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Transportation Time and Freight Cost

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Abstract

This paper develops a model of freight transportation market, in which transportation time is endogenously determined in the market. Two types of transportation contract are considered: delivery with and without time designation. Theoretical analysis suggests that, in the presence of the uncertainty in transportation time, shippers choosing the time designation spend longer time for delivering cargos. We estimate the freight charge function, expressway choice model, and transportation time function, using microdata of freight flow in Japan. Based on the estimated freight charge function, we confirm the theoretical predictions. We also obtain the values of willingness to pay for time designation, as an alternative measure to evaluate the reliability value of transportation.

1. Introduction

Transportation cost includes not only monetary cost but also time cost. Time cost is not directly measurable, so this paper concerns the method to estimate its value from available information. Development of transport technologies improve the productivity of transport industry, which are in large part due to reduction of transportation time through increase in speed. Reduction of transportation time has great benefit on the economy: transport firms (carriers) save labor and capital costs; manufacturing firms (shippers) increase the value of their products; consumers enjoy fast delivery (e.g., increasing availability of fresh foods produced in distant locations). In longer term, these benefits would be enhanced by modifying the ways of organizing economic activities; changes in location of firms, reorganization of supply chain network, introducing more elaborate logistics (e.g., just-in-time system), etc.

For the purpose of policy analysis, changes in transportation time are evaluated in monetary unit, by using the value of transportation time saving (VTTS) to convert saving of a unit transportation time (e.g., one hour) into monetary value. It is reported in many cost-benefit analyses for transportation improvement projects that the saving of time cost constitutes the largest portion of the benefit. Transportation improvement projects also reduce the uncertainty in transportation time. The benefits from reduction of the uncertainty are measured by using the value of reliability (VOR).

There have been a large number of empirical studies on VTTS by transportation researchers. However, most studies focus on VTTS for passenger transportation, and relatively little contributions have been made on freight transportation. Recently, Small (2012) provides comprehensive review on valuation of travel time, but excludes freight transportation. Researchers suffer from the lack of reliable data allowing for sufficient empirical investigation[1]. Another difficulty arises from the fact that freight transportation is much more complex than passenger transportation. Unlike the case of passenger transportation where the decision makers are the passengers themselves, a large number of players are involved in shipping goods. Furthermore freight transportation flows are highly heterogeneous: goods with a wide range of size and weight are transported by using different types and size of vehicles, and by adopting complex logistic operations.

[1] This is partly because firms involved in freight transport may be reluctant to release confidential information especially on transportation cost.

According to Zamparini and Reggiani (2007), there are two methods to measure the value of time for freight transportation: (i) factor cost method; (ii) willingness to pay method. The manual of cost benefit analysis for highway construction project in Japan[2] adopts (i) factor cost method, in which the monetary value of time saving is equal to the sum of wage rate of the driver, opportunity cost of the truck (interest rate times the value of vehicle) and the cargo. The most widely adopted is (ii) willingness to pay method, in which VTTS is obtained as the marginal rate of substitution between money and time, based on the parameter estimates of discrete choice model. The choice should involve trade-off between "fast and expensive" and "slow and cheap" alternatives. Bergkvist (2001) considers utility (profit)- maximizing problem for shipping firm with two different transportation alternatives (1 and 0) conditional on transportation -related attributes such as transportation cost and transportation time and estimates the VTTS as the marginal rate of substitution between transportation time and transportation costs. Kawamura (2000) uses Stated Preferences data for truck driver's choice between express lanes and ordinary lanes on a freeway to estimate the distribution of VTTS based on the random parameter logit model.

As for the value of reliability (VOR), Shams et al. (2017) provide the review of existing researches and report that there are large variations in the VOR values among research works. There are two main approaches to measure VOR for freight transportation: the discrete choice models and the inventory management approach (Shams et al. (2017)). The former is more commonly used because of its validity and robustness. The framework of discrete choice approach is similar to that of passenger transportation, and the utility function is mainly based on the scheduling approach of Noland and Small (1995) and the mean-variance approach adopted by Jackson and Jucker (1982)[3].

Massiani(2008) recently presents a different approach applying the hedonic price theory (Rosen (1974)), and evaluate the value placed by shippers on faster transportation. He considers the equilibrium in the freight market and derives the value of transportation time that is equal to the derivative of freight charge with respect to transportation time. Using interview data collected in France, he estimates hedonic price equation of freight charge including weight, transportation time and speed as explanatory variables, then calculate the value of time.

[2] The document explaining the method in Japan is available from http://www.mlit.go.jp/road/ir/ir-council/hyouka-syuhou/4pdf/s1.pdf .

[3] Fosgerau and Karlström (2010) have shown that, under some plausible assumptions, the mean-variance model is derived from the optimal conditions for the scheduling model.

We further develop the method based on the hedonic approach by explicitly formulating how transportation time is determined as market outcome. In the model, the freight charge, the price of transportation services, is determined through interaction in the transportation market, where shippers demand and carriers supply transportation services. We assume that shippers are willing to pay higher price for faster delivery, which requires additional cost for carriers. Consequently equilibrium freight charge tends to be higher for shorter transportation time, such as express delivery fee in postal service. Output of transportation service is a bundle of multiple attributes such as quantity, distance, and transportation time, thereby freight charge is also a function of multiple attributes. Our model distinguish between the transportation technology and firm's effort for reducing transportation time: the former is exogenous for firms, and for the market. This formulation has a merit that the effects of technological change (including infrastructure improvement) are more rigorously evaluated: equilibrium transportation time under new technology is determined in the market where transportation firms choose the level of effort in response to technological change. Two types of transportation contract are considered: delivery with and without time designation. Theoretical analysis suggests that, in the presence of the uncertainty in transportation time, shippers choosing the time designation incur the cost of scheduling delay, and willing to pay higher freight charge to avoid that. We estimate the freight charge function, expressway choice model, and transportation time function, using microdata from the 2015 Net Freight Flow Census (NFFC), in which information on freight charge, weight, origin and destination, and transportation time for individual shipment are obtained. Based on the estimated freight charge function, we obtain the values of willingness to pay for time designation.

Let us briefly look at the facts about freight transportation time. Figure 1 shows the distribution of average speed among individual shipments. Average speed of a shipment is the distance between origin and destination divided by the transportation time, i.e., the total time taken from departure to arrival. We observe the wide variations of speeds that is difficult to explain merely by the differences in the physical conditions such as vehicles' performances, drivers' skills, or road conditions. Furthermore, Figure 2 plots transportation time against distance. It is easily seen that transportation times are quite different among shipments for given distance. Our hypothesis is that variation of transportation times may be explained by differences in carriers' effort to meet various needs of shippers on transportation time.

< Insert Figure 1 and 2 here >

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. Theoretical framework

We extend the model in Konishi, Mun, Nishiyama and Sung (2014) by incorporating the uncertainty in transportation time. Accordingly, we develop the models for two types of contract between shipper and transportation firm (carrier) : delivery with and without time designation. For convenience of explanation, we first presents the model assuming no uncertainty in transportation time in Subsection 2.1. Subsection 2.2 introduces the uncertainty and develop the model for delivery without time designation and with time designation.

2.1 The model with no uncertainty in transportation time

2.1.1 Cost of a trucking firm and choice of transportation time

We focus on the transportation service by chartered truck that a transportation firm uses a single truck exclusively to transport the goods ordered by a single shipper. Basic inputs for producing transportation service are capital (trucks), labor (drivers), fuel, expressway service. We assume that firm can reduce transportation time by using additional resource, which is called the effort hereafter. This effort may include additional labor such as more skillful driver, and auxiliary driver to save the time for break, or additional capital such as using a truck with high performance engine allowing for higher speed, installing the equipment to reduce the time for loading and unloading, etc. The cost for each shipment is the sum of the expenditures for inputs as follows

$$C_{ij} = r^L L_{ij} + r^K K_{ij} + r^X X_{ij} + r_{ij}^H H + r^Y Y_{ij} \tag{2.1}$$

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 expressway usage that is represented by a dummy variable taking H=1 when the truck uses expressway, and H=0 otherwise. Y_{ij} is the amount of effort made for reduction of the transportation cost. r^L, r^K, r^X, r_{ij}^H, and r^Y are respectively the wage rate, capital rental rate, fuel price, expressway toll, and unit cost of effort[4]. Labor input is measured in terms of time devoted by drivers, t_{ij}, represents the actual or total transportation time, which includes not only driving time but also time for loading and unloading, rest breaks, etc. The 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 also measured in terms of time. Also note that the larger truck should be used to carry a larger lot size of cargo. We denote by q the lot size of shipment measured in weight, and 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 depends on weight (shipment size) q and speed s, thus represented by the function $e(q,s)$[5]. Expressway toll depends on the distance and weight of the truck, and is written as $r_{ij}^H = r^H(q, d_{ij})$. The amount of effort is written as $Y_{ij} = yd_{ij}$, where y is the effort level per unit transportation distance. This formulation implies that the amount of effort is the sum of efforts at every kilometer en route.

Let us denote by t_{ij}^N the shortest time for driving between i and j along the road network, which depends on the choice of expressway use, H, as follows

$$t_{ij}^N = Ht_{ij}^{N1} + (1-H)t_{ij}^{N0} \tag{2.2}$$

where t_{ij}^{N1} and t_{ij}^{N0} are respectively the driving times via expressway and ordinary road. We assume that actual transportation time is determined as follows.

$$t_{ij} = f(t_{ij}^{N1}, t_{ij}^{N0}, H, y) = f(t_{ij}^N, y) \tag{2.3}$$

The function $f(t_{ij}^{N1}, t_{ij}^{N0}, H, y)$ is increasing with t_{ij}^{N1} and t_{ij}^{N0}, and decreasing with y and H. t_{ij}^{N1} and t_{ij}^{N0} are interpreted to represent the transportation technology. For example, development of new engine technology may reduce t_{ij}^{N1} and t_{ij}^{N0}. Improvement of infrastructures such as higher quality of expressways (milder curves, less steep gradient) is also interpreted as a technological development. We consider (2.3) as a production function since it

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[4] Note that factor prices do not depend on the locations of origin, destination, or origin-destination pair, because it is unknown where these factors are procured. In our model, only expressway toll is defined for origin-destination pair.

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

depends on the transportation technology and the levels of inputs, y and H [6].

Incorporating the above assumptions into (2.1), we have

$$C_{ij} = r^L t_{ij} + r^K g(q) t_{ij} + r^X e(q, s_{ij}) d_{ij} + r^H (q, d_{ij}) H + r^Y y d_{ij} \tag{2.4}$$

We solve the cost minimization problem to obtain the cost function $C_{ij}(q, d_{ij}, t_{ij})$.

Each carrier chooses the levels of inputs, y and H, to minimize the cost, subject to the constraint (2.3).

The optimality condition with respect to H is

$$\begin{aligned} H^* &= 1, \quad \text{if } C_{ij}\big|_{H=0} - C_{ij}\big|_{H=1} > 0 \\ H^* &= 0, \quad \text{if } C_{ij}\big|_{H=0} - C_{ij}\big|_{H=1} < 0 \end{aligned} \tag{2.5}$$

where * denote the optimal choice and $C_{ij}\big|_{H=1}$ and $C_{ij}\big|_{H=0}$ are transportation costs for the cases of expressway use and ordinary road only, respectively. As t_{ij} is given, y^* is determined by solely inverting (2.3) as follows

$$y^* = f^{-1}\left(t_{ij}, t_{ij}^{N1}, t_{ij}^{N0}, H^*\right) = y\left(t_{ij}, t_{ij}^{N}\right) \tag{2.6}$$

where $y\left(t_{ij}, t_{ij}^{N1}, t_{ij}^{N0}, H\right)$ is increasing with t_{ij}^{N1} and t_{ij}^{N0}, and decreasing with t_{ij} and H. Plugging the solutions y^* and H^* into (2.4) yields the cost function as follows,

$$C_{ij}(q, d_{ij}, t_{ij}) = r^L t_{ij} + r^K g(q) t_{ij} + r^X e(q, s_{ij}) d_{ij} + r^H (q, d_{ij}) H^* + r^Y y^* d_{ij} \tag{2.7}$$

In the above cost function, q, d_{ij}, t_{ij} are all considered as output variables. In other words, freight transportation is a bundle of multiple characteristics produced by the trucking firm.

The price of a transportation service, freight charge, is also defined for a bundle of characteristics as $P_{ij}(q, d_{ij}, t_{ij})$. The profit of the firm is $P_{ij}(q, d_{ij}, t_{ij}) - C_{ij}(q, d_{ij}, t_{ij})$. So the optimality condition to maximize the profit with respect to transportation time is

$$\frac{\partial P_{ij}(q, d_{ij}, t_{ij})}{\partial t_{ij}} = \frac{\partial C_{ij}(q, d_{ij}, t_{ij})}{\partial t_{ij}}$$

[6] (2.2) and (2.3) indicate that H, and y are substitute inputs: if expressway is not used, more effort is required to transport at a certain time. Expressway use is also interpreted as an effort to reduce time for transportation. Thus y should be considered as the effort other than expressway use.

Following Rosen (1974), we use the offer function that is the freight charge that the carrier is willing to accept on (q, d_{ij}, t_{ij}) attaining the given level of profit. The offer function $\phi(q, d_{ij}, t_{ij}; \pi)$ is defined as follows

$$\phi(q, d_{ij}, t_{ij}; \pi) = C_{ij}(q, d_{ij}, t_{ij}) + \pi \tag{2.8}$$

We assume that there are a sufficiently large number of trucking firms competing for getting the job (i.e., the order from shippers). So the transportation time in equilibrium satisfy the following conditions.

$$\frac{\partial \phi(q, d_{ij}, t_{ij}; \pi)}{\partial t_{ij}} = \frac{\partial C_{ij}(q, d_{ij}, t_{ij})}{\partial t_{ij}} \tag{2.9a}$$

$$P_{ij}(q, d_{ij}, t_{ij}) = \phi(q, d_{ij}, t_{ij}; \pi) \tag{2.9b}$$

2.1.2 Shippers and market equilibrium

Each shipper seeks to minimize the transportation cost that is the sum of freight charge and time cost, $P_{ij}(q, d_{ij}, t_{ij}) + vt_{ij}$ where v is called the value of time for the shipper. If the shipper is a manufacturing firm, v is equal to the marginal increase in revenue or marginal decrease in production cost induced by marginal decrease in transportation cost. We use the bid function that shipper is willing to pay for freight charge on various combinations of (q, d_{ij}, t_{ij}) at a given level of transportation cost, τ. The bid function $\psi(q, d_{ij}, t_{ij}; \tau)$ is defined as

$$\psi(q, d_{ij}, t_{ij}; \tau) = \tau - vt_{ij} \tag{2.10}$$

Equilibrium is characterized as follows

$$\frac{\partial \psi(q, d_{ij}, t_{ij}; \tau)}{\partial t_{ij}} = -v \tag{2.11a}$$

$$P_{ij}(q, d_{ij}, t_{ij}) = \psi(q, d_{ij}, t_{ij}; \tau) \tag{2.11b}$$

Combining (2.9) and (2.11), the following relations should hold in market equilibrium

$$P_{ij}(q, d_{ij}, t_{ij}) = C_{ij}(q, d_{ij}, t_{ij}) + \pi \tag{2.12a}$$

$$\frac{\partial P_{ij}(q, d_{ij}, t_{ij})}{\partial t_{ij}} = \frac{\partial C_{ij}(q, d_{ij}, t_{ij})}{\partial t_{ij}} = -v \tag{2.12b}$$

2.2 The model with uncertainty in transportation time

2.2.1 Case of no time designation

Following Fosgerau and Karlström (2015), we express the transportation time as

$$t_{ij} = \mu_{ij} + \sigma_{ij} x \tag{2.13}$$

where μ_{ij} and σ_{ij} are the expected value and standard deviation of transportation time, respectively. x is a standardised random variable with mean 0, variance 1, density $\zeta(x)$, and cumulative distribution $Z(x)$.

Under the uncertainty, the carrier seeks to minimize the expected cost. In the case of delivery without time designation, expected cost is written simply by replacing t_{ij} in (2.7) by μ_{ij} in (2.13)

$$C_{ij}(q, d_{ij}, \mu_{ij}) = r^L \mu_{ij} + r^K g(q)\mu_{ij} + r^X e(q, s_{ij}) d_{ij} + r^H (q, d_{ij}) H^* + r^Y y^* d_{ij} \tag{2.14a}$$

where

$$\begin{aligned} H^* &= 1, \quad \text{if } C_{ij}\big|_{H=0} - C_{ij}\big|_{H=1} > 0 \\ H^* &= 0, \quad \text{if } C_{ij}\big|_{H=0} - C_{ij}\big|_{H=1} < 0 \end{aligned} \tag{2.14b}$$

$$y^* = f^{-1}\left(\mu_{ij}, t_{ij}^{N1}, t_{ij}^{N0}, H^*\right) = y\left(\mu_{ij}, t_{ij}^{N}\right) \tag{2.14c}$$

The shipper's objective becomes minimizing the expected transportation cost, $P_{ij}(q, d_{ij}, \mu_{ij}) + v\mu_{ij}$. We obtain the equilibrium solution $(P_{ij}(q, d_{ij}, \mu_{ij}^*), \mu_{ij}^*)$ in the same way as Subsection 2.1.2.

$$P_{ij}^*(q, d_{ij}, \mu_{ij}^*) = C_{ij}(q, d_{ij}, \mu_{ij}^*) + \pi \tag{2.15a}$$

$$\frac{\partial P_{ij}(q, d_{ij}, \mu_{ij}^*)}{\partial \mu_{ij}} = \frac{\partial C_{ij}(q, d_{ij}, \mu_{ij}^*)}{\partial \mu_{ij}} = -v \tag{2.15b}$$

where

$$\frac{\partial C_{ij}(q, d_{ij}, \mu_{ij}^*)}{\partial \mu_{ij}} = r^L + r^K g(q) + r^Y \frac{\partial y\left(\mu_{ij}^*, t_{ij}^N\right)}{\partial \mu_{ij}} d_{ij} \tag{2.15c}$$

2.2.1 Case of time designation

Some shippers may want the cargo to arrive at the scheduled time. In this case, the shippers contract with the carriers to deliver the cargo at the specified time. If the arrival of the cargo is too early or too late from the scheduled time, the shippers incur the costs and the carriers should be subject to penalty. We formulate the model of scheduling choice by the carrier and shipper (i.e., choice of departure time against the designated arrival time) in this subsection.

Suppose a carrier (trucking firm) takes an order for transporting a cargo from region i to j. The order specifies the schedule of transportation, i.e., departure time, t_i^d , and arrival time, t_j^a. If the truck arrives earlier than t_j^a, it should wait until then. On the other hand, the carrier has to pay the penalty for late arrival. We assume that the penalty is proportional to the length of delay, $t_i^d + t_{ij} - t_j^a$. In this setting, the expected freight cost for the carrier is written as follows,

$$C_{ij} = r^L \overline{t_{ij}} + r^K g(q)\overline{t_{ij}} + r^X e(q_{ij}, s_{ij})d_{ij} + r^H (q, d_{ij})H + r^Y y\left(\mu_{ij}, t_{ij}^N\right)d_{ij} + r^S ESD_{ij} \tag{2.16}$$

where $\overline{t_{ij}}$ is the expected time that the truck should spend for delivering the cargo, r^S is the penalty per unit length of scheduling delay, and ESD_{ij} is the expected scheduling delay. (2.16) is different from (2.14) in that the expected scheduling delay cost (penalty), $r^S ESD$, is added, and the expected time for delivery, $\overline{t_{ij}}$, replaces μ_{ij}. As seen in (2.16), we assume that the effort function, $y\left(\mu_{ij}, t_{ij}^N\right)$, depend on μ_{ij}. This implies that the effort to reduce the transportation time affects the expected transportation time, μ_{ij} only. In the time designated delivery, the expected time for delivery, $\overline{t_{ij}}$, is different from μ_{ij}.

The expected scheduling delay is expressed as

$$\begin{aligned} ESD_{ij} &= \int_{\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}}^{\infty} (t_i^d + \mu_{ij} + \sigma_{ij}x - t_j^a)\zeta(x)dx \\ &= (t_i^d + \mu_{ij} - t_j^a)\left(1 - \mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}\right)\right) + \sigma_{ij}\int_{\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}}^{\infty} x\zeta(x)dx \end{aligned} \tag{2.17}$$

(2.16) defines the freight cost based on the expected length of time that the driver and truck actually spend for the cargo delivery, that is $\overline{t_{ij}}$, which is defined as follows

$$\overline{t_{ij}} = (t_j^a - t_i^d)\mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}\right) + \int_{\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}}^{\infty} (\mu_{ij} + \sigma_{ij}x)\zeta(x)dx \tag{2.18}$$

The first term of (2.18) represents the expected length of time in the case that the truck arrives earlier than the scheduled arrival time. In this case, the truck does not deliver the cargo immediately upon arrival, but waits until the scheduled time. So the time spent for the cargo delivery is equal to $t_j^a - t_i^d$, regardless the realized transportation time. Note that

$\mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}\right)$ is the probability that this situation, i.e., early arrival, arises. The second term implies that, in the case of late arrival, the truck delivers the cargo as soon as its arrival at the destination.

In the case of time designated delivery, the carrier chooses not only the effort level to reduce the transportation time, μ_{ij}, but also the time of departure, t_i^d. So the profit maximizing conditions are

$$\frac{\partial P_{ij}(q, d_{ij}, t_i^d, \mu_{ij})}{\partial \mu_{ij}} = \frac{\partial C_{ij}(q, d_{ij}, t_i^d, \mu_{ij})}{\partial \mu_{ij}} \tag{2.19a}$$

$$\frac{\partial P_{ij}(q, d_{ij}, t_i^d, \mu_{ij})}{\partial t_i^d} = \frac{\partial C_{ij}(q, d_{ij}, t_i^d, \mu_{ij})}{\partial t_i^d} \tag{2.19b}$$

where

$$\frac{\partial C_{ij}(q, d_{ij}, t_i^d, \mu_{ij})}{\partial \mu_{ij}} = \left[r^L + r^K g(q) + r^S\right]\left(1 - \mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}\right)\right) + r^Y \frac{\partial y\left(\mu_{ij}, t_{ij}^N\right)}{\partial \mu_{ij}} d_{ij} \tag{2.20a}$$

$$\frac{\partial C_{ij}(q, d_{ij}, t_i^d, \mu_{ij})}{\partial t_i^d} = -\left[r^L + r^K g(q)\right]\mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}\right) + r^S\left(1 - \mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}\right)\right) \tag{2.20b}$$

Generally, either shipper (consignor) or consignee can be the client of transportation service. In any case, they prefer shorter transportation time and shorter scheduling delay. To be consistent throughout the paper, we assume that the shipper represents the demand side of the transportation service. The shipper's objective is to minimize the transportation cost that is the sum of freight charge, time cost, and scheduling delay cost, $P_{ij}(q, d_{ij}, t_i^d, \mu_{ij}) + v\overline{t_{ij}} + \omega ESD_{ij}$, where ω is the value of reliability for the shipper.

Equilibrium conditions are defined, similarly with (2.15), as follows

$$P_{ij}(q, d_{ij}, t_i^d, \mu_{ij}) = C_{ij}(q, d_{ij}, t_i^d, \mu_{ij}) + \pi$$

(2.21a)

$$\frac{\partial P_{ij}(q, d_{ij}, t_i^d, \mu_{ij})}{\partial \mu_{ij}} = \frac{\partial C_{ij}(q, d_{ij}, t_i^d, \mu_{ij})}{\partial \mu_{ij}} = -(v + \omega)\left(1 - \mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}\right)\right) \tag{2.21b}$$

$$\frac{\partial P_{ij}(q,d_{ij},t_i^d,\mu_{ij})}{\partial t_i^d}=\frac{\partial C_{ij}(q,d_{ij},t_i^d,\mu_{ij})}{\partial t_i^d}=-v\mathrm{Z}\left(\frac{t_j^a-t_i^d-\mu_{ij}}{\sigma_{ij}}\right)-\omega\left(1-\mathrm{Z}\left(\frac{t_j^a-t_i^d-\mu_{ij}}{\sigma_{ij}}\right)\right)$$

(2.21c)

Addition of the condition with respect to scheduling choice, (2.21c), is a difference from the case without time designation. Substituting (2.20a) and (2.20b) into (2.21b) and (2.21c), respectively, we have

$$\mathrm{Z}\left(\frac{t_j^a-t_i^d-\mu_{ij}}{\sigma_{ij}}\right)=\frac{r^L+r^K g(q)+r^Y\frac{\partial y\left(\mu_{ij},t_{ij}^N\right)}{\partial \mu_{ij}}d_{ij}+v+r^S+\omega}{r^L+r^K g(q)+v+r^S+\omega} \qquad (2.22a)$$

$$\mathrm{Z}\left(\frac{t_j^a-t_i^d-\mu_{ij}}{\sigma_{ij}}\right)=\frac{r^S+\omega}{r^L+r^K g(q)+v+r^S+\omega} \qquad (2.22b)$$

The LHS of (2.22a) and (2.22b) are the same, and thereby the following relation should hold

$$r^L+r^K g(q)+r^Y\frac{\partial y\left(\mu_{ij},t_{ij}^N\right)}{\partial \mu_{ij}}d_{ij}=-v \qquad (2.23)$$

(2.23) is consistent with (2.15b). In words, at equilibrium, the derivative of the freight cost function with respect to the expected transportation time is equal to the value of time for the shipper, in both cases with and without time designation.

The equilibrium condition of scheduling choice, (2.22b), is rewritten as follows,

$$t_j^a-t_i^d=\mu_{ij}+\sigma_{ij}\mathrm{Z}^{-1}\left(\frac{r^S+\omega}{r^L+r^K g(q)+v+r^S+\omega}\right) \qquad (2.24)$$

The second term on the RHS of the above expression is positive. This implies that the scheduled (or, contractually committed) transportation time, $t_j^a-t_i^d$, is longer than μ_{ij}. In other words, the departure time is chosen such that the truck running at the average speed would arrive sufficiently earlier than the designated time.

We examine the effect of uncertainty on the expected transportation time by differentiating (2.18) with respect to σ_{ij}

$$\frac{\partial \overline{t_{ij}}}{\partial \sigma_{ij}}=-\mathrm{Z}\left(\frac{t_j^a-t_i^d-\mu_{ij}}{\sigma_{ij}}\right)\frac{\partial t_i^d}{\partial \sigma_{ij}}+\int_{\frac{t_j^a-t_i^d-\mu_{ij}}{\sigma_{ij}}}^{\infty}x\zeta(x)dx>0 \qquad (2.25)$$

since $\frac{\partial t_i^d}{\partial \sigma_{ij}} < 0$ [7]. In words, increase in the uncertainty would increase the expected transportation time.

The effect on the freight cost is expressed as follows

$$\frac{\partial C_{ij}}{\partial \sigma_{ij}} = \left[r^L + r^K g(q) \right] \frac{\partial \overline{t_{ij}}}{\partial \sigma_{ij}} + r^S \frac{\partial ESD_{ij}}{\partial \sigma_{ij}} \tag{2.26}$$

where $\frac{\partial ESD_{ij}}{\partial \sigma_{ij}} = \left[1 - \mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}} \right) \right] \frac{\partial t_i^d}{\partial \sigma_{ij}} + \int_{\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}}^{\infty} x \zeta(x) dx$ is ambiguous, since $\frac{\partial t_i^d}{\partial \sigma_{ij}} < 0$.

Inserting (2.25) into (2.26), we obtain

$$\frac{\partial C_{ij}}{\partial \sigma_{ij}} = r^S \mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}} \right) \left[\frac{1 - \mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}} \right)}{\mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}} \right)} - \frac{r^L + r^K g(q)}{r^S} \right] \frac{\partial t_i^d}{\partial \sigma_{ij}} + \left[r^L + r^K g(q) + r^S \right] \int_{\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}}^{\infty} x \zeta(x) dx \tag{2.27}$$

The sign of $\frac{\partial C_{ij}}{\partial \sigma_{ij}}$ is positive if the bracketed term in the first term on the RHS of the above expression is positive. The analysis so far is summarized as follows.

Proposition *In the case of time designated delivery, increase in the uncertainty leads to*

(i) increase in the expected time for the cargo delivery;

(ii) increase in the freight cost if the following inequality holds

$$\frac{1 - \mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}} \right)}{\mathrm{Z}\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}} \right)} - \frac{r^L + r^K g(q)}{r^S} < 0 \tag{2.28}$$

---

[7] Since the RHS of (2.22b) is constant, $\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}$ on the LHS should be constant. Increase in σ_{ij} should lead to decrease in t_i^d, thus $\frac{\partial t_i^d}{\partial \sigma_{ij}} < 0$ is true.

In reality, the probability of late arrival in the time designated delivery, $1-Z\left(\frac{t_j^a - t_i^d - \mu_{ij}}{\sigma_{ij}}\right)$, should be kept very small, close to zero. Thus the first term of (2.28) is likely to be smaller than the second term, in such case, $\frac{\partial C_{ij}}{\partial \sigma_{ij}} > 0$ is true. Note that the condition (2.28) is only a sufficient condition. Even if it does not hold, the freight cost can be increased by increasing the uncertainty. We examine the above predictions by empirical analysis in the following sections.

We next examine the effect of the designation of arrival time on the freight cost. As we have shown, in the time designated delivery, the carriers spend more time for delivery and also incur the scheduling delay cost. So one may conjecture that the freight cost should be larger in the case of time designation. However, the relation is not obvious, as below.

Suppose that a shipper wants to transport a cargo with weight equal to q from i to j, and seeks a carrier to take the order. We compare the freight costs under two equilibria: with and without time designation. Let C_{ij}^D and C_{ij}^N be the equilibrium freight costs for the cases with and without time designation, respectively. C_{ij}^N is obtained by applying the equilibrium condition (2.14a) to (2.15a). Likewise C_{ij}^D is obtained by substituting (2.16) with (2.22b) and (2.23) to (2.21a). Then we have the following expression[8],

$$C_{ij}^D - C_{ij}^N = \left[r^L + r^K g(q)\right]\left(\bar{t}_{ij} - \mu_{ij}^N\right) + r^Y\left[y\left(\mu_{ij}^D, t_{ij}^N\right)d_{ij} - y\left(\mu_{ij}^N, t_{ij}^N\right)d_{ij}\right] + r^S ESD_{ij}$$

where μ_{ij}^D and μ_{ij}^N are respectively the expected transportation times for cases with and without time designation. The first term is positive, since $\bar{t}_{ij} > \mu_{ij}^N$ by definition. The third term is also positive. However, the second term is ambiguous since $\mu_{ij}^N < \mu_{ij}^D$ might be the case theoretically. Empirical analysis will also address this question.

3. Econometric Model

3.1 Case of no time designation

3.1.1 Model specification

8 We assume here that transportation routes are the same in both cases with and without time designation.

We assume that truck rent $g(q)$ depends linearly on the size of shipment, q, since truck size is determined so as to accommodate the cargo of size q, $g(q) = \alpha_1 + \alpha_2 \ln q$. The fuel efficiency $e(q, s)$ of trucks is typically an increasing function of q, and a U-shaped function of speed s. We assume that one can drive at different but fixed speeds at s^1 on the expressway and s^0 on ordinary roads, and thus

$$e(q,s) = e(q,s^1)H + e(q,s^0)(1-H)$$

Functional form of y^* in (2.6) is specified as $y^* = \alpha_3 \frac{\mu_{ij}}{d_{ij}} + \alpha_4 \frac{\left(t_{ij}^N - \mu_{ij}\right)^2}{d_{ij}}$, where we expect $\alpha_3 < 0,\ \alpha_4 > 0$.

We assume that the price is determined depending also on other factors $Z = (Z_1, \cdots, Z_4)$, as

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

$\gamma' Z$ includes the proxy variables of trucking firm's profit, represented by π in (2.12a) and, other factors affecting the transportation cost.

Allowing parameters $\beta_i, i = 1,2,3,4$, our empirical model of freight charge function is written as:

$$P_{ij}(q, d_{ij}, \mu_{ij}) = \beta_1 \mu_{ij} + \beta_2 \ln[q] \mu_{ij} + \beta_3 \left[r^X e(q,s) d_{ij} + r^H (q, d_{ij}) H \right] + \beta_4 \left(t_{ij}^N - \mu_{ij}\right)^2 + \sum_{k=1}^{4} \gamma_k Z_k + \varepsilon_P \quad (3.1)$$

where

$$\beta_1 = r^L + r^K \alpha_1 + \alpha_3,$$
$$\beta_2 = r^K \alpha_2 > 0$$
$$\beta_3 > 0,$$
$$\beta_4 = \alpha_4 > 0.$$

Note that sign of β_1 is unknown, because it is sum of the parameters $r^L > 0,\ r^K \alpha_1 > 0,\ \alpha_3 < 0$ which have different sign. We introduce definition of explanatory variables in Section 4.1 using Table 1.

In our model, expressway usage is supposed to be endogenous variable in decision making of trucking firms as described in Section 2. $C_{ij}\big|_{H=0} - C_{ij}\big|_{H=1}$ in (2.5) is specified as

$$C_{ij}\big|_{H=0} - C_{ij}\big|_{H=1} = \eta_0 + \eta_1 (t_{ij}^{N0} - t_{ij}^{N1}) + \eta_2 \left[r^X (e(q,s^0) d_{ij}^0 - e(q,s^1) d_{ij}^1) - r^H (q, d_{ij}^1) \right]$$

We apply the probit model to the binary choice whether to use expressway.

$$H = \text{Prob}\left[C_{ij}\big|_{H=0} - C_{ij}\big|_{H=1} > \varepsilon_H \right]$$

where ε_H is a standard normal distribution.

Transportation time is also supposed to be endogenous variable, which is a function of t_{ij}^N as discussed in 2.1. We further take account of the effects of shipment size, transportation distance and carried commodity type on transportation time. Transportation time function is specified as follows,

$$\mu_{ij} = \kappa_0 + \kappa_1 t_{ij}^N + \delta^{\bar{q}}\left(\kappa_4 + \kappa_5 t_{ij}^N\right) + \sum_{k=1}^{8} \rho_k D_k \qquad \text{if} \quad t_{ij}^N \le t^S \qquad (3.2a)$$

$$\mu_{ij} = \kappa_2 + \kappa_3 t_{ij}^N + \delta^{\bar{q}}\left(\kappa_4 + \kappa_5 t_{ij}^N\right) + \sum_{k=1}^{8} \rho_k D_k \qquad \text{if} \quad t_{ij}^N \ge t^S \qquad (3.2b)$$

where t_{ij}^N is the shortest driving time as (2.2) and $\delta^{\bar{q}}$ is a dummy variable taking $\delta^{\bar{q}} = 1$ if the cargo is heavier than $\bar{q}$ and $\delta^{\bar{q}} = 0$ otherwise. D_k is commodity-specific dummy variables. NFFC classifies the shipments into nine groups by the variety of transported commodities[9]. Therefore we use eight commodity-specific dummy variables, i.e. $AFP\ dummy,\ FP\ dummy,\ MP\ dummy,\ MM\ dummy,\ CH\ dummy,\ LI\ dummy,$ $MMA\ dummy,\ SG\ dummy$. We take Metal & Machinery Products ($MM\ dummy$) as the base line. $AFP\ dummy$ is dummy variable taking $AFP\ dummy = 1$ when the classification of carried commodity is Agricultural and Fishery Products and $AFP\ dummy = 0$ otherwise. Similarly, $FP\ dummy,\ MP\ dummy,\ MM\ dummy,$ $CH\ dummy,\ LI\ dummy,\ MMA\ dummy$, and $SG\ dummy$ are dummy variables standing for Agricultural and Fishery Products, Forest Products, Mineral Products, Metal & Machinery Products, Chemical Products, Light Industrial Products, Miscellaneous Manufacturing, and Specialty Products , respectively. $\kappa_0, \kappa_1, \kappa_2, \kappa_3, \kappa_4, \kappa_5$ are unknown parameters. Transport time function should be continuous at $t_{ij}^N = t^S$, whereby the following relation is satisfied.

$$\kappa_2 = \kappa_0 + \left(\kappa_1 - \kappa_3\right) t^S \qquad (3.2c)$$

Using (3.2a), (3.2b) and (3.2c), transport time function is rewritten as,

---

[9] Classification into groups and the detailed commodities in each group are described in Appendix1.

$$\mu_{ij} = \kappa_0 + \kappa_1\left(\lambda t_{ij}^N + t^S - \delta^t t^S\right) + \kappa_3\left(1-\delta^t\right)\left(t_{ij}^N \text{-} t^S\right) + \delta^{\bar{q}}\left(\kappa_4 + \kappa_5 t_{ij}^N\right) + \sum_{k=1}^{8}\rho_k D_k \tag{3.3}$$

where,

$$\delta^t = 1 \qquad \text{if} \quad t_{ij}^N < t^S$$

$$\delta^t = 0 \qquad \text{if} \quad t_{ij}^N > t^S$$

We suppose $\kappa_4 > 0$ and $\kappa_5 > 0$. $\kappa_4 > 0$ means that loading and unloading takes more time if the cargo is heavier than $\bar{q}$. $\kappa_5 > 0$ means the speed of a truck tends to be slower for carrying heavier cargo.

3.1.2 Model estimation

Firstly, we implement a probit estimation for dependent variable H which is endogenous variable.

$$E\left(H \mid \omega\right) = P\left\{\eta_0 + \eta_1(t_{ij}^{N0} - t_{ij}^{N1}) + \eta_2\left[r_i^X e\left(q, s^0\right)\left(d_{ij}^0 - d_{ij}^1(1-\theta)\right) - r^H(q, d_{ij}^1)\right] + \eta_3 d50\_dummy \geq \varepsilon_H\right\} \tag{3.4}$$

where $\omega = \left\{(t_{ij}^{N0} - t_{ij}^{N1}), \left[r_i^X e\left(q, s^0\right)\left(d_{ij}^0 - d_{ij}^1(1-\theta)\right) - r^H(q, d_{ij}^1)\right], d50\_dummy\right\}$ and θ is the ratio of saving fuel consumption from using the expressway, $\theta = 1 - \dfrac{e\left(q, s^1\right)}{e\left(q, s^0\right)}$.

t_{ij}^{N0} and t_{ij}^{N1} are the shortest driving time via ordinary road and expressway, respectively. d_{ij}^0 and d_{ij}^1 are the transportation distance via ordinary road and expressway, respectively. $d50\_dummy$ is a dummy variable that takes the value one when the travel distance is 50km or less and zero otherwise. This variable is included to explain the tendency that trucks do not use expressways for short distance trips. After estimating the choice of expressway function of (3.4), we can obtain the predictor of $\hat{H}$, and calculate $\hat{t}_{ij}^N$ by (3.5).

$$\hat{t}_{ij}^N = \left[t_{ij}^{N1}\hat{H} + t_{ij}^{N0}\left(1-\hat{H}\right)\right] \tag{3.5}$$

Secondly, as stated earlier, t_{ij} and t_{ij}^N depend on the choice of expressway use, *H*. Since H is endogenous, we use the predictor $\hat{H}$ from regression (3.2) as the regressor, then transportation time function is estimated as,

$$\mu_{ij} = \kappa_0 + \kappa_1\left(\mu\hat{t}_{ij}^N + t^S - \mu t^S\right) + \kappa_3\left(1-\mu\right)\left(\hat{t}_{ij}^N \text{-} t^S\right) + \delta^{\bar{q}}\left(\kappa_4 + \kappa_5\hat{t}_{ij}^N\right) + \sum_{k=1}^{8}\rho_k D_k + \varepsilon_t \quad (3.6)$$

We obtain the predicted values, $\hat{H}$ from (3.4), $\hat{t}_{ij}^N$ from (3.5), and $\hat{\mu}_{ij}$ from (3.6). Finally, replacing t_{ij} , t_{ij}^N and H in eq.(3.1) by $\hat{\mu}_{ij}$, $\hat{t}_{ij}^N$ and $\hat{H}$ respectively, we obtain third stage regression equation as,

$$P_{ij}(q, d_{ij}, \hat{\mu}_{ij}) = \beta_1\hat{\mu}_{ij} + \beta_2\ln[q]\hat{\mu}_{ij} + \beta_3\left[r_i^X d_{ij} e\left(q, s^0\right)\left(1-\theta\hat{H}\right) + r^H(q, d_{ij})\hat{H}\right] + \beta_4(\hat{t}_{ij}^N - \hat{\mu}_{ij})^2 + \sum_{k=1}^{4}\gamma_k Z_k + \varepsilon_P$$

(3.7)

Applying OLS estimation to (3.7), we obtain 2SLS estimates of β, γ which are consistent under the endogeneity.

3.2 Case of time designated delivery

We use the same specifications of functional forms for $g(q),\ e(q,s),\ y^*$, as in the case of no time designation. In the case of time designation, we add terms representing the uncertainty in transportation time, σ_{ij}, as follows

Expressway choice:

$$C_{ij}\big|_{H=0} - C_{ij}\big|_{H=1}$$
$$= \eta_0 + \eta_1(t_{ij}^{N0} - t_{ij}^{N1}) + \eta_2\left[r^X(e(q,s^0)d_{ij}^0 - e(q,s^1)d_{ij}^1) - r^H(q, d_{ij}^1)\right] + \eta_3(\sigma_{ij}^0 - \sigma_{ij}^1)$$

Transportation time:

$$t_{ij} = \kappa_0 + \kappa_1\left(\lambda t_{ij}^N + t^S - \delta^t t^S\right) + \kappa_3\left(1-\delta^t\right)\left(t_{ij}^N - t^S\right) + \delta^{\bar{q}}\left(\kappa_4 + \kappa_5 t_{ij}^N\right) + \kappa_6\sigma_{ij} + \sum_{k=1}^{8}\rho_k D_k$$

Freight charge:

$$P_{ij}(q, d_{ij}, \hat{t}_{ij}) = \beta_1\hat{t}_{ij} + \beta_2\ln[q]\hat{t}_{ij} + \beta_3\left[r_i^X d_{ij} e\left(q, s^0\right)\left(1-\theta\hat{H}\right) + r^H(q, d_{ij})\hat{H}\right]$$
$$+ \beta_4(\hat{t}_{ij}^N - \hat{t}_{ij})^2 + \beta_5\sigma_{ij} + \sum_{k=1}^{4}\gamma_k Z_k$$

As discussed in theoretical part, we expect $\eta_3 > 0$ and $\kappa_6 > 0$.

The method of model estimation is parallel to that described in Section 3.1.2.

4. Empirical Results

4.1 Data Description

Table 1 provides the data definitions, descriptions, and sources to construct these variables.

< Insert Table 1 here>

We use the data from the NFFC conducted by the MLIT to obtain data on individual freight charge P_{ij}, shipment 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, transshipment, and the driver's break etc.

The 2015 NFFC census randomly selected 64,917 domestic establishment samples from 584,841 establishments engaged in mining, manufacturing, wholesale trade, and warehousing industry. The collection rate of the survey was 36.5%, and the survey results of 16,063 establishments. Each selected establishment report shipments for a three-day period. This produces a total sample size around 900,000 shipments, each of which has information on the origin and the destination, freight charge (Yen), P_{ij}, shipment size (ton), q, transportation time (hours), t_{ij}, the industrial code of the shipper and consignee, the code of commodity transported and main modes of transportation, etc. We also collect data on transportation distance d_{ij}, toll payments r^H, the number of trucking firm and the number of trucks, etc. The data for t_{ij}^N and d_{ij} are obtained by the shortest driving time and distance, which are 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 transportation 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 shortest driving times between 1,916 municipalities as the time between the jurisdictional offices along the road network with NITAS for the cases of expressway use and ordinary road only, respectively.

Compare transportation time t_{ij} and the shortest driving time t_{ij}^N using Table 2. The mean and median of t_{ij} are 5.48 and 3 hours respectively. On the other hand, t_{ij}^N's mean and median are 2.72 and 1.67 hours. The mean of t_{ij} is more than twice as large as t_{ij}^N, and t_{ij} seems to be more diverse among trucking firms and shipments in average. This is because t_{ij} includes not only driving time but also loading, unloading and the driver's break. We also calculate the coefficients of variation for t_{ij} and t_{ij}^N that are 1.389 and 1.081, respectively. In variance level, t_{ij} is more diverse than t_{ij}^N.

$\sigma_k^2(t_{ij})$ represents transportation time variance and is for time designation model. We implement a rolling estimation for the transportation time variances for each one km using a bandwidth of plus or minus 3 km between 1 to 1,642km. k denotes the distance from 1 to 1,642km.

The fuel cost r_i^X is average diesel oil price in October 2015 which is published by the Oil Information Center. The fuel efficiency of trucks at speed s^0 on ordinary roads for varying weight of shipment, are given as follows; (unit: liter per kilometers)

$$e(q, s^0) = \begin{cases} 0.107, \text{if } \quad q < 1 \\ 0.162, \text{if } 1 \le q < 2 \\ 0.218, \text{if } 2 \le q < 4 \\ 0.264, \text{if } 4 \le q < 6 \\ 0.296, \text{if } 6 \le q < 8 \\ 0.324, \text{if } 8 \le q < 10 \\ 0.346, \text{if } 10 \le q < 12 \\ 0.382, \text{if } 12 \le q < 17 \end{cases}$$

We refer to "Automobile Fuel Efficiency List" conducted by MLIT to get the fuel efficiency of truck for hire. To implement estimation, we need to obtain a suitable value of θ to construct the explanatory variables. We assume $\theta = 0.3$, which is derived in Konishi, Mun, Nishiyama and Sung (2012), based on empirical study by Oshiro, Matsushita, Namikawa and Ohnishi (2001).

Expressway toll $r^H(q,d)$ is from East Nippon Express Company (E-NEXCO), and associated with the each shipment's lot size and distance.

$$r^H(q,d) = \begin{cases} 0.84*(150+24.6*d)*1.08 \ \ if \quad q<2 \\ 0.84*(150+1.2*24.6*d) \ *1.08 \ \ if \quad 2 \le q < 5, \\ 0.84*(150+1.65*24.6*d)*1.08 \ \ if \quad q \ge 5 \end{cases}$$

Toll per km is 24.6 yen/ km for truck size (q) smaller than 2 ton. The rate is increased for heavier trucks, so 1.2 or 1.65 is multiplied. While examining $r^H(q,d)$, we also reflect the tapering rate. We apply the 25% discount rate for distance exceeding 100km and 200km or less, and 30% discount for distance over 200km. There is a discount when the truck uses the electronic toll collection system (ETC) by 16%, thereby 0.84 is multiplied. We also reflect 8% consumption tax, thereby 1.08 is multiplied.

Z includes other explanatory variables, that can affect the price. Specifically, we use $Border - dummy\ (Z_1)$, $\frac{Q_i}{trucks}(Z_2)$, $imb(Z_3)$ and $num\ truck\ firms\ (Z_4)$. Also, we include $Tokyo\_Osaka\ dummy$ and $Hokkaido\ dummy$. MLIT estimates the aggregated trade volume between prefectures based on shipments data from NFFC and publishes it via website[10], and we use these data for Q_i, Q_{ji} and Q_{ij} to construct the variables, $\frac{Q_i}{trucks}(Z_2)$ and $imb = \frac{Q_{ij}}{Q_{ji}}(Z_3)$. We composed $num\ truck\ firms\ (Z_4)$ variable as the number of trucking firms 1,000 people of prefecture of origin i.

We would like to mention that definitions of region are different among the variables. P_{ij}, t_{ij}, t_{ij}^N, H_{ij}, q_{ij}, d_{ij}, and $\sigma_k^2(t_{ij})$ are municipality level data considering with both origin and destination regions, while r_i^X, r^H, $\frac{Q_i}{trucks}(Z_2)$, and $num\ truck\ firms_i\ (Z_4)$ belong to prefecture of origins. $imb = \frac{Q_{ij}}{Q_{ji}}(Z_3)$ is prefectural level data made by origin and destination regions.

Other variables are as follows. $Tokyo\_Osaka\ dummy$ is included in the estimation to see if there is a difference in transport time or freight charge due to Tokyo or Osaka being the origin or the destination. $Hokkaido\ dummy$ represents the differences in transport time or freight charge within Hokkaido. In order to examine the commodity-specific effects on the transportation time and freight charge, we use eight dummy variables for classification of carried commodities. Eight shipping commodity-specific dummy variables, i.e. $AFP\ dummy$, $FP\ dummy$, $MP\ dummy$, $MM\ dummy$, $CH\ dummy$, $LI\ dummy$, $MMA\ dummy$, $SG\ dummy$. $MM\ dummy$ is the base line.

The descriptive statistics of these variables used in the estimation are summarized in Table 2.

< Insert Table 2 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 transportation 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.

[10] http://www.mlit.go.jp/seisakutokatsu/census/census-top.html

Excludes cases where shipments were made from Hokkaido, Okinawa, or other remote islands to other regions, and cases where shipments were made from other regions to Hokkaido, Okinawa, or other remote islands; [2] In order to capture the expressway effects on P_{ij} clearly, we keep shipments which used only ordinary road and only expressway; it means that we dropped the shipments using expressway for only a portion of the trip; [3] We suppose one truck is allocated for each shipment. In reality the maximum load capacity of a single truck would be 16ton: if q is over 16ton, carriers need multiple trucks. Thus, we removed the shipments if q is over 16ton; [4] Observations with an average speed is more than 100 km/h calculated in Figure 1 were removed; [5] Since we focus on the transportation service by chartered truck, we keep the observations of which main transportation mode is chartered truck ; [6] We removed the shipments that origin and destination are in the same municipalities to focus on inter-regional freight transportation; [7] We removed observations without data of freight charge P_{ij}.

Finally, we have the target dataset with 57,613 shipments.

4.2 Estimation Results

4.2.1 Expressway choice model

The estimation results for probit models of expressway choice in (3.4) are shown in Table 3[11]. We obtain significant estimates with expected signs for explanatory variables.

< Insert Table 3 here>

The coefficients of the difference between the driving time for using expressway and ordinary road ($t_{ij}^{N0} - t_{ij}^{N1}$) are significantly positive as expected, i.e., $\eta_1 = 0.231$ and 0.187, for the time designated delivery and no time designated delivery, respectively. This parameter represents the costs of inputs dependent on time such as wage of the driver and opportunity cost of the vehicle. The driving time can be saved by using expressway. η_2 is the coefficient of the difference between monetary costs for using expressway and ordinary road. The monetary cost is the sum of the fuel cost and expressway toll. When an expressway is used, a toll is required while fuel cost can be saved, thus we expected positive sign of η_2. We obtain

[11] Appendix 4-1 shows estimation results for designated date delivery and designated the morning or afternoon delivery.

the positive coefficients for two cases. η_3 is the coefficient of the dummy variable ($d50\_dummy$) that takes the value one when the distance is 50km or less and zero otherwise. We expected that it has a negative sign since trucks is less likely to use expressway for short-distance transportation. We found the expected sign and significant for the coefficients.

In the case of time designated delivery, we add the difference in transportation time variance between ordinary road and expressway as an explanatory variable. It is observed that transportation time variances via expressway are smaller than that via ordinary road. So trucks seeking less uncertainty would prefer using expressway. We expect that the coefficient for this variable η_4 should be positive. We implement a rolling estimation for the transport time variances for each one km using a bandwidth of plus or minus 3 km between 1 to 1,642km. We calculated the difference between the transport time variance when using only general roads and the transport time variance when using expressways. Estimation result is that η_4 is positive. The larger the difference in the variance of the transportation time by whether or not the expressway is used in a given distance band, the higher the probability of using the expressway.

The coefficients η_0 of the constant term are significantly negative only for no time designation result. This implies that the trucking firms prefer ordinary road to using expressway even if $t_{ij}^{N0} = t_{ij}^{N1}$ and monetary costs for using expressway and ordinary road are the same.

4.2.2 Transportation time function

Table 4 shows the estimation results of transportation time function in (3.6)[12]. We estimate the model for different values of $\bar{q}$ (i.e.,$1,2,\cdots,16$) to construct the dummy variable $\bar{\delta}^q$ and for different value of T^s(i.e.,$1,2,\cdots,32$) to construct δ^t. $\bar{\delta}^q$is a dummy variable taking $\bar{\delta}^q = 1$ if the cargo is heavier than $\bar{q}$ and $\bar{\delta}^q = 0$ otherwise. δ^t is a dummy variable taking $\delta^t = 1$ if $\hat{t}_{ij}^N$ is shorter than T^s and $\delta^t = 0$ otherwise. We made a time threshold (T^s) of 1 hour to 32 hours in 1 hour increments, and a cargo weight threshold ($\bar{q}$) of 1 ton to 16 tons in 1 ton increments. We created combinations of T^s and $\bar{q}$ and estimated equation (3.6) for all combinations. The combination with the highest adj R^2 was selected as the estimation result of equation (3.6). We chose the combination of ($T^s = 12, \bar{q} = 1$) for no time

[12] We show the estimation results for designated date delivery and designated the morning or afternoon delivery in Appendix 4-2.

designated delivery and ($T^s = 10, \bar{q} = 6$) for Time-designated delivery.

< Insert Table 4 here>

The coefficients of the driving time ($\hat{t}_{ij}^N$) are significantly positive. The value of κ_1 for the time designated delivery (1.060) is smaller than that for the no time designation (1.132). This suggests that, in the case of time designated delivery, trucks spend additional time (e.g., waiting near the destination) to deliver the cargo on time under the variability of transportation time (due to traffic congestion, weather conditions, or other unexpected events). It should also be noted that the values of κ_3 are larger than the values of κ_1. The estimates of κ_3 are 2.277 for the time designated delivery and 3.936 for no time designated delivery. This may reflect the fact that truck drivers, particularly those who travel long distance, make obligatory rest stops every certain hours[13]. κ_4 is the constant dummy coefficient and κ_5 the slope dummy coefficient. We expected both κ_4 and κ_5 are positive. The positive value of κ_5 suggests that the speed of a truck carrying heavier cargo tends to be slower. However, estimate of κ_4 for time-designation is a significantly negative, this may reflect that trucking firms use automated loading and unloading systems such as forklift and more convenient packaging in order to save time when carrying heavier cargo. κ_6 is only for time-designation estimation. We implement a rolling estimation for the transport time variances for each one km using a bandwidth of plus or minus 3 km between 1 to 1,642km. We expect κ_6 should be positive. The coefficient is positive and the larger the variance of the transport time in a certain distance band, the longer the transport time.

$Tokyo\_Osaka\ dummy$ is included in the estimation to see if there is a difference in transport time due to Tokyo or Osaka being the origin or the destination. The coefficients are positive and significant for both no time designation and time specification. This means that transportation to or from Tokyo or Osaka takes longer time than transportation to or from other regions. We also add $Hokkaido\ dummy$ to the estimation to observe the differences of transportation time within Hokkaido, the coefficient for time designation is negative and significant.

[13] By law, a driver is not allowed to drive again in a day after the driver has accumulated 13 hours of on-duty time in the day. The consecutive hours of driving are also limited to 4 hours following a break of at least 30 minutes.

In order to examine the commodity-specific effects on the transportation time, we use eight dummy variables for classification of carried commodities. Metal & Machinery Products (MM dummy) is taken as the base line. In case of no time designation result, the Forest Products and Miscellaneous Manufacturing (MMA) are not statistically significant, but coefficients of the other shipping commodities are significantly negative and smaller than the baseline MM dummy's one. For Time-designation result, only FP is not statistically significant, MMA is significantly positive at 1.228, and the others are negative and significant.

4.2.3 Freight charge function

The results for estimation of (3.7) are shown in Table 5[14]. We adopt $\hat{H}$, $\hat{t}_{ij}^N$ and $\hat{t}_{ij}$ from the results of Table 3 and 4 as explanatory variables to control the endogeneity.

< Insert Table 5 here>

β_1, the coefficient of transportation time ($\hat{t}_{ij}$), is significantly negative in the both cases of time designated delivery and no time designated delivery. As discussed in Section 3, this term depends on two effects, one is related to the wage and truck rent, while the other is the amount of effort to reduce the transportation cost. The former has a positive effect and the latter has the negative effect on the freight charge P. We obtained the estimate of -1076.9 for time designated delivery and -4587.5 for no time designated delivery, and thus we know that the negative effect is dominant. β_2 is also the coefficient related to the truck rent. As the rent of larger trucks must be higher than smaller ones, this coefficient is expected to be positive and indeed it is in both cases. β_3 is the coefficient of the sum of fuel consumption and expressway toll, for which we obtained significantly positive estimates. β_4, the coefficient of $\left(\hat{t}_{ij} - \hat{t}_{ij}^N\right)^2$, is also significantly positive as expected in both cases. We found the positive coefficients for both cases, but only time designation result is statistically significant. As $\hat{t}_{ij}$ is getting closer to $\hat{t}_{ij}^N$, more effort of the trucking firms is required. The development of transportation technology reduces t_{ij}^N, thereby less effort is required. β_5 is only for time-designation

[14] Appendix 4-3 shows estimation results for designated date delivery and designated the morning or afternoon delivery.

estimation. We adopt same transport time variances in Table 4 as an explanatory variable. We expect β_5 should be positive. The coefficient is positive and the larger the variance of the transport time in a certain distance band, more expensive the freight charge.

We introduce several control variables as follows. $Border\ dummy$, takes value one if the destination is located in the region next to the origin (the region sharing the border). The coefficient is significantly negative in case of time designated delivery. This result may reflect that freights to very close places do not waste carriers' time for the return drive and thus the opportunity cost is lower. In case of no time designated delivery, the coefficient of variable $Border - dummy$ is positive but not significant. 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, but it turns out to be insignificant in both cases. We include $\frac{Q_i}{trucks}$ and $num\ truck\ firms$ as proxies of competition in the truck transportation market. The coefficient of $\frac{Q_i}{trucks}$ is negative and insignificant in both cases. In the case of no time designated delivery the coefficients are negative but not significant. The coefficient of $num\ truck\ firms$ for time designated delivery, we observe the coefficient is positive and significant.

We also include $Tokyo\_Osaka\ dummy$ and $Hokkaido\ dummy$ as Table 4. We only observed the coefficient of $Tokyo\_Osaka\ dummy$ for time designation result is statistically significant, and its positive value.

In order to examine the commodity-specific effects on the freight charge, we use eight dummy variables for classification of carried commodities as Table 4. Metal & Machinery Products (MM dummy) is taken as the base line. In case of no time designation result, the coefficients of all commodities are not significant. On the other hand, we found the negative values and significant of all commodities coefficients on time-designation estimation results.

4.3 Time designation, transportation time and freight cost

Theoretical analysis suggests that, in the case of time designated delivery, the carriers spend longer time for delivery than in the case of no time designation. In addition, the carriers also incur the scheduling delay cost. However, it is generally ambiguous whether the freight cost in the case of time designation is larger. We empirically address this point.

Table 6 shows transportation time and freight charge with and without time designation, for representative combination of shipment size (q) and transportation distance (d). We choose the representative values of q and d around 10,30,50,70,90 percentiles[15].

< Insert Table 6 here>

It is seen that transportation time for time designated delivery is longer than that without time designation. This result is consistent with the theoretical prediction: the carriers choose the departure time excessively earlier to reduce the possibility of late arrival. On the other hand, the results on the freight charges are ambiguous, as theory suggests. The freight charges with time designation are smaller than that without time designation for short distance transportation, while the relation is reversed for short distance. For long distance, the uncertainty in transportation time is larger, and thereby the carrier should arrange the schedule so that the possibility of late arrival is minimized. This response should require the additional cost and the carrier would offer the higher price for freight charge. As we observe the time designated delivery in reality, there are shippers who accept the higher freight charge for time designated delivery. Thus the difference in freight charges between cases with and without time designation can be a measure of willingness to pay for arrival on time. This value can be an alternative measure of reliability of transportation. For example, from Table 6, the difference is 11403 Yen for transporting 2 tons of cargo over a distance of 360km, that is larger than 20 % of freight charge. This suggests that the arrival of cargo on time may have great values.

5. Conclusion

This paper presents a model of freight transportation, in which the freight charge and transportation time are determined through interaction in the transportation market, where shippers demand and carriers supply transportation services. A remarkable feature of our model is that two types of transportation contract are considered: delivery with and without time designation. We estimate the freight charge function, expressway choice model, and transportation time function, using microdata from the 2015 Net Freight Flow Census (NFFC). Based on the result of estimation, we confirm the theoretical prediction that increase in the uncertainty leads to increase in the expected time for the cargo delivery and increase in the freight cost. The carriers spend longer time for delivery in the case of time designation. We

[15] These values are based on Appendix 2 showing the distributions of d and q.

propose an alternative measure of reliability value: the difference in transportation time and freight cost between two cases with and without time designation. This measure evaluates the value of delivery on time.

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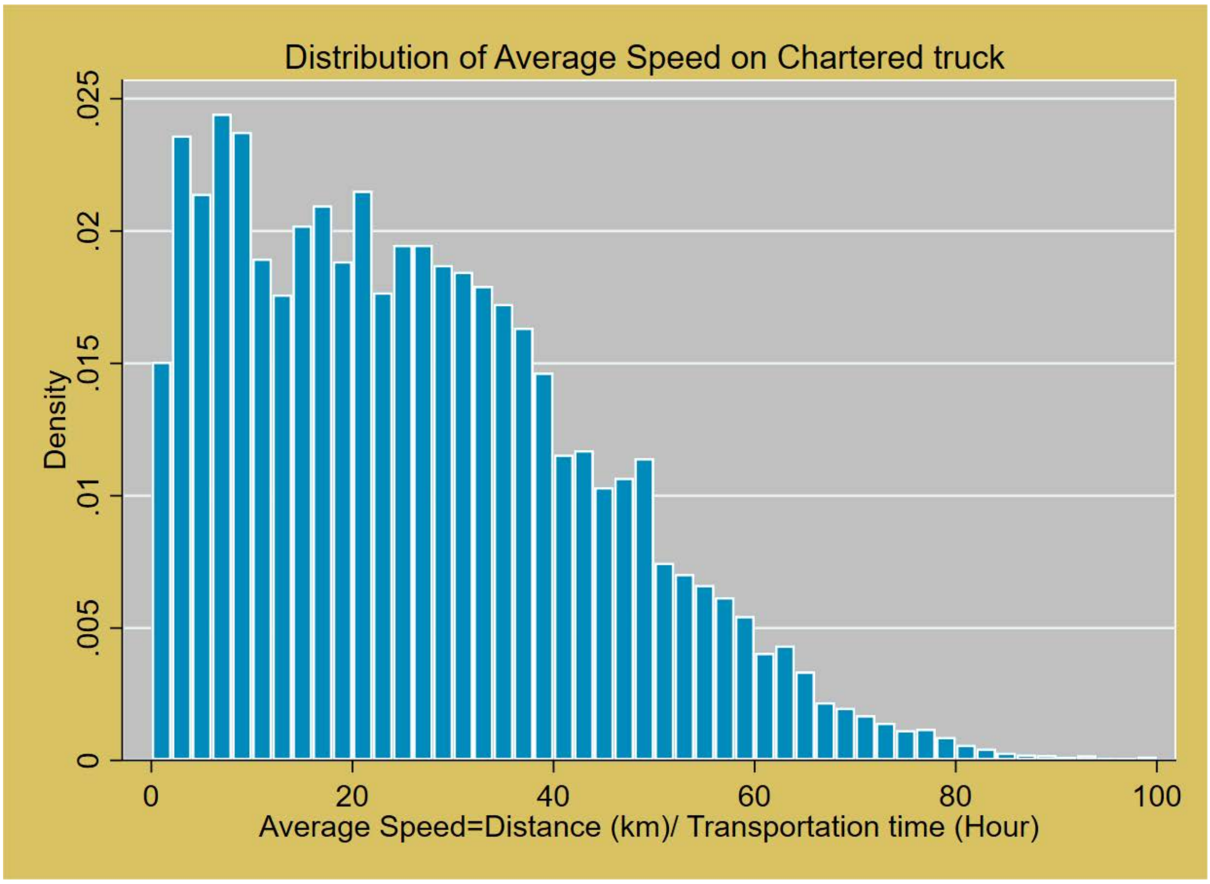
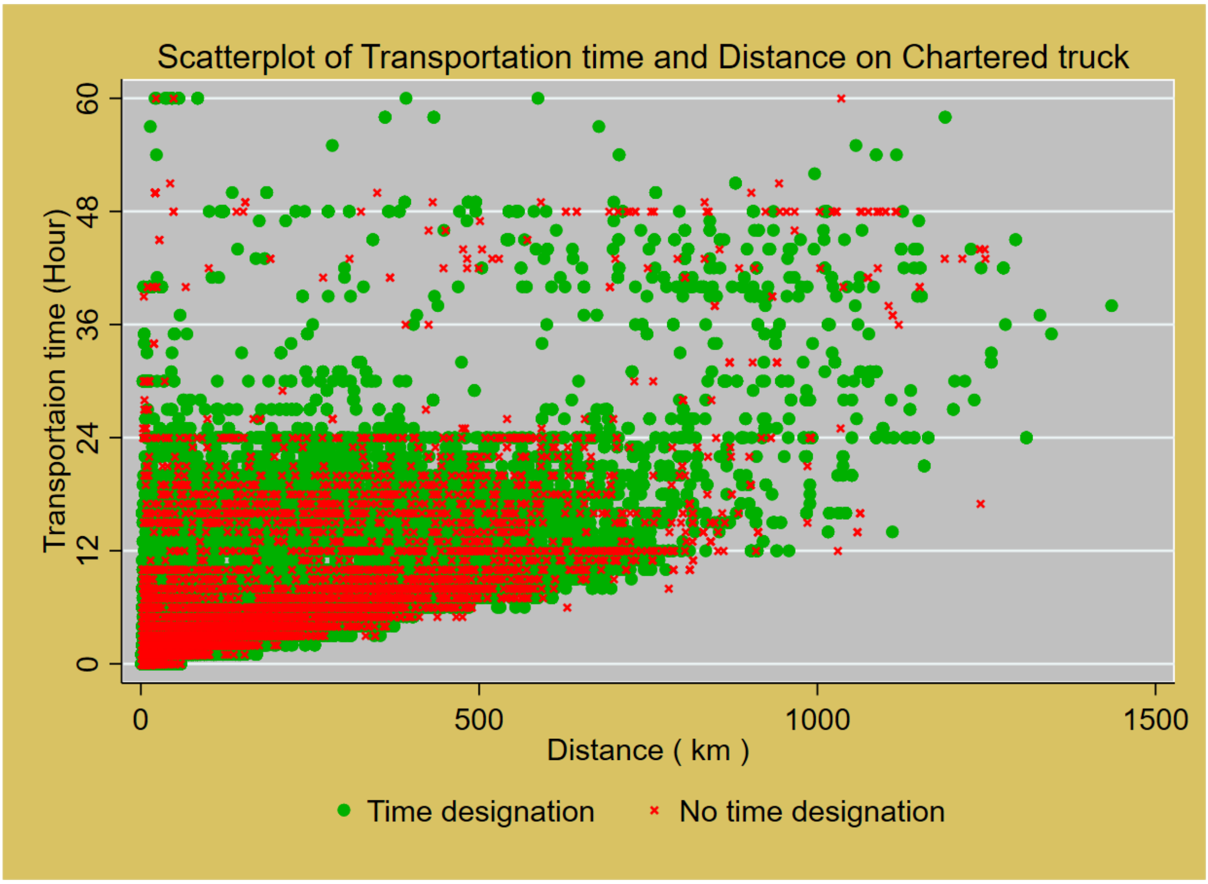
Figure 1. Distribution of average speed



Source: Authors' creation based on data from the 2015 Net Freight Flow Census (NFFC) of Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

Figure 2. Transportation time against Distance



Source: Authors' creation based on data from the 2015 Net Freight Flow Census (NFFC) of Ministry of Land, Infrastructure, Transport and Tourism (MLIT).

Table 1. Variable Descriptions and Sources of Data

Variable	Unit	Description	Source
P_{ij}	Yen	Freight charge (Dependent var.)	Net Freight Flow Census (Three-day survey) conducted by MLIT
t_{ij}	Hour	Transportation time (Dependent var.)	Net Freight Flow Census (Three-day survey) conducted by MLIT
H_{ij}		Dummy variable = 1 if expressway is used; otherwise, 0 (Dependent var.)	Net Freight Flow Census (Three-day survey) conducted by MLIT
t_{ij}^N	Hour	The shortest driving time	National Integrated Transport Analysis System (NITAS) conducted by MLIT
$\sigma_k^2(t_{ij})$	$Hour^2$	Transportation time (t_{ij}) variance calculated for each distance band (k)	National Integrated Transport Analysis System (NITAS) conducted by MLIT
q_{ij}	Ton	Lot size (Disaggregated weight of individual) shipments	Net Freight Flow Census (Three-day survey) conducted by MLIT
d_{ij}	km	Transportation distance between the origin and the destination	National Integrated Transport Analysis System (NITAS) conducted by MLIT
$e(q, s^0)$	l/km	Fuel Efficiency $e(q,s^0) = \begin{cases} 0.107, \text{if } q < 1 \\ 0.162, \text{if } 1 \le q < 2 \\ 0.218, \text{if } 2 \le q < 4 \\ 0.264, \text{if } 4 \le q < 6 \\ 0.296, \text{if } 6 \le q < 8 \\ 0.324, \text{if } 8 \le q < 10 \\ 0.346, \text{if} 10 \le q < 12 \\ 0.382, \text{if} 12 \le q < 17 \end{cases}$	Automobile Fuel Efficiency List conducted by MLIT
r^H	Yen	Expressway toll $r_i^H = (\text{toll per 1km} \times \text{travel distance} \times \text{ratio for vehicle type} \times \text{tapering rate} + 150) \times 1.08 \times \text{ETC discount}(=0.84)$ *toll per 1km =24.6 yen/km *ratio for vehicle type ⇒ 1.0 ($q \le 2$), 1.2 ($2 < q < 5$), 1.65 ($5 \le q$) *tapering rate ⇒ 1.0 if $d_{ij} \le 100$ $(100km \times 1.0 + (d_{ij} - 100km) \times (1 - 0.25))/d_{ij}$	East Nippon Express Company (E-NEXCO)

Table 1. Variable Descriptions and Sources of Data (Continued)

Variable	Unit	Description	Source
r^H (continued)	Yen	if $100 < d_{ij} \leq 200$ $(100km \times 1.0 + 100km \times (1 - 0.25) + (d_{ij} - 200km) \times (1 - 0.30))/d_{ij}$ if $200 < d_{ij}$	
r^X	Yen	The general retail fuel (diesel oil) price in October 2015 by prefecture	Petroleum Product Price Survey conducted by the Oil Information Center.
$Border\ dummy$ (Z_1)		Dummy variable = 1 if the trips between the two regions are contiguous; otherwise, 0	Net Freight Flow Census (Three-day survey)conducted by MLIT
$\frac{Q_i}{trucks}$ (Z_2)		$\frac{Aggregated\ weigt\ of\ Region\ i\ (Origin)}{number\ of\ trucks}$	Net Freight Flow Census (Three-day survey) Freight business number of vehicles conducted by MLIT
imb (Z_3)		Trade volume imbalances $imb = \frac{Agg.weight\ of\ Destination\ to\ Origin}{Agg.weight\ of\ Origin\ to\ Destinaiton}$	Net Freight Flow Census (Three-day survey)
$num\ truck\ firms$ (Z_4)		The number of truck firms per 1,000 people by prefecture	Number of freight carriers conducted by MLIT Census conducted by MIC
$Tokyo\_Osaka\ dummy$		Dummy variable=1 if transport with origin in Tokyo or Osaka, and transport with destination in Tokyo or Osaka; otherwise, 0	Net Freight Flow Census (Three-day survey) conducted by MLIT
$Hokkaido\ dummy$		Dummy variable=1 if transport within Hokkaido; otherwise, 0	Net Freight Flow Census (Three-day survey) conducted by MLIT
$Shipping\ commodity\ dummy$		Eight shipping commodity-specific dummy variables, i.e. $AFP\ dummy$, $FP\ dummy$, $MP\ dummy$, $MM\ dummy$, $CH\ dummy$, $LI\ dummy$, $MMA\ dummy$, $SG\ dummy$. $MM\ dummy$ is the base line. For example,$AFP\ dummy$ takes 1 when the classification of shipping commodity is Agricultural and Fishery Products; otherwise,0. The detailed commodities in each group are described in Appendix1.	Net Freight Flow Census (Three-day survey) conducted by MLIT

Table2. Descriptive Statistics (No time designation and Time designation)

	Obs.	Mean	Median	S.D.	Min.	Max.
P	41294	37064.15	22000.00	74328.80	100.00	4174000.00
t	57613	5.48	3.00	7.61	1.00	117.00
H	54520	0.44	0.00	0.50	0.00	1.00
t^N	52748	2.72	1.67	2.94	0.01	32.87
$\sigma_k^2(t_{ij})$	57613	20.19	9.20	33.15	0.12	562.21
$\frac{\sigma_k(t_{ij})}{k}\|_{H=1}$	33137	0.016	0.011	0.012	0.006	0.239
$\frac{\sigma_k(t_{ij})}{k}\|_{H=0}$	47024	0.017	0.011	0.014	0.006	0.169
q	57613	3.95	2.27	4.11	0.00	16.00
d_{ij}	57613	138.47	69.00	170.33	1.00	1537.00
$e(q, s^0)$	57613	5.74	4.58	2.56	2.62	9.32
r_i^H	55718	4731.52	2328.23	5726.26	142.04	53379.91
r_i^x	57613	110.58	110.60	3.97	103.00	123.60
$Border\ dummy$ $(Z1)$	57613	0.67	1.00	0.47	0.00	1.00
Q_i/num_trucks $(Z2)$	57613	11.19	10.61	4.46	3.17	34.34
imb $(Z3)$	57613	1.48	1.00	7.60	0.02	718.90
$num\ truck\ firms_i$ $(Z4)$	57613	0.46	0.43	0.13	0.22	0.96
$Tokyo\ Osaka\ dummy$	57613	0.15	0.00	0.35	0.00	1.00
$Hokkaido\ dummy$	57613	0.02	0.00	0.13	0.00	1.00
$AFP\ dummy$	57613	0.05	0.00	0.22	0.00	1.00
$FP\ dummy$	57613	0.00	0.00	0.06	0.00	1.00
$MP\ dummy$	57613	0.02	0.00	0.13	0.00	1.00
$MM\ dummy$	57613	0.39	0.00	0.49	0.00	1.00
$CH\ dummy$	57613	0.24	0.00	0.43	0.00	1.00
$LI\ dummy$	57613	0.16	0.00	0.37	0.00	1.00
$MMA\ dummy$	57613	0.08	0.00	0.27	0.00	1.00
$SG\ dummy$	57613	0.05	0.00	0.21	0.00	1.00

Table 3. Estimation Results of Expressway Choice (*H*)

Dependent var. H	No time designation	Time designation
$t_{ij}^{N0} - t_{ij}^{N1}$ (η_1)	0.187***	0.231***
	(0.015)	(0.009)
$r_i^X e\left(q, s^0\right)\left(d_{ij}^0 - d_{ij}(1-\theta)\right) - r^H\left(q, d_{ij}^1\right)$ (η_2)	0.0000202**	0.0000224***
	(0.000)	(0.000)
$d50\_dummy$ (η_3)	-0.997***	-0.449***
	(0.053)	(0.024)
$\sigma_{k,H=0}^2(t_{ij}) - \sigma_{k,H=1}^2(t_{ij})$ (η_4)		0.00188**
		(0.001)
Constant (η_0)	-0.0839**	-0.0281
	(0.031)	(0.015)
Observations	6162	24047
Pseudo R^2	0.115	0.065

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 4. Estimation Results of Transportation time (t_{ij})

Dependent var. t_{ij}	No time designation	Time designation
$\delta^t \hat{t}_{ij}^N + t^s - \delta^t t^s$	1.132***	1.060***
(κ_1)	(0.044)	(0.025)
$(1-\delta^t)\left(\hat{t}_{ij}^N - t_s\right)$	3.936***	2.277***
(κ_3)	(0.213)	(0.077)
$\delta^{\bar{q}}$	-0.521	-0.714***
(κ_4)	(0.268)	(0.135)
$\delta^{\bar{q}} \hat{t}_{ij}^N$	0.366***	0.106***
(κ_5)	(0.052)	(0.028)
$\sigma_k^2(t_{ij})$		0.0382***
(κ_6)		(0.002)
Tokyo Osaka dummy	1.010***	0.200*
	(0.205)	(0.101)
Hokkaido dummy	-0.622	-1.125***
	(0.559)	(0.290)
AFP dummy	-1.319***	-2.377***
(D_1)	(0.354)	(0.213)
FP dummy	-0.760	1.688
(D_2)	(0.652)	(1.348)
MP dummy	-1.612**	-2.425***
(D_3)	(0.620)	(0.404)
CH dummy	-0.497**	-0.999***
(D_5)	(0.185)	(0.099)
LI dummy	-1.090***	-1.187***
(D_6)	(0.306)	(0.103)
MMA dummy	0.0430	1.228***
(D_7)	(0.341)	(0.137)
SG dummy	-1.646**	-1.912***
(D_8)	(0.572)	(0.184)
Constant	1.880***	2.378***
(κ_0)	(0.254)	(0.089)
Observations	6162	24047
R^2	0.410	0.447
Adjusted R^2	0.409	0.446

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: δ^q is a dummy variable taking $\delta^q = 1$ the cargo is heavier than $\bar{q}$ and $\delta^q = 0$ otherwise. δ^t is a dummy variable taking $\delta^t = 1$ if $\hat{t}_{ij}^N$ is shorter than T^s and $\delta^t = 0$ otherwise.
We pick $(T^s = 12, \bar{q} = 1)$ and $(T^s = 1\bar{0}, \bar{q} = 6)$ for the estimation result in the case of No time-designated delivery and Time-designated delivery, respectively.

Table 5. Estimation Results of Freight Charge (P_{ij})

Dependent var. P_{ij}	No time designation	Time designation
$\hat{t}_{ij}$	-4587.5***	-1076.9**
(β_1)	(1152.799)	(397.650)
$\ln\left(q\hat{t}_{ij}\right)$	5874.3***	7356.6***
(β_2)	(1059.096)	(320.957)
$r_i^x d_{ij} e(q.s^0)\left(1-\theta\hat{H}\right)+r^H(q,d_{ij})\hat{H}$	4.118***	2.376***
(β_3)	(0.544)	(0.123)
$(\hat{t}_{ij}-\hat{t}_{ij}^N)^2$	93.61	28.54**
(β_4)	(63.821)	(9.548)
$\sigma_k^2(t_{ij})$		72.81*
(β_5)		(30.782)
Z_1	-5835.0	5520.4***
(γ_1)	(4641.487)	(1109.373)
Z_2	-324.0	-178.3
(γ_2)	(359.769)	(100.664)
Z_3	-15.46	-278.7
(γ_3)	(69.426)	(167.354)
Z_4	-2938.3	6512.7*
(γ_4)	(14188.118)	(3191.171)
Tokyo Osaka dummy	-2690.8	7072.2***
	(4351.320)	(1116.525)
Hokkaido dummy	-11861.4	-2203.0
	(11641.611)	(3260.891)
AFP dummy	-4286.6	-13966.2***
(DP_1)	(7460.995)	(2504.802)
FP dummy	-15288.2	-11871.1
(DP_2)	(13156.736)	(14384.194)
MP dummy	-17956.0	-27347.8***
(DP_3)	(12602.748)	(4482.945)
CH dummy	2773.0	-15493.1***
(DP_5)	(3759.294)	(1138.846)
LI dummy	-5933.6	-10469.2***
(DP_6)	(6414.522)	(1239.557)
MMA dummy	9899.3	-8048.0***
(DP_7)	(6853.963)	(1553.926)
SG dummy	2068.8	-18522.0***
(DP_8)	(11690.520)	(2130.867)
Constant	27631.4*	14955.4***
β_0	(11817.740)	(3233.320)
Observations	6162	24024
R^2	0.060	0.209
Adjusted R^2	0.057	0.209

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6. Transportation time and freight charge with and without time designation

q	d	Transport time			Freight Charge		
(km)	(ton)	*Time designation*	*No time designation*	*Difference*	*Time designation*	*No time designation*	*Difference*
0.10	20.00	3.07	2.61	0.46	4136.17	9419.28	-5283.11
0.10	40.00	3.56	3.11	0.46	5712.25	9418.68	-3706.44
0.10	70.00	4.39	3.61	0.78	8952.57	11859.14	-2906.57
0.10	140.00	6.39	4.87	1.53	14932.43	13773.48	1158.94
0.10	360.00	10.69	8.67	2.02	26990.14	18623.33	8366.81
1.00	20.00	3.07	2.61	0.46	21337.79	23427.04	-2089.25
1.00	40.00	3.56	3.11	0.46	23175.09	23907.49	-732.40
1.00	70.00	4.39	3.61	0.78	26753.35	26894.56	-141.21
1.00	140.00	6.39	4.87	1.53	33576.91	30309.23	3267.69
1.00	360.00	10.67	8.66	2.02	48192.94	39707.55	8485.40
2.00	20.00	3.07	2.33	0.74	26779.00	28584.88	-1805.89
2.00	40.00	3.56	2.98	0.58	28959.94	29376.66	-416.72
2.00	70.00	4.39	3.65	0.74	33128.56	33053.61	74.95
2.00	140.00	6.40	5.31	1.08	41196.42	37359.04	3837.37
2.00	360.00	10.69	10.34	0.34	59615.93	49046.22	10569.70
5.00	20.00	3.07	2.33	0.74	33890.64	34485.99	-595.35
5.00	40.00	3.56	2.98	0.58	36446.49	35797.53	648.96
5.00	70.00	4.39	3.66	0.74	41423.97	41055.68	368.28
5.00	140.00	6.40	5.32	1.08	50989.37	47798.28	3191.09
5.00	360.00	10.74	10.41	0.33	73983.80	67011.83	6971.97
10.00	20.00	2.42	2.33	0.09	38262.47	39287.62	-1025.15
10.00	40.00	2.96	2.98	-0.02	41548.18	41328.88	219.30
10.00	70.00	3.84	3.66	0.19	47357.32	47421.87	-64.55
10.00	140.00	5.96	5.32	0.64	58549.93	56459.04	2090.90
10.00	360.00	10.63	10.38	0.25	85635.27	82691.54	2943.73

Appendix 1. Classification and Commodity

Classification	Commodity
Agricultural & Fishery Products ($AFP\ dummy$)	Wheat
	Rice
	Miscellaneous grains ・ Beans
	Fruits & Vegetables
	Wool
	Other livestock products
	Fishery products
	Cotton
	Other agricultural products
Forest Products ($FP\ dummy$)	Raw wood
	Lumber
	Firewood and charcoal
	Resin
	Other forest products
Mineral Products ($MP\ dummy$)	Coal
	Iron ores
	Other metallic ore
	Gravel, Sand, Stone
	Limestone
	Crude petroleum and natural gas
	Rock phosphate
	Industrial salt
	Other non-metallic mineral
Chemical Products ($CH\ dummy$)	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

Appendix 1. Classification and Commodity (Continued)

Classification	Commodity
Chemical Products ($CH\ dummy$)	Other chemical products
Light Industrial Products ($LI\ dummy$)	Pulp
	Paper
	Spun yarn
	Woven fabrics
	Sugar
	Other food preparation
	Beverages
Metal & Machinery Products ($MM\ dummy$), $Baseline$	Iron and steel
	Non-ferrous metals
	Fabricated metals products
	Industry machinery products
	Other transportation equipment
	Precision instruments products
	Other machinery products
Miscellaneous Manufacturing ($MMA\ dummy$)	Book, printed matter and record
	Toys
	Apparel and apparel accessories
	Stationery, sporting goods and indoor games
	Furniture accessory
	Other daily necessities
	Wood products
	Rubber products
	Other miscellaneous articles
Industrial Wastes & Recycle Products ($EP\ dummy$)	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
Specialty Products ($SG\ dummy$)	Feed and manure Containing animal and vegetable waste
	Transportation container made of metal
	Other transportation container
	Mixture

Appendix 2. Distribution of transportation distance (d) and shipment size (q)

	No time designation		**Time designation**	
Statistics	*d*	*q*	*d*	*q*
Mean	138.6	4.357	138.4	3.831
Variance	29734.2	19.35	28800.4	16.102
Standard Deviation	172.4	4.399	185.5	4.013
p10	13.0	0.100	16.0	0.100
p30	34.0	1.000	38.0	0.974
p50	65.0	2.530	71.0	2.184
p70	141.0	6.000	142.0	5.000
p90	387.0	11.650	362.0	10.342

Appendix 3-1. Descriptive Statistics (No time designation)

	Obs.	Mean	Median	S.D.	Min.	Max.
P	8692	31519.81	16000.00	109406.20	100.00	4174000.00
t	13046	5.20	3.00	8.14	1.00	110.00
H	12158	0.36	0.00	0.48	0.00	1.00
t^N	11695	2.81	1.63	3.12	0.01	27.77
$\sigma_k^2(t_{ij})$	13046	19.66	7.23	31.64	0.12	373.95
q	13046	4.36	2.53	4.40	0.00	16.00
d_{ij}	13046	138.57	65.00	172.44	2.00	1241.00
$e(q, s^0)$	13046	5.58	4.58	2.58	2.62	9.32
r_i^H	12527	4613.77	2297.47	5522.57	142.04	40929.59
r_i^x	13046	110.69	110.60	4.15	103.00	123.60
$Border\ dummy$ $(Z1)$	13046	0.68	1.00	0.47	0.00	1.00
Q_i/num_trucks $(Z2)$	13046	11.04	10.08	4.81	3.17	34.34
imb $(Z3)$	13046	1.78	1.00	15.52	0.02	718.90
$num\ truck\ firms_i$ $(Z4)$	13046	0.47	0.43	0.13	0.22	0.96
$Tokyo\ Osaka\ dummy$	13046	0.14	0.00	0.35	0.00	1.00
$Hokkaido\ dummy$	13046	0.03	0.00	0.16	0.00	1.00
$AFP\ dummy$	13046	0.06	0.00	0.24	0.00	1.00
$FP\ dummy$	13046	0.01	0.00	0.11	0.00	1.00
$MP\ dummy$	13046	0.05	0.00	0.22	0.00	1.00
$MM\ dummy$	13046	0.29	0.00	0.45	0.00	1.00
$CH\ dummy$	13046	0.35	0.00	0.48	0.00	1.00
$LI\ dummy$	13046	0.08	0.00	0.28	0.00	1.00
$MMA\ dummy$	13046	0.05	0.00	0.22	0.00	1.00
$SG\ dummy$	13046	0.04	0.00	0.20	0.00	1.00

Appendix 3-2. Descriptive Statistics (Time designation)

	Obs.	Mean	Median	S.D.	Min.	Max.
P	32602	38542.32	24000.00	61615.11	100.00	2160000.00
t	44567	5.56	3.00	7.45	1.00	117.00
H	42362	0.46	0.00	0.50	0.00	1.00
t^N	41053	2.69	1.67	2.88	0.09	32.87
$\sigma_k^2(t_{ij})$	44567	20.34	10.56	33.58	0.12	562.21
q	44567	3.83	2.18	4.01	0.00	16.00
d_{ij}	44567	138.44	71.00	169.71	1.00	1537.00
$e(q, s^0)$	44567	5.78	4.58	2.55	2.62	9.32
r_i^H	43191	4765.67	2347.15	5783.61	142.04	53379.91
r_i^x	44567	110.55	110.60	3.91	103.00	123.60
$Border\ dummy$ $(Z1)$	44567	0.67	1.00	0.47	0.00	1.00
Q_i/num_trucks $(Z2)$	44567	11.23	10.61	4.36	3.17	34.34
imb $(Z3)$	44567	1.39	1.00	2.05	0.02	210.30
$num\ truck\ firms_i$ $(Z4)$	44567	0.46	0.43	0.13	0.22	0.96
$Tokyo\ Osaka\ dummy$	44567	0.15	0.00	0.35	0.00	1.00
$Hokkaido\ dummy$	44567	0.02	0.00	0.12	0.00	1.00
$AFP\ dummy$	44567	0.05	0.00	0.21	0.00	1.00
$FP\ dummy$	44567	0.00	0.00	0.04	0.00	1.00
$MP\ dummy$	44567	0.01	0.00	0.08	0.00	1.00
$MM\ dummy$	44567	0.42	0.00	0.49	0.00	1.00
$CH\ dummy$	44567	0.20	0.00	0.40	0.00	1.00
$LI\ dummy$	44567	0.18	0.00	0.39	0.00	1.00
$MMA\ dummy$	44567	0.09	0.00	0.28	0.00	1.00
$SG\ dummy$	44567	0.05	0.00	0.21	0.00	1.00

Appendix 4-1. Estimation Results of Expressway Choice (H) on designated date delivery and designated the morning or afternoon delivery

Dependent var. H	Time designation (day)	Time designation (AM/PM)
$t_{ij}^{N0} - t_{ij}^{N1}$ (η_1)	0.275***	0.202***
	(0.011)	(0.011)
$r_i^X e\left(q, s^0\right)\left(d_{ij}^0 - d_{ij}(1-\theta)\right) - r^H\left(q, d_{ij}^1\right)$ (η_2)	-0.00000692	0.0000119**
	(0.000)	(0.000)
$d50\_dummy$ (η_3)	-0.622***	-0.696***
	(0.035)	(0.036)
$\sigma_{k,H=0}^2(t_{ij}) - \sigma_{k,H=1}^2(t_{ij})$ (η_4)	-0.000476	0.000915
	(0.001)	(0.001)
Constant (η_0)	-0.442***	-0.0930***
	(0.021)	(0.023)
Observations	14438	11295
Pseudo R^2	0.146	0.105

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix 4-2. Estimation Results of Transportation time (t_{ij}) on designated date delivery and designated the morning or afternoon delivery

	Time designation (day)	Time designation (AM/PM)
$\delta^t \hat{t}_{ij}^N + t^s - \delta^t t^s$	1.498***	1.375***
(κ_1)	(0.037)	(0.032)
$(1-\delta^t)\left(\hat{t}_{ij}^N - t_s\right)$	2.784***	2.171***
(κ_3)	(0.120)	(0.108)
$\delta^{\bar{q}}$	-0.582*	-1.147***
(κ_4)	(0.250)	(0.216)
$\delta^{\bar{q}} \hat{t}_{ij}^N$	-0.231***	0.000483
(κ_5)	(0.049)	(0.040)
$\sigma_k^2(t_{ij})$	0.0233***	0.0173***
(κ_6)	(0.003)	(0.002)
Tokyo Osaka dummy	0.306*	-0.305*
	(0.153)	(0.138)
Hokkaido dummy	-1.660*	-2.004***
	(0.672)	(0.457)
AFP dummy	-3.483***	0.708*
(D_1)	(0.251)	(0.295)
FP dummy	-2.058	-1.319
(D_2)	(1.122)	(1.021)
MP dummy	-1.828***	-1.303**
(D_3)	(0.534)	(0.505)
CH dummy	-0.475**	1.027***
(D_5)	(0.146)	(0.143)
LI dummy	-0.640**	0.691***
(D_6)	(0.196)	(0.160)
MMA dummy	-0.606**	-0.132
(D_7)	(0.189)	(0.188)
SG dummy	-2.119***	-1.333***
(D_8)	(0.344)	(0.292)
Constant	2.548***	1.898***
(κ_0)	(0.145)	(0.140)
Observations	14438	11295
R^2	0.392	0.466
Adjusted R^2	0.391	0.465

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Note: δ^q is a dummy variable taking $\delta^q = 1$ the cargo is heavier than $\bar{q}$ and $\delta^q = 0$ otherwise. δ^t is a dummy variable taking $\delta^t = 1$ if $\hat{t}_{ij}^N$ is shorter than T^s and $\delta^t = 0$ otherwise.
We pick ($T^s = 10, \bar{q} = 8$) and ($T^s = \bar{1}1, \bar{q} =$) for the estimation result in the case of No time-designated delivery and Time-designated delivery, respectively.

Appendix 4-3. Estimation Results of Freight Charge (P_{ij}) on designated date delivery and designated the morning or afternoon delivery

Dependent var. P_{ij}	Time designation (day)	Time designation (AM/PM)
$\hat{t}_{ij}$	-2432.7***	-1408.0***
(β_1)	(236.801)	(257.819)
$\ln\left(q\hat{t}_{ij}\right)$	5171.2***	5567.1***
(β_2)	(255.514)	(299.680)
$r_i^x d_{ij} e(q.s^0)\left(1-\theta\hat{H}\right)+r^H(q,d_{ij})\hat{H}$	2.497***	2.445***
(β_3)	(0.091)	(0.099)
$(\hat{t}_{ij}-\hat{t}_{ij}^N)^2$	31.57***	19.19*
(β_4)	(8.706)	(9.384)
$\sigma_k^2(t_{ij})$	148.9***	27.28
(β_5)	(25.263)	(19.949)
Z_1	-3087.2*	-1890.2
(γ_1)	(1219.170)	(1215.656)
Z_2	106.1	-65.32
(γ_2)	(109.728)	(100.184)
Z_3	88.53	247.2
(γ_3)	(50.330)	(155.923)
Z_4	3215.1	-5645.9
(γ_4)	(3261.672)	(3655.070)
Tokyo Osaka dummy	-5447.6***	-831.3
	(1147.019)	(1060.732)
Hokkaido dummy	11537.1*	-1850.8
	(5048.700)	(3510.887)
AFP dummy	-8950.7***	-4802.7*
(DP_1)	(2115.595)	(2192.767)
FP dummy	-19131.4*	1030.6
(DP_2)	(8202.800)	(7571.224)
MP dummy	-21349.0***	-11972.8**
(DP_3)	(3913.467)	(3728.362)
CH dummy	-5467.7***	-6090.6***
(DP_5)	(1086.195)	(1104.202)
LI dummy	4860.2***	1196.3
(DP_6)	(1470.359)	(1195.343)
MMA dummy	257.9	-762.4
(DP_7)	(1437.960)	(1392.689)
SG dummy	1982.9	-4147.7
(DP_8)	(2576.832)	(2200.872)
Constant	18805.1***	19572.2***
(β_0)	(3211.205)	(2974.403)
Observations	14424	11292
R^2	0.261	0.330
Adjusted R^2	0.260	0.329

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$