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Determinants of Transport Costs for Inter-regional Trade

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Abstract

This paper presents a microeconomic model of inter-regional freight transportation based on careful formulation of cost structure in trucking firm and market equilibrium, which takes into account the feature of transport service as a bundle of multiple characteristics. We estimate the parameters of the model using the micro-data of inter-regional freight flows from the 2005 Net Freight Flow Census in Japan. Estimation results show that the determinants of transport cost incorporated in the model have significant effects in the ways that the model predicts. The degree of competition also have significant effect on freight charge. It is shown that there exist significant scale economies with respect to lot size and long-haul economies. Quantitative extents of these effects are also demonstrated.

1. Introduction

Transport cost over the distance is a major impediment of trade at any spatial scale, international or interregional. Reducing transport cost has significant benefits for the economy, such that more firms sell their products in distant locations, and consumers enjoy lower prices and larger variety. Understanding the structure of transport cost is essential for the policy making to design efficient transportation systems that contribute reduction of transport cost and thereby enhance the gains from trade.

There are several approaches to quantitative analysis of transport cost. Gravity model has been used to describe the pattern of trade flow that volume of trade between countries is decreasing with distance, which is a proxy of transport cost. Anderson and Wincoop (2004) derive the gravity equation from general equilibrium model of international trade, and propose the method to measure the transport cost in terms of ad valorem tax equivalent. Another approach is to use the data of fob exporting price and cif importing price between the same trading partners, then the cif/fob ratio is taken as a measure of transport costs. Limao and Venables (2001) use cif/fob ratio as the dependent variable of the regression to examine various determinants of transport cost, including infrastructure quality. These methods based on indirect information are developed mainly for international trade to cope with data availability problem. At inter-regional level (within the same country), Combes and Lafourcade (2005) develop a method to compute generalized transport cost between regions. They combine GIS data and various sources that include traffic condition, energy prices, technology, infrastructure, and the market structure of the transport industry. Based on a shift-share analysis of these components for road transport, they find out that changes in the market structure (-21.8%) and in technology (-10.9%) are the real engines of the decrease of transport costs for the period 1978-1998 in France. By contrast, the infrastructure contributes at 3.2% for the decrease of transport costs.

This paper empirically investigates the structure of transport costs for interregional trade, by using the micro-data of freight charge. Note that the freight charges are determined through interaction in the transport market, where shippers demand and carriers (transport firms) supply transport services. Thus freight charges paid by shippers should reflect the cost incurred by carriers. We focus on road transport, reflecting the fact that trucking has a dominant share in transporting goods between regions in Japan. In 2005, 91.2% of overall domestic freight volume is transported by trucks (sum of operating carriers and private trucks), while the second largest share is 7.8% by coastal shipping. We formulate a simple model of trucking market and derive the freight charge equation. By estimating the parameters of freight charge equation, we examine the effects of various factors on the level of freight charge. We use the micro-data from the 2005 Net Freight Flow Census (NFFC), in which information on freight charge and other variables for individual shipment are obtained. The NFFC is drawn from stratified random samples of actual shipments, which is the best available data on inter-regional shipments. The data for other explanatory variables such as distance, toll payment and wage are obtained from various sources. An advantage of our method is that our data represent the costs actually incurred by shippers or carriers, unlike the one based on constructed data by Combes and Lafourcade (2005). We further examine the existence of scale economies with respect to lot size (weight) and long-haul economies: transport cost per unit weight is decreasing with weight; transport cost per distance is decreasing with distance.

The rest of the paper is organized as follows. The next section presents the model of freight transportation. Section 3 specifies the equations for estimation, and Section 4 describes the data for empirical analysis and presents the results of estimation. Section 5 concludes the paper.

2. The Model

A trucking firm produces transport service between separated locations by using capital (trucks), labor (drivers), and fuel as inputs. In practice, a single trucking firm takes orders of shipments with various sizes, origin/destination pairs (distance). The sum of these shipments for a given period of time becomes the output of the firm that is compatible with the standard definition in the model of production[1]. On the other hand, we consider the cost structure of each shipment. More specifically, we formulate the cost function of transport service by chartered truck, by which transport firm uses a single truck exclusively to transport the goods ordered by a single shipper[2].

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[1] In this context, there is a substantial body of literature on cost structure of motor carrier firms. Among them, Allen and Liu (1995) use firm-level data of motor carriers to examine the presence of scale economies in freight transportation. In contrast, we use the data for each shipment that provide useful information for the analysis of inter-regional transport cost structure.

[2] Other type widely adopted is the consolidated truck service that a single truck carries

The cost for each shipment is the sum of the expenditures for inputs and highway toll if it is used as follows

$$C_{ij} = r_i^L L_{ij} + r_i^K K_{ij} + r_i^X X_{ij} + r_{ij}^H H$$

(2.1)

where L_{ij}, K_{ij} and X_{ij} are respectively the quantities of labor, capital and fuel that are used to transport a good from region *i* to region *j*. *H* is the highway dummy taking *H*=1 when the truck uses highway and *H*=0 otherwise. r_i^L, r_i^K, r_i^X and r_{ij}^H are respectively the wage rate, capital rental rate fuel price, and highway toll[3]. Labor input is measured in terms of time devoted by drivers, t_{ij}, which includes not only driving time but also time for loading and unloading, rest break, etc. Capital cost for each shipment is considered to be the opportunity cost of using a truck for the time required to complete the trip, so measured in terms of time too. Also note that the larger truck should be used to carry larger lot size of cargo. Let us denote by q the lot size of shipment measured in weight, then capital input is represented by $g(q)t_{ij}$, where $g(q)$ is an increasing function of q. It is observed that fuel consumption per distance depend on weight (lot size) q and speed s_{ij}, thus represented by the function $e(q, s_{ij})$[4]. Highway toll depends on the distance and weight of the truck, is written as $r_{ij}^H = r^H(q, d_{ij})$. Incorporating the assumptions above into (2.1), the cost function is written as follows,

$$C_{ij}(q, d_{ij}, t_{ij}) = r_i^L t_{ij} + r_i^K g(q) t_{ij} + r_i^X e(q, s_{ij}) d_{ij} + r^H(q, d_{ij}) H$$

(2.2)

In the above cost function, q, d_{ij}, t_{ij} are all considered as output variables. This implies that a freight transportation is a bundle of multiple characteristics produced by trucking firm. This is different from the conventional definition of output variable in transportation, i.e., the

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cargos collected from several shippers.

[3] We assume that locations of trucking firm and origin of trip are the same. So wage rate and capital rental rate at the origin are applied. Firms may purchase fuel at any locations along the route, so fuel prices should be given for origin-destination pair. However, we assume that fuel price at the origin is applied, considering the difficulty of getting information concerning where trucks purchase fuel.

[4] $e(q, s)$ is increasing with weight q. On the other hand, the relation between fuel consumption and speed is U-shaped: $e(q, s)$ is decreasing (increasing) with s at lower (higher) speed.

product of quantity and distance ($q_{ij} \cdot d_{ij}$, according to our notations). Empirical analysis in the subsequent section examines whether conventional definition is appropriate.

Price of transport service, freight charge, is also defined for a bundle of characteristics as $P_{ij}(q, d_{ij}, t_{ij})$. We consider the market equilibrium in a similar manner to the hedonic theory developed by Rosen (1974), as follows. The market for freight transport is segmented by pairs of origin and destination. Suppose that there are shippers in region i that demand the transport service, where the origin of transportation is the same as the location of the shipper. Each shipper looks for the firm that undertakes the order of transportation every time it is required to transport the good of the size q_{ij}, from i to j[5]. We assume that there are a number of trucking firms willing to take the order as long as freight charge, $P_{ij}(q, d_{ij}, t_{ij})$ exceeds the cost, $C_{ij}(q, d_{ij}, t_{ij})$. The shipper solicits bids and awards the order to the lowest bidder. Let us assume that all trucking firms in the market ij have the same production technology. The bid submitted by a firm *n* is $C_{ij}(q, d_{ij}, t_{ij}) + \delta_{ij}^n + \upsilon_{ij}^n$, where δ_{ij}^n is the profit added over the cost and υ_{ij}^n is a random variable that reflects the attitude of the firm at the time of bidding. Each firm chooses δ_{ij}^n to maximize the expected value of profit, $R^n \delta_{ij}^n$, where R^n is the probability that the firm *n* wins the bid. Note that R^n depends not only on the bid by the firm *n* but also on the bids by its competitors. So the bidding competition is formulated as a game. In equilibrium, the following relation should hold.

$$P_{ij}(q, d_{ij}, t_{ij}) = C_{ij}(q, d_{ij}, t_{ij}) + \delta_{ij}^* \qquad (2.3)$$

where $\delta_{ij}^* = \min_n \left\{ \delta_{ij}^n + \upsilon_{ij}^n \right\}$[6]. By using a similar but more general model, Holt (1979) shows that increasing the number of bidders decreases the equilibrium bid. Following this result, we expect that δ_{ij}^* is decreasing with the number of trucking firms in the market ij. We allow different degree of competition in the market for trucking transport since the number of trucking firms may vary by locations[7]. In the empirical analysis, we use several proxy

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[5] Distance is determined once origin i and destination j are given.

[6] With this formulation, perfect competition is a special case that $\delta_{ij} = 0$.

[7] Since the deregulation of entry and price setting started in 1991, the number of trucking firms in Japan has increased consistently, with the number of trucking firms in 2004 about 1.5 times that in 1990. The growth rate in the numbers of employees and truck drivers is relatively slower than that of trucking firms. This means that the scale of trucking firms is becoming smaller and the trucking industry is becoming more competitive. At local level,

variables to explain the variation of δ_{ij}^*.

3. Econometric Model and Methods

Based on the theory we have developed in the previous section, we estimate the cost function of trucking firms using the Net Freight Flow Census data, which is described in detail in the following section. We need to take it into account that the data comes from surveys to shippers, not trucking firms, which means that we must estimate cost function without input/output data of suppliers. In order for this, we assume certain relationship between the freight charge and its cost (2.3).

3.1 Regression specification

Remember that the cost of carrying cargo of weight *q* ton from a region *i* to region *j* that is located at distance of d_{ij} km is decomposed into four components, drivers' wage, truck rent, fuel expenditure and highway toll if it is used, as follows:

$$C_{ij}(q, d_{ij}, t_{ij}) = r_i^L t_{ij} + r^K g(q) t_{ij} + r_{ij}^X e(q,s) d_{ij} + r^H(q, d_{ij}) H$$

Suppose that truck rent $g(q)$ depends linearly on the size of the truck $w^T(q)$, or $g(q) = \alpha_1 + \alpha_2 w^T(q)$. Truck size (defined by categories according to weight without cargo) is determined so that the truck accommodates the cargo of size *q*.[8] The fuel-efficiency $e(q,s)$ of trucks is typically an increasing function of the total truck weight $q + w^T(q)$, and a U-shaped function of speed *s*. We assume that one can drive at different but fixed speeds s^H on highway and s^L on local road, and thus

$$e(q,s) = \begin{cases} c^H\left(q + w^T(q)\right) & \text{highway} \\ c^L\left(q + w^T(q)\right) & \text{local road} \end{cases}$$

where c^H and c^L are the fuel consumption per weight for speeds at s^H and s^L, respectively, and $c^H < c^L$ is assumed.

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however, sizes of markets vary widely depending on the level of economic activities in the regions of origin and destination and the distance between them.

[8] Details of the relation between lot size and truck size are described in Section 4.

Highway toll $r^H(q,d_{ij})$ depends on the truck size and the distance,

$$r^H(q,d_{ij}) = a + b\rho_1(w^T(q))\rho_2(d_{ij})d_{ij}$$

where $\rho_1(w^T(q))$ is toll per distance applied for the truck category of $w^T(q)$ and $\rho_2(d_{ij})$ represents the discount factor for long distance use of highway.

We assume that the price is determined depending also on other factors $Z = (Z_1,\cdots,Z_7)$, as

$$P_{ij}(q,d_{ij},t_{ij}) = C_{ij}(q,d_{ij},t_{ij}) + \gamma' Z + \gamma_7 t_{ij}$$

$\gamma' Z$ includes trucking firm's profit, represented by δ_{ij}^* in (2.3), other factors affecting the cost, and demand-side effects that comes from preferences of shippers. These variables are described in Table 1. Qi_sum/trucks (Z_3), num-truck-firms (Z_5) are proxy to the degree of competition, thereby the determinants of profit. intra-dummy (Z_1) is a dummy variable that takes the value one when it is the intra-regional trade and zero otherwise. The variable border-dummy (Z_2), takes the value one when the two regions are contiguous and zero otherwise. These two dummy variables are included to capture some nonlinearity in terms of d_{ij}. The variable *imb* (Z_4) represents the trade imbalance calculated as $imb = Q_{ji}/Q_{ij}$, where Q_{ji} is the trade volume from region j to i and Q_{ij} is the trade volume from region i to j. If a truck carries goods on both ways of a return trip, then the firm is willing to accept cheaper freight charge compared with the case that the truck returns without cargo. iceberg (Z_6) is a proxy to the price of goods transported, which is included to examine if iceberg-type cost applies in our data. As the demand side factor, we include t_{ij} $(=Z_7)$ because it is more favorable for shippers if the goods (can) reach the destination earlier in general.

< insert Table 1. Variable Descriptions and Sources of Data here>

Allowing parameters η_i, $i = 1,2,3,4$, our empirical model turns out to be:

$$P_{ij}(q,d_{ij},t_{ij}) = \eta_1 r_i^L t_{ij} + \eta_2 r_i^K \left\{\alpha_1 + \alpha_2 w^T(q)\right\} t_{ij} + \eta_3 r_{ij}^X \left\{c^H H + c^L(1-H)\right\}(q + w^T(q))d_{ij}$$
$$+ \eta_4 r^H(q,d_{ij})H + \gamma_7 t_{ij} + \gamma' Z + \varepsilon$$

γ_7 is the parameter representing the preference of shippers and thus expected to be negative. $c^H H + c^L(1-H)$ in the term of fuel consumption is further rewritten as $c^L(1-\theta H)$, where

$\theta = 1 - \frac{c^H}{c^L}$ is the ratio of saving fuel consumption from using highway. We use empirical evidences concerning c_H / c_L. To this end, re-parameterizing above equation, we have the final form of econometric model,

$$P_{ij}(q, d_{ij}, t_{ij}) = \beta_0 + \beta_1 r_i^L t_{ij} + \beta_2 t_{ij} + \beta_3 w^T(q) t_{ij} + \beta_4 r_{ij}^X (1 - \theta H)(q + w^T(q)) d_{ij} + \beta_5 r^H(q, d_{ij}) H + \gamma' Z + \varepsilon$$

(3.1)

and thus, the explanatory variables are

$$\{r_i^L t_{ij},\ t_{ij},\ w^T(q) t_{ij},\ r_{ij}^X (1-\theta H)(q + w^T(q)) d_{ij},\ r^H(q, d_{ij}) H,\ Z\}.$$

We expect the following parameters sign,

$$\beta_0 > 0$$
$$\beta_1 = \eta_1 > 0,$$
$$\beta_2 = \eta_2 r_i^K \alpha_1 + \gamma_7$$
$$\beta_3 = \eta_2 \alpha_2 > 0,$$
$$\beta_4 = \eta_3 c^L > 0,$$
$$\beta_5 = \eta_4 > 0.$$

On the sign of γ, we expect the followings. When *imb* (Z_4) is large, the driver is likely to have freight on the way home and the price may be lower. Also, the opportunity cost of empty drive is smaller for shorter trips. For this reason, γ_4 is expected to be negative. We include *Qi*_sum/trucks (Z_3) and num-truck-firms (Z_5) in region *i* as proxies to competition in the transportation market *ij*[9]. If Z_3 is large, there are not enough trucks in the region relative to the quantity of goods to be carried out of the region. Then the competition should not be tough and the price will be higher. Therefore γ_3 is expected to be positive. If Z_5 is large, we may regard there are too many trucking firms which results in tough competition. Then, the price will be lower and γ_5 is expected to be negative. Iceberg hypothesis implies that transport cost is positively correlated with value of the good, so the coefficient of iceberg (Z_6) should have positive sign. Expected signs of coefficients discussed so far are summarized in Table 2.

[9] This is equivalent to assuming that competition takes place among trucking firms located in the same region as shipper.

< insert Table 2. Expected Signs of Coefficients here>

3.2 Endogeneity and 2SLS estimation

We can think of implementing OLS (ordinary least squared) estimation of eq.(3.1). There may, however, be endogeneity in some explanatory variables. We drop subscripts *i* or *ij* unless it is ambiguous. First, *t* can be endogenous because if there are no requests on arrival time from the shipper, trucking firms can decide the length of time spent for the freight efficiently. This is especially the case when the goods are consolidated. Also, *H* can be endogenous because the trucking firm can decide if he/she uses highway or not depending on his/her own convenience. In such cases of endogenous regressors, OLS estimation does not provide consistent estimates.

A solution is to apply 2SLS (two-stage least squares) estimation using suitable instrumental variables. Valid instruments must have correlation with the endogenous regressors, but uncorrelated with the error terms. In the present context, we may pick *d* and the dummy variable of time-designated delivery D_T as its instruments. Both of the two variables are determined by the shipper and thus they are considered to be exogenous, but are correlated with *H*. We use *d* again as the instrument for *t*. It is likely that the carriage time *t* depends on the distance *d* between the home and destination, however *d* is exogenous for the trucking firm because it is determined by the order of the shippers. Thus, in the first stage, we run a probit estimation for dependent variable *H* regressing on d, D_T,

$$E(H \mid d, D_T) = P(\delta_0 + \delta_1 d + \delta_2 D_T \geq u \mid d, D_T)$$

(3.2)

where *u* is a standard normal variate. We implement OLS for t;#

$$E(t \mid d) = \kappa_0 + \kappa_1 d \qquad .$$

(3.3)

Taking into account that *t* is likely to depend also on *H*, we may want to include *H* as an additional regressor to (3.3),

$$E(t \mid d, H) = \kappa_0 + \kappa_1 d + (\kappa_2 + \kappa_3 d)H \ .$$

However, as previously stated, *H* is also endogenous and thus it is not a suitable IV. What we can do instead is to use the predictor $\hat{H}$ from regression (3.2) as the regressor, or,

$$E(t \mid d, \hat{H}) = \kappa_0 + \kappa_1 d + (\kappa_2 + \kappa_3 d)\hat{H}$$

(3.4)

We obtain $\hat{H}$, the predicted values of H from (3.2), and $\hat{t}$, the predictor of t from either (3.3) or (3.4). Replace t and H in eq.(3.1) by $\hat{t}$ and $\hat{H}$ respectively, we obtain second stage regression equation,

$$P_{ij}(q, d_{ij}, t_{ij}) = \beta_0 + \beta_1 r_i^L \hat{t}_{ij} + \beta_2 \hat{t}_{ij} + \beta_3 w^T(q)\hat{t}_{ij} + \beta_4 r_{ij}^X (1 - \theta\hat{H})(q + w^T(q))d_{ij} + \beta_5 r^H(q, d_{ij})\hat{H} + \sum_{k=1}^{6} \gamma_k Z_k + \varepsilon.$$

(3.5)

Applying OLS estimation to (3.5), we obtain 2SLS estimates of β, γ which are consistent under endogeneity. (3.5) is slightly different from textbook 2SLS in the sense that some of the endogenous variables are multiplied by exogenous variables. We show that OLS of (3.5) works in Appendix 2.

4. Data and Empirical Results

We formulate an estimation model of the freight charge equation and explain the estimation strategies in previous section. In this section, first, we list dependent variable and covariates from the 2005 Net Freight Flow Census (NFFC), the National Integrated Transport Analysis System (NITAS) and other statistics. NFFC provides the micro-data of inter-regional shipments, NITAS is a system that Ministry of Land, Infrastructure, and Transport (MLIT) developed to compute the transport distance, time, and cost between arbitrary locations. Moreover, we adopt demand size and degree of competition of transportation market to control regional heterogeneity by other statistics. Second, we show the data construction for our empirical study and then, discuss the empirical results.

4.1 Data Description

In the previous section, we show the estimation model in eq. (3.5);

$$P_{ij}(q, d_{ij}, t_{ij}) = \beta_0 + \beta_1 r_i^L \hat{t}_{ij} + \beta_2 \hat{t}_{ij} + \beta_3 w^T(q)\hat{t}_{ij} + \beta_4 r_{ij}^X (1 - \theta\hat{H})(q + w^T(q))d_{ij} + \beta_5 r^H(q, d_{ij})\hat{H} + \sum_{k=1}^{6} \gamma_k Z_k + \varepsilon.$$

Dependent variable is freight charges P_{ij} and the explanatory variables are

$$\{r_i^L t_{ij},\ t_{ij},\ w^T(q)t_{ij},\ r_{ij}^X(1-\theta H)(q+w^T(q))d_{ij},\ r^H(q,d_{ij})H,\ Z\}$$

Z includes other explanatory variables, that can affect the price. Specifically, we use intra-dummy (Z_1), border-dummy (Z_2), *Qi*_sum/trucks (Z_3), *imb* (Z_4), num-truck-firms (Z_5), iceberg (Z_6). Table 1 provides the data sources to construct these variables.

We use the data from the NFFC conducted by the MLIT to obtain data on individual freight charge P_{ij}, lot size q and transportation time t_{ij} which each shipment actually spent. We notify t_{ij} might include times for loading and unloading of cargos, transhipment and the driver's break etc, which would be very diverse with trucking firms and shipments.

The 2005 census uses 16698 domestic establishment samples randomly selected from about 683,230 establishments engaged in mining, manufacturing, wholesale trade, and warehousing industry. Each selected establishment report shipments for a three-day period. This produce a total sample size of over 1,100,000 shipments, each of which has information on the origin and the destination, P_{ij}, q, t_{ij}, the industrial code of the shipper and consignee, the code of commodity transported and main modes of transport, etc. We also collect data on transport distance d_{ij}, wage rate r_i^L, toll payments r^H, the number of trucking firm and the number of trucks, etc. The data on the transport distance d can be calculated by using the NITAS from the information of the origin and the destination for each shipment in NFFC. NITAS is a system that MLIT developed to compute the transport distance, time, and cost between arbitrary locations along the networks of transportation modes such as automobiles, railways, ships, and airlines. It searches for transportation routes according to various criteria, such as the shortest distance, the shortest time, or the least cost. We compute the transport distance between 2,052 municipalities as the distance between the jurisdictional offices along the road network with NITAS under the condition of minimizing the generalized cost, which consists of the fuel cost, the time cost, and the toll payment.

The driver's average wage per hour in the prefecture of origin r_i^L is calculated using the data on the monthly average regularly paid wages, the average days worked, and the average hours worked for large size and small-middle size truck drivers. These data are taken from the report by the Statistics Bureau of the Ministry of Internal Affairs and Communication.

The general retail fuel r_i^X is average diesel oil price in October 2005 for prefecture of origin which is published by the Oil Information Center. Truck size $w^T(q)$ is given by weight of truck without cargo for categories according to lot size, as follows;

$$w^T(q) = \begin{cases} 2.356, & \text{if } q \le 2 \\ 2.652, & \text{if } 2 < q \le 3 \\ 2.979, & \text{if } 3 < q \le 4 \\ 3.543, & \text{if } 4 < q \le 5 \\ 5.533, & \text{if } 5 < q \le 12 \\ 7.59, & \text{if } 12 < q \le 14 \\ 8.765, & \text{if } 14 < q \end{cases}$$

We refer to Hino Motor's product specification[11] to get $w^T(q)$. Highway toll $r^H(q,d)$ is from East Nippon Express Company (E-NEXCO), and associated with the each shipment's lot size and distance.

$$r^H(q,d) = \begin{cases} 0.84*(150+24.6*d)*1.05 & if\ \ q<2 \\ 0.84*(150+1.2*24.6*d)*1.05 & if\ \ 2 \le q < 5, \\ 0.84*(150+1.65*24.6*d)*1.05 & if\ \ q \ge 5 \end{cases}$$

0.84, 150yen and 1.05 are ETC or highway card discount, fixed cost and consumer tax. Toll per km is 24.6 yen/ km and exists vehicle type ratio (1.2, 1.65) that associate with the truck size $w^T(q)$ or q as below. While examining $r^H(q,d)$, we also reflect the tapering rate. If $100 < d \le 200$, we can get the discount rate 25% for distance which excess 100km , and if $d > 200$, 25% discount for $100 < d \le 200$ and 30% discount for distance over 200km are applied. There is a discount when the truck runs during the late night or early morning hours using ETC when there is 30% or 50% discount. This is also considered in computing $r^H(q,d)$.

MLIT estimates the overall trade volume between prefectures based on shipments data from NFFC and publishes it via website[12], and we use these data for Q_i , Q_{ji} and Q_{ij} to construct the variables, Qi_sum/trucks (Z_3) and *imb* (Z_4) . We composed num-truck-firms

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11 http://www.hino.co.jp/j/product/truck/index.html

12 . http://www.mlit.go.jp/seisakutokatsu/census/census-top.html

(Z_5) variable as 1000 times the number of trucking firms per capita of prefecture of origin i. iceberg(Z_6) is defined by the monetary value (unit:Yen) of annual shipments divided by its total volume (unit: ton) of annual shipments[13].

We would like to mention that definitions of region are different among the variables. t_{ij} and d_{ij} are municipality level data considering with both origin and destination regions, while r_i^L, r_{ij}^X, r^H, Q_i_sum/ trucks(Z_3), and num-truck-firms (Z_5) belong to prefecture of origins. imb(Z_4) is prefectural level data made by origin and destination regions.

The descriptive statistics of these variables used in the estimation are summarized in Table 3.

< insert Table 3. Descriptive Statistics here>

In order to construct a target dataset for our analysis, first, we abstract from the full dataset, the data on the shipments which used the trucks as the main modes of transport and then remove the shipments with the following conditions: [1] Since this study focuses on the trucking industry, we exclude observations in regions that are inaccessible via a road network. Hokkaido, Okinawa and other islands are excluded; [2] In order to observe of the highway effects on P_{ij} clearly, we keep shipments which used only local road or only highway; [3] We suppose one truck and one driver are allocated for each shipment. We estimate that large truck's maximum load capacity would be less than 16ton, it means if q is over 16ton, carriers need multiple trucks. Thus, we removed the shipments if q is over 16ton;[4] We removed observations without freight charge P_{ij} data.

After abstracting our target dataset, 424693 shipments and 8155 shippers remain (full data set has 112,654 shipments and 16,698 shippers).

4.2 Estimation results

We estimated the econometric model eq. (3.5) using the data described in the previous section. To implement estimation, we need to obtain a suitable value of θ to construct the

[13] These data are obtained from NFFC annual survey to firms in manufacturing or wholesale industry. Thus samples of shipments from the same firm should have the same value of iceberg(Z_6)

explanatory variable $r_{ij}^X(1-\theta\hat{H})(q+w^T(q))d_{ij}$. θ represents the fuel efficiency ratio of diesel trucks under two different speed on highway and local road. It is computed using the result by Oshiro, Matsushita, Namikawa and Ohnishi (2001), who claim that

$$y(s)=17.9/s-9.6s+0.073s^2+560.1$$

where $y(s)$ is the fuel consumption efficiency (cc/km) and s is speed (km/hour). The weight is not controlled, but we can obtain an approximate ratio of $\theta=1-c_H/c_L$ assuming the efficiency ratio does not change with the weight of trucks. For example, supposing s^L =30(km/h) on local road, the efficiency is $y(30)$ =338.4(cc/km). Similarly, when s^H =70 on highway, we have $y(70)$ =246.1. Combining the results, we obtain

$$\theta=1-\frac{c_H}{c_L}=1-\frac{(q+w^T(q))/e(q,s_H)}{(q+w^T(q))/e(q,s_L)}=1-\frac{e(q,s_L)}{e(q,s_H)}\approx 1-\frac{246.1}{338.4}=0.273$$

when average speed on highway and local road are 70km/h and 30km/h respectively. In Table 5, we report estimation results for $\theta=0.2,0.3,0.4,0.5$.

As suggested in Section 3, we implemented both OLS and 2SLS estimation. Table 4 gives two kinds of estimates for all, chartered cargo and consolidated cargo observations with $\theta=0.3$, which we think the most reasonable value of θ. First we compare OLS and 2SLS regression shown in the table . Second column to the seventh give OLS estimation results, while eighth column to the thirteenth provide 2SLS estimates. In view of the estimation result of model 4, the coefficients of $r^L t$ and $r^H(w_T)H$ are not significant, which is obviously inappropriate. Those estimates for model 10 are all appropriate including the signs of the parameters. We think that OLS estimation must be suffered from endogeneity bias. We believe that 2SLS is the suitable estimation method in the present model and data[14].

< insert Table 4. Estimation Results here>

Our main results are 2SLS estimation for chartered freights, because there must be endogeneity in some explanatory variables as pointed out in Section 3.2 and discussed above.

[14] We implemented 2SLS estimation for different sets of instruments based on the discussion in Section 3, namely we take (3.3) and (3.4) in the first stage regression. The difference is that we use $\hat{H}$ or not in the first stage estimation of t. In view of the estimates, we see the parameter estimates are not too different, and the significance of variables does not change much. Therefore we report results only for (3.4). We also note that both regressors are significant in (3.4).

We expect the sign of the estimates as stated in Section 3, which is also tabulated in Table 2. The main estimation results are shown in Table 4, model 10. We obtain significant estimates with mostly right signs. The coefficient of labor input is significantly positive as expected with $\beta_1 = 1.3696$. It is interesting that the level is between one and two. If goods are carried only one driver all the time, the coefficient must be unity. But when they are carried for a long distance by, say, two drivers, one taking a rest while the other drives, it will be two. If the data is the mixture of the two, it will take a value in [1,2]. We may also consider the case when there are no cargo on the returning trip. In this case, trucking firm may like to charge the cost for two ways as well. β_2, the coefficient of time, is significantly negative. As discussed in Section 3, the sign depends on two effect, one is related to the truck rent and the other is the shippers' preference. The former has a positive effect and the latter has the negative effect on the price P, thus we know that the latter dominates. β_3 is also the coefficient related to the truck rent. As the rent of larger trucks must be higher than smaller ones, this coefficient is likely to be positive. β_4 is the coefficient of fuel consumption which is expected to be positive, and indeed it is. We cannot discuss about its appropriate level as it depends on the mileage parameter of trucks. β_5 is the coefficient of highway toll, which is also significantly positive. As in the case of labor coefficient β_1, we expect this value be in [1,2] because if the freighters do not have goods on his/her return trip, they may like to charge the shippers the highway toll of two ways. Indeed, the value is 1.2356 which lies in [1,2].

For additional variables of Intra Dummy and Border Dummy, the coefficients are significantly negative. It may reflect that freights to very close places do not waste carriers' time for the return drive and thus the opportunity cost is lower. We also include imb variable as the opportunity cost. imb is regarded as a proxy to the probability of obtaining a job on the way back home. We expected that it has a negative impact on *P*, and it is right, but it turns out to be insignificant. We include *Qi* sum/trucks and num-truck- firm as proxies of freight industry competition. The coefficients are negative as expected, but only the latter is significant. We include iceberg to examine if the iceberg type freight cost applies or not. The coefficient is positive as iceberg hypothesis claims, but insignificant in our analysis. We conclude that this hypothesis does not hold in Japanese truck freight industry.

We pick $\theta = 0.3$ as the default value based on the discussion in the beginning of this section. We examined the sensitivity by estimating the same model for different values of

$\theta = 0.2, 0.3, 0.4, 0.5.$ The results are shown in Table 5. The estimates are rather stable for all coefficients except those of $w^T t$ and $r^H(w_T)H$. The coefficient of $r^H(w_T)H$ becomes insignificant when $\theta = 0.2,$ while that of $w^T t$ remains significantly positive for all values of $\theta,$ but the level changes much. One possible reason for this instability may be the way of construction of w^T. We construct w^T as stated in the previous section, but it should include noise which may not be ignorable. The present data does not provide us with any information what size of trucks are used for each service in fact, and thus we cannot go further. A possible remedy is to use instruments for w^T in the estimation. We pursue this direction in the future research.

< insert Table 5. Estimation results with different θ here>

We estimated the model using the data of consolidated freights also only for comparison. We do not believe our theoretical model suitably accommodate the case of consolidation, because the cost structures must be different between the two services. We conjecture that the freighters are likely to offer cheaper rate for consolidated service than chartered because the cost can be shared more efficiently among the shippers. However, we cannot confirm this conjecture straightforwardly comparing, say estimates of models 10 and 12. We should carefully construct the model of freight price of consolidated freight service and estimate it.

NFFC classifies the shipments into nine groups by the variety of transported commodities; Agricultural and Fishery Products, Forest Products, Mineral Products, Metal & Machinery Products, Chemical Products, Light Industrial Products, Miscellaneous Manufacturing, Industrial Wastes and Recycle Products and Specialty Products. For example, high-valued and/or perishable commodities are expected to raise cost of trucking firm because they often require careful handling and/or faster transport service. We have already shown that the value of commodities does not affect the price of freight (see the coefficient of iceberg in model 10 of Table 4). In order to examine the commodity-specific effects on the freight charge, we also estimate the model for each commodity. Classification into groups and the detailed commodities in each group are described in Appendix. Table 6 provides the estimates for the eight categories. The levels and signs of the coefficients appear to be relatively appropriate for Metal & Machinery, Chemical Products and Light Industrial Manufacturing, where sample sizes are significantly larger than the others.

< insert Table 6. Commodity-wise Estimation Results here>

4.3 Scale economies and long-haul economies

Figures 1 and 2 plot elasticities of freight charge with respect to lot size *q* and distance *d*, which are calculated by the following formulas.

$$E_q(q,d) = \beta_4 \tilde{r}^X (1-\theta H) d \cdot q / \tilde{P}(q,d)$$

$$E_d(q,d) = \left[(\beta_1 \tilde{r}^L + \beta_2 + \beta_3 w^T(q))(\kappa_1 + H\kappa_3) + \beta_4 \tilde{r}^X (1-\theta H)(q + w^T(q)) + \beta_5 \frac{\partial r_H(w^T(q),d)}{\partial d} H \right] \frac{d}{\tilde{P}(q,d)}$$

where $\tilde{r}^X$ and $\tilde{r}^L$ are respectively the sample means of fuel price and wage rate shown in Table 3, $\tilde{P}(q,d)$ is obtained by substituting *q*, *d*, and sample means of other explanatory variables into (3.5).

Values of $E_q(q,d)$ and $E_d(q,d)$ provide the information on scale economies and long-haul economies: scale economies exists if $E_q(q,d) < 1$, and long-haul economies exists if $E_d(q,d) < 1$. The values shown in Figures 1,2 are significantly lower than 1, which indicates the existence of scale economies and long-haul economies in freight transportation. $E_q(q,d)$ is increasing with q from 0.05 (at $q = 1$ ton) to 0.45 (at $q = 16$ ton), while $E_d(q,d)$ is increasing with *d* from 0.1 (at $d = 50$ km) to 0.8 (at $d = 800$ km). These results suggest that scale economies are stronger than long-haul economies.

As stated in footnote 1, the majority of existing studies on cost structure of motor carriers are based on firm-level data, and report that the motor carrier industry has a constant returns to scale technology. In contrast, our study shows the significant scale economies at individual shipment level, which is important from the viewpoint of the shippers. Note that freight charge per shipment is the real transport cost perceived by shippers, which they should take into account in making various decisions, such as choices of plant location, the geographical extent of shipping destinations (i.e., market area), etc. We do not find the literature on econometric estimation of long-haul economies in inter-regional transportation.

To obtain quantitative insights, we calculate the values of freight charge per ton km for various combinations of *q* and *d*, as in Table 7. This calculation incorporates the effect of lot size through choice of truck size that is ignored in calculation of elasticities since marginal change in q does not affect $w^T(q)$. The table shows the results for two cases: using highway and local road. Differences between two cases contain the effects of several factors working in opposite directions, such as shippers' higher willingness to pay (+), trucking firm's cost saving from shorter transport time (-), and toll payment (+). In fact, the freight charges in the case using highway are higher if q and d are smaller, while the relations are reversed if q is larger. This may be attributed to the toll structure that toll rate per weight is decreasing with truck size. In other words, highway use is advantageous for larger lot size of cargo. It is seen from the table that variations in the unit freight charges for different combinations of q and d are quite large, e.g., from $\tilde{P}(1,50) = 431.66$ (using highway) to $\tilde{P}(16,800) = 19.14$ (using local road). We also observe that the effects of changing lot size or distance vary depending on the level of q and d. Notwithstanding these results, it is somewhat surprising that the unit freight charges have similar values if the products of q and d, $q \cdot d$, are the same. For fixed value of $q \cdot d = 800$, we have $\tilde{P}(2,400) = 41.45$, $\tilde{P}(4,200) = 40.04$, $\tilde{P}(8,100) = 41.32$, $\tilde{P}(16,50) = 39.02$. This suggests that the conventional definition of output, ton km, turns out to be a good approximation.

5. Conclusion

This paper presents a microeconomic model of inter-regional freight transportation based on careful formulation of cost structure in trucking firm and market equilibrium, which takes into account the feature of transport service as a bundle of multiple characteristics. We estimate the parameters of the model using the micro-data of inter-regional freight flows in Japan. Estimation results show that the determinants of transport cost incorporated in the model have significant effects in the ways that the model predicts. The degree of competition also have significant effect on freight charge. It is shown that there exist significant scale economies with respect to lot size and long-haul economies. Quantitative extents of these effects are also demonstrated.

We could extend the framework of empirical analysis to various directions in the future research. First, time is a very important determinant of transport cost as shown in the regression results. Shippers have an increasing willingness to pay for fast delivery, while trucking firms benefit from saving of opportunity costs of labor (driver) and capital (truck). It is well recognized that transportation time savings account for the greatest part of the benefits from transport infrastructure improvement. Literature on estimating the value of transport time saving in freight transportation is relatively scarce compared with passenger transportation. It is worth tryng to develop a methodology to measure the value of time using the micro-data of freight charge. In this regard, we should note that transport time is an endogenous variable, which shippers and trucking firms choose to optimize some objective. Second, this paper focuses on the chartered truck service that has a relatively simple cost structure. We do not explicitly formulate the model of the consolidated truck service, although it has a large share in inter-regional freight transportation. It is known that firms providing consolidated truck service adopt very complex production process, such that they collect, consolidate, and distribute their shipments through networks consisting of terminals and breakbulk centers. Firms use advanced information and communication technologies, and construct their own infrastructure such as terminals. Explicit modeling may be beyond the scope of our purpose, but tractable framework that captures essential features of the service and suitable for empirical analysis is needed. Third, there is an important research question regarding the widely observed fact that transport cost is decreasing over time. This may be explained by technological improvement and increasing degree of competition due to deregulation. Which force is dominant? To address the question, we should develop the methodology to define and measure the productivity in transport sector, for which the conventional methods, such as TFP in manufacturing sector, are not applicable. Finally, factor price changes or infrastructure improvement can have significant effects on the behavior of agents as well as the equilibrium price of freights, which obviously affect the social welfare. Structural estimation enables us to evaluate such effects unlike simple regression estimation. We are planning to estimate the simultaneous equation system of freight price determination, time spent for delivery and highway dummy, which are related in a complex manner. Research on this direction is currently under way.

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Table1. Variable Descriptions and Sources of Data

Variable	Unit	Description	Source
P_{ij}	Yen	Freight charge	Net Freight Flow Census (Three-day survey)
r_i^L	Yen/Hour	Wage rate $r_i^L = \dfrac{\text{Monthly Contractual Cash Earnings}}{\text{Sceduled hours worked +over time}}$ *Monthly Contractual Cash Earnings= $\begin{cases} \text{It is for small sized and medium sized truck driver} & \text{if } q \le 2 \\ \text{It is for small sized and medium sized truck driver} & \text{if } 2<q<5 \\ \text{It is for large sized truck driver} & \text{if } 5 \le q. \end{cases}$	Basic Survey on Wage Structure, The Japan Institute for Labor Policy and on Training
t_{ij}	Hour	Transportation time	Net Freight Flow Census (Three-day survey)
w^T	Ton	Vehicle weight $w^T(q) = \begin{cases} 2.356, & \text{if } q \le 2 \\ 2.652, & \text{if } 2 < q \le 3 \\ 2.979, & \text{if } 3 < q \le 4 \\ 3.543, & \text{if } 4 < q \le 5 \\ 5.533, & \text{if } 5 < q \le 12 \\ 7.59, & \text{if } 12 < q \le 14 \\ 8.765, & \text{if } 14 < q \end{cases}$	Hino Motors http://www.hino.co.jp/j/product/truck/index.html
r_{ij}^X	Yen	The general retail fuel (diesel oil) price on October 2005	Monthly Survey, The Oil Information Center
q	Ton	Lot size (Disaggregated weight of individual) shipments	Net Freight Flow Census (Three-day survey)
d_{ij}	km	Transport distance between the origin and the destination	National Integrated Transport Analysis System (NITAS)
r^H		Highway toll r_i^L = (toll per 1km × travel distance × ratio for vehicle type × tapering rate+150) × 1.05 × ETC discount(=0.84) *toll per 1km =24.6 yen/km *ratio for vehicle type $\Rightarrow$ 1.0 ($q \le 2$), 1.2 ($2 < q < 5$), 1.65 ($5 \le q$) *tapering rate $\Rightarrow$ 1 .0 if $d_{ij} \le 100$ $(100km \times 1.0 + (d_{ij} - 100km) \times (1-0.25)) / d_{ij}$ if $100 < d_{ij} \le 200$ $(100km \times 1.0 + 100km \times (1-0.25) + (d_{ij} - 200km) \times (1-0.30)) / d_{ij}$ if $200 < d_{ij}$	East Nippon Express Company (E-NEXCO)

Table1. Variable Descriptions and Sources of Data

Variable	Unit	Description	Source
H		Dummy variable = 1 if highway is used; otherwise, 0	Net Freight Flow Census (Three-day survey)
intra-dummy (Z_1)		Dummy variable = 1 if it is for intra-regional trade; otherwise, 0	
border-dummy (Z_2)		Dummy variable = 1 if the trips between the two regions are contiguous; otherwise, 0	
trucks	Vehicle per million people	The number of vehicles for business use by prefecture	Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism
Qi_sum/trucks (Z_3)		$\frac{\text{Aggregated weight of Region i(origin)}}{\text{trucks}}$	Net Freight Flow Census (Three-day survey) Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism
imb (Z_4)		Trade imbalances $\text{imb}=\frac{\text{Aggregated weight from Destination to Origin}}{\text{Aggregated weight from Origin to Destination}}$	Logistics Census, Ministry of Land, Infrastructure, Transport and Tourism http://www.mlit.go.jp/seisakutokatsu/census/8kai/syukei8.html
num-truck-firms (Z_5)	Company per million people	The number of truck firms by prefecture Note: It is the number of general cargo vehicle operation if the main transport mode is charted and it is the number of special cargo vehicle operation if the main transport mode is consolidated service.	Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism
iceberg (Z_6)	millions of yen/ton	The proxy for the properties of iceberg transport costs $\text{iceberg}=\frac{\text{The value of shipment of manufactruing industry \& wholesaler}}{\text{Estimated weight}}$	Net Freight Flow Census (Annual survey)

Table2. Expected Signs of Coefficients

Variable	Parameter	Expected Sign
$r_i^L t_{ij}$	β_1	+
t_{ij}	β_2	+/−
$w^T t_{ij}$	β_3	+
$(1-\theta H) r_{ij}^X (q + w^T) d_{ij}$	β_4	+
$r^H (q, d_{ij}) H$	β_5	+
intra-dummy (Z_1)	γ_1	−
border-dummy (Z_2)	γ_2	−
Qi_sum/trucks (Z_3)	γ_3	+
imb(Z_4)	γ_4	−
num-truck-firms (Z_5)	γ_5	−
iceberg (Z_6)	γ_6	0/+

Table3. Descriptive Statistics

Variable	Observation	Mean	Standard deviation.	Minimum	Maximum
P_{ij}	267464	11092	25109.27	0	1974000
r_i^L	267464	1431.877	158.5789	1058.893	2102.116
t_{ij}	171421	13.81583	10.3067	0	240
w^T	267464	2.763294	1.114429	2.356	8.765
r_{ij}^X	267464	106.7367	1.925654	103	115
q	267464	1.382141	2.931356	0.001	16
d_{ij}	267464	276.7717	282.261	0	2074.325
H	178316	0.455399	0.498008	0	1
r^H	267464	3103.874	2834.133	79.38	29364.5
intra-dummy (Z_1)	267464	0.203351	0.402492	0	1
border-dummy (Z_2)	267464	0.222576	0.415977	0	1
trucks	267464	7.925581	1.347962	4.462233	10.41118
Qi_sum/trucks (Z_3)	267464	14.5522	5.116037	5.04197	64.76187
imb(Z_4)	267431	1.357611	5.765526	0	322
num-truck-firms (Z_5)	267464	0.13336	0.201309	0	0.674584
iceberg (Z_6)	204171	25.52643	342.5804	0.000019	36475

Table4. Estimation Results

Variables	**OLS**						**2SLS**					
	All		**Chartered cargo**		**Consolidated cargo**		**All**		**Chartered cargo**		**Consolidated cargo**	
	model1	model2	model3	model4	model5	model6	model7	model8	model9	model10	model11	model12
$r_i^L t_{ij}$	0.1569	0.2358	0.1125	0.2132	0.094	0.0809	0.3907	0.4942	1.4342	1.3696	0.1366	0.1869
	[5.49]***	[7.40]***	[0.68]	[1.22]	[9.65]***	[6.01]***	[9.97]***	[9.85]***	[7.13]***	[5.95]***	[10.34]***	[10.54]***
t_{ij}	-2536.0556	-2111.7866	-1148.8058	-1783.5209	-11301.7321	-11419.7068	-2840.7801	-2146.0242	-2010.2248	-3088.7248	4134.9585	4709.3272
	[-39.63]***	[-31.10]***	[-5.11]***	[-7.51]***	[-10.52]***	[-9.69]***	[-33.63]***	[-17.25]***	[-6.83]***	[-9.42]***	[6.57]***	[7.01]***
$w^T(q)t_{ij}$	676.7453	600.0916	359.7132	455.9242	4710.0306	4759.4979	-196.3241	-420.9516	314.6108	223.4514	-4920.8122	-5243.7421
	[28.89]***	[21.87]***	[14.11]***	[14.76]***	[10.34]***	[9.52]***	[-4.40]***	[-8.11]***	[5.60]***	[3.37]***	[-17.22]***	[-17.12]***
$r_{ij}^x(1-\theta H)(q+w^T(q))d_{ij}$	0.7306	0.8296	2.9449	2.6334	-0.1038	-0.0548	0.1695	0.1689	0.0977	0.1002	0.5395	0.5526
	[17.26]***	[17.45]***	[27.06]***	[21.86]***	[-5.26]***	[-2.56]**	[43.75]***	[36.70]***	[18.39]***	[15.91]***	[81.03]***	[72.90]***
$r^H(q,d_{ij})H$	0.0765	0.0706	0.0757	0.0688	0.0343	0.04	2.8277	2.4949	-1.1421	1.2356	6.3681	6.3889
	[45.44]***	[34.50]***	[40.79]***	[29.70]***	[22.01]***	[17.46]***	[18.18]***	[10.27]***	[-2.76]***	[2.34]**	[69.37]***	[61.17]***
intra-dummy		-2665.6454		-7354.314		767.2074		-2683.2158		-6040.096		248.8293
		[-10.99]***		[-16.16]***		[4.89]***		[-10.43]***		[-12.06]***		[2.53]**
border-dummy		1262.1755		-2775.4975		1152.8691		-195.5927		-1928.8795		706.9904
		[6.20]***		[-6.89]***		[8.55]***		[-1.15]		[-5.19]***		[8.99]***
Q_i_sum/trucks		86.8057		71.5525		31.5204		80.5111		-5.4344		56.0054
		[7.83]***		[2.86]***		[5.59]***		[12.56]***		[-0.23]		[17.07]***
imb		-40.8524		-104.4216		-6.6512		-12.2542		-41.4546		-1.8139
		[-4.26]***		[-1.01]		[-1.56]		[-2.42]**		[-0.80]		[-0.60]
num-truck-firms		26345.0031		-1739.0477		-112714.3285		24136.4124		-5892.8665		-196343.6211
		[44.44]***		[-1.47]		[-4.87]***		[60.05]***		[-4.66]***		[-17.31]***
iceberg		-0.1791		1.8205		-0.2154		-0.124		0.9196		0.0175
		[-1.26]		[0.95]		[-4.72]***		[-1.37]		[0.83]		[0.26]
Constant	12768.3942	2879.6988	12595.3986	18101.7652	2496.5544	1968.1952	13810.8297	9066.0948	8872.7262	19841.6146	19061.3234	18884.3862
	[100.30]***	[9.04]***	[81.48]***	[20.57]***	[24.31]***	[11.49]***	[61.03]***	[19.25]***	[19.54]***	[17.47]***	[93.07]***	[75.78]***
Adj-R	0.5239	0.5489	0.5015	0.5079	0.1233	0.1321	0.4882	0.5096	0.4503	0.4449	0.387	0.3925
Obs	136756	104471	64866	51602	71890	52869	267464	204138	83807	67204	183657	136934

Table5. Estimation results with different θ

Variables	$\theta = 0.2$	$\theta = 0.3$	$\theta = 0.4$	$\theta = 0.5$
$r_i^L t_{ij}$	1.3976 [6.05]***	1.3696 [5.95]***	1.3302 [5.82]***	1.2765 [5.62]***
t_{ij}	-2947.0307 [-9.00]***	-3088.725 [-9.42]***	-3280.766 [-9.96]***	-3533.381 [-10.64]***
$w^T(q)t_{ij}$	301.2809 [4.72]***	223.4513 [3.37]***	143.1586 [2.07]**	65.5954 [0.90]
$r_{ij}^X(1-\theta H)(q+w^T(q))d_{ij}$	0.0887 [14.93]***	0.1002 [15.91]***	0.113 [16.84]***	0.1267 [17.62]***
$r^H(q,d_{ij})H$	0.343 [0.63]	1.2356 [2.34]**	2.373 [4.61]***	3.7885 [7.41]***
intra-dummy	-6148.4718 [-12.17]***	-6040.096 [-12.06]***	-5942.274 [-11.99]***	-5868.238 [-12.00]***
border-dummy	-2004.2914 [-5.35]***	-1928.88 [-5.19]***	-1862.516 [-5.07]***	-1815.141 [-5.00]***
$\frac{Q_i\_sum}{trucks}$	-6.0736 [-0.25]	-5.4344 [-0.23]	-4.9084 [-0.20]	-4.5952 [-0.19]
imb	-41.3682 [-0.79]	-41.4546 [-0.80]	-41.3512 [-0.81]	-40.9696 [-0.81]
num-truck-firms	-5894.8293 [-4.66]***	-5892.867 [-4.66]***	-5884.539 [-4.67]***	-5867.273 [-4.66]***
iceberg	0.9121 [0.81]	0.9196 [0.83]	0.9267 [0.84]	0.9326 [0.85]
Constant	19021.4032 [16.79]***	19841.615 [17.47]***	20834.193 [18.27]***	22007.239 [19.16]***
Adj-R	0.4439	0.4449	0.4461	0.4473
Obs	67204	67204	67204	67204

* p<0.1, ** p<0.05, *** p<0.01

Table6. Commodity-wise Estimation Results

Variables	Agricultural and Fishery	Forest Products	Mineral Products	Metal & Machinery	Chemical Products	Light Industrial Products	Miscellaneous Manufacturing	Industrial Wastes&Recycle
$r_i^L t_{ij}$	1.6496 [1.59]	0.162 [0.29]	-0.8648 [-0.36]	-0.4482 [-1.14]	1.6633 [3.20]***	1.5568 [7.11]***	1.3882 [3.73]***	6.3472 [1.93]*
t_{ij}	-2561.0204 [-1.79]*	243.0995 [0.23]	-1096.7526 [-0.31]	-419.4358 [-0.83]	-3751.921 [-4.35]***	-3779.0085 [-9.63]***	-2339.1046 [-5.07]***	-8126.1005 [-2.10]**
$w^T(q)t_{ij}$	-173.8142 [-0.51]	-237.7669 [-1.93]*	-771.304 [-1.98]**	659.1312 [4.56]***	-209.4111 [-1.14]	521.6024 [8.58]***	353.2259 [3.50]***	1701.7024 [2.17]**
$r_{ij}^X(1-\theta H)(q+w^T(q))d_{ij}$	0.1705 [4.56]***	0.0712 [8.01]***	0.1324 [6.44]***	0.067 [4.98]***	0.1691 [10.53]***	0.0588 [10.61]***	0.0643 [7.75]***	-0.2029 [-2.24]**
$r^H(q,d_{ij})H$	-2.0151 [-1.61]	-1.593 [-0.13]	9.5851 [2.89]***	1.2463 [1.51]	1.7528 [1.25]	1.3704 [2.37]**	-1.5765 [-1.75]*	17.7173 [2.58]**
intra-dummy	-8232.0333 [-4.90]***	-5122.1026 [-2.05]**	-6125.6849 [-2.04]**	-6529.3893 [-7.22]***	-2119.4816 [-1.93]*	-3650.417 [-5.70]***	-13080.2737 [-11.85]***	7464.9411 [0.98]
border-dummy	-5029.6144 [-3.29]***	5140.8904 [2.07]**	3440.0146 [1.39]	-2279.0405 [-3.35]***	1254.581 [1.76]*	-302.3857 [-0.54]	-7503.931 [-7.62]***	17916.8437 [2.63]***
$\frac{Q_i\_sum}{trucks}$	1.657 [0.01]	-362.9136 [-4.81]***	-237.2564 [-1.05]	20.7556 [0.61]	-263.8902 [-4.00]***	64.8614 [2.10]**	770.605 [9.58]***	704.3764 [0.91]
imb	-474.0811 [-1.04]	-180.2589 [-2.30]**	-367.6703 [-2.88]***	-1.5696 [-0.03]	-117.7831 [-1.10]	-192.5421 [-1.88]*	-523.1289 [-1.54]	1667.9274 [1.43]
num-truck-firms	950.372 [0.25]	15661.2271 [1.61]	-772.8903 [-0.10]	-2831.8592 [-1.37]	-22356.248 [-6.92]***	7515.3657 [4.57]***	-1898.6012 [-0.63]	6509.1668 [0.44]
iceberg	343.6572 [3.03]***	31.7562 [1.76]*	7491.0812 [3.01]***	0.1851 [0.17]	-9.637 [-2.40]**	-7.2245 [-0.76]	-66.2656 [-1.42]	-2.4393 [-3.16]***
Constant	16114.02 [4.09]***	15485.3189 [3.64]***	25134.0726 [3.36]***	17777.1192 [8.80]***	28794.1274 [8.62]***	9611.4704 [5.68]***	10388.154 [3.99]***	-12010.2366 [-0.77]
Adj-R	0.6088	0.7666	0.6911	0.4672	0.3562	0.6636	0.5778	0.2832
Obs	1894	352	195	24444	17776	13524	6325	468

* $p<0.1$, ** $p<0.05$, *** $p<0.01$

Table7. The values of freight charge per ton km

		50km	100km	200km	400km	800km
1t	Local Road	284.2518	153.986	88.85312	56.28667	40.00344
	Highway	431.6629	230.0651	127.2556	75.44867	49.54521
2t	Local Road	147.4611	82.32825	49.76181	33.47858	25.33697
	Highway	219.5661	118.7672	67.36246	41.45901	28.50728
4t	Local Road	83.48051	49.93575	33.16337	24.77718	20.58408
	Highway	116.0308	65.77632	40.04586	27.05998	20.56705
8t	Local Road	56.12454	37.34685	27.95801	23.26359	20.91638
	Highway	66.15758	41.32738	28.49758	21.99973	18.75081
16t	Local Road	39.12315	28.46548	23.13664	20.47223	19.14002
	Highway	39.02973	26.80259	20.68901	17.27973	15.67876

Figure1. Elasticity of freight charge with respect to lot size (q)

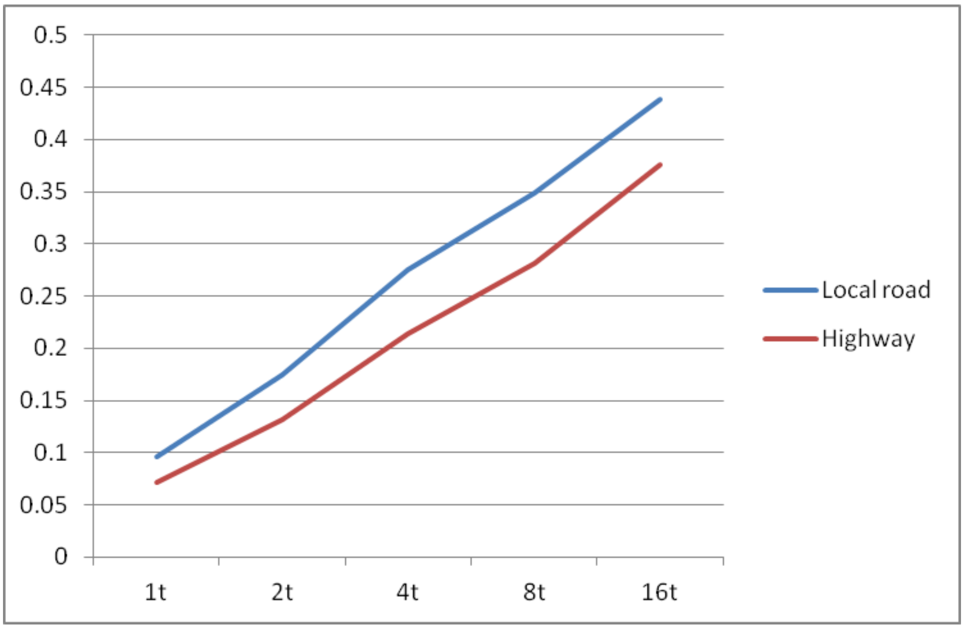
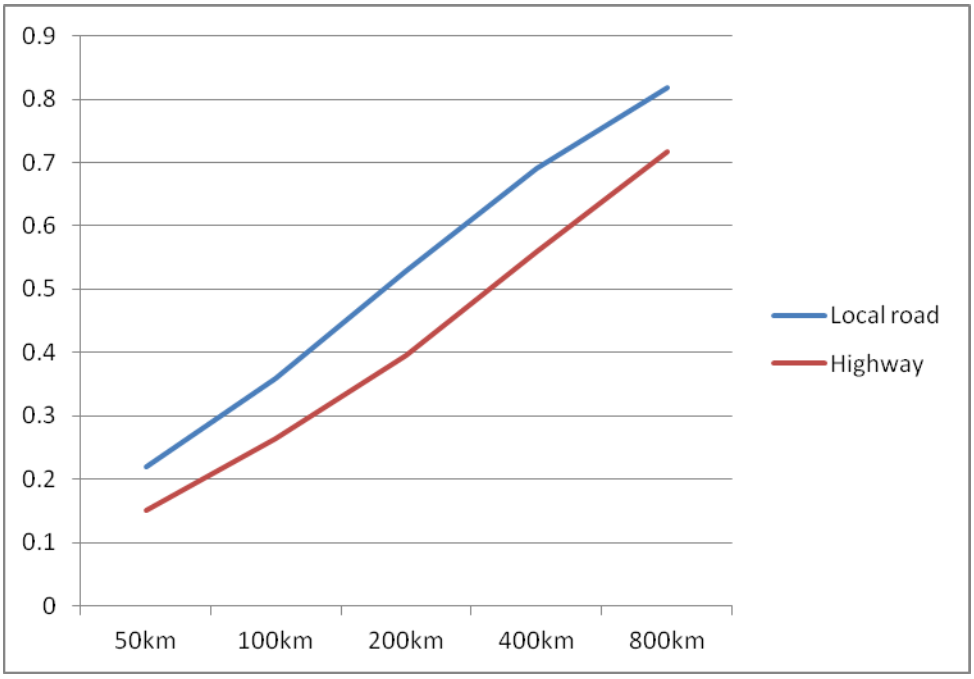


Figure2. Elasticity of freight charge with respect to distance (d)



Appendix .Classification of Commodities

Classification	Commodity
Agricultural and Fishery Products	Wheat
	Rice
	Miscellaneous grains ・ Beans
	Fruits & Vegetables
	Wool
	Other livestock products
	Fishery products
	Cotton
	Other agricultural products
Forest Products	Raw wood
	Lumber
	Firewood and charcoal
	Resin
	Other forest products
Mineral Products	Coal
	Iron ores
	Other metallic ore
	Gravel, Sand, Stone
	Limestone
	Crude petroleum and natural gas
	Rock phosphate
	Industrial salt
	Other non-metallic mineral
Metal & Machinery Products	Iron and steel
	Non-ferrous metals
	Fabricated metals products
	Industry machinery products
	Electrical machinery products
	Motor vehicles
	Motor vehicle parts
	Other transport equipment
	Precision instruments products
	Other machinery products
Light Industrial Products	Pulp
	Paper
	Spun yarn
	Woven fabrics
	Sugar
	Other food preparation

	Beverages

Appendix.Classification and Commodity

Classification	Commodity
Chemical Products	Cement
	Ready mixed-concrete
	Cement products
	Glass and glass
	Ceramics wares
	Other ceramics products
	Fuel oil
	Gasoline
	Other petroleum
	Liquefied natural gas and liquefied petroleum gas
	Other petroleum products
	Coal coke
	Other coal products
	Chemicals
	Fertilizers
	Dyes, pigments and paints
	Synthetic resins
	Animal and vegetables oil, fat
	Other chemical products
Miscellaneous Manufacturing	Book, printed matter and record
	Toys
	Apparel and apparel accessories
	Stationery,sporting goods and indoor games
	Furniture accessory
	Other daily necessities
	Woodproducts
	Rubber products
	Other miscellaneous articles
Industrial Wastes & Recycle Products	Discarded automobile
	Waste household electrical and electronic equipment
	Metal scrap
	Steel Waste Containers and Packaging
	Used glass bottle
	Other waste containers and packaging
	Waste paper
	Waste plastics
	Cinders
	Sludge
	Slag
	Soot
	Other industrial waste

Appendix 2

Consider the following endogenous regression model.

$y_1 = \beta_0 + \alpha_1 x_1 y_2 + \beta' x + \varepsilon$

where y_1, y_2 are endogenous and x_1, x are exogenous variables. OLS regression does not provide us consistent estimates because $x_1 y_2$ is an endogenous variable in general. Supposing *z* is a valid instrument for y_2, or it satisfies

$E(\varepsilon z) = 0,\ Cov(y_2, z) \neq 0$,

then letting $\hat{y}_2 = \hat{\gamma}_0 + \hat{\gamma}_1 z$ be the OLS predictor of y_2 given *z*, $x_1 \hat{y}_2$ is a valid instrument for $x_1 y_2$.

Sketch of the proof. It suffices to show that

$$\frac{1}{n}\sum_{i=1}^{n} x_{1i}\hat{y}_{2i}\varepsilon_i \xrightarrow{p} 0.$$

Now

$$\frac{1}{n}\sum_{i=1}^{n} x_{1i}\hat{y}_{2i}\varepsilon_i = \frac{1}{n}\sum_{i=1}^{n} x_{1i}(\hat{\gamma}_0 + \hat{\gamma}_1 z_i)\varepsilon_i = \frac{\hat{\gamma}_0}{n}\sum_{i=1}^{n} x_{1i}\varepsilon_i + \frac{\hat{\gamma}_1}{n}\sum_{i=1}^{n} x_{1i} z_i \varepsilon_i .$$

Because $\hat{\gamma}_0 \xrightarrow{p} \gamma_0$, $\hat{\gamma}_1 \xrightarrow{p} \gamma_1$, and $\frac{1}{n}\sum_{i=1}^{n} x_{1i}\varepsilon_i \xrightarrow{p} 0$, $\frac{1}{n}\sum_{i=1}^{n} x_{1i} z_i \varepsilon_i \xrightarrow{p} 0$ by the exogeneity of (x_{1i}, z_i), we have the desired result.