Logist. Res. (2012) 4:113–125
DOI 10.1007/s12159-012-0073-1

ORIGINAL PAPER

Estimation of the benefits for shippers from a multimodal transport network

Gernot Thorsten Liedtke

Received: 24 October 2011 / Accepted: 14 February 2012 / Published online: 7 March 2012

Abstract This paper develops an economic assessment of a multimodal transport network for single pallets. A shipment-size choice model is estimated to calculate the shippers' reactions and their economic benefits from that transport network. In the model, the major factor influencing logistics decisions—the balance between warehouse and storage cost—is explicitly taken into account. The functional form is deduced from the first-order condition of the minimization problem of total logistics cost. Transport cost is expressed in the form of a complex function depending on shipment size and transport distance in order to capture the effect of economies of scale in transportation. The model parameters are estimated based on empirical data from two major German corporations. Simulations show that the new intermodal transportation system has a significant impact on the shipment-size distributions changing them in favor of smaller shipments. This leads especially to significant reductions in warehouse costs. Finally, some implications of the analytical results on transport policy are provided: To foster green logistics and achieve further modal shifts from road to rail, public financial support and the regulatory framework have to enable railways to consolidate small and logistics demanding shipments at an industrial scale.

1 Introduction

The transport logistics sector is characterized by a high degree of competition, cascades of subcontracting and horizontal collaborations. Profit margins are rather low. In this environment, the development of innovative services becomes a crucial condition for companies in order to compete successfully in the market. The key issue for the success of innovative services lies on the additional benefits offered to the customers. If these offers meet the requirements of a certain group of customers, an increased willingness-to-pay may be expected.

Up to now in Germany and other surrounding European countries, railways have been concentrating on three types of transport services: full-trains, single-wagon transport and intermodal transport. The market for less-than-truck-load transports has been lost to road-based transport logistics service providers. Given the already existing high-performance systems of single-wagon transports, these transport networks could be opened to single pallets, too. This way, railways could extend their range of services toward more logistics demanding transports and become actual logistics service providers. For this purpose, multimodal transshipment facilities could be established at the existing hubs of the single-wagon transport networks.

A possibility to implement such a transportation system has been analyzed in the project LOGOTAKT funded by the German Federal Ministry of Economics. The basic idea is to conduct small consignments down to single palettes through a synchronized multimodal system. Processes in consolidation centers, routing and dispatching should be organized at an industrial scale. Cost savings should be realized through consolidation and mass transportation. At the same time, more efficient supply chains could be set up and the multimodal transport network could contribute to save energy resources and to reduce climate impacts. The economic viability has been analyzed from both, a business and a welfare perspective. Welfare impacts include the effects on external cost. Given the wide scope of the

G. T. Liedtke (✉)
Institute for Economic Policy Research (IWW),
Karlsruhe Institute of Technology (KIT),
Kaiserstr. 12, 76131 Karlsruhe, Germany
e-mail: liedtke@kit.edu

LOGOTAKT project, we intend to answer two questions in this paper: How are the shippers' reactions on this new transportation system and which are the potential cost savings for the shippers? For this purpose, a micro-behavior model has been developed based on the total logistic cost (TLC) approach.

The TLC approach has been widely applied in freight transportation analysis for the last decades [2, 3, 5]. Unfortunately, there are only few publications using the TLC approach as a basis for the construction of an empirically calibrated choice model. In addition, these efforts do not capture the effect of economies of scale in transportation—the decrease in unit cost with increasing shipment size. Our proposed TLC model explicitly treats the shipment-size decisions at a short- and mid-term horizon.

Basically, shippers determine their shipment size by finding a balance between storage and transport cost. Storage cost, such as capital costs in inventory, increases proportionally to shipment size, whereas transport cost decreases inversely. Other relevant decisions such as warehouse location choice—significantly influencing the total logistic costs—are treated as given and fixed in this model. This specific market is defined through all palletized goods and their respective transports with shipment sizes between one and thirty pallets at a national or even international scale.

The paper is structured as follows. A brief overview on the LOGOTAKT system is presented in Sect. 2. Then, a TLC model is developed that considers economies of scale in transportation reflected through the tariff structure (Sect. 3). Section 4 is dedicated to the extraction and the estimation of the major influencing variable in TLC approach. A simulation of the effects from the introduction of the intermodal transport system and an interpretation of the results close this paper in Sect. 5.

2 Short description of the LOGOTAKT system

Because of the regulatory framework and the system of financial grants given to the railways, two different types of railway-based freight transportation systems have emerged. On the one hand, there are the intermodal transports: Shuttle trains for containers link about 100 terminals spread all over Germany mostly to the hub sea-ports. On the other hand, there is the transport network for single wagons. The core network consists of about ten big marshalling yards, where freight wagons are interchanged between trains. There are regular train connections between the marshalling yards. On most major links, there are about four departures per day. Therefore, there is a high transport frequency on all direct and indirect connections on this core network. Furthermore, the national single-wagon network system is connected to the single-wagon networks of surrounding European countries.

Realizing economies of scale in the marshalling yards and profiting from competitive transport cost on the main links, the core single-wagon network is highly competitive compared to other transport models, especially on long distances. However, significant cost occurs when bringing the wagons from the sidings of the shippers and recipients to the hubs. In addition, most manufacturers and warehouses no longer have physical access in the form of railway sidings. Industry is more and more fragmented, and the structure of shipments is shifting toward smaller transport lot sizes.

For this reason, transport cases of less than one truckload are no longer carried by railways today. These smaller shipments are awarded to transport logistics service providers. They are setting up milk-run systems, operate overland transport networks for mixed cargo, or they collaborate within mixed cargo networks. For these types of logistics service providers, railways have some fundamental disadvantages. Firstly, the usage of intermodality creates additional transport links. Especially, the interfaces (terminals) and additional actors in the transport chain cause significant process- and transaction-cost. Secondly, road-based forwarders have good reasons to use their own trucks on the main runs. And thirdly, in intercontinental container transportation, the networks are scarce, and there is only a low transport frequency between intermodal terminals. For transport logistics service providers, the usage of the single-wagon networks is also not a practical option because the processes of moving single wagons from the logistics warehouses to the marshalling yards are too time-consuming, expensive and unreliable.

Against this background, the project LOGOTAKT was launched.[1] The project aimed at studying a new type of transport system combining elements of single-wagon networks, intermodal networks and mixed cargo networks. For this purpose, warehouses for the transshipment and consolidation of single pallets should be established at the existing central marshalling yards. They are called Railports. It is planned to use curtain side containers, and thus, two operations at Railports could be possible: (1) transshipment of single pallets from one curtain side container (pre-haul) to another container located on a carrying wagon or (2) intermodal transshipment of whole curtain side containers using a traditional crane. Especially, the transshipment of single pallets could be realized at an industrial scale using state-of-the art warehouse technologies. Information systems could help to bridge the gaps between the

[1] The LOGOTAKT project is financed by the German Federal Ministry of economics and Technology. It started 2008 and finishes by the end of 2010. See http://www.logotakt.de.

planning and information systems of the different carriers, and due to better information transfer, per formant decision support systems could be used to optimize dispatching, tour planning and routing.

Putting all these elements together, railways could be integrated into a transportation system offering high-frequency and standardized transport services over long distances serving a more and more fragmentized demand. Such a transport system—which would be perceived from the shippers as a kind of conveyor band or as a kind of express service for single pallets—could improve the performance of logistics chains significantly.

The project LOGOTAKT analyzes different aspects of this transport system. Firstly, a business model has to be developed. Secondly, the regulatory framework has to be adapted, since terminals are considered essential facilities and since single-wagon networks constitute some kind of natural monopolies. Thirdly, an infrastructure enabling the communication between the partners constituting the multimodal network has to be conceived. As a final step, the economic viability of the whole system has to be demonstrated. The economic viability contains different aspects: the viability for the industry and the effects on total welfare (including saving of external cost). The proof of the economic viability is necessary to justify possible investment grants to the investors and operators of Railports.

In the progress of this paper, we will concentrate on the calculation of the benefits for the industry. The high intensity of competition in the transport markets give reason to assume that the providers of the multimodal transport network determine their tariffs according to the principles of activity-based costing. Under this assumption, the producer surplus only consists of the benefits for the shippers. Confronted with modified transport tariff systems, they will adapt their warehouse policies and profit from logistics cost reductions.

3 Development of a simplified TLC model with economies of scale

This section develops a simplified TLC model that considers a complex transport cost function. In most cases, transport cost per pallet decreases with increasing shipment size. This will be called “economies of scale in the transport cost function.” The extended TLC model will be used as the basis for the formulation of an econometric shipper model. The section is organized in three parts: First, a short overview over the relevant literature is provided. Then, the traditional TLC model is presented. Finally, the model is extended with a complex function of transport cost.

3.1 The concept of total logistics cost (TLC)

The idea of TLC dates back to Harris [8]. He was the first to develop a normative Economic Order Quantity model (EOQ model). He identified three main cost drivers of the total logistics cost: purchasing cost, order cost and holding/warehouse cost. The minimization of the TLC function results in the economic order quantity. This simple approach provides the fundament for many modern research streams in logistics and transport sciences. Beuthe et al. [3] and Gudehus [7] describe drivers of logistics cost in detail and develop variations of the TLC model. Hensher and Button [9] use the TLC model to simulate logistics decisions. De Jong and Ben-Akiva [5] develop a descriptive micro-simulation model of shipment sizes for Sweden and Norway, where the following cost drivers are the most relevant: order cost, transport cost, consolidation and distribution costs, cost of deterioration and damage during transit, capital cost of goods during transit, inventory cost, capital cost of inventory and stock-out cost. Park [10] develops a discrete choice model for lot size and mode-choices on a partial TLC model. However, for her econometric model, she had no information on the delivery frequencies and thus, on the flow of goods. Wisentjindawat [11] develops a micro-simulation model for urban freight movements based on a TLC model. In the context of setting up a descriptive model explaining the structure of wholesale systems, Friedrich [6] develops a TLC model that is able to capture economies of scale in transport by incorporating a complex transport tariff function.

3.2 Functional form of the simplified total logistics cost model

In the general case, the total logistics cost function can be represented as follows:

$$TLC = p \cdot Q + c(q,d) \cdot \frac{Q}{q} + (w + p \cdot h) \cdot \frac{q}{2} \quad (1)$$

where Q microscopic flow of goods ([paletts/time]), q lot size or average order quantity ([pallets]), p unit value of the goods ([EUR/pallet]), d distance between sender and recipient of the goods, h imputed capital cost rate for inventory holding ([%/year]), w warehouse storage cost per unit per year ([EUR/pallet/year]), $c(q,d)$ variable transport costs depending on q and d.

In extension to the standard model developed by Harris [8], we have substituted in (1) the fixed ordering cost by the variable transport cost term (second term in the TLC function). It is assumed that in modern warehouse systems, fixed ordering costs have a relatively low impact on total costs and thus, they could be neglected. The last term in (1) expresses the cost of inventory holding taking into account the storage cost per unit and capital cost of inventory. Capital costs of goods in transit are not taken into account for two reasons. Firstly, transport lead times are relatively short in our case, and secondly, they do not differ among different choice alternatives. In (1), capital cost occurring for the shipper is excluded. The reason for this is that they do not occur in every delivery relationship (depending on the production process). In addition, cost terms related to unit handling costs in warehouse, safety stock and uncertainties, such as uncertainty in lead time and uncertainty in consumers' demand, are also not incorporated in this simple TLC model.[2]

3.3 Variable transport cost

The tariff system of transport logistics companies is quite complex. Tariffs usually depend on two factors: transport quantity and distance. Transport tariffs enter into the TLC formula of the shippers as variable (i.e., a lot size dependent) transport cost. The structure of transport tariffs can be understood when having a look at the structure of the existing mixed cargo networks and milk-run systems: There are hub and spoke structures as well as complex tour patterns and thus, tariffs reflect the following cost components:

1. Cost for the avenue and departure journey (independent of shipment size),
2. cost for loading and unloading (depending on shipment size),
3. transshipment cost (within a multichain transport network),
4. a proportion of the overhead cost allocated to different clients of the forwarder.

In order to integrate complex transport tariff structures into the TLC model, suitably parameterized transport cost functions are required.

We will focus on a quadratic function for describing the transport cost since it fits well to the structure of transport tariffs. Since these tariffs are usually given in the form of tables differentiating cost per pallet per distance band, the parameters of the tariff functions can be determined for each distance band. The quadratic function for the transport tariffs can be expressed as follows:

$$c_t(q,t) = \left(\alpha(d) + \beta(d)\cdot q + \chi(d)\cdot q^2\right)\cdot c_{full}(d) + u \qquad (2)$$

where $c_t(q,t)$, transport cost function; q, average order quantity; $\alpha(d)$, $\beta(d)$, $\chi(d)$, parameters in dependence of transport distance d; $c_{\text{full}}(d)$, tariff of a full load transport in dependence of distance d; u error term. Determining these parameters leads to the distance-specific models shown in Table 1.

Figure 1 shows typical transport cost functions differentiated by distance. These functions express the percentage of costs (y-axis) in relation to the capacity utilized by the shipper (x-axis).

For instance, when shipping 15 pallets in one trip instead of 30 (the full truckload capacity), about 75% of the full-truck tariff has to be paid in almost all cases, independently of the forwarding distance. The proportionate fixed cost compared to the full truckload cost decreases with an increasing transport distance. Economies of scale are manifested in the order of specific fixed cost and in the concave shape of the cost function.

By substituting the second term of Eq. 1 with the quadratic function for the transport cost (Eq. 2), the following expression is obtained:

$$\begin{aligned}\text{TLC}_{\text{QM}} = {} & p\cdot Q + \left(\alpha(d) + \beta(d)\cdot q + \chi(d)\cdot q^2\right)\cdot c_{\text{full}}(d) \\ & \cdot Q/q + (w + p\cdot h)\cdot q/2\end{aligned} \qquad (3)$$

By determining the first derivative of Eq. 3 with respect to q, the "economic order quantity" (EOQ) results in:

$$\text{EOQ}_{\text{QM}} = \sqrt{\frac{\alpha(d)\cdot 2\cdot c_{\text{full}}(d)\cdot Q}{\chi(d)\cdot Q\cdot c_{\text{full}}(d) + (w + h\cdot p)/2}} \qquad (4)$$

Equation 4 could be used to calculate the optimum shipment size analytically. For this purpose, the necessary parameters for such a normative decision support model are available. They are based on the company's financial and process-cost data. For this study, however, revealed data describing logistics behavior are available. This data comprise revealed shipment cases of the shippers, and this gives the possibility to estimate the parameters of (4) statistically. By doing so, factors on logistic decision making that are outside the limited scope of a simple TLC minimization could be captured by the behavior model and be considered the economic assessment. Furthermore, the "true" weight that firms actually attribute on inventory cost can be extracted.

4 Estimation of a TLC-based shipper model

In this section, a TLC-based shipment-size choice model is estimated using revealed shipment data. In a first step, the available data are presented. In a second step, the influence of the value density of commodities on shipment-size decisions is analyzed. Then, a linear econometric model is formulated. Ultimately, the core explaining variable—the effective perceived warehouse cost rate—is estimated.

[2] There is a relationship between lot size and risk. However, if uncertain processes (demand fluctuations, delays) are approximated with Laplace-Gauss distributions, there is only a weak (logarithmic) relationship between risk and lot size in the economic optimum balancing risk and cost. In case studies, the authors have found that in practice safety-stock decisions are not carried out using the "full-blown" TLC approach.

Table 1 Parameters for the transport cost function differentiated by distance class

Distance class (km)	From (km)	To (km)	α	β	χ	C_{full} (€)	R^2	p value
25	0	50	0.2544708	0.0319615	−0.0002425	235	0.93	<2.2e−16
75	50	100	0.2300638	0.0341254	−0.0002876	283	0.94	<2.2e−16
125	100	150	0.2288866	0.0342789	−0.0002935	327	0.93	<2.2e−16
175	150	200	0.2057484	0.0361682	−0.0003296	351	0.94	<2.2e−16
225	200	250	0.2023297	0.0366008	−0.0003409	396	0.94	<2.2e−16
275	250	300	0.1537941	0.0409876	−0.0004335	475	0.96	<2.2e−16
325	300	350	0.148612	0.0418184	−0.0004553	502	0.96	<2.2e−16
375	350	400	0.1075063	0.0451619	−0.0005205	566	0.97	<2.2e−16
425	400	450	0.082193	0.0474068	−0.0005667	630	0.97	<2.2e−16
475	450	500	0.0569898	0.0495526	−0.0006102	703	0.98	<2.2e−16
525	500	550	0.0571699	0.0496953	−0.0006157	722	0.98	<2.2e−16
575	550	600	0.04	0.051104	−0.000643	775	0.98	<2.2e−16
625	600	650	0.0249332	0.0523779	−0.0006682	828	0.98	<2.2e−16
675	650	700	0.0173217	0.0530737	−0.0006832	874	0.98	<2.2e−16
725	700	750	0.0104854	0.0536987	−0.0006967	921	0.98	<2.2e−16

Fig. 1 Proportion of full-truck load cost in function of shipment size

4.1 Description of data base and descriptive statistics

The data comprise detailed historical data of freight transportation cases from two major German companies. For each shipper–recipient relation, the shipments over a 1-year period are recorded.

Company *A* belongs to the thermo-technology sector. The data set of *A* reflects a typical distribution system, where shipments from several companies are distributed to different local distribution centers. Basically, company *A* faces the problem to replenish local warehouses. Company *B* is an automobile manufacturer. The data set of *B* contains all deliveries from the suppliers to four distinct automobile factories.

Figure 2 shows the geographical distribution of consignors and recipients. When plotting origins and destinations of all transport relations, one can see that senders and receivers of Data set *A* are uniformly distributed all over Germany (see Fig. 3). However, Data set *B* contains only data from the postal code 7 region. In total, we have 682 transport relations for company *A* and 525 transport relations of company *B*. There are 17,458 observed shipments for company *A* and 26,165 for company *B*. The data may be considered as representative for the target market of the multimodal transport network LOGOTAKT.

Figure 3 shows the frequency distribution over transport lot sizes in pallets. For both data sets, small lot sizes are dominating.

With regard to our TLC model, we can base our analysis on travelled distance (d), annual shipped quantity (Q), observed lot size (q) and the value per pallet (only for Data set *A* available).

For the upcoming analysis, all relations with an average delivery frequency of more than two loads per day are excluded (meaning for example a daily delivery). It can be assumed that a significant proportion of these transport flows relates to just-in-time deliveries. Therefore, these shipments are most probably not part of the inbound flows being stocked in the warehouse facilities (they eventually flow through). For those cases, the application of a TLC model is no longer justified.

Additionally, all relations having an annual flow of goods less than 10 pallets are excluded from the analysis. As a total result, we only consider transport relations with warehousing activities and subject of a respective warehousing policy. As a consequence of this process, the cleaned database for *A* includes 265 relations (17,107 shipments), and the database for *B* includes 209 relations (8,427 shipments).

4.2 Determination of explaining variables

The following two parameters need to be estimated: capital cost rate (h) and warehouse cost rate (w). Since relation-

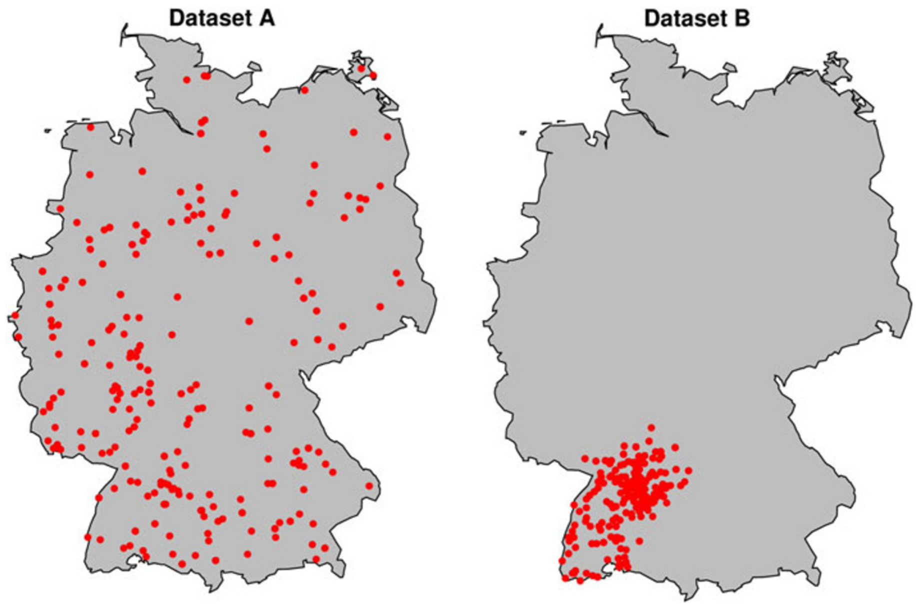

Fig. 2 Spatial distributions of shippers in the two data sets

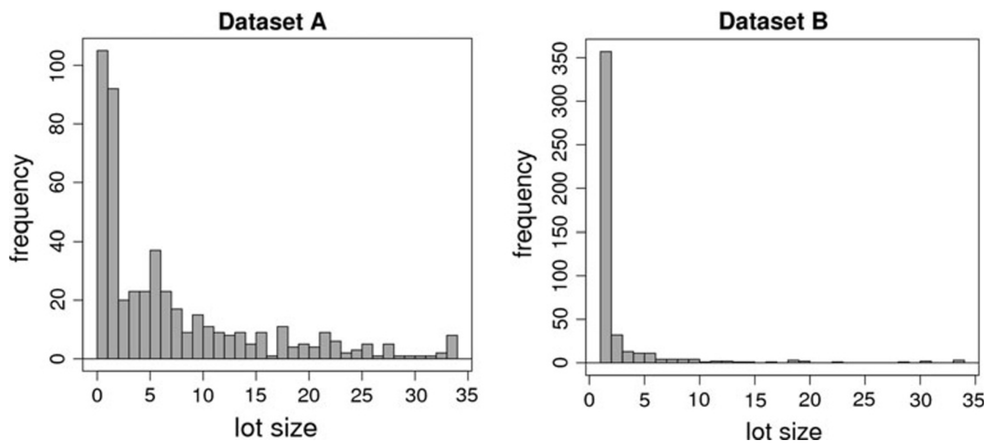

Fig. 3 Frequency distribution of lot sizes

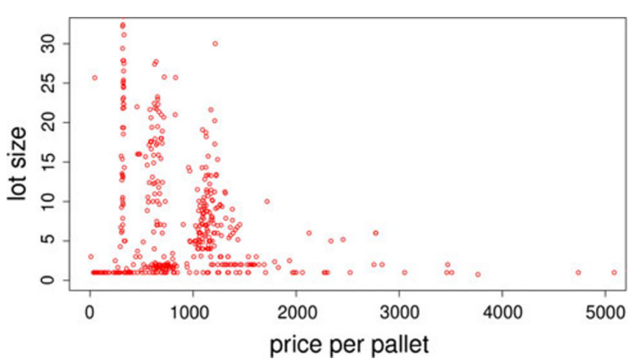

Fig. 4 Scatterplot of lot size and value per pallet

specific information on the commodity value densities was only indicated in the Data set *A*, we examined whether the commodity value significantly affects shipment sizes as it is generally predicted by TLC models. Figure 4 shows the interdependence between lot size ([pallets]) and the respective value of the pallet. A detailed view on correlations between the variables is given in the "Appendix."

At a first glance, it seems that there is no systematic correlation between value density (measured in the commodities' purchase prices per pallet) and chosen lot size. This raises the suspicion that the value density is not suited as an explaining variable. This question was further examined by analyzing the effect of either including the value density or excluding it in the regression. The F test and t test of a simple linear regression show a significant deterioration in the goodness of fit if p is included. According to [1] and [4], this means that—in this special case—the value density should be dropped from the set of explaining variables. The results of our tests are indicated in Table 2. The physical characteristics of the transported goods seem to be more important for lot-size decisions than capital tie-up.

Table 2 Effect of including and excluding parameter p in estimation for Data set *A*

Model	Including parameter p		Excluding parameter p	
	F value	*t* value	*F* value	*t* value
HM	591.686	24.325	1,038.276	32.222
QM	116.885[a]	10.043[a]	168.069[a]	12.590[a]

[a] Weighted mean

This result indicates that—in our case—shippers would base their frequency decisions on some kind of perceived "average value" of the shipments. A practical interpretation is that both warehouse and inventory costs are projected into a form of effective warehouse cost. Therefore, in our further analysis, only the annual quantity of goods and the effective average warehouse cost rate are considered as explaining variables (in Data set *B*, we had no choice since the value densities have not been available due to data privacy reasons).

4.3 Formulation of a linear econometric model and parameter estimation

Since we do not have information about the actual total logistic cost in our empirical data, we assume that shippers are cost optimizers, and thus, the shipment size minimizing logistics cost can be determined through the first-order condition of the TLC minimization leading to the "economic order quantity." These "optimum" shipment sizes are expressed in Eq. 5 for the standard Harris model (HM). Equation 6 shows the same expression in the case of a quadratic transport cost function. In both expressions, "$w + p \cdot h$" is substituted by "γ"

$$\text{HM:}\quad \text{EOQ}^2_{\text{HM}} = 2 \cdot Q \cdot c_{\text{full}} \cdot 1/\gamma \qquad (5)$$

$$\text{QM:}\quad (\alpha/\text{EOQ}^2_{\text{QM}} - \chi)^{-1} = 2 \cdot Q \cdot c_{\text{full}} \cdot 1/\gamma \qquad (6)$$

In this context, the substitution variable γ can be understood as the resulting effective warehouse cost rate perceived by the logistics decision-maker. This variable expresses all forms of factors opposed to inventory holding such as inventory cost for the shipper, warehouse-space scarcity, inventory holding cost or additional incentives by the upper management toward a reduction in circulating assets.

Equations 5 and 6 serve as regression functions; they are linear in their parameters. The estimated values for the yearly warehouse cost per pallet are listed in Table 3.

The regression results show that all the extended EOQ-models fit to the data. All *p* values are lower than 0.04 that leads to a falsely rejection of the null hypothesis—that *Q* has no systematic impact on lot sizes—by less than 4%. Comparing the coefficient of determination, the fit for Data set

Table 3 Estimations of yearly effective perceived warehouse cost per pallet and year

Model	Data set	Estimated γ (Euro)	R^2	*p* value (*t*)
HM	A	3,587	0.68	≤2.2e−16***
QM	A	1,320	0.78	0.0018**
HM	B	5,136	0.30	≤2.2e−16***
QM	B	1,689	0.57	0.03*

* $p<0.05$; ** $p<0.01$; *** $p<0.001$

A is much better than for Data set *B*. A possible reason for this result can be found in the structure of the lot-size distribution. In Data set *B*, small lot sizes are dominating, and the range of different lot sizes per annual order quantity is high. This causes high residual values in the lower lot-size region. The result of the regression is plotted in the figures in the "Appendix," which show observed data and predicted values for lot sizes over quantity of yearly pallets.

It is difficult to compare the results with reference values from the literature. While being aware of the logistics' weaknesses, we could relate the warehouse cost to the average value of the commodities. The values per palette are given in the Data set *A*, while the average value for the Data set *B* can be deduced by a comprehensive market research where commodity prices per pallet were calculated for specific industrial sectors based on the German production statistics (PRODCOM). The imputed resulting warehouse rate by data set and model are indicated in Table 4.

Similar values were found by Park [10]. Using a total logistics cost model with fixed transport cost, Park estimates a warehouse rate of 45.6%, which is similar to our result.[3] In a second step, Park introduces quality parameters of the railways reducing the estimated warehouse cost rates by about 50%. In our case, however, this extension of the model would not have made sense, since we are dealing only with one truck-based transport market (mixed cargo and partial loads).

5 Simulation of the new high-frequency transport services on warehouse policies

Using the results of our estimated lot-size model and thus having fixed our reference case, we can study the effects of the sketched intermodal and high-frequency transport service. There are two scenarios: Scenario *A* relates to the distributing company and Scenario *B* relates to the sourcing network of a manufacturer. In this section, firstly, the

[3] In our case we have only considered the storage cost of either the recipient or the shipper. A TLC model for both sides of the supply relationship and warehouse activities on both sides of the chain would provide 50% of the warehouse cost rates indicated in Table 4.

Table 4 Estimated effective perceived warehouse cost rates

Model	Data set	Value per pallet	Warehouse rate (%)*
HM	A	2,634	136.2
QM	A	2,634	50.1
HM	B	2,288	224.5
QM	B	2,288	73.8

*Estimated warehouse rates on mean price per pallet values

details of the transport tariff function for the LOGOTAKT system are worked out based on the principles of activity-based costing. Then, the shipment-size choice models of the two scenarios are confronted with the modified transport cost function, and the impact on shipment size distribution and cost is computed.

5.1 Transport cost function of LOGOTAKT

In order to determine the transport cost function of LOGOTAKT according to the principles of activity-based costing, its main processes and the differences to existing transport systems are shown. The new transport network of the LOGOTAKT project is characterized as follows:

1. High-performance transshipment points at central locations—especially at the central marshalling yards of the railways (the hubs of the single-wagon transport system). They are called "Railports."
2. High-frequency transports on the main links of the transport system (for instance, in the form of additional loads on the existing block trains).
3. Regular tours connecting the Railports with shippers and recipients.
4. Intelligent combination of pickups and deliveries on the same tour.
5. Synchronization of transport service taking into account the demand for such transport services.

Analyzing the transport costs of LOGOTAKT, it becomes clear that the following reasons lead to cost reductions:

1. The time needed for loading and unloading can be reduced because of the possibility to establish regular business processes.
2. The transshipment cost within the transport network can be reduced through automation. It is, therefore, crucial that the system has a certain critical mass of turnover.
3. The distances between shippers and recipients on the delivery and collection tours are reduced since the Railports have a much higher turnover—and thus, more clients in a region—than the existing warehouses of forwarders.

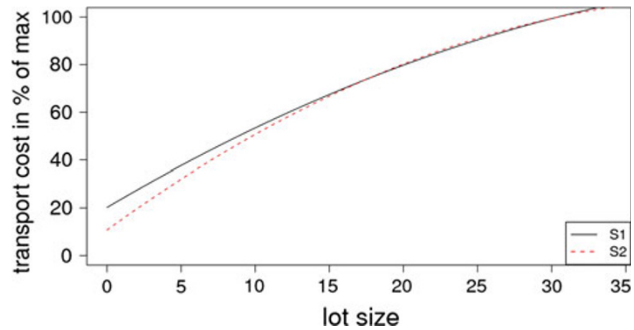

Fig. 5 Change in transport cost curve from S1 to S2

Table 5 Cost structure for S1 and S2

Data set/ scenario	Transport cost (th. Euro)	Warehouse cost (th. Euro)	Total cost (th. Euro)
A/S1	3,537	1,668	5,206
A/S2	3,566	1,383	4,950
B/S1	2,665	1,228	3,894
B/S2	2,583	1,020	3,603

Table 6 Percentage of cost change for A and B compared to the reference case

Data set	Variation of transport cost (%)	Variation of warehouse cost (%)	Variation of total logistics cost (%)
A	+1	−17	−5
B	−3	−17	−7

4. Because of the high transport frequency on the main links, regular transport and logistics processes could be set up (for instance, regular framework tours).
5. Shippers can combine shipments for several recipients on one outgoing truck.

Transport cost is calculated based on a full-cost approach. All occurring cost is allocated to the shipments according to the principles of activity-based costing. Thereby, tariff tables for different distance classes are calculated. They could then be transformed into the transport cost functions.

Figure 5 exemplarily shows the initial tariff curve S1 (reference case) and the resulting tariff curve for the intermodal transport network S2 for a transport distance of 400 km.

For both scenarios, the impact of the modified tariff tables on shipment sizes as well as on transport and warehouse cost is calculated. The results are shown in Table 5. Table 6 provides the relative changes of the cost components.

In both cases—recall that case *A* is a distribution system and *B* a sourcing system in production—the new type of transport service leads to a reduction in the total logistics cost

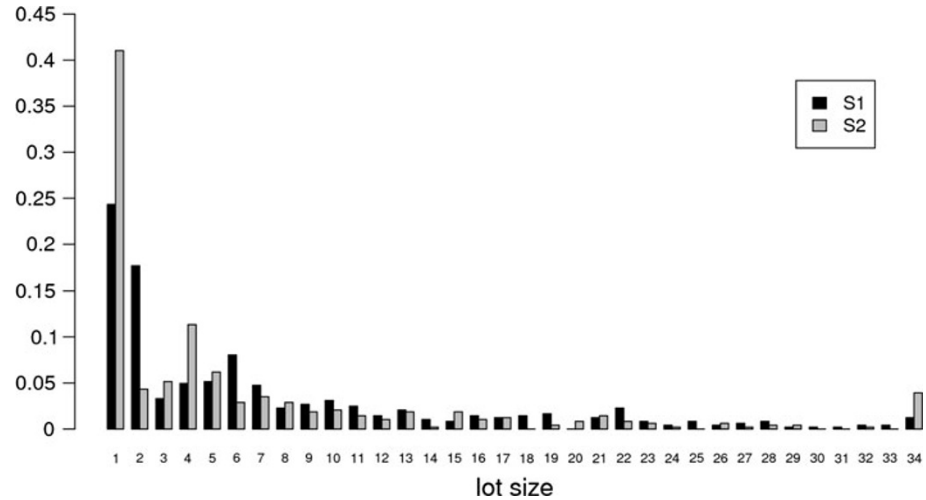

Fig. 6 Changed lot-size distribution for A

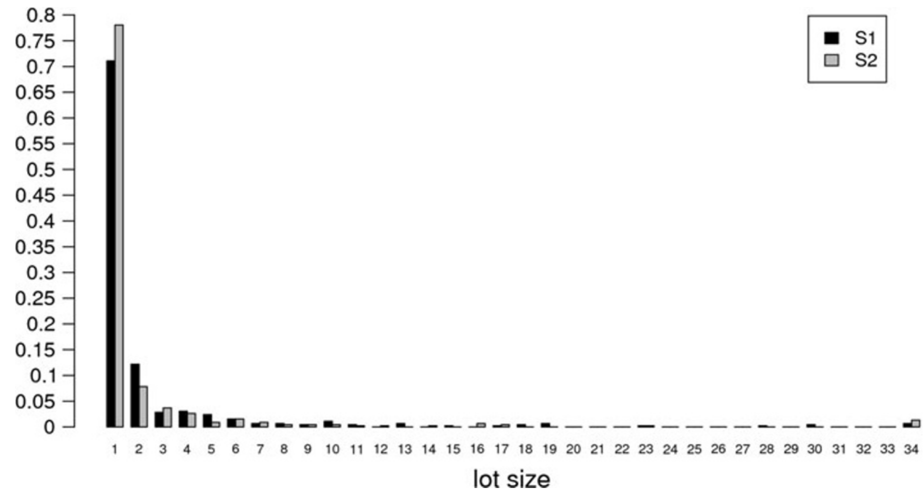

Fig. 7 Changed lot-size distribution for B

of about 5–7%. However, the detailed adaptation mechanisms of the two companies differ significantly from each other.

Since transport cost is reduced by LOGOTAKT, company *A* increases delivery frequencies significantly (see Fig. 6). This effect is also reflected in the results of Table 6. Although the transport tariffs are lower than in the existing systems, *A*'s transport cost increases by 1%. Company *B* also increases frequencies (see Fig. 7), but still it reduces dispenses for transport. In both cases, it turns out that the cost savings mainly result from a reduction in warehouse cost and not from reduced transport cost.

6 Conclusion

When opening the existing transport systems for single railway cars to palletized cargo, railways could profit from the prospering markets of less-than-truckload and single pallet transports carried over long distances at a national or even continental scale. This was the main idea of the project LOGOTAKT. On the main links of the conceived multimodal transport network, railways could carry consolidated transports of many shippers. Here, they benefit from significantly lower mileage-dependent transport cost compared to truck-based transports. LOGOTAKT offers regular and high frequency connections between shippers and recipients on a national scale (and in a second stage on a European scale).

For the demonstration of economic viability of such a system and for the justification of investment grants supporting the development of intermodal infrastructure, an integrated behavior and assessment model have been set up to deal with the specific characteristics of this market, a continuous choice model has been developed. Using the first-order condition of the TLC optimization problem as its functional form, it was possible to set up a relationship between the annual flow of goods and shipment size (respectively frequency). By doing so, we included the main drivers of the shipper's logistics behavior—logistics cost reductions by balancing out transport- and inventory cost. To explicitly study the effects and the willingness-to-pay resulting from a variation of the transport tariffs, the presented model expresses transport cost as a complex function.

Estimating the shipment size model with two empirical data sets, we deduced annual warehouse cost rates of about 1,300–1,700 EUR per pallet and year. This value reflects several factors:

- The scarcity of warehouse space,
- calculated warehouse cost (including capital cost and running expenses),
- the perceived cost of "complexity,"
- the risk that commodities will not be consumed entirely,
- the wish of the company's higher management to reduce the circulating assets,
- the imputed capital cost of the stocks and
- warehouse cost at the other side of a supply–recipient relationship if that cost is considered by the decision-making entity).

Applying our model to the new intermodal transport system "LOGOTAKT," the analysis reveals interesting implications for the examined company types. Company *A* distributing commodities to points of sale can significantly reduce total logistic costs by shipping smaller lot sizes with LOGOTAKT. Company *A*'s transport cost increases by 1% while its warehouse cost is reduced by 17%. At the same time, Company *B* being the manufacturing company reduces transport cost by 3% and warehouse cost by 17%.

For policy makers, our analysis shows that railways could successfully enter into the flourishing transport markets for logistics demanding goods that are shipped at a high frequency and in small consignments. For this purpose, railways have to be set into a position of handling small lot sizes efficiently. Therefore, a competitive rail transport system requires a strong alliance of road freight operators and of railways closing the gap between rail networks and shippers and recipients. LOGOTAKT could be an example for such an alliance between peers where railways can beneficially operate the main links between Railports. Also, road operators can make use of intelligent planning solutions for consolidating shipments in collection and distribution tours, respectively. Especially, if such a transport system could be extended to operate on a European scale, the benefits would become even higher.

However, high investments cost for the multimodal transshipment infrastructure occurs. This induces the risk of sunk cost. If railway companies cannot manage the risk, the state could support the provision of the necessary infrastructure while setting the regulation for essential facilities accordingly to keep the market open for competition. Against the background of ambitious goals for climate change control—the EU Commission suggests in the Transport Policy White Paper of 2011 to extend the market share for railways on distances longer than 300 km to at least 30% until 2030 and 50% until 2050—more focus will have to be laid on the processing and consolidation of small consignments down to pallet units at intermodal freight centers to prepare them for long-distance transport by rail or waterways.

Appendix

See Figs. 8, 9, and 10.

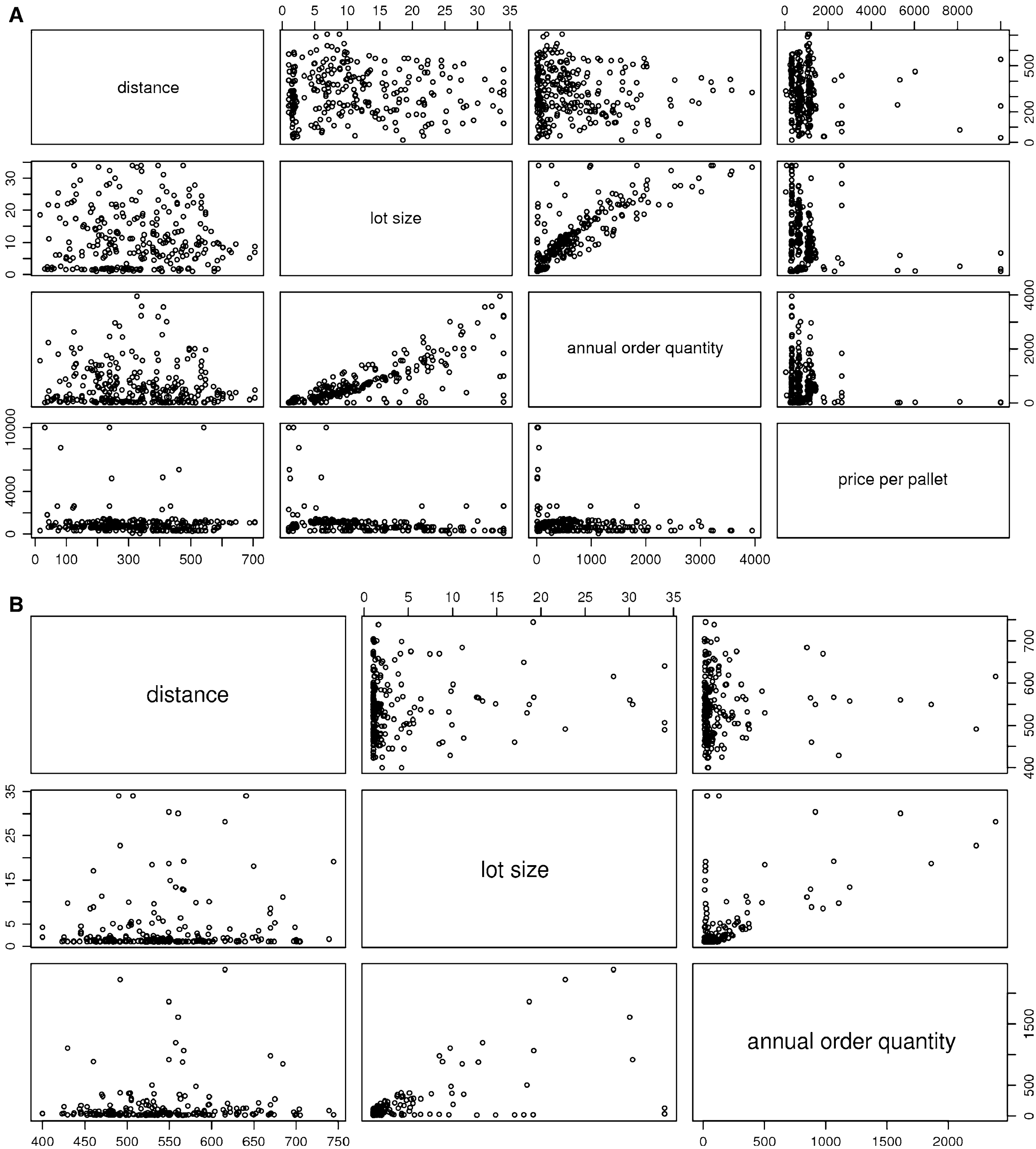

Fig. 8 Scatterplot matrix for **a** dataset A, **b** dataset B

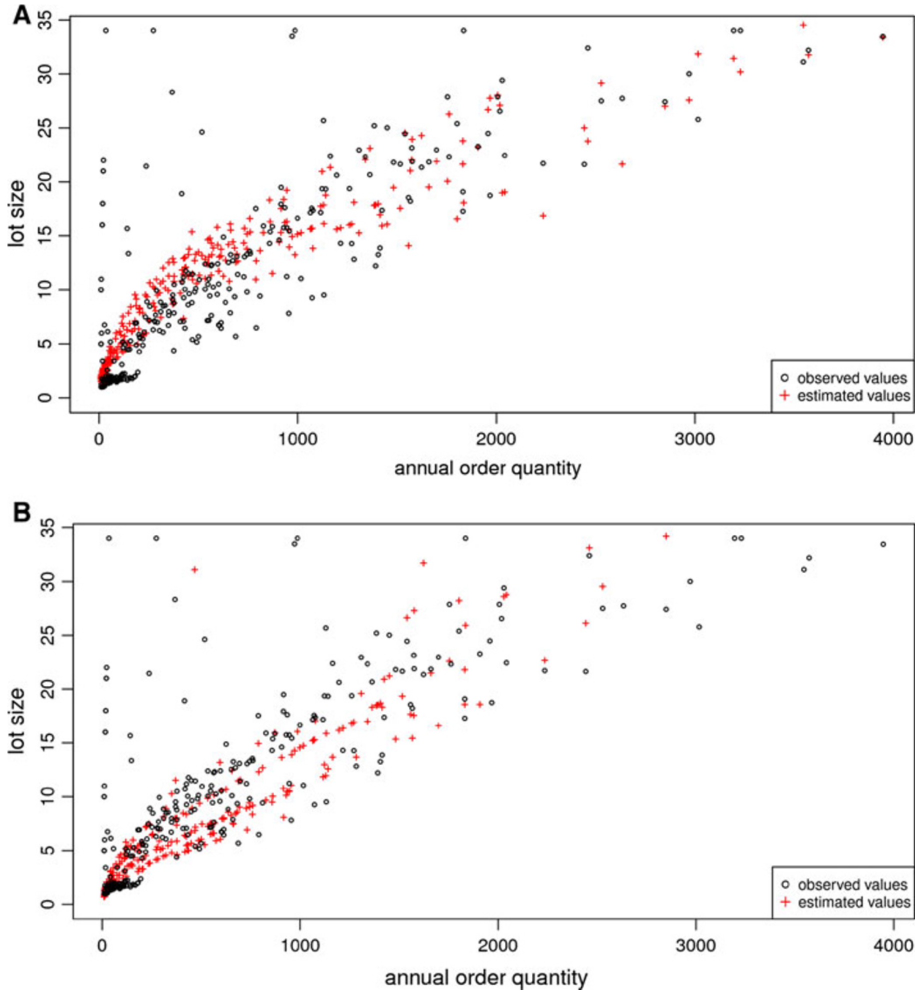

Fig. 9 Dataset A: **a** Hm, **b** QM

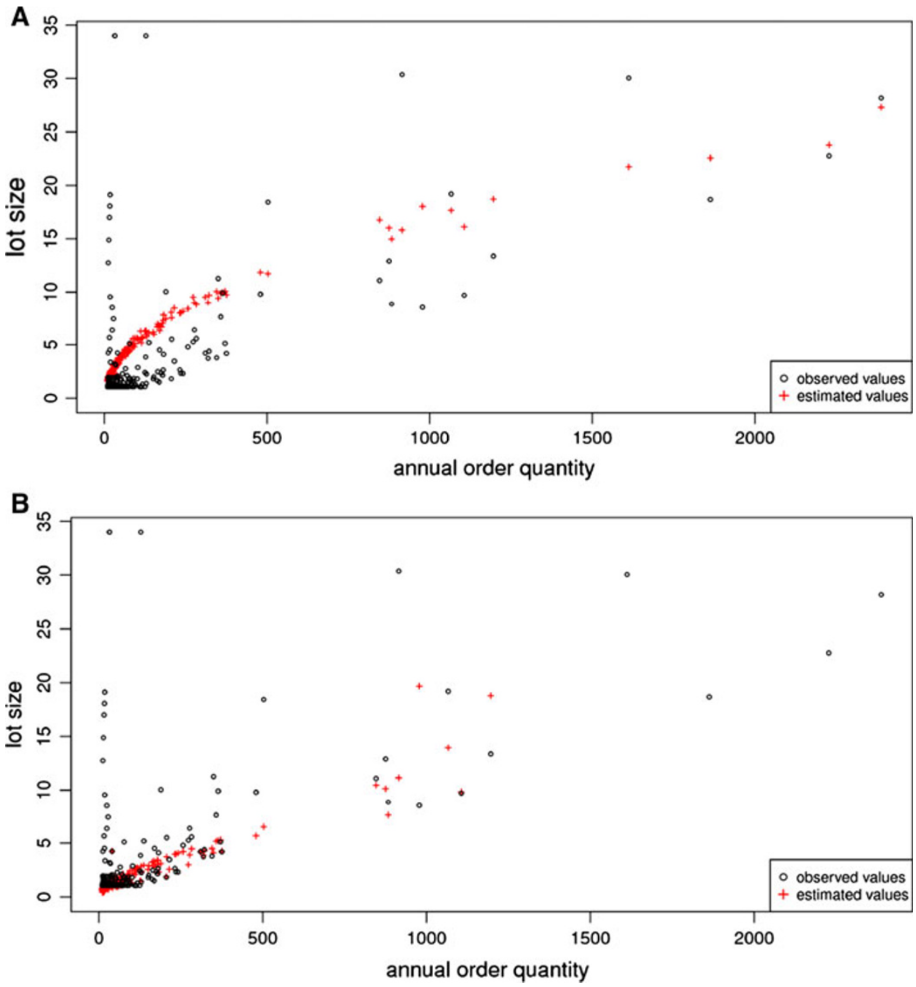

Fig. 10 Dataset B: **a** Hm, **b** QM

References

1. Backhaus K et al (2006) Multivariate Analysemethoden: eine anwendungsorientierte Einführung. Springer, Berlin
2. Baumol WJ, Vinod HD (1970) An inventory theoretic model of freight transport demand. Manage Sci 16(7):413–421
3. Beuthe M, Vandaele E, Witlox F (2004) Total logistics cost and quality attributes of freight transportation. In: Selected papers of the WCTR 2004 in Istanbul
4. Bortz J (2005) Statistik für Human- und Sozialwissenschaftler. Springer, Heidelberg
5. De Jong G, Ben-Akiva M (2007) A micro-simulation model of shipment size and transport chain choice. Transp Res B Methodol 41(9):950–965
6. Friedrich H (2010) Simulation of logistics in food retailing for freight transportation analysis. Dissertation, Karlsruhe Institute of Technology. http://digbib.ubka.uni-karlsruhe.de/volltexte/1000020602
7. Gudehus T (2004) Logistik. Springer, Berlin
8. Harris F (1913) How many parts to make at once. Mag Manage 10(2):135–136
9. Hensher D, Button K (2000) Handbook of transport modelling. Pergamon, Amsterdam
10. Park J (1995) Railroad marketing support system based on the freight choice model. PhD. Massachusetts Institute of Technology
11. Wisentjindawat W (2006) Micro-simulation of freight agents in supply chain for modeling urban freight movement. PhD, Nagaoka University of Technology