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Abstract
This paper presents an alternative approach to measuring the values of transport time for freight transportation, and examines its applicability through empirical analysis. We develop a model of the freight transportation market, in which carriers incur the cost associated with the effort to reduce transport time, and transport time is endogenously determined in the market. We estimate the freight charge function, expressway choice model, and transport time function, using microdata of freight flow in Japan collected by the Ministry of Land, Infrastructure, Transport and Tourism. Based on the estimated freight charge function, we obtain the values of transport time for shippers as an implicit price in the hedonic theory. The estimated values of transport time for shippers are larger than those obtained by the widely adopted method based on the discrete choice model. We also develop a method to evaluate the benefit of time-saving technological change (including infrastructure improvement) based on the hedonic approach. Application to the evaluation of expressway construction suggests that the benefits calculated by our method tend to be larger than those based on the other methods.

Keywords: Value of time, Transportation service, Micro-shipments data, Evaluation of expressway
JEL classification: D24, L91, R41

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1. Introduction

Transport 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 transport time through increase in speed. Reduction of transport 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 transport time are evaluated in monetary unit, by using the value of transport time saving (VTTS) to convert saving of a unit transport time (e.g., one hour) into monetary value. It is reported in many cost-benefit analyses for transportation project that the saving of time cost constitutes the largest portion of the benefit.

This paper presents an approach to measuring the values of time cost for freight transportation, and examines its applicability through empirical analysis.

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 transport. Unlike the case of passenger transport where the decision makers are the passengers themselves, a large number of players are involved in shipping goods. Furthermore freight transport 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.

According to Zamparini and Reggiani (2007), there are two methods to measure the value

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

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 transport alternatives (1 and 0) conditional on transport-related attributes such as transport cost and transportation time and estimates the VTTS as the marginal rate of substitution between transport time and transport 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.

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 transport time that is equal to the derivative of freight charge with respect to transport time. Using interview data collected in France, he estimates hedonic price equation of freight charge including weight, transport time and speed as explanatory variables, then calculate the value of time.

We further develop the method based on the hedonic approach by explicitly formulating how transport time is determined as market outcome. In the model, the freight charge, the price of transportation services, is determined through interaction in the transport market, where shippers demand and carriers supply transport 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 transport time, such as express delivery fee in postal service. Output of transport service is a bundle of multiple attributes such as quantity, distance, and transport time, thereby freight charge is also a function of multiple attributes. Our model distinguish between the transport technology and firm's effort for reducing transport time: the former is exogenous for firms, and for the market. This formulation has a merit that the effects of technological change (including infrastructure

[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 .

improvement) are more rigorously evaluated: equilibrium transport time under new technology is determined in the market where transport firms choose the level of effort in response to technological change. We estimate the parameters of freight charge function, using microdata from the 2005 Net Freight Flow Census (NFFC) collected by the Ministry of Land, Infrastructure, Transport and Tourism, in which information on freight charge, weight, origin and destination, and transport time for individual shipment are obtained. Based on the estimated freight charge function, we obtain the values of transport time for shippers (VTTS) as implicit price in the hedonic theory. We further present a method to evaluate the welfare effect of time-saving technological change based on the hedonic approach[3]. The method is applied to evaluation of expressway construction. Then we compare the results with those obtained by the existing method.

Let us briefly look at the facts about freight transport 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 transport 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 transport time against distance. It is easily seen that transport times are quite different among shipments for given distance. Our hypothesis is that variation of transport times may be explained by differences in carriers' effort to meet various needs of shippers on transport 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

[3] Massiani argues that hedonic approach is useful only for estimation of marginal effect, so does not deal with the benefit evaluation.

We extend the model in Konishi, Mun, Nishiyama and Sung (2012) by incorporating the following features: (i) shippers' preference to shorter transport time; (ii) the effort of trucking firm to reduce transport time; (iii) equilibrium transport time in implicit market based on hedonic approach (Rosen (1974)). This section presents the cost function of trucking firm, followed by behavior of a shipper and market equilibrium.

2.1 Cost of a trucking firm and choice of transport time

We focus on the transport service by chartered truck that a transport firm uses a single truck exclusively to transport the goods ordered by a single shipper. Basic inputs for producing transport service are capital (trucks), labor (drivers), fuel, expressway service. We assume that firm can reduce transport 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

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

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 transport 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 transport 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

[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.

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 $r_{ij}^{H} = r^{H}(q_{ij}, d_{ij})$. The amount of effort is written as $Y_{ij} = yt_{ij}$, where y is the effort level per unit transport time. This formulation implies that the amount of effort is the sum of efforts at each moment of time 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 transport 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 transport 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 depends on the transport technology and the levels of inputs, y and H[6].

Incorporating the above assumptions into (2.1), we have

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

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

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[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.

[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.

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 transport 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,

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

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 transport 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 transport time is

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

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 transport time in equilibrium satisfy the following conditions.

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

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

2.2 Shippers and market equilibrium

Each shipper seeks to minimize the transport 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 transport 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 transport cost, τ. The bid function $\psi(q, d_{ij}, t_{ij}; \tau)$ is defined as

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

Equilibrium is characterized as follows

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

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

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

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

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

In the empirical analysis, we estimate the freight charge function $P_{ij}(q, d_{ij}, t_{ij})$, whereby its derivative gives the value of travel time v. Note that (2.12b) requires $\frac{\partial P_{ij}(q, d_{ij}, t_{ij})}{\partial t_{ij}} < 0$ at t_{ij} in equilibrium.

2.3 Evaluating the benefit of time-saving technological change

This subsection presents a method to evaluate the benefit of transport technology development that decreases the transport time. Infrastructure improvement is also considered as a development of transport technology. Recall that transport technology is represented as

t_{ij}^{N} in (2.2). Let us consider the effect of the change from $t_{ij}^{N(A)}$ to $t_{ij}^{N(B)}$, where $t_{ij}^{N(B)} < t_{ij}^{N(A)}$. This causes shift of the carriers cost function from $C_{ij}^{A}(q, d_{ij}, t_{ij})$ to $C_{ij}^{B}(q, d_{ij}, t_{ij})$, whereby the offer function shifts from $\phi^{A}(q, d_{ij}, t_{ij}; \bar{\pi})$ to $\phi^{B}(q, d_{ij}, t_{ij}; \bar{\pi})$, as shown in Figure 3. Observe that the offer curve shifts downward by change from $t_{ij}^{N(A)}$ to $t_{ij}^{N(B)}$, since less effort is required to transport the cargo for the given hours of transport time. We assume that the value of time *v* is not affected by changes in transport technology: *v* is determined by shippers' preference. So the equilibrium transport time for the cases of $t_{ij}^{N(A)}$ and $t_{ij}^{N(B)}$ are determined by t_{ij}^{A} and t_{ij}^{B}, respectively. Note that carrier's profit is unchanged with technological change. Thus total economic benefit caused by the change described above is measured by reduction of shippers cost from τ^{A} to τ^{B}.

< Insert Figure 3 here>

3. Econometric Model

3.1 Model specification

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*, $g(q) = \alpha_1 + \alpha_2 q$. 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 $y^* = \alpha_3 + \alpha_4 \frac{t_{ij}^{N}}{t_{ij}^{2}}$, 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

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

$\gamma' Z$ 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:

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

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.

Transport 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, transport distance and carried commodity type on transport time. Transport time function is specified as follows,

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

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

where t_{ij}^N is the shortest driving time as (2.2) and $\delta^{\bar{q}}$ is a dummy variable to describe the effect of shipment size taking $\delta^{\bar{q}} = 1$ if the cargo is heavier than $\overline{q}$ 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[7]. Therefore we use eight commodity-specific dummy variables, i.e. $AFPdummy\,(D_1)$, $FPdummy\,(D_2)$, $MPdummy\,(D_3)$, $SGdummy\,(D_4)$, $CHdummy\,(D_5)$, $LIdummy\,(D_6)$, $MMAdummy\,(D_7)$, $EPdummy\,(D_8)$. We take Metal & Machinery Products as the base line. $AFPdummy$ is dummy variable taking $AFPdummy = 1$ when the classification of carried commodity is Agricultural and Fishery Products and $AFPdummy = 0$ otherwise. Similarly, $FPdummy$, $MPdummy$, $SGdummy$, $CHdummy$, $LIdummy$, $MMAdummy$ and $EPdummy$ are dummy variables standing for Forest Products, Mineral Products, Specialty Products, Chemical Products, Light Industrial Products, Miscellaneous Manufacturing, and Industrial Wastes and Recycle Products, respectively. $\kappa_0, \kappa_1, \kappa_2, \kappa_3, \kappa_4, \kappa_5$ are unknown parameters.

We assume that slope with respect to t_{ij}^N is not constant: the slope for long distance trip (κ_3) is different from that for short distance trip (κ_1). t^S is threshold value of driving time. Transport time function should be continuous at $t_{ij}^N = t^S$, whereby the following relation is satisfied.

$$\kappa_2 = \kappa_0 + (\kappa_1 - \kappa_3)t^S \tag{3.2c}$$

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

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

where,

$$\delta^t = 1 \qquad \text{if} \quad t_{ij}^N < t^S$$
$$\delta^t = 0 \qquad \text{if} \quad t_{ij}^N > t^S$$

In the equation, $\delta^{\bar{q}}$ can be both the constant and slope dummy variables for the weight of cargo, respectively. We suppose $\kappa_4 > 0$ and $\kappa_5 > 0$. $\kappa_4 > 0$ means that loading and

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

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.

3.2 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 transport 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 transport time function is estimated as,

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

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

$$P_{ij}(q,d_{ij},t_{ij}) = \beta_1\hat{t}_{ij} + \beta_2 q\hat{t}_{ij} + \beta_3\left[r_i^X d_{ij} e\left(q,s^0\right)\left(1-\theta\hat{H}\right) + r^H(q,d_{ij})\hat{H}\right] + \beta_4\frac{\hat{t}_{ij}^N}{\hat{t}_{ij}} + \sum_{k=1}^{4}\gamma_k Z_k + \varepsilon_P \tag{3.7}$$

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

4. Empirical Results

4.1 Data Description

In the previous section, we show the estimation model in eq. (3.1);

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

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

$$\{t_{ij},\ qt_{ij},\ \left[r_i^X e\left(q,s^0\right) d_{ij}\left(1-\theta H\right) + r^H(q,d_{ij})H\right], \frac{t_{ij}^N}{t_{ij}}, Z\}$$

Z includes other explanatory variables, that can affect the price. Specifically, we use $Border\text{-}dummy\ (Z_1)$, $Q_i/trucks\ (Z_2)$, $imb\ (Z_3)$ and $num\text{-}truck\text{-}firms\ (Z_4)$. Table 1 provides the data definitions and sources to construct them.

< Insert Table 1 here>

We use the microdata from the NFFC conducted by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT hereafter) 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 2005 census uses 16,698 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 produces a total sample size of over 1,100,000 shipments, each of which has information on the origin and the destination, freight charge(Yen), P_{ij}, shipment size (ton), q, transport time (hours),

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}, 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 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 shortest driving times between 2,052 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 7.11 and 5 hours respectively. On the other hand, t_{ij}^N's mean and median are 4.34 and 3.08 hours. 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 0.935 and 0.879, respectively. In variance level, t_{ij} is more diverse than t_{ij}^N. The fuel cost r_i^X is average diesel oil price in October 2005 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)

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

We refer to Ministry of Economy, Trade and Industry's specification to get the fuel efficiency of truck for hire[8]. 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.

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

Toll per km is 24.6 yen/ km for truck size(q) smaller than 2ton. 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 use the electronic toll collection system (ETC) by 16%, thereby 0.84 is multiplied. We also reflect 5% consumption tax, thereby 1.05 is multiplied.

MLIT estimates the aggregated trade volume between prefectures based on shipments data from NFFC and publishes it via website[9], and we use these data for Q_i , Q_{ji} and Q_{ij} to construct the variables, $Q_i/trucks$ (Z_2) and imb (Z_3). We composed $num\text{-}truck\text{-}firms$ (Z_4) variable as 1000 times the number of trucking firms per capita of prefecture of origin i.

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

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,

8 http://www.enecho.meti.go.jp/ninushi/pdf/060327c-14.pdf
9 http://www.mlit.go.jp/seisakutokatsu/census/census-top.html

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; [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] Since we focus on the transport service by chartered truck, we keep the observations of which main transportation mode is chartered truck ; [5] We removed the shipments that origin and destination are in the same prefecture to focus on inter-regional freight transportation. [6] We removed observations without data of freight charge P_{ij}.

Finally we have the target dataset with 76,663 shipments.

4.2 Estimation Results

We estimate the econometric model of (3.4), (3.6) and (3.7) in the previous section, Table 3, 4 and 5 show the results, respectively. Note that carrier's cost could be different depending on whether the shipper designate the delivered time or not. So we classify the data into two groups: time designated delivery and no time designated delivery. and then estimate the same model separately.

4.2.1 Expressway choice model

The estimation results for probit models of expressway choice in (3.4) are shown in Table 3. 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., $\eta_1 = 0.1441$ and 0.1384, 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 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.

Using estimation results, we calculate the VTTS by the willingness to pay method, the marginal rate of substitution between transportation time and monetary cost, namely $\frac{\eta_1}{\eta_2}$. The VTTS for using expressway is 2,606Yen and 1,972Yen per hour, in the case of time designated delivery and the case of no time designated delivery. Kawamura (2000) obtained the estimates of mean VTTS as $23.4/hour for choice of express lane on the freeway in US, which is similar to our estimates above. He didn't find significant differences for the effect of shipment size on VTTS. We examine the case of including $q(t_{ij}^{N0} - t_{ij}^{N1})$ as an explanatory variable, but we didn't obtained expected results in (3.4), so we suppress the results here. However, as shown later, we found the strong effect of shipment size on VTTS based on the estimates of freight charge by (3.7).

The VTTS for using expressway in the case of time designated delivery is higher than no time designated delivery, which is related to the delivery time reliability. Delivery time guarantees is the important factor representing the quality of trucking firm's service, especially for time designated delivery, and it is expected to be improved it by using expressway.

The coefficients η_0 of the constant term are significantly negative. 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 Transport time function

Table 4 shows the estimation results of transport time function in (3.6). We estimate the model for different values of $\overline{q}$ (i.e., $3, 4, 6, 8, 10$) to construct the dummy variable $\delta^{\overline{q}}$. Regardless of the value of $\overline{q}$, the estimation results of all coefficients are qualitatively similar. We chose $\overline{q}=3$ for no time designated delivery and $\overline{q}=4$ for designated delivery, according to the criterion of maximizing $\overline{R}^2$. We set $t^S=13$, which is chosen by the same method as the value of $\overline{q}$.

< 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 (1.2149) is larger than that for the no time designation (0.9995). 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 transport 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 3.1981 for the time designated delivery and 2.1146 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[10]. 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, estimates of κ_4 are 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.

In order to examine the commodity-specific effects on the transport time, we use eight dummy variables for classification of carried commodities and their interaction term with the driving time. Metal & Machinery Products is taken as the base line. The coefficients of dummy variable for Specialty Products are significant negative. The slope and constant for Specialty Products are -1.1988 for the time designated delivery and -1.2713 for no time designated delivery, which are significant. The estimates of dummy variable for

[10] 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.

Miscellaneous Manufacturing are significant positive. The total effect for Miscellaneous Manufacturing are 0.7363 for the time designated delivery and 2.2816 for no time designated delivery.

4.2.3 Freight charge function

The results for estimation of (3.7) are shown in Table 5. We also estimate the model without including other factors Z which are given in Columns 2 and 4. 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.

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< 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 transport cost. The former has a positive effect and the latter has the negative effect on the freight charge P. We obtained the estimate of -2086.68 for time designated delivery in Model 2 and -2575.76 for no time designated delivery in Model 4, 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 $\frac{\hat{t}_{ij}^{N}}{\hat{t}_{ij}}$, is also significantly positive as expected in both cases. As $\hat{t}_{ij}$ is getting closer to $\hat{t}_{ij}^{N}$, more effort of the trucking firms is required. The development of transport technology reduces t_{ij}^{N}, thereby less effort is required.

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 $Q_i / trucks$ and $num - truck - firms$ as proxies of competition in the truck transportation market. The coefficient of $Q_i / trucks$ is negative and significant in the case of time designated delivery, but in the case of no time designated delivery the coefficients are positive and not significant.

4.3 Values of transport time

As shown by (2.12b), shippers' value of time is obtained by the derivative of freight charge function with respect to transport time. Under our specification, we have

$$v = -\frac{\partial P_{ij}\,(q, d_{ij}, t_{ij})}{\partial t_{ij}} = -\beta_1 - \beta_2 q + \beta_4 \frac{t_{ij}^N}{t_{ij}^{\ 2}} \qquad (4.1)$$

We computed the values of *v* for various combinations of shipment size and distance, as follows. For given d_{ij}, t_{ij}^{N0} and t_{ij}^{N1} are computed by the following formulas, which are obtained by regression of t_{ij}^{N0} and t_{ij}^{N1} on d_{ij}.

$$t_{ij}^{N0} = 0.401 + 0.0215 d_{ij}$$

$$t_{ij}^{N1} = 0.4813 + 0.0119 d_{ij}$$

These values are substituted to (3.5) and (3.6) to obtain t_{ij} in (4.1). The results are shown in Table 6 and Table 7.

< Insert Table 6 here>

< Insert Table 7 here>

The values of *v* range between -4,093Yen/hour and 2,851 Yen/hour. Negative values for *v* are obtained when $\frac{\partial P_{ij}(q, d_{ij}, t_{ij})}{\partial t_{ij}} > 0$. In this case, calculated values of *v* should not be considered as the values of transport time. This situation is described in Appendix 2.

Around the sample mean (*d* = 200, *q* = 4), the value is 1,232Yen/hour (for time designated delivery) and 1,966 Yen/hour (without time designation). These values are smaller than $\frac{\eta_1}{\eta_2}$

(2,606Yen and 1,972Yen) obtained by the willingness to pay method based on discrete choice model of expressway use in 4.2.2. We observe that the value of *v* is larger as transport distance d_{ij} is shorter, or as shipment size *q* is smaller. A decrease in transport time saves the labor cost and capital cost (a part of β_1 and $\beta_2 q$ in (4.1) above), but requires more effort of the carrier (third term). The former effect reduces the level of freight charge, thus would negatively affect the value of time. The latter effect associated with the effort works in opposite direction. Shipment size *q* is related to the capital cost. Thus increase in *q* enhances the former effect, thereby induces lower values of *v*. As for the effect of distance *d*, transporting longer distance requires more time if the same level of effort is made. So the third term of (4.1) $\beta_4 \frac{t_{ij}^N}{t_{ij}^2}$ decreases with distance. Interpretation is that the level of effort to reduce one hour of transport time is smaller for longer distance trip: it is harder to reduce one hour for a trip with 5 hours (20% reduction) than for a trip with 20 hours (5% reduction).

4.4 Benefit of expressway construction

We apply the model to evaluation of the benefit from time saving by expressway construction. We compare two cases, with and without expressway, where the former is taken as the benchmark[11]. Consider the benchmark case that expressway is available on the route connecting regions i and j, where distance between them is d_{ij}. Carriers can choose whether to use expressway or not[12]. So we compute $\hat{H}$, t_{ij}^N by (3.4), (3.5), to obtain t_{ij}^B by (3.6) which correspond to the situation of Point B in Figure 3. Then we obtain the freight charge $P_{ij}(q, d_{ij}, t_{ij}^B)$ by (3.7) and the value of time *v* by (4.1), which correspond to the situation of Point B in Figure 3. On the other hand, if no expressway route is available between regions i and j, carriers have no choice but using ordinary roads, thus $\hat{H} = 0$, $t_{ij}^N = t_{ij}^{N0}$ are applied to (3.7) to obtain the cost function $C_{ij}^A(q, d_{ij}, t_{ij})$ for the case without expressway. Equilibrium transport time in this case, t_{ij}^A (Point A in Figure 3) is obtained by solving

[11] Thus it might be more appropriate to say that we evaluate the effect of removing expressways on freight transportation market.

[12] Note that carriers may not use expressway even if it is available.

$\frac{\partial C_{ij}^{A}(q,d_{ij},t_{ij})}{\partial t_{ij}} = -v$ for t_{ij}. By putting this t_{ij}^{A} to $C_{ij}^{A}(q,d_{ij},t_{ij})$, we have $P_{ij}(q,d_{ij},t_{ij}^{A})$.

Shipper's benefit of expressway construction is calculated by

$$\tau^{A} - \tau^{B} = P_{ij}(q,d_{ij},t_{ij}^{A}) - P_{ij}(q,d_{ij},t_{ij}^{B}) + v(t_{ij}^{A} - t_{ij}^{B})$$

Note that use of expressway involves toll payment, which is included in the cost incurred by carrier $C_{ij}^{B}(q,d_{ij},t_{ij})$. For the economy as a whole, this payment should be cancelled out as the toll revenue of the expressway operator. So we should add the revenue from expressway toll to the benefit above: total benefit per trip is $\tau^{A} - \tau^{B} + r^{H}(q,d)H$.

Note that the value of time v is not known when $\frac{\partial P_{ij}\left(q,d_{ij},t_{ij}\right)}{\partial t_{ij}} > 0$. In this case, we show the benefit of expressway construction as the change in freight charge i.e., $P_{ij}(q,d_{ij},t_{ij}^{A}) - P_{ij}(q,d_{ij},t_{ij}^{B})$ in Appendix 2. t_{ij}^{A} and t_{ij}^{B} are calculated by $t_{ij}^{A} = t_{ij}^{N} = t_{ij}^{N0}$ and $t_{ij}^{B} = t_{ij}^{N} = t_{ij}^{N1}\hat{H} + t_{ij}^{N0}(1-\hat{H})$, respectively. As described in Appendix 2, this underestimates the benefit of expressway construction.

Table 8 and 9 show the social benefit per shipment calculated for various combinations of shipment size q and distance d. Shipper's benefits, the changes in transport costs, $\tau^{A} - \tau^{B}$, range between 626 Yen and 18,625 Yen per shipment: expressways have positive benefits for all cases. Shipper’s benefits are greater for longer distance. Even if $P_{ij}^{A} - P_{ij}^{B}$ have negative values, transport cost for the shipper is smaller in the case with expressway, i.e., $\tau^{A} - \tau^{B} > 0$: from the viewpoint of shippers, losses from more expensive freight charges are more than offset by the gain from reduction of time cost, $v\left(t_{ij}^{A} - t_{ij}^{B}\right)$. As for the effect of shipment size, $P_{ij}^{A} - P_{ij}^{B}$ is increasing with q. This effect is attributed to difference in the term $\beta_4 q\left(t_{ij}^{A} - t_{ij}^{B}\right)$, i.e., $q\left(t_{ij}^{A} - t_{ij}^{B}\right)$. On the other hand, $v\left(t_{ij}^{A} - t_{ij}^{B}\right)$ is decreasing with q.

< Insert Table 8 and 9 here>

Our method of evaluation is different from the existing methods, factor cost method or willingness to pay method. The value of time calculated in our paper is the opportunity cost for shipper. On the other hand, both factor cost method and willingness to pay method measure the value of time for carrier. Let us compare the values of benefit obtained above with those by other methods, around the sample mean at q =4 and d = 200.

The factor cost method evaluates the benefit of time saving by the formula as

$$v^f\left(t_{ij}^A - t_{ij}^B\right)$$

where v^f is the sum of driver's wage rate and opportunity cost of the truck, t_{ij}^B and t_{ij}^A are respectively the transport times with and without time saving. We use the value in the cost-benefit manual in Japan for v^f, 3861Yen per hour. We assume that t_{ij}^A is the transport times via ordinary road calculated by NITAS, i.e., $t_{ij}^A = t_{ij}^{N0}$, and t_{ij}^B is the expected value of transport time when expressway is available, i.e., $t_{ij}^B = t_{ij}^{N1}H + t_{ij}^{N0}(1-H)$ [13].

The formula for the willingness to pay method is basically the same:

$$v^w\left(t_{ij}^A - t_{ij}^B\right)$$

Where v^w is the marginal rate of substitution between time and money, for which we use the value obtained in Section 4.3, i.e., $v^w = 2606$ Yen/hour. t_{ij}^A and t_{ij}^B are the same as above. Then we have the values of benefit by three methods as follows.

Factor cost method: 3,088 Yen

Willingness to pay method: 2,084 Yen

Our method: 3,133 Yen

The value of benefit by our method is larger than those by other methods[14]. Our method incorporate the effect on the cost associated with effort of carriers. And thereby the value of time (for shippers) is larger.

5. Conclusion

This paper presents an alternative approach to measuring the values of transport time for freight transportation. We develop a model of freight transportation market, in which carriers incur the cost associated with the effort to reduce transport time, transport time is determined

13 In other methods, transport times are not obtained by market equilibrium as in our method.

14 Our method still underestimates the benefit of expressway, since we neglect the benefit from mitigating the traffic congestions.

as the market outcome. We estimate the freight charge equation, expressway choice model, and transport time equation, using microdata of freight flow in Japan. Then we obtain the estimates of value of time for shippers that are larger than those based on the existing methods, such as factor cost method and willingness to pay method. We further develop a method to evaluate the benefit of time-reducing technological change (including infrastructure improvement) based on hedonic approach. Application to the evaluation of expressway construction suggests that the benefits calculated by our method tend to be larger than those based on the other methods.

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Figure 1. Distribution of average speed

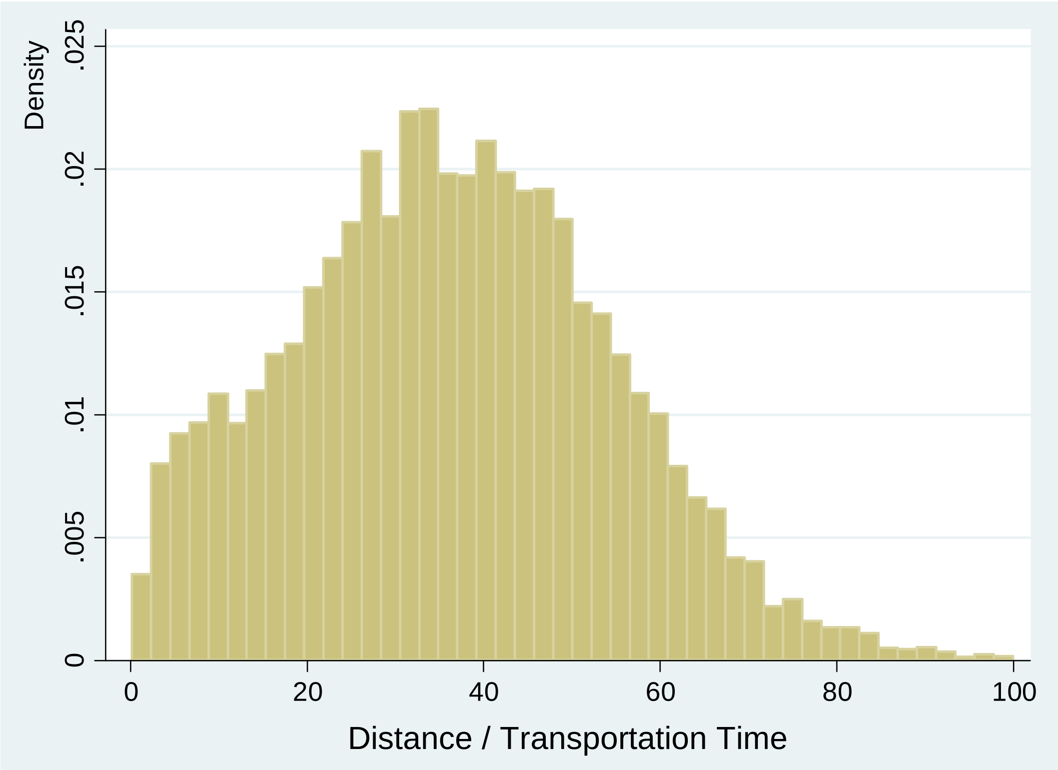

Figure 2. Transport time against Distance

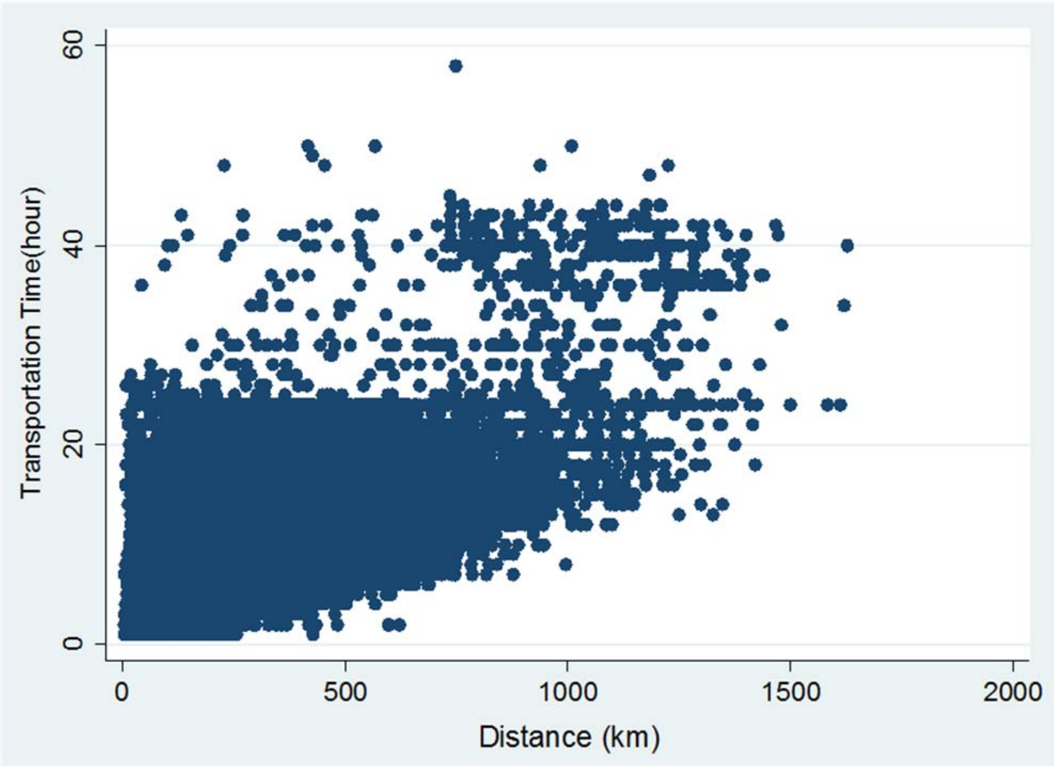

Figure 3. Benefit of time-saving technological change

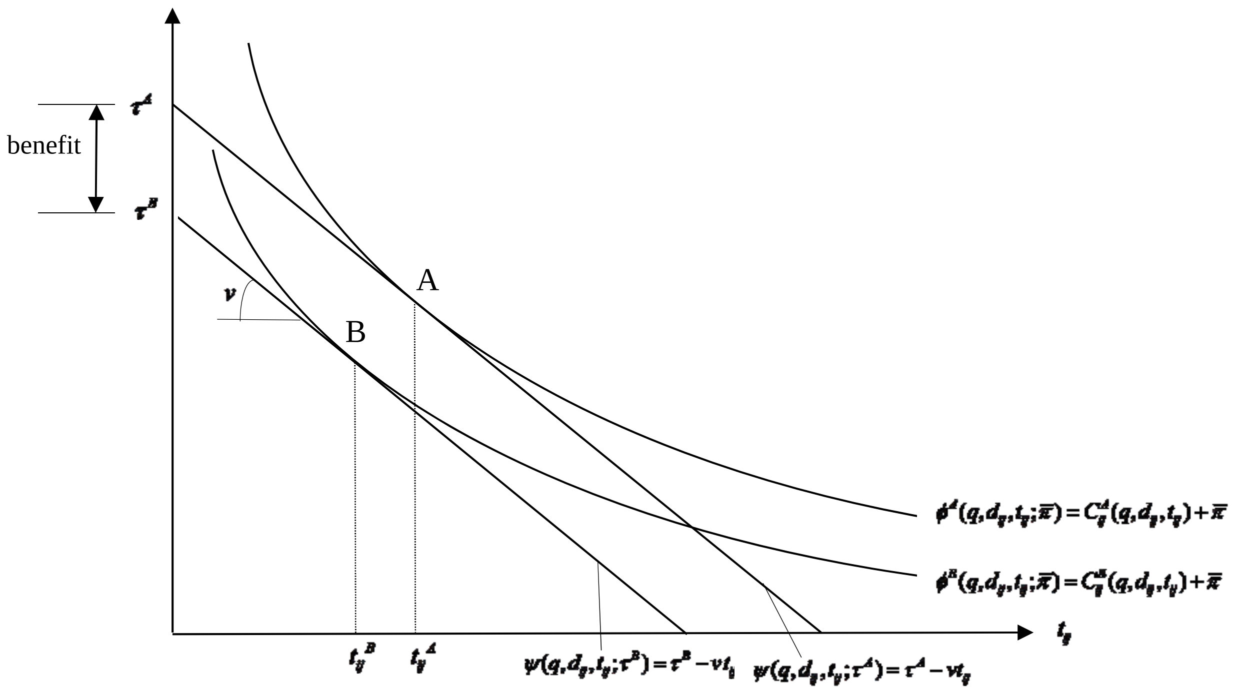

Table 1. Variable Descriptions and Sources of Data

Variable	Unit	Description	Source
P_{ij}	Yen	Freight charge	Net Freight Flow Census (Three-day survey)
t_{ij}	Hour	Transportation time	Net Freight Flow Census (Three-day survey)
t_{ij}^{N}	Hour	The shortest driving time	National Integrated Transport Analysis System (NITAS)
q	Ton	Lot size (Disaggregated weight of individual) shipments	Net Freight Flow Census (Three-day survey)
r_i^X	Yen	The general retail fuel (diesel oil) price on October 2005	Monthly Survey, The Oil Information Center
$e\left(q, s^0\right)$	l/km	Fuel Efficiency $e(q,s^0)=\begin{cases}0.107, & \text{if } q<1\\ 0.162, & \text{if } 1\le q<2\\ 0.218, & \text{if } 2\le q<4\\ 0.264, & \text{if } 4\le q<6\\ 0.296, & \text{if } 6\le q<8\\ 0.324, & \text{if } 8\le q<10\\ 0.346, & \text{if } 10\le q<12\\ 0.382, & \text{if } 12\le q<17\end{cases}$	Ministry of Economy, Trade and Industry
d_{ij}	km	Transport distance between the origin and the destination	National Integrated Transport Analysis System (NITAS)
r^H		Expressway 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 ⇒ 1.0 ($q \le 2$), 1.2 ($2 < q < 5$), 1.65 ($5 \le q$) *tapering rate ⇒ 1 .0 if $d_{ij} \le 100$ $(100km \times 1.0 + (d_{ij} - 100km) \times (1-0.25)) / d_{ij}$ 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)

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

Variable	Unit	Description	Source
H		Dummy variable = 1 if expressway is used; otherwise, 0	Net Freight Flow Census (Three-day survey)
$Border-dummy$ (Z_1)		Dummy variable = 1 if the trips between the two regions are contiguous; otherwise, 0	
$Q_i/trucks$ (Z_2)		$\frac{\text{Aggregated weight of Region i(origin)}}{\text{trucks}}$	Net Freight Flow Census (Three-day survey) Policy Bureau, Ministry of Land, Infrastructure, Transport and Tourism
imb (Z_3)		Trade imbalances $imb=\frac{\text{Aggregated weight from Destination to Origin}}{\text{Aggregated weight from Origin to Destination}}$	Logistics Census, Ministry of Land, Infrastructure, Transport and Tourism http://www.mlit.go.jp/seisakukutokatsu/census/8kai/syukei8.html
$num-truck-firms$ (Z_4)	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

Table2. Descriptive Statistics

	Observation	Mean	Median	Standard deviation	Minimum	Maximum
P_{ij}	64168	35969.27	25000	44860.48	0	1974000
t_{ij}	54424	7.107416	5	6.64457	1	240
t_{ij}^{N}	49832	4.337971	3.083333	3.811116	0.133333	34.08333
q	64168	4.448082	3	4.168215	0.011	16
$e(q_{ij}, s^{0})$	64168	5.395692	4.58	2.525126	2.62	9.32
d_{ij}	49832	239.6474	164.2515	221.4005	4.225	1628.149
H	53503	0.444405	0	0.496904	0	1
r_i^{X}	64168	106.3782	106	1.935705	103	115
r^{H}	49832	5784.828	4214.726	5070.592	223.9707	42187.16
$Border\text{-}dummy\ (Z_1)$	64168	0.435279	0	0.495797	0	1
$Q_i/trucks\ (Z_2)$	64168	15.18482	14.85513	5.114886	5.04197	64.76187
$imb\ (Z_3)$	64168	1.215013	0.9221444	3.627663	0	274.0773
$num\text{-}truck\text{-}firms\ (Z_4)$	64168	0.432962	0.4208442	0.099294	0.26638	0.674584

Table 3. Estimation Results of Expressway Choice (H)

Variables	Time-designated delivery	No Time-designated delivery
$t_{ij}^{N0} - t_{ij}^{N1}$	0.1441	0.1384
(η_1)	[27.02]***	[8.45]***
$r_i^X e(q, s^0)(d_{ij}^0 - d_{ij}^1(1-\theta)) - r^H(q, d_{ij}^1)$	0.0553	0.0702
(η_2)	[13.39]***	[5.10]***
$d50\_dummy$	-0.5222	-0.6868
(η_3)	[-24.41]***	[-10.44]***
Constant	-0.1934	-0.3508
(η_0)	[-15.85]***	[-9.19]***
Pseudo R^2	0.0357	0.0388
Observations	42823	5130

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

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

Variables	Time-designated delivery	No Time-designated delivery	Variables	Time-designated delivery	No Time-designated delivery
$\delta^t \hat{t}_{ij}^N + \sigma - \delta^t \sigma$	1.2149	0.9995	*EPdummy*	-0.767	-1.6566
(κ_1)	[68.47]***	[22.02]***	(D_8)	[-1.30]	[-4.10]***
$(1-\delta^t)(\hat{t}_{ij}^N - \sigma)$	3.1981	2.1146	$AFPdummy * \hat{t}_{ij}^N$	0.1123	-0.2473
(κ_3)	[20.36]***	[9.50]***	(λ_1)	[0.98]	[-1.18]
$\delta^{\bar{q}}$ ※	-0.7552	-1.0744	$FPdummy * \hat{t}_{ij}^N$	0.226	-0.2092
(κ_4)	[-8.85]***	[-4.21]***	(λ_2)	[3.37]***	[-3.35]***
$\delta^{\bar{q}} \hat{t}_{ij}^N$ ※	0.0374	0.2303	$MPdummy * \hat{t}_{ij}^N$	-0.0461	-0.7625
(κ_5)	[1.91]*	[4.42]***	(λ_3)	[-0.33]	[-2.32]**
AFPummy	-0.1617	1.1417	$SGdummy * \hat{t}_{ij}^N$	0.8452	-0.1628
(D_1)	[-0.43]	[1.15]	(λ_4)	[6.31]***	[-1.97]**
FPdummy	-2.1353	-0.6236	$CHdummy * \hat{t}_{ij}^N$	-0.0433	-0.1259
(D_2)	[-8.36]***	[-2.02]**	(λ_5)	[-1.84]*	[-1.72]*
MPdummy	-0.5942	0.2411	$LIdummy * \hat{t}_{ij}^N$	-0.2804	-0.0114
(D_3)	[-1.14]	[0.20]	(λ_6)	[-11.55]***	[-0.17]
SGdummy	-2.0441	-1.1085	$MMAdummy * \hat{t}_{ij}^N$	-0.1106	-0.2889
(D_4)	[-7.76]***	[-2.49]**	(λ_7)	[-3.62]***	[-3.70]***
CHdummy	0.061	0.0365	$EPdummy * \hat{t}_{ij}^N$	0.0561	0.1432
(D_5)	[0.58]	[0.08]	(λ_8)	[0.33]	[0.80]
LIdummy	1.5475	-0.528	Constant	2.0114	2.5262
(D_6)	[14.27]***	[-2.03]**	(κ_0)	[26.87]***	[11.43]***
MMAdummy	0.8469	2.5706	Adj- R^2	0.4166	0.3777
(D_7)	[5.88]***	[5.99]***	Observations	43088	5362

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

※ As mentioned above, δ^q is a dummy variable taking $\delta^{\bar{q}} = 1$ the cargo is heavier than $\bar{q}$ and $\delta^q = 0$ otherwise. We pick $\bar{q}$ = 3 and $\bar{q}$ = 4 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})

Variables	Time-designated delivery		No Time-designated delivery	
	Model 1	Model 2	Model 3	Model 4
$\hat{t}_{ij}$	-1895.7862	-2086.6874	-2645.926	-2575.7618
(β_1)	[-10.85]***	[-11.29]***	[-5.84]***	[-5.32]***
$q\hat{t}_{ij}$	386.0746	385.3938	440.8634	442.5437
(β_2)	[22.67]***	[23.26]***	[7.23]***	[7.23]***
$r_i^X d_{ij} e(q,s^0)(1-\theta\hat{H}) + r^H(q,d_{ij})\hat{H}$	2.1198	2.1507	2.4317	2.3957
(β_3)	[12.81]***	[13.84]***	[5.51]***	[5.32]***
$\frac{\hat{t}_{ij}^N}{\hat{t}_{ij}}$	10912.2853	7990.7465	10807.3303	11822.8711
(β_4)	[2.35]**	[2.01]**	[3.46]***	[3.15]***
Border-dum my (Z_1)		-3252.4791		846.9554
		[-5.51]***		[0.83]
Q_i */trucks* (Z_2)		-89.2525		93.3888
		[-3.10]***		[0.66]
imb (Z_3)		-8.3358		-21.14
		[-0.21]		[-0.43]
num-truck-firms (Z_4)		-5880.5413		1302.97
		[-4.03]***		[0.26]
Constant	13735.9701	21786.6314	13673.8871	10505.777
	[6.57]***	[9.80]***	[6.00]***	[2.37]**
Adj-R^2	0.4860	0.4872	0.3505	0.3501
Observations	42823	42823	5130	5130

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

Table 6. The VTTS and Time for the case of Time-designated delivery

q	2			4			6			8			16		
d	t^N	t	v	t^N	t	v	t^N	t	v	t^N	t	v	t^N	t	v
100	2.2	4.6	2118.8	2.2	4.6	1347.8	2.2	4.0	883.9	2.2	4.0	113.4	2.2	4.0	-2969.1
200	3.8	6.7	2004.9	3.9	6.7	1232.7	3.9	6.1	614.0	3.9	6.1	-155.9	3.9	6.1	-3237.2
400	6.9	10.4	1824.2	7.0	10.5	1050.5	7.2	10.2	328.9	7.2	10.2	-440.2	7.1	10.1	-3519.7
800	12.4	17.0	1656.2	12.6	17.3	880.9	13.4	18.6	83.9	13.3	18.2	-677.0	13.0	17.5	-3737.7

Table 7. The VTTS and Time for the case of No Time-designated delivery

q	2			4			6			8			16		
d	t^N	t	v	t^N	t	v	t^N	t	v	t^N	t	v	t^N	t	v
100	2.2	4.8	2851.8	2.2	4.2	2296.1	2.3	4.2	1406.9	2.3	4.2	522.2	2.2	4.2	-3017.3
200	4.0	6.5	2799.6	4.0	6.4	1966.6	4.1	6.5	1070.2	4.1	6.5	186.4	4.0	6.4	-3351.2
400	7.3	9.8	2583.0	7.4	10.5	1590.7	7.7	10.9	685.4	7.6	10.8	-197.1	7.5	10.7	-3732.0
800	13.3	16.1	2296.2	13.6	18.8	1260.5	14.6	21.2	303.4	14.5	20.9	-572.9	14.2	20.2	-4093.5

Table 8. Benefit from time saving by expressway construction
For the case of Time-designated delivery

q	d	t_{ij}^{N0}	t_{ij}^{A}	t_{ij}^{N1}	t_{ij}^{B}	$r^H H$	v	$P_{ij}^{A} - P_{ij}^{B}$	$v\left(t_{ij}^{A} - t_{ij}^{B}\right)$	$\tau^A - \tau^B$	$\tau^A - \tau^B + r^H H$
2	100	2.6	5.0	2.2	4.6	1008.9	2118.8	-203.3	839.7	636.4	1645.3
	200	4.7	7.4	3.8	6.7	1857.3	2004.9	-450.0	1439.2	989.1	2846.4
	400	9.0	11.9	6.9	10.4	3808.5	1824.2	-1167.8	2637.8	1469.9	5278.4
	800	17.6	20.3	12.4	17.0	8966.2	1656.2	-3202.2	5436.1	2233.9	11200.1
4	100	2.6	5.0	2.2	4.6	1181.8	1347.8	100.6	526.3	626.8	1808.7
	200	4.7	7.4	3.9	6.7	2167.9	1232.7	100.0	865.4	965.5	3133.4
	400	9.0	11.9	7.0	10.5	4411.9	1050.5	-55.7	1472.1	1416.3	5828.3
	800	17.6	20.5	12.6	17.3	10298.9	880.9	-660.4	2779.8	2119.5	12418.3
6	100	2.6	4.3	2.2	4.0	1533.4	883.9	423.2	280.2	703.4	2236.8
	200	4.7	6.7	3.9	6.1	2747.6	614.0	626.4	361.0	987.4	3735.0
	400	9.0	11.4	7.2	10.2	5369.4	328.9	921.1	388.3	1309.4	6678.8
	800	17.6	21.3	13.4	18.6	11860.0	83.9	1455.8	228.2	1683.9	13544.0
8	100	2.6	4.3	2.2	4.0	1540.4	113.4	670.8	36.1	706.9	2247.3
	200	4.7	6.7	3.9	6.1	2772.3	-155.9	794.4		794.4	3566.7
	400	9.0	11.4	7.2	10.2	5458.4	-440.2	1792.3		1792.3	7250.7
	800	17.6	21.0	13.3	18.2	12191.3	-677.0	4307.4		4307.4	16498.6
16	100	2.6	4.3	2.2	4.0	1555.3	-2969.1	1503.6		1503.6	3058.8
	200	4.7	6.7	3.9	6.1	2823.9	-3237.2	3313.0		3313.0	6136.9
	400	9.0	11.3	7.1	10.1	5644.8	-3519.7	7588.5		7588.5	13233.4
	800	17.6	20.3	13.0	17.5	12876.0	-3737.7	18625.2		18625.2	31501.2

Note : The value of time v is not known if $\frac{\partial P_{ij}\left(q, d_{ij}, t_{ij}\right)}{\partial t_{ij}} > 0$. In this case, we show the value of $P_{ij}^{A} - P_{ij}^{B}$ as the benefit of expressway construction, which is calculated by using $t_{ij}^{B} = t_{ij}^{N1}$ and $t_{ij}^{A} = t_{ij}^{N0}$.

Table 9.Benefit from time saving by expressway construction
For the case of No Time-designated delivery

q	d	t_{ij}^{N0}	t_{ij}^{A}	t_{ij}^{N1}	t_{ij}^{B}	$r^H H$	v	$P_{ij}^A - P_{ij}^B$	$v\left(t_{ij}^A - t_{ij}^B\right)$	$\tau^A - \tau^B$	$\tau^A - \tau^B + r^H H$
2	100	2.6	5.1	2.2	4.8	843.2	2851.8	-176.2	948.9	1301.6	1615.9
	200	4.7	7.1	4.0	6.5	1540.3	2799.6	-329.1	1583.5	1610.5	2794.7
	400	9.0	10.9	7.3	9.8	3140.5	2583.0	-863.5	2793.9	2043.5	5070.9
	800	17.6	18.5	13.3	16.1	7437.7	2296.2	-2651.3	5610.4	2851.7	10396.8
4	100	2.6	4.5	2.2	4.2	981.4	2296.1	196.8	659.9	1270.5	1838.1
	200	4.7	6.9	4.0	6.4	1779.0	1966.6	189.9	1050.7	1549.8	3019.6
	400	9.0	11.6	7.4	10.5	3575.5	1590.7	-22.4	1741.2	1924.3	5294.3
	800	17.6	21.4	13.6	18.8	8294.5	1260.5	-915.5	3290.7	2600.4	10669.6
6	100	2.6	4.5	2.3	4.2	1247.5	1406.9	421.3	378.5	1178.9	2047.2
	200	4.7	7.0	4.1	6.5	2174.8	1070.2	588.8	512.6	1363.3	3276.1
	400	9.0	11.8	7.7	10.9	4075.0	685.4	772.9	627.4	1546.7	5475.4
	800	17.6	23.3	14.6	21.2	8411.6	303.4	955.7	627.1	1791.5	9994.5
8	100	2.6	4.5	2.3	4.2	1255.9	522.2	664.0	141.5	1188.0	2061.4
	200	4.7	6.9	4.1	6.5	2204.0	186.4	1026.9	90.5	1384.6	3321.4
	400	9.0	11.8	7.6	10.8	4181.5	-197.1	1329.1		1329.1	5510.6
	800	17.6	23.1	14.5	20.9	8824.6	-572.9	3018.1		3018.1	11842.7
16	100	2.6	4.5	2.2	4.2	1273.6	-3017.3	1359.6		1359.6	2633.2
	200	4.7	6.9	4.0	6.4	2265.7	-3351.2	2935.2		2935.2	5200.8
	400	9.0	11.7	7.5	10.7	4407.0	-3732.0	6542.2		6542.2	10949.2
	800	17.6	22.5	14.2	20.2	9701.7	-4093.5	15496.7		15496.7	25198.4

Appendix1. Classification and Commodity

Classification	**Commodity**

Agricultural & Fishery Products ($AFPummy$)	Wheat
	Rice
	Miscellaneous grains ・ Beans
	Fruits & Vegetables
	Wool
	Other livestock products
	Fishery products
	Cotton
	Other agricultural products
Chemical Products ($CHummy$)	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
Forest Products ($FPummy$)	Raw wood
	Lumber
	Firewood and charcoal
	Resin
	Other forest products
Light Industrial Products ($LIummy$)	Pulp
	Paper
	Spun yarn
	Woven fabrics
	Sugar
	Other food preparation
	Beverages

Appendix1. Classification and Commodity

Classification	Commodity
Industrial Wastes	Discarded automobile

& Recycle Products $\left(EPummy\right)$	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
Miscellaneous Manufacturing $\left(MMAummy\right)$	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
Mineral Products $\left(MPummy\right)$	Coal
	Iron ores
	Other metallic ore
	Gravel, Sand, Stone
	Limestone
	Crude petroleum and natural gas
	Rock phosphate
	Industrial salt
	Other non-metallic mineral
Specialty products $\left(SGummy\right)$	Feed and manure Containing animal and vegetable waste
	Transportation container made of metal
	Other transportation container
	Mixture
Metal & Machinery Products $\left(Baseline\right)$	Iron and steel
	Non-ferrous metals
	Fabricated metals products
	Industry machinery products
	Other transport equipment
	Precision instruments products
	Other machinery products

Appendix 2. Equilibrium and benefit evaluation in the case of $\frac{\partial P_{ij}\left(q, d_{ij}, t_{ij}\right)}{\partial t_{ij}} > 0$

If $\frac{\partial P_{ij}\left(q, d_{ij}, t_{ij}\right)}{\partial t_{ij}} > 0$ for all $t > t_{ij}^{N}$, equilibrium is not determined at the tangency point as in Figure 3. In this case, both shipper and carrier prefer as short transport time as possible. So equilibrium transport time will be the shortest time for given transport technology, such as points A and B in the figure below.

Let us suppose that the change in transportation technology causes shift of the carriers' offer curve from $\phi^{A}(q, d_{ij}, t_{ij}; \overline{\pi})$ to $\phi^{B}(q, d_{ij}, t_{ij}; \overline{\pi})$. The benefit of change in transportation technology is measured by the reduction of shippers cost from τ^{A} to τ^{B}. However, since the value of time *v* is not known, $\tau^{A} - \tau^{B}$ cannot be evaluated accurately. We instead use the change in freight charge, $P^{A} - P^{B}$ as approximate estimate. In the figure, $\tau^{A} - \tau^{B}$ is measured as the length AD while $P^{A} - P^{B}$ is AC. Thus $P^{A} - P^{B}$ underestimates the benefit by Δ.