Empirical Shipment Size Model for Urban Freight and its Implications

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Abstract
Modeling shipment size for intra-city shipments is a subject that has not been sufficiently addressed in past research, despite its growing importance in disaggregate freight modeling. While past research on shipment size estimation mainly focuses on inter-city shipments, intra-city shipments differ from them in various aspects. In filling this research gap, this study estimates shipment size models using the records of intra-city shipments, identifying the effects of factors and heterogeneity on the shipment size selection mechanism. The estimated coefficients are also compared against their theoretical values derived from a conceptual economic order quantity model. The estimated empirical models highlight the characteristics of intra-city shipments and indicate the importance of both receiver function and commodity type, and also vehicle operation type, in capturing the nuances of the selection mechanism among intra-city shipments.

Understanding and replicating agent behaviors related to urban freight is recognized as an important research topic along with the growing concern about the impact of freight vehicles on urban mobility and sustainability, as well as the interests of planners in urban freight management (1). Existing literature that analyzes or models shipment sizes focuses on inter-city (or inter-regional) shipments. On the other hand, modeling shipment size in the urban freight context has not been addressed to the extent that meets its importance. Shipment size modeling often relies on the concept of the economic order quantity (EOQ) model, which provides a theoretical basis for the relationship between the optimum shipment size and the unit costs of ordering, transporting, and inventory (2–4). However, a conceptual EOQ model with theoretical coefficient values may not be applicable for intra-city (or intra-metropolitan) shipments because of their characteristics, which are different from inter-city shipments in various ways. The transport cost structure for intra-city shipments is, in general, more complex because of the greater potential for multiple-delivery/pickup tours, the more dynamic and unpredictable urban traffic conditions, and the higher costs for delivery/pickup parking. Furthermore, the inventory capacities of receivers of intra-city shipments are often low, especially those of small offices and stores, (at least, partially) because of their high shadow prices of inventory. Moreover, the characteristics of receivers of intra-city shipments (e.g., function type), generally speaking, are more diverse than those of receivers of inter-city shipments. All these features underline the need for the detailed analysis of the shipment size selection mechanism for intra-city shipments.

In this paper, “shipment” is defined as goods, or a bundle of goods, that are transported together at the same time between a shipper and a receiver (5). While in some studies of inter-regional shipments, a shipment is assumed to consist of a sequence of legs that connect the first origin, intermediate facilities, and the last destination, in this paper, a movement of goods that is destined to, originated from, or both, an intermediate facility is also considered a “shipment.” Furthermore, it is considered that each shipment can be associated with a commodity flow contract (hereafter called simply “contract”). A contract is defined as a specification of the total commodity flow (in weight) between a supplier and a receiver per time period. The focus of the present research is business-to-business shipments.

A set of models are estimated for unveiling how the above-mentioned features of intra-city shipments play a role...
role in shipment size selection. This modeling approach considers the nuances in the shipment size choice mechanism attributable to both commodity and receiver function type, which have not been addressed by the past research. This analysis is especially important for understanding the link between the commodity flow and shipment frequency, which has significant impact on associated urban freight traffic. While the estimated models are integrated to an agent-based urban freight simulating system, named SimMobility Freight (6), the main objective of this research is not to propose "better" predictive models but to understand the shipment size selection mechanism for intra-city shipments in depth.

The rest of the paper is organized as follows; a literature review that focuses on shipment size estimation; a description of the conceptual model for intra-city shipment sizes; the data and empirical model formulation; the result of empirical model estimation; and the conclusions drawn from the research.

**Literature Review**

The conversion from commodity flow to vehicle flow is an important step in commodity-based freight modeling. Conventional models use constant load factors for converting commodity flow to truck trips for simplification, dismissing the decision mechanism for shipment size as well as vehicle loading. Even urban freight models that have been recently introduced omit or simplify such a mechanism. Moeckel and Donnelly (7) use load factors in their model for the Chicago Metropolitan Area and Nuzzolo and Comi (8) use average shipment sizes defined for four transport service types.

The importance of shipment size estimation is, on the other hand, recognized for freight models that focus on the logistics decisions in a disaggregate manner. The shipment size model used in an urban freight simulator developed by Wisetjindawat and Sano (9), called "ordering frequency model," is a simplified EOQ model that depends only on the quantity of commodity flow and trip distance. Wisetjindawat et al. (10) introduce another version which further considers industry type, that is, warehouse, manufacturer, or retailer. These models do not consider commodity type and assume that storage cost (called "holding cost") is constant across all receivers. In a conceptual framework for urban freight modeling proposed by Roorda et al. (11), shipment size (called "order quantity") is treated as the function of demand size, ordering cost, and carrying cost but storage cost is not included. In a national scale model, Liedtke (12) uses the theoretical total logistics cost including storage, ordering and handling costs, and transport rate, for a heuristic optimization module to determine shipment size. For a spatial scale greater than a city, several articles propose joint models for mode choice and shipment or vehicle size. The underlying hypothesis is that the choice of shipment size is not independent of that of transport mode/truck size. For example, Abate and de Jong (3) estimate a discrete-continuous model of shipment size and vehicle size class, using the data from the Danish heavy trucks trip diary in 2006/2007, a national scale survey data set. A two-step estimation method is used to remove the simultaneity bias that occurs in the decisions on shipment and vehicle sizes. Abate et al. (13) propose a discrete-discrete model for transport mode chain and shipment size as a part of the national freight transport model for Sweden. Similarly, Stinson et al. (14) estimate a nested logit model for transport mode (defined as the first level) and discretized shipment size (defined as the second level) using records from the U.S. Commodity Flow Survey Microdata. Pourabdollahi et al. (15) propose a copula-based joint model for freight mode and shipment size. A list of the studies that focus on a modeling approach for similar joint decisions is provided by Irannezhad et al. (16); none of those studies exclusively focus on intra-city shipments.

Irannezhad et al. (16) estimate a joint model for shipment size and vehicle type choice using data that cover a considerable number of intra-city shipments in Mashhad, Iran. While their main research focus is model formulation, the result of the model estimation is insightful, indicating the existence of relationships between delivery time and shipment size and between vehicle size and shipment characteristics, as well as the difference in the choice mechanism between shippers and carriers. However, their model does not consider information about receivers, who are the key stakeholders on shipment size selection, such as receivers' inventory costs, which presumed highly important for intra-city shipments.

Many modeling studies use an EOQ model as the theoretical basis for selecting the independent variables (3, 4, 9, 17–19), although the variables which are actually used in model estimation vary depending on data availability. Combes (2) assesses the validity of a conceptual EOQ model with theoretical coefficient values by comparing it with an empirical shipment size model estimated using domestic shipment records from the French ECHO database. The analysis confirms that the estimated coefficients of total commodity flow and the value of goods roughly match with their theoretical values. He also confirms that shipment size depends on vehicle operation type, that is, full-truckload, less-than-truckload, or multiple deliveries/pickups.

As discussed above, the existing research on shipment size mainly focuses on areas that are larger than a city. Some urban freight models cover a shipment size model but receiver-side information, which we hypothesize as comprising key factors on shipment size choice for intra-city shipments, is not considered. Shipments to two
different locations, one in a business district in the city center and another in a suburb, should have different values for inventory costs (i.e., storage cost) which differ between those locations. This research attempts to fill this research gap. Shipment size models are estimated by considering receiver information for intra-city shipments using the data from a large metropolitan area. Whether a conceptual EOQ model with theoretical coefficient values is directly applicable for intra-city shipments is also examined, as Combes (2) did with national shipment records.

**Benchmark Conceptual Model for Intra-City Shipment Size**

As discussed in the literature review, the EOQ model is widely used because of its solid theoretical basis that relies on the assumption of cost minimization. In this section, a theoretical formulation for an intra-city shipment size model is derived, following the typical approach to derive a conceptual EOQ model. It is assumed that the total logistics cost (TLC) for a contract \( i \) is the sum of three different cost components, namely:

\[
\text{TLC}_i = \text{Transport Cost}_i + \text{Inventory Cost}_i + \text{Capital Cost during Transport}_i
\]  

(1)

Transport cost and inventory cost incurred by the receiver for contract \( i \) are assumed as follows:

\[
\text{Transport Cost}_i = \frac{Q_i}{q_i} \cdot o_i(q_i, d_i)
\]  

(2)

\[
\text{Inventory Cost at the Receiver}_i = q_i/2 \cdot w_i
\]  

(3)

where \( Q_i \) is the size of the contract; \( q_i \) is the shipment size; \( d_i \) is the shipment distance; \( o_i(q_i, d_i) \) is the transport cost per shipment; and \( w_i \) is the storage cost per unit.

Transport cost and the product of the shipment frequency and the per-shipment unit cost (Equation 2). The per-shipment unit cost is defined as the function of the shipment size (in relation to weight) and the shipment distance. \( \beta_1 \) and \( \beta_2 \) in Equation 3 should differ by commodity as the transport cost of some commodities is potentially more sensitive to the size of the shipment than that of others. The inventory cost to the receiver is the product of the shipment frequency and the per-shipment unit cost (Equation 2). The per-shipment unit cost is defined as the function of the shipment size (in relation to weight) and the shipment distance. \( \beta_1 \) and \( \beta_2 \) in Equation 3 should differ by commodity as the transport cost of some commodities is potentially more sensitive to the size of the shipment than that of others. The inventory cost to the receiver is defined as Equation 4, following the typical practice for the derivation of the EOQ model. \( q_i/2 \) is the average level of inventory.

Assuming shippers for intra-city shipments often handle high frequency shipments for many different contracts, the marginal effect of a shipment size for a single contract on the shipper’s inventory cost can be negligible. Thus, the inventory cost at the shipper side is assumed to be independent from the shipment size for a single contract. Furthermore, the capital cost during transportation is the product of total commodity flow, interest rate, value of goods, and travel time, and therefore is independent of the shipment size. Thus, Equation 1 can be rewritten as:

\[
\text{TLC}_i = \frac{Q_i}{q_i} \cdot (\beta_1 + \beta_2 \cdot q_i) \cdot d_i + q_i/2 \cdot w_i + \text{other costs independent from } q_i
\]  

(5)

Minimizing TLC in Equation 5 with respect to \( q_i \) results in:

\[
q_i = \sqrt{2 \cdot Q_i / \beta_1 \cdot d_i / w_i}
\]  

(6)

\[
\ln q_i = 1/2 \ln Q_i + 1/2 \ln d_i - 1/2 \ln w_i + 1/2 \ln 2 \beta_1
\]  

(7)

Equation 7 is a theoretical formulation of shipment size (i.e., a conceptual EOQ model with theoretical coefficient values). This equation will be used as a benchmark for comparison with the empirical models estimated in this study.

**Data and Model**

**Data**

For the empirical model estimation, the shipment records collected by 2013 Tokyo Metropolitan Freight Survey (TMFS) were used. The TMFS targets the establishments that are engaged in freight activities in the Tokyo metropolitan area, which has a typical monocentric urban system with the highest population and business densities around its center (Figure 1). Information about the establishments and their outbound and inbound shipment records were collected in the survey. In total, 20,583 inbound shipment records by 3,961 establishments were...
used for the model estimation. These shipment records are classified into eight commodity types and four receiver function types (office, factory, shop or restaurant, and logistics facility), as shown in Table 1. The records of shipments to office and shop or restaurant are relatively small as the TMFS was designed to target the freight-activity intensive facilities (i.e., factories and logistics facilities). However, this bias in the samples is not a concern for model estimation, as a model is estimated for each commodity type and receiver function combination, as described in the following subsection.

Table 1. Sample Size by Commodity Type and Receiver Function Type

| Commodity                        | Office | Factory | Shop/restaurant | Logistics facility |
|----------------------------------|--------|---------|-----------------|--------------------|
| Agricultural products            | 101    | 849     | 78              | 427                |
| Food products                    | 176    | 1,003   | 160             | 1,580              |
| Light manufacturing products     | 587    | 2,744   | 107             | 1,102              |
| Wood and paper products          | 341    | 347     | 26              | 364                |
| Minerals, ore, stone, cement, ceramics, or glass | 124    | 610     | 32              | 83                 |
| Metals or articles of metal      | 368    | 3,616   | 21              | 317                |
| Machinery, appliances, and mechanical parts | 519    | 2,193   | 78              | 414                |
| Chemicals, rubber, or plastics   | 342    | 1,595   | 40              | 239                |

Table 2. Shipment Size by Commodity–Receiver Type Category

| Commodity type                        | Mean (and SD) of shipment size in kg | One-way ANOVA | Kruskal-Wallis test |
|---------------------------------------|-------------------------------------|---------------|---------------------|
|                                       |                                     | F   | p-value | chi-squared | p-value |
| Agricultural products                 | 3,181 (5,034)                      | 9.43| 0.000   | 81.1        | 0.000   |
| Food products                         | 1,090 (2,614)                      | 41.46| 0.000   | 472.3       | 0.000   |
| Light manufacturing products          | 574 (2,321)                        | 14.25| 0.000   | 512.4       | 0.000   |
| Wood and paper products               | 674 (1,693)                        | 6.94 | 0.000   | 97.4        | 0.000   |
| Minerals, ore, stone,                 | 5,589 (13,527)                     | 13.73| 0.000   | 121.4       | 0.000   |
| cement, ceramics, or glass            | (11,228)                           |      |         |             |         |
| Metals or articles of metal           | 1,157 (2,639)                      | 11.60| 0.000   | 73.9        | 0.000   |
| Machinery, appliances,                | 667 (2,460)                        | 5.49 | 0.001   | 212.1       | 0.000   |
| and mechanical parts.                 | (1,695)                            |      |         |             |         |
| Chemicals, rubber, or plastics        | 1,108 (2,226)                      | 28.96| 0.000   | 134.4       | 0.000   |

Note: SD = standard deviation; ANOVA = analysis of variance.

The mean shipment size, together with the standard deviation (SD) in parentheses, is shown in Table 2 for each commodity–receiver function combination. The SDs are higher than the means for all combinations because the distributions of shipment sizes are positively skewed to a significant degree. Table 2 also shows the results of the two statistical tests, one-way analysis of variance (ANOVA) and Kruskal-Wallis test, which compare the mean shipment sizes across different receiver functions. Both tests indicate statistically significant differences in the mean shipment size among receiver function types for all eight commodity types.

The summary statistics of the independent variables are shown in Table 3. As the exact contract sizes associated with shipment records are not available from the TMFS, estimated values are used. The average contract size for intra-city shipments was computed based on the total inbound flow, the number of suppliers, and the share of intra-city shipments, all of which are available at the establishment level. The average contract size of each receiver establishment is used as the size of the contracts.
associated with the establishment. The exact geographical locations of shipment receivers are available, as well as shippers’ locations at the municipality level. Those data were used to calculate shipment distance, which is the length (km) of the network-based shortest path between the shipper and the receiver, and the land price at the receiver’s location (i.e., a 1 km-by-1 km polygon where the receiver is located). The land price data, which is originally from the public archives of the Government of Japan, was provided by the Tokyo Planning Commission of the Tokyo Metropolitan Region.

**Specifications for Empirical Model**

The selection of shipment size for intra-city shipments is expected to depend greatly on the receiver’s characteristics, especially facility function type. Unlike inter-city shipments, for which facility function types of shippers and receivers are predominantly factories and logistics facilities (e.g., warehouses and distribution centers), a considerable share of intra-city shipments are sent to retail shops, restaurants, and offices. These different facility functions should have different inventory management strategies. Furthermore, the mechanism for selection of the shipment size should also differ by commodity type. The shipment records were segmented by commodity type and receiver function type to analyze the differences in the shipment size decision-making mechanism.

The model is specified as a linear model with the log-transformed shipment size as the dependent variable. The log of shipment size for the contract $i$ of a receiver $n$ of function type $f$ for commodity type $c$ is given by the following equation.

$$
\ln s_{c,f,n} = \beta_{const} + \beta_{lfshp} \cdot dum_{lfshp,c,f,n} + \beta_{size} \cdot \ln c_{size,n} + \beta_{dist} \cdot \ln dist_{c,f,n} + \beta_{LP} \cdot \ln LP_{n} + \beta_{distLP} \cdot \ln LP_{n}
$$  

(8)

where $c_{size,n}$ is the contract size in relation to weight (metric tons per year); $dum_{lfshp,c,f,n}$ is a dummy variable, which is 1 if the shipper is a logistics facility and 0 otherwise; $dist_{c,f,n}$ is the distance between the supplier and the receiver (km); $LP_{n}$ is the land price at the receiver’s location (million JPY per m²); and $\beta_{const}$, $\beta_{lfshp}$, $\beta_{size}$, $\beta_{dist}$, $\beta_{distLP}$, and $\beta_{LP}$ are the parameters to be estimated.

$\beta_{lfshp}$ (or $\beta_{dist}$, $\beta_{distLP}$ in case the shipper is a logistics facility), and $\beta_{LP}$ are equivalent to the elasticities of the shipment size with respect to contract size, shipment distance, and land price, respectively. $c_{size,n}$ is known as a key determinant of the shipment size (2). A higher coefficient of $c_{size,n}$ indicates that the change in commodity flow is accommodated more by change in shipment size and less by change in shipment frequency. If the shipment size follows the theoretical formulation (Equation 7), its coefficient, $\beta_{c_{size}}$, must be around 0.5. Another variable, dist,$\_r$, is relevant to transport cost and if the transport cost increases with shipment distance, then the coefficient shows a positive sign. The interaction of dist,$\_r$ and dum,$\_lfshp$, is also considered, assuming the shipments from logistics facilities would be more likely treated by multiple-delivery tours, which results in a different transport cost structure from the other shipments. It should be noted that, while not available for this analysis, it would be ideal to consider the variables that directly characterize the transport mode, such as full-truckload, less-than-truckload or parcel shipping (2). $LP_{n}$ is a proxy of inventory cost on the receiver side (i.e., $w_{i}$ in Equation 7), for which the coefficient is expected to be negative. During the process of the analysis, other variables were also tested, such as travel time (as a variable related to travel cost), and population and employment densities at the receiver’s location (as a proxy of inventory cost). These variables are not included in the final models since those included in Equation 8 give better model fits and provide reasonable coefficient estimates. It should be noted that the land price is not considered for the shipments shipped to logistics facilities, which are, by nature, intermediate locations. The variable is not appropriate as a proxy of the inventory cost for this specific facility type since the land price correlates with the accessibility to the destinations of subsequent shipments from logistics facilities. Furthermore, when a supply chain is driven by demand-side (i.e., pull logistics) and travel time is short and predictable, the operator of a logistics facility simply tries to minimize handling time in the facility, regardless of shipment size. The least squares method is used to estimate coefficients.

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**Table 3. Summary Statistics of Independent Variables (before Log Transformation)**

| Variable                        | Mean   | Median | Min. | Max. |
|---------------------------------|--------|--------|------|------|
| Contract size (metric tons per year) | 1040.6 | 69.4   | 0.0  | 89887.5 |
| Distance between supplier and receiver (km) | 36.5   | 26.1   | 0.6  | 214.0 |
| Land price (million JPY per m²)    | 0.167  | 0.092  | 0.005 | 12.126 |

Note: Min. = minimum; Max. = maximum; JPY = Japanese Yen.
Results

Estimated Empirical Model

Tables 4 and 5 show the results of the model estimation. Generally speaking, the model fits tend to be higher for shipments to offices or shops/restaurants than those to factories or logistics facilities. The models for food and wood and paper products to logistics facilities have the lowest adjusted $R^2$, 0.29 and 0.30 respectively, highlighting the non-homogeneous nature of those shipment types. In contrast, the models for agricultural and food products to offices and shops/restaurants show very high $R^2$ in the range between 0.78 and 0.81, implying their homogeneity in shipment size decision mechanism within the commodity–receiver type categories.

The estimated coefficients indicate the heterogeneity of the effects of considered variables by receiver function and commodity type; the difference by receiver function type is especially noteworthy. First of all, the constants ($b_{const}$) for all commodity types indicate that the sizes of shipments to logistics facilities tend to be much larger than the shipments to other facility types when the values of all three independent variables are the same. On the other hand, the shipments to offices and shops or restaurants are relatively small, seemingly because of the nature of the commodities shipped to these facilities (e.g., finished products with small size packages). Subtle differences in the commodities would not be captured by the eight commodity types used for the analysis. In case the shipments to those facilities are from logistics facilities, the shipment size tends to be larger, especially the shipments to offices.

Second, the coefficients of the contract size are significant with the 95% confidence interval for all cases. Those for factories (as receivers) are around 0.52–0.61, which is consistent with the value of the EOQ model shown in Equation 7 (i.e., 0.5), indicating that the theoretical coefficient is applicable to the shipments to factories. On the other hand, the coefficients of shop or restaurant are quite high: 0.74 when all commodity types are included, and greater than 0.8 for agricultural, food, and light manufacturing products. This indicates that the increase in shipment size is almost proportional to that in contract size. The result suggests that, for some products, such as food products received at shops and restaurants, the frequency of the deliveries tends to be fixed and, therefore, an increase in the demand (i.e., contract size) is catered for by increase in the shipment size.

Third, as for the effect of distance, most of the estimated coefficients are significant, with positive signs, although there are some exceptions. Distance plays a relatively greater role in the sizes of shipments to factories. This is understandable as shipments to factories are often full truckloads, and a large portion of the transport cost can be explained by the shipment distance. As for commodity type, agricultural products show greater coefficient values than the other commodity types; again, this is likely because of the full-truckload shipping for this commodity type. The effect of distance is reduced when the shipments are from logistics facilities. Such effects are observed especially when the receivers are offices, shops or restaurants. Together with the effects of $dum_{ship}$, which are often positive to those receivers, this suggests that transport costs for shipments from logistics facilities are less dependent on distance and more dependent on frequency. The combined effect of $\ln\text{dist}$. and $dum_{ship} \cdot \ln\text{dist.}$ shows even positive signs for some commodities (food and wood and paper products) sent from logistics facilities to offices. It seems that, in some cases, a large spatial service coverage for deliveries enables further consolidation of small shipments, which results in cheaper costs for longer distance shipments. Only for the shipments of light manufacturing goods to shops and restaurants is the effect of distance significantly negative when they are from locations other than logistics facilities. A close look at the samples indicates that this is caused by the records of shipments from offices or shops/restaurants to shops/restaurants; several very small shipments (typically, less than 5 kg) sent from distant locations results in this seemingly contradictory effect. The above results underline the complexity of transport cost structure for intra-city shipments and indicate that whether shipments are moved in a full truckload or less-than truckload needs to be predicted simultaneously, akin to a shipment size mode choice model for inter-city shipments.

Lastly, a large share of the estimated coefficients of land price are significant, with the expected sign (negative). The effects of land price are especially remarkable when the receivers are offices. Storage is not the main function of this facility type and therefore its shadow price of storage must be high.

Conclusion

This research addresses a research gap related to shipment size modeling for intra-city shipments. The models were estimated using shipment data from the Tokyo metropolitan area for different commodity type–receiver type combinations and the estimated models are discussed, comparing them with the benchmark conceptual EOQ model.

Combes (2) validates the use of the conceptual EOQ model for shipments at the national level. However, this analysis indicates that it is inappropriate to use a conceptual model, instead of empirical models, for urban freight traffic estimation, because of the over-simplification of the logistics cost structure. The authors argue that, for
| Commodity type               | Constant | dum_ship | ln c_size | ln dist | dum_ship × ln dist | ln LP | Coef. | S.E. | t-val. | Coef. | S.E. | t-val. | Coef. | S.E. | t-val. | Coef. | S.E. | t-val. | Adj. R² |
|-----------------------------|----------|----------|-----------|---------|-------------------|-------|-------|------|--------|-------|------|--------|-------|------|--------|-------|------|--------|--------|
| Receiver function: office   |          |          |           |         |                   |       |       |      |        |       |      |        |       |      |        |       |      |        |        |
| Agricultural products       | -1.03    | 0.54     | -1.91     | 2.93    | 1.10              | 2.66* | 0.57  | 0.04 | 12.9*  | 0.57  | 0.04 | 12.9*  | 0.71  | 0.17 | 4.10*  | -0.49 | 0.31 | 1.60  | -0.83 | 0.13 | -6.47* | 0.78   |
| Food products               | 1.64     | 0.45     | 3.65*     | 1.05    | 0.66              | 1.60  | 0.87  | 0.04 | 23.6*  | -0.02 | 0.13 | -0.14  | -0.66 | 0.19 | -3.39* | -0.05 | 0.10 | -0.46  | 0.81   |
| Light manufacturing products| 2.17     | 0.23     | 9.38*     | 0.23    | 0.38              | 0.61  | 0.58  | 0.02 | 32.1*  | -0.02 | 0.07 | -0.23  | -0.03 | 0.11 | -0.28  | -0.24 | 0.06 | -4.28* | 0.67   |
| Wood and paper products     | 0.51     | 0.21     | 2.42*     | 2.02    | 0.36              | 5.56* | 0.86  | 0.03 | 29.5*  | 0.27  | 0.06 | 4.28*  | -0.45 | 0.11 | -3.97* | -0.15 | 0.06 | -2.40* | 0.77   |
| Minerals, ceramics, glass, etc.| 1.96   | 0.72     | 2.72*     | 0.32    | 1.19              | 0.27  | 0.58  | 0.05 | 11.9*  | 0.42  | 0.18 | 2.30*  | 0.00  | 0.38 | 0.00   | 0.01  | 0.14 | -0.10  | 0.56   |
| Metals or articles of metal | 1.32     | 0.25     | 5.21*     | 0.58    | 0.44              | 1.33  | 0.74  | 0.03 | 27.1*  | 0.09  | 0.08 | 1.05   | -0.09 | 0.13 | -0.66  | -0.23 | 0.07 | -3.25* | 0.76   |
| Machinery, mechanical parts, etc.| 0.94   | 0.25     | 3.77*     | 0.34    | 0.44              | 0.77  | 0.62  | 0.03 | 23.9*  | 0.20  | 0.08 | 2.54*  | -0.12 | 0.13 | -0.94  | -0.21 | 0.06 | -3.54* | 0.61   |
| Chemicals, rubber, or plastics | 1.19   | 0.36     | 3.28*     | 1.21    | 0.61              | 2.00* | 0.76  | 0.03 | 22.2*  | 0.32  | 0.09 | 3.39*  | -0.34 | 0.18 | -1.94  | -0.02 | 0.08 | -0.22  | 0.62   |
| All commodity types         | 1.18     | 0.11     | 10.6*     | 0.89    | 0.19              | 4.63* | 0.68  | 0.01 | 66.0*  | 0.19  | 0.03 | 5.47*  | -0.26 | 0.06 | -4.50* | -0.25 | 0.03 | -9.62* | 0.68   |
| Receiver function: factory  |          |          |           |         |                   |       |       |      |        |       |      |        |       |      |        |       |      |        |        |
| Agricultural products       | 0.89     | 0.24     | 3.78*     | 0.27    | 0.31              | 0.89  | 0.59  | 0.02 | 38.4*  | 0.59  | 0.06 | 10.0*  | 0.01  | 0.09 | 0.15   | 0.02  | 0.06 | 0.32   | 0.73   |
| Food products               | 2.88     | 0.31     | 9.26*     | -0.94   | 0.43              | -2.16*| 0.52  | 0.02 | 28.8*  | 0.09  | 0.08 | 1.11   | 0.21  | 0.12 | 1.76   | -0.10 | 0.06 | -1.51  | 0.48   |
| Light manufacturing products| 1.21     | 0.09     | 14.0*     | 0.70    | 0.24              | 2.93* | 0.58  | 0.01 | 48.0*  | 0.34  | 0.03 | 12.4*  | -0.28 | 0.07 | -3.98* | -0.15 | 0.03 | -5.36* | 0.53   |
| Wood and paper products     | 1.96     | 0.34     | 5.85*     | 0.08    | 0.64              | 0.13  | 0.55  | 0.03 | 16.5*  | 0.27  | 0.10 | 2.60*  | 0.02  | 0.20 | 0.08   | -0.09 | 0.09 | -1.06  | 0.48   |
| Minerals, ceramics, glass, etc. | 3.57   | 0.32     | 11.0*     | 0.06    | 0.43              | 0.14  | 0.54  | 0.02 | 30.1*  | 0.13  | 0.06 | 2.13*  | -0.07 | 0.12 | -0.58  | -0.08 | 0.05 | -1.54  | 0.60   |
| Metals or articles of metal | 2.02     | 0.10     | 20.2*     | 0.17    | 0.23              | 0.72  | 0.61  | 0.01 | 59.2*  | 0.20  | 0.03 | 6.86*  | 0.02  | 0.07 | 0.30   | -0.09 | 0.03 | -3.01* | 0.54   |
| Machinery, mechanical parts, etc. | 1.20   | 0.14     | 8.36*     | -0.68   | 0.34              | -2.02*| 0.58  | 0.01 | 50.2*  | 0.27  | 0.04 | 7.25*  | 0.05  | 0.10 | 0.48   | -0.31 | 0.04 | -7.56* | 0.57   |
| Chemicals, rubber, or plastics | 1.93    | 0.24     | 8.11*     | -0.11   | 0.42              | -0.26 | 0.55  | 0.02 | 29.8*  | 0.29  | 0.06 | 4.89*  | 0.01  | 0.12 | 0.12   | -0.08 | 0.05 | -1.64  | 0.42   |
| All commodity types         | 1.51     | 0.06     | 27.3*     | 0.16    | 0.12              | 1.39  | 0.60  | 0.00 | 121*   | 0.31  | 0.02 | 20.0*  | -0.05 | 0.03 | -1.57  | -0.13 | 0.02 | -8.53* | 0.57   |

Note: *Significant at a 95% confidence level (two-tailed). Coef. = coefficient; S.E. = standard error.
Table 5. Estimated Coefficients of Shipment Size Models (Receiver Function: Shop or Restaurant and Logistics Facility)

| Commodity type                        | Coef. | S.E. | t-val. | Coef. | S.E. | t-val. | Coef. | S.E. | t-val. | Coef. | S.E. | t-val. | Coef. | S.E. | t-val. | Adj. R² |
|---------------------------------------|-------|------|--------|-------|------|--------|-------|------|--------|-------|------|--------|-------|------|--------|---------|
| **Receiver function: shop or restaurant** |       |      |        |       |      |        |       |      |        |       |      |        |       |      |        |         |
| Agricultural products                 | 0.55  | 0.49 | 1.11   | 0.41  | 0.69 | 0.59   | 0.90  | 0.06 | 13.9*  | 0.54  | 0.18 | 3.03*  | -0.48 | 0.25 | -1.90  | 0.03    | 0.12 | 0.24   | 0.80    |
| Food products                         | 1.77  | 0.29 | 6.03*  | -0.12 | 0.44 | -0.27  | 0.84  | 0.04 | 22.9*  | -0.07 | 0.10 | -0.74  | 0.12  | 0.15 | 0.77   | 0.10    | 0.07 | 1.39   | 0.81    |
| Light manufacturing products          | 1.68  | 0.21 | 7.89*  | -0.80 | 0.80 | -1.01  | 0.81  | 0.06 | 14.3*  | -0.35 | 0.11 | -3.26* | 0.76  | 0.26 | 2.87*  | -0.10   | 0.08 | -1.30  | 0.71    |
| Five commodity types                  | 1.76  | 0.62 | 2.85*  | 1.01  | 0.77 | 1.31   | 0.58  | 0.05 | 12.0*  | 0.09  | 0.17 | 0.54   | -0.45 | 0.23 | -1.96  | -0.32   | 0.14 | -2.29* | 0.48    |
| All commodity types                   | 1.19  | 0.20 | 6.07*  | 0.62  | 0.33 | 1.86   | 0.74  | 0.03 | 29.1*  | 0.18  | 0.07 | 2.41*  | -0.22 | 0.11 | -2.05* | -0.08   | 0.06 | -1.50  | 0.65    |
| **Receiver function: logistics facility** |       |      |        |       |      |        |       |      |        |       |      |        |       |      |        |         |
| Agricultural products                 | 1.57  | 0.37 | 4.26*  | 2.18  | 0.52 | 4.22*  | 0.41  | 0.04 | 9.75*  | 0.58  | 0.09 | 6.57*  | -0.21 | 0.15 | -1.46  | na      | na   | na     | 0.42    |
| Food products                         | 2.56  | 0.25 | 10.1*  | 0.37  | 0.31 | 1.22   | 0.51  | 0.02 | 22.8*  | 0.23  | 0.06 | 4.02*  | 0.03  | 0.09 | 0.34   | na      | na   | na     | 0.29    |
| Light manufacturing products          | 1.60  | 0.28 | 5.61*  | 0.57  | 0.34 | 1.70   | 0.65  | 0.02 | 30.2*  | 0.38  | 0.07 | 5.15*  | -0.08 | 0.10 | -0.79  | na      | na   | na     | 0.46    |
| Wood and paper products               | 4.27  | 0.36 | 11.8*  | 0.32  | 0.45 | 0.72   | 0.32  | 0.03 | 11.4*  | -0.08 | 0.11 | -0.67  | 0.18  | 0.15 | 1.22   | na      | na   | na     | 0.30    |
| Minerals, ceramics, glass, etc.       | 3.60  | 0.66 | 5.43*  | -2.18 | 0.69 | -3.14* | 0.55  | 0.05 | 10.6*  | 0.10  | 0.16 | 0.65   | 0.63  | 0.21 | 3.04*  | na      | na   | na     | 0.74    |
| Metals or articles of metal           | 0.45  | 0.42 | 1.08   | 0.80  | 0.48 | 1.65   | 0.86  | 0.04 | 23.6*  | 0.33  | 0.10 | 3.19*  | -0.21 | 0.14 | -1.50  | na      | na   | na     | 0.67    |
| Machinery, mechanical parts, etc.      | 3.05  | 0.38 | 8.13*  | 1.10  | 0.56 | 1.97   | 0.66  | 0.03 | 21.6*  | 0.08  | 0.11 | 0.74   | -0.58 | 0.16 | -3.62* | na      | na   | na     | 0.57    |
| Chemicals, rubber, or plastics        | 4.29  | 0.45 | 9.49*  | -1.09 | 0.84 | -1.31  | 0.51  | 0.04 | 13.5*  | 0.03  | 0.11 | 0.30   | 0.20  | 0.24 | 0.83   | na      | na   | na     | 0.44    |
| All commodity types                   | 2.57  | 0.12 | 20.6*  | 0.34  | 0.16 | 2.08*  | 0.56  | 0.01 | 56.2*  | 0.20  | 0.03 | 6.08*  | -0.01 | 0.05 | -0.31  | na      | na   | na     | 0.42    |

Note: *Significant at a 95% confidence level (two-tailed). Coef. = coefficient; S.E. = standard error; na = not applicable.

aFive commodity types ("wood and paper products", "minerals, ceramics, glass, etc.", "metals or articles of metal", "machinery, mechanical parts, etc.", and "chemicals, rubber, or plastics") are merged as the sample size for each of the five types is too small to estimate models independently.
making an EOQ model applicable, rather complex (and heterogeneous) cost structures should be reflected in the formulation. Further, it may even require the formulation from the perspective of profit maximization, instead of the minimization of the total logistics cost, as logistics decisions nowadays are driven by such broader perspectives. For example, Hesse and Rodrigue (20) argue that logistics should be viewed as the integrated transport demand driven by the reciprocal relationship between the induced and derived demand functions.

The model fit varies across different categories, reflecting the homogeneity/heterogeneity in shipment size decision mechanism within those categories. The model coefficients obtained from the analysis indicate the importance of considering both receiver function and commodity type to capture the heterogeneity in the shipment size selection mechanism. Furthermore, consideration of the shipper function (i.e., logistics facility/ non-logistics facility) allows for differences in transport cost structure to be taken into account. Ideally, vehicle operation type (e.g., vehicle tour type and full-truckload/less-than-truckload shipping), rather than shipper function type, should be considered for estimating a model. The present analysis implies that shipment size and vehicle operation are highly likely to be simultaneous decisions. The development of the joint model for shipment size and vehicle operation decisions is an important future research task. For the development of such a sophisticated model, it is critical to explore methods for collecting shipment-level data with details such as time of delivery, type of tour for the delivery, and traffic conditions over a day. It is also worth mentioning that logistics operations have been evolving over the decades and the future follow-up research that tracks their influences on the shipment size mechanism will be important.

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Author Contributions
The authors confirm contribution to the paper as follows: study conception and design: T. Sakai, A. Alho, M. Ben-Akiva; data collection: T. Hyodo; analysis and interpretation of results: T. Sakai; draft manuscript preparation: T. Sakai, A. Alho. All authors reviewed the results and approved the final version of the manuscript.

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The authors do not have permission to share data.

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