time range of four months is examined in each simulation experiment. In the module for result calculation the market shares of the ports are calculated for each federal state (defined as the share of arrived TEU in each port of all created TEU in the federal state) as well as the modal split in hinterland transport for each port (defined as share of arrived TEU by each transport mode). In the calibration process and following analysis the ports of Hamburg and Bremerhaven as well as Antwerp and Rotterdam are evaluated as pairs together. For an intermodal operator it should be less decisive if the containers are transported to Hamburg or Bremerhaven because the transport routes are very similar (most of the trains have one part for each port and are split in the shunting yard of Maschen). Therefore the relevant competition for intermodal operators is supposed to be between the northern and western ports.

The model was validated in an expert workshop with managers of an intermodal operator and a manager of a port authority from one of the considered ports. The port choice model was validated in expert interviews with decision makers of shippers, carriers and freight forwarders.Calibration is performed by minimizing the deviation of the values for market share and modal split compared to respective data from the NECTM. The calibration parameters are the VOT and capacity limits for trains and barges. The results of the calibration process are shown in Table 1.

The market share of the ports is reproduced with only small deviations. Since in the simulation other ports of the Hamburg – Le Havre range are neglected the market share of the four considered ports sum up to 100 % (the statistical data of NECTM also shows a negligible market share of other ports for Hesse, Baden-Württemberg and Rhineland-Palatine). Also the modal split for Antwerp and Rotterdam almost equals the statistical data. The modal split for rail transport towards Hamburg and

Bremerhaven is approximately 20 percentage-points too high (road transport is 20 percentage-points too low respectively). When comparing the simulation results to real data in general the simplified model assumptions should be taken into account. Furthermore the assumption of a rational utility-maximizing choice behavior does not necessarily represent real-world decision making processes with highest accuracy especially regarding transport mode choice. Elbert and Seikowsky (2017) show that biasing effects could imply an increased rigidness to modal shift from road transport to intermodal rail transport. One example is loss aversion (in form of fearing reduced transport quality) that is especially prevalent in small and medium sized companies. A further aspect that is not considered in the model is transport reliability. Because of a possible lower punctuality in rail transport in general decision makers might prefer road transport (Reis 2014).

Table 1: *Resulting values from model calibration (reference data from NECTM in brackets)*

Calibration parameters	Market share of ports	Modal split
	Hamburg and Bremerhaven	
VOT: 4 *Train capacity*: 20 TEU *Barge capacity*: 250 TEU	*Hesse*: 52.4 % (55.6 %) *Baden-Württemberg*: 43.0 % (46.3 %) *Rhineland-Palatine*: 14.7 % (11.9 %)	*Road*: 0.8 % (21.1 %) *Rail*: 99.2 % (78.8 %) *Inland waterway*: 0 % (0 %)
	Antwerp and Rotterdam	
	Hesse: 47.6 % (44.4 %) *Baden-Württemberg*: 57.0 % (53.7 %) *Rhineland-Palatine*: 85.3 % (88.1 %)	*Road*: 17.9 % (16.8 %) *Rail*: 19.5 % (21.0 %) *Inland waterway*: 62.6 % (61.6 %)

The impact of changing rail freight rates towards Hamburg and Bremerhaven is analysed by the means of parameter variation. The relation-specific rates are varied in the range of 30 % till 300 % of the provided rates of the intermodal operator. Rates for rail and inland waterway transport towards Antwerp and Rotterdam are left constant.

This scenario enables the analysis of several possible real-world developments. One cause of changing rates could be profit maximization of intermodal operators. When the offered train capacity is constant the operators will seek a revenue maximizing rate for their services. It can further be assumed that because of the substitutable nature of the transport services the rates of different operators for a specific relation are equal. Another reason could be that the rail infrastructure company (DB Netz AG) considers higher track access charges because of the high utilization of the rail links towards the German deep-sea ports (for covering higher maintenance costs or financing punctual capacity expansions). Intermodal operators (and railway undertakings) may then decide to pass their increased costs to their customers.

With each rate-level a separate simulation run is conducted with fixed seed of the random number generator for ensuring reproducibility. The gained results are described in the next section. Considering the deviation of modal split towards Hamburg/Bremerhaven because of the explained model restrictions the analysis should be interpreted as a first estimation of general market trends. The results should illustrate the application of the simulation approach in market studies with regard to freight rates. For further practical applications the integration of the neglected influence factors (bounded-rationality choice, reliability of transport modes) into the model is a necessary prerequisite.

3 Results

The market share of Hamburg and Bremerhaven in the federal states and the overall revenue of the intermodal rail services towards the northern ports (relative to rate 100 %) in dependence of the changed rates are depicted in Figure 2. In the calibrated model with the provided rates by the intermodal operator (factor 100 %) the market shares in Hesse and Baden-Württemberg are substantially higher than in Rhineland-Palatine. The differences are caused by the geographical proximity of Rhineland-Palatine to Antwerp and Rotterdam and the high number of intermodal inland waterway connections from terminals in this federal state (53 % of the overall TEU of Rhineland-Palatine are transported by barge towards Antwerp and Rotterdam). In Baden-Württemberg the market share for Antwerp and Rotterdam is large along the Rhine corridor (75 % or higher). On the opposite for the region around Stuttgart, that also creates a high transport volume, more than 50 % of the containers are transported towards Hamburg and Bremerhaven. In Hesse the northern parts of the state show a market share of almost 100 % towards Hamburg and Bremerhaven. In the central and southern parts the transport volume is approximately divided equally among the ports.

Regarding changes in the rates the curves indicate a very inelastic demand in the range of 30 % till 130 % (for Baden-Württemberg and Rhineland-Palatine) or 180 %, respectively (for Hesse). As the results show a rate reduction (compared to the current rates of 100 %) will not generate additional transport demand towards the northern ports. The reason is a lack of free capacity on the rail connections. They are almost fully utilized at a rate of 100 %. In consequence additional revenues on the basis of a rate reduction can only be created by expanding capacity. However in this case the intermodal operators must also consider the costs for the additional capacity for identifying possible profit growths.

The almost constant market shares for growing rates up to 130 % or 180 % result on the one hand from geographical conditions. Accordingly some regions can be classified as dedicated for the northern or western ports (for example northern Hesse or western Rhineland-Palatine). On the other hand the amount of rail connections towards the northern ports is considerably higher than towards the western ports for most of the intermodal terminals. This better transport offer can be seen as relevant differentiation characteristic in the port competition which provides the scope for intermodal operators to increase their rates towards Hamburg and Bremerhaven.

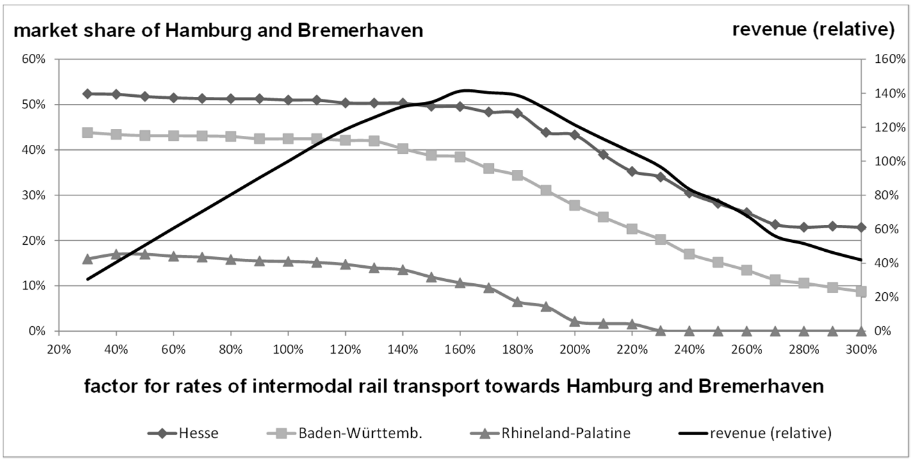

Figure 2: *Market shares for federal states and revenue of the intermodal rail services towards the northern ports (relative to rate 100 %) in dependence of freight rates for intermodal rail transport towards Hamburg and Bremerhaven*

Further growing rates above 130 % or 180 % cause approximately linear falling market shares of the northern ports. In Baden-Württemberg the transport volumes shift from rail transport towards the northern ports to inland waterway transport towards the western ports. The transport volumes on the waterway increase by 100 % when the rates for rail transport rise from 100 % to 300 %. In this case the barge is also preferred in the central and eastern parts of the state although considerable higher transport times, especially for the inland waterway connections from the terminal in Stuttgart. Due to the high transport costs only a small fraction is shifted to road transport (the TEU on road from Baden-Württemberg towards Antwerp and Rotterdam only increase by 18 % when rates for rail transport are tripled). Rail transport towards the western ports cannot profit and increases only by 3 % because there is no free capacity for additional transport volumes. Therefore a large potential for this transport option could be present if capacities are increased.

In contrast to Baden-Württemberg in Hesse the road transport towards the western ports is the clearly preferred option in case of higher rail rates. The TEU on road grow by 355 % for tripled rail rates, whereas rail and inland waterway transport towards Antwerp and Rotterdam increase only by 18 % and 16 % respectively. For the central and southern parts of Hesse road transport towards Hamburg and Bremerhaven is no alternative since the distance is higher than towards the Netherlands or Belgium. Only in the northern parts around Kassel the market shares remain unchanged. For very high rail rates the TEU of this region are transported on road towards the northern ports.

In Rhineland-Palatine the small market share for the northern ports (which is generated in the south-west around Mainz and Ludwigshafen) falls to 0 % when rail transport becomes more expensive. In this case road transport towards the western ports increases by 61 %, inland waterway transport only by 7 %. However with additional capacity for the waterway transport the modal split could change significantly.

In summary the described shifts of transport volumes cause a parabolic revenue curve for the intermodal rail services towards the northern ports (also shown in Figure 2). A maximum revenue can be achieved at a rate of approximately 160 % of the current freight rates. Therefore from the perspective of the intermodal operators a large potential for increasing revenues by raising their rates towards Hamburg and Bremerhaven could be present. The results further indicate that the market shares of the northern ports are quite robust in case of growing hinterland transport costs, implying a relative strong market position at least in Hesse and Baden-Württemberg.

4 Conclusion and Outlook

The simulation experiments reveal an inelastic transport demand towards the northern ports even for substantial increases in rates for rail transport towards Hamburg and Bremerhaven. Limitations of the results are the simplified model assumptions. A consideration of capacity expansions in rail and waterway transport could impact the market shares along with the seaside connectivity and port infrastructure.

Further research should not only integrate those factors in the analysis. Moreover it should be investigated how the decision behaviour could vary in dependence of the respective actor who is responsible for the overall coordination of the transport chain (shipper, carrier or freight forwarder). As example for the ocean carrier the capacity utilization of own assets (container vessels and terminals) is of great importance and could result in a bundling of transport volumes in one specific port. On contrary freight forwarders might be in general not bound to certain ports and could exploit rate differences almost immediately. Not least further empirical studies are needed in how far bounded rationality plays a role in port choice (among other things in form of loss aversion that could prevent decision makers from shifting ports or transport mode).

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