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TIME-SERIES ANALYSIS OF URBAN RAIL SUPPLY IN TOKYO, JAPAN, FROM 1920 TO 2010

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ABSTRACT

In this study, the factors that have affected the urban rail supply in Tokyo were analyzed using time-series data for the period 1920–2010. A direct model of urban rail supply was developed, which incorporated the demand for urban rail travel, urban rail travel speed, conditions of alternative urban transportation modes, and socio-economic conditions as explanatory variables. The model was estimated by the Bayesian model averaging approach, which provided robust estimation results even with multivariate time-series data. Additionally, a model framework that can avoid simultaneous biases caused by the interdependence of variables in the urban transportation market was applied. The results showed that the investment in urban rail was in response to urban rail demand such that the urban rail demand induced investment in the urban rail supply directly, and through rail speed, it could affect the supply indirectly as well. The slower travel speeds of buses and trams also increased investment in urban rail supply; however, the reaction of the urban rail supply to car ownership was weak; gasoline price was negatively correlated with the urban rail supply; and population or employment is positively correlated with the urban rail supply. Finally, the lessons learnt from analyzing the past rail supply in Tokyo were discussed from the perspective of emerging large cities.

Keywords: Urban rail supply, Time-series data, Bayesian model averaging, Tokyo

INTRODUCTION

Tokyo is one of the most transit-oriented cities in the world (*1*); it has a large and dense urban rail network to provide efficient rail service (*2*). The 2008 Person Trip Survey in Tokyo showed that the modal share of rail was 30%, followed by cars (29%), in the Tokyo metropolitan area. It is widely known that historical processes have resulted in the current rail-oriented city of Tokyo. The National Railways started urban rail services in Tokyo in 1904. Subsequently, many rail operators started operation in suburban areas for providing urban rail service. The major framework of the urban rail network, excluding subways, in Tokyo was completed by the 1920s, when the first major suburbanization (1920–35) started in the modern history of Tokyo. Trams played an important role in the central area before World War II, but they were replaced by the subway network during the 1960–70s, which was the period of the second major suburbanization (1955–70) in Tokyo. The operation of the first subway commenced in 1927, and other subway lines started their operations during the postwar period. Thereafter, a direct-through connection system between suburban rail lines and subway lines was introduced from the 1960s mainly because the subway network was established later than the suburban rail network. Both private and public rail operators have continuously invested to increase the capacity of rail service to date through measures such as upgrading double-track lines to quadruple-track lines. In Japan, rapid motorization commenced in the 1960s; nevertheless, rail network has continued to attract a significant number of commuters in Tokyo (*3, 4, 5*).

Various factors could have affected the urban rail supply over time in Tokyo. High demand for urban rail travel might have stimulated rail investment, which is termed “demand-responsive” or “induced” investment; at the same time, the degradation in the service levels of alternative transportation modes such as trams could also have promoted urban rail investment. Additionally, urban rail supply might have been correlated to the urban growth and demographic changes of the city. What is the factor that has strongly affected the urban rail supply, thus leading to the establishment of a rail-oriented Tokyo?

This study investigates a series of urban rail investments using statistical data covering the period from 1920 to 2010 in Tokyo. The urban rail supply was empirically analyzed considering the urban-rail travel demand, rail travel speed, conditions of alternative transportation modes, and socio-economic conditions as explanatory variables. The simultaneous biases that could arise from the interdependence of variables in the urban transportation market are addressed in the model framework. This study extends our earlier work (*6*) that dealt with multivariate time-series data of Tokyo by introducing the Bayesian model averaging (BMA) approach, which enables a robust estimation of the model.

The remainder of the paper is organized as follows. A literature review of related studies is presented next. Subsequent section presents the method, including three hypotheses, model structure, and time-series analysis, followed by the description of the dataset used for empirical analysis. Then, the estimation method and its results are presented along with a discussion. Finally, the findings are summarized and policy implications for rail investments are presented.

LITERATURE REVIEW

Many studies have intensively analyzed travel demand as a function of policy options such as fares, income, and service levels of transportation. Literature reviews and meta-analyses on the elasticities of travel demand have been reported with regard to public transportation (e.g., *7*, *8*, *9*).

Although there are studies for the estimation of production or cost function of urban rail firms (e.g., *10*, *11*, *12*), however, few studies have analyzed the urban rail supply of a city. Albalate and Bel (*13*) and Taylor et al. (*14*) include the estimation for the supply of urban public-transit with a city-level cross-sectional dataset. Voith (*15*) also includes the estimation for service levels and prices of urban rail service incorporating urban rail demand with a station-level panel dataset. They typically analyze the determinants of public-transit ridership, in which the model for public-transit supply is simultaneously estimated. However, they focus on the demand in the analysis because the implicit framework in their analyses might still be that the demand mostly determines the public-transit market.

This study concerns the determinants of public-transit market, which relates to the question why such an urban rail market emerged. Thus, our concerns are conceptually for the long-run. As an approach to the long-run analysis, we highlight supply-side actions that are typically assumed to determine fundamentals of the market. In summary, this study analyzes how the urban rail market, represented by the urban rail supply, has emerged in relation to factors such as urban rail demands, alternative transportation modes, and socioeconomic conditions.

METHOD

Hypotheses

Tokyo's urban rail market has unique characteristics: private rail companies provide many of the rail services, the rail network was developed under the guidance of the central government, and rail users suffered from chronic traffic congestion for many years (*2*).

This study presents three hypotheses regarding the urban rail supply in Tokyo. The first hypothesis is that higher urban rail demands induced more urban rail supply. Note that some studies describing the history of urban transportation planning in Tokyo presented qualitative evidence of "demand-driven" or "demand-following" supply of urban rail in the past where increasing travel demands seemed to promote rail investment (*16*, *17*).

The second hypothesis is that degrading service levels of alternative transportation modes increased urban rail supply. This generally means that market competition among multiple transportation modes significantly influences the investment in the urban rail network.

The third hypothesis is that rapid urban growth promoted urban rail supply. It is typically pointed out that the timing of transit investments is important for successful investments because the impacts of such investments on land use are the greatest just prior to an upswing in regional growth (*1*).

Model

FIGURE 1 shows the hypothetical causal relationships among the major factors related to urban rail supply. This schematic is based on the assumptions of relationships among urban rail supply, level of rail service, and urban rail travel demand following the framework in Cervero (*18*) that analyzed the effects of roadway supply on the car travel demand. First, increases in urban rail supply such as the investment in rail

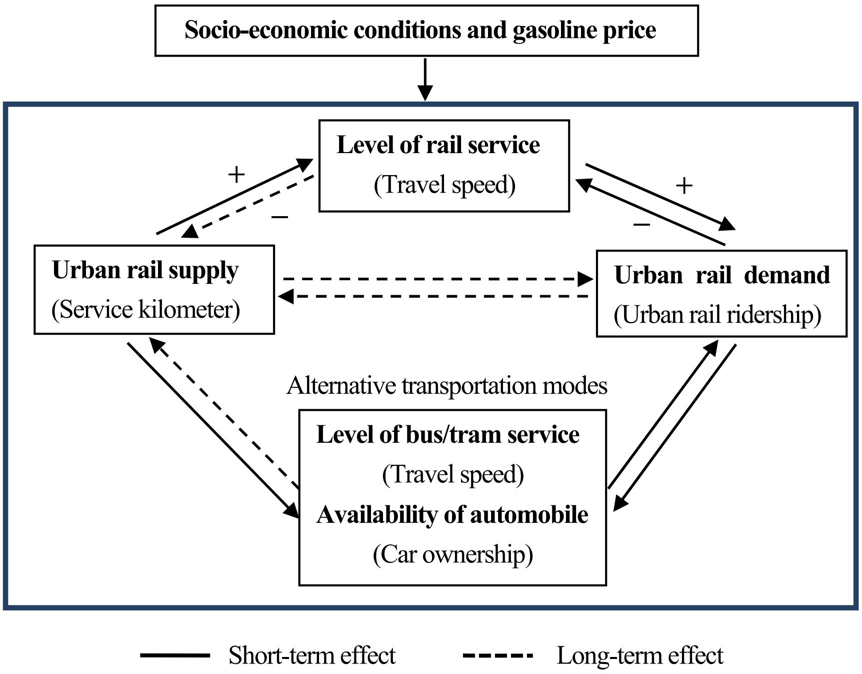

FIGURE 1 Hypothetical relationships related to urban rail supply.

stocks are expected to positively affect the level of urban rail service, which also positively affects urban rail demand. Simultaneously, a larger urban rail demand negatively affects the level of rail service. However, it may take a longer time for changes to occur in urban rail supply in response to changes in the level of rail service; the expected sign of this effect might be negative in order to realize the equilibrium of supply, demand, and service level. Second, urban rail supply is also expected to affect urban rail demand in the long run. For example, urban rail supply affects land-use within a city (e.g., land development near the stations), which in turn affects urban rail demand (e.g., people living near the stations tend to use the rail more) (*19*). Note that there is no direct causal link from the land-use to urban rail supply in our framework. Third, urban rail demand also affects the urban rail supply: this effect is termed the "demand-response" investment or "induced" investment. In our framework, we have assumed two demand-response effects on urban rail supply: one is the positive indirect effect of urban rail demand working through the level of rail service on urban rail supply, and the other is the positive direct effect of urban rail demand on urban rail supply. The former is a demand-response investment to improve the level of rail service that might have been degraded because of a larger urban rail demand. The latter is the response of the urban rail supply to the urban rail demand when the level of rail service is maintained constant: this may be a demand-responsive investment mainly for accommodating a larger urban rail demand.

FIGURE 1 is also based on the assumption of the potential influences of alternative transportation modes on urban rail supply. It takes longer for the urban rail supply to respond to the level of bus or tram service and the availability of automobiles than for a reverse effect.

Finally, all relationships in the urban transportation market are assumed to be influenced by exogenous factors such as gasoline price and socio-economic conditions such as income level, population, age distribution, and employment in the city.

We assumed urban rail supply would take longer to respond to the factors in the urban transportation market. This is because there are substantial lags between the plan or decision of supply for an urban rail line and the start of its operation (i.e., urban rail supply) due to the several years needed for its construction.

This study explicitly considers this time lag. Planners/suppliers are assumed to consider the conditions of the urban transportation (and land-use) market given the socio-economic conditions and gasoline price of the city. Thus, the plan for an urban rail supply at time t are made at time $t-n$ considering the conditions of the urban transportation market at time $t-n$ (e.g., modeling) and predicted socioeconomic conditions and gasoline price at time t (e.g., demand forecasts).

$$Plan_{t-n} = f\left(D_{t-n}, LOSr_{t-n}, LOSb_{t-n}, CAR_{t-n}, SE_t^p\right) \tag{1}$$

where D_{t-n} is the urban rail demand at time $t-n$, $LOSr_{t-n}$ is the level of urban rail service at time $t-n$, $LOSb_{t-n}$ is the level of bus/tram service at time $t-n$, CAR_{t-n} is the availability of automobile at time $t-n$, and SE_t^p represents the predicted socioeconomic conditions and gasoline price at time t. We assume the prediction for the socioeconomic conditions and gasoline price are made rationally, that is, $SE_t^p = SE_t$ where SE_t represents the socioeconomic conditions and gasoline price at time t. Then, these imply following urban rail supply model:

$$S_t = f(Plan_{t-n}) = f(D_{t-n}, LOSr_{t-n}, LOSb_{t-n}, CAR_{t-n}, SE_t) \tag{2}$$

where S_t is the urban rail supply at time t. As such, the urban rail supply is regressed on the lags of the variables in the urban transportation market. Because the lag variables are predetermined for urban rail supply, we can avoid simultaneous biases that could arise from the interdependence between the urban rail supply and those urban transportation variables, in the estimation of the supply model.

Thus, the urban rail supply model analyzes how the urban rail supply reacted to the variables in the urban transportation market and how it correlated with the exogenous factors of the urban transportation market. The former could reflect relatively active factors in the supply such as intensions of planners as assumed in the first and second hypotheses while the latter could reflect relatively passive factors in the supply as assumed in the third hypothesis.

Time-Series Analysis

The urban rail supply model is assumed as a linear regression model with time-series data. As the typical practice in the time-series analysis, we use the log first difference, $\ln x_{t+1} - \ln x_t = \ln(x_{t+1}/x_t)$ for every continuous variable[1] x at time t, to transform the variables into stationary processes. This is because most variables are trended and are not stationary in our data[2]. The log difference refers to the growth rate of variable x from time t to $t+1$ for the marginal difference of x. Additionally, the average growth rate of variables is investigated to focus on the long-run variation in the variables. This is because the growth rates over intervals as short as five years are influenced considerably by short-term or temporary forces called the "business cycles" that are not typically considered in the long-run analysis (*21*). Then, arithmetic average

[1] The continuous variable here means all variables except for the socioeconomic variables that show the share (see, TABLE 1). The variables showing the share are used as their original levels.

[2] In fact, the augmented Dickey–Fuller test implies that most variables are significantly unit root processes. Regressions among the variables of unit root processes could lead to spurious regression where highly significant relationships among the variables are obtained regardless of their actual relationships. Differentiation of the variables is one of the measures for preventing spurious regression (*20*).

of the growth rate during an interval of 10 years, i.e., $(1/10)\sum_{t}^{t+10-1}\ln(x_{t+1}/x_t)$, is used for every continuous variable in our yearly data. For example, the model assumes that the average annual growth rate of the urban rail supply from 1990 to 2000 can be explained by the average growth rates of lagged variables from 1980 to 1990, average growth rates of gasoline prices and continuous socioeconomic variables from 1990 to 2000, and the other socioeconomic variables of 1990. Note that the coefficient estimates for continuous variables in the above model are regarded as the (long-run) elasticities of the urban rail supply with respect to the corresponding variables.

We do not include a lagged dependent variable as one of the potential explanatory variables. The inclusion of it assumes an adjustment process to some desired level or long-run situation (equilibrium) in the model (*22*). Rather, our model explains the changes in the long-term equilibrium over time because it is not certain that the long run equilibrium is represented by some constant relationship over this study period.

DATASET

Data Used

The dataset used in our empirical study covers the geographical area of Tokyo Metropolis (Tokyo-*to*), which falls under the jurisdiction of Tokyo Metropolitan Government. Note the study area does not correspond to the Tokyo metropolitan area, but is just a part of it. Only the data of Tokyo Metropolis was used because official statistical reports on historical data are available throughout the study period for this area. Additionally, it may be difficult to define the geographical coverage of the metropolitan area throughout the study period because it has been dynamically changing. Urbanized areas in the Tokyo metropolitan area were located only within the area of Tokyo Metropolis before the 1950s, but since the 1960s, they have expanded beyond the border of Tokyo Metropolis. Nevertheless, Tokyo Metropolis has included a large part of the urbanized area of the Tokyo metropolitan area over time, and this means that our study area can represent a considerable part of the urban activities of Tokyo.

The original dataset includes yearly time-series data from 1920 to 2010 and the data from 1910 to 2010 for the lagged variables. The study period includes almost the entire period of the urban rail development in Tokyo. In this case, we could avoid referring to the initial condition of the urban rail market in the analysis. In addition, the period from 1920 is included because the first national census of Japan was conducted in 1920, and reliable and consistent socio-demographic data are available from this period.

The data from 1935 to 1949 are not directly used because of drastic changes in the population and economy in 1945 due to the bombing of Tokyo and people's evacuation from Tokyo. After the war ends in 1945, there was a recovery period with the unstable economy (i.e., high inflation) typically for five years in Japan. Thus, we basically exclude the values from 1945 to 1949 to avoid the direct influences of World War II. Because the continuous variables are used as the average for (forward) 10-year intervals, we need to take 10-year buffers before 1945.

The other yearly changes found in the variables are not substantial compared to the yearly change directly affected by World War II. Then, the other year-specific effects such as the Great Kanto earthquake in 1923 can be captured by the year-dummy variables used in the analysis.

Descriptive Statistics

TABLE 1 summarizes the descriptive statistics of the dataset used in our empirical study. The dataset includes urban rail supply, urban rail demand, levels of urban rail and bus/tram service, availability of automobile, socio-economic conditions, and gasoline price.

TABLE 1 Descriptive Statistics of Dataset

Variable	Unit	Mean	Standard Deviation	Min.	Max.
Supply, demand, and level of urban rail service					
Service kilometers of urban rail network	Km	576.4	185.9	215.6	885.7
Ridership of urban rail service	thousand passengers	3458.0	2276.8	1619.0	6462.0
Average travel speed of urban rail service	km/h	40.3	2.4	32.0	43.8
Level of bus/tram service and availability of automobile					
Average travel speed of bus/tram service	km/h	12.9	1.3	10.7	14.8
Car ownership	thousand vehicles	1269.0	1277.2	0.1	3424.0
Socioeconomic conditions and gasoline price					
Gross Regional Precut (GRP)	trillion JPY (2005 prices)	33.2	28.1	3.9	85.8
Population	million persons	9.4	2.9	3.7	12.1
Share of population aged 15–64		0.71	0.04	0.65	0.75
Share of population aged >65		0.05	0.04	0.03	0.16
Share of male population		0.51	0.01	0.50	0.53
Share of employees in the population aged >15		0.61	0.02	0.55	0.63
Share of employees in manufacturing industry		0.32	0.07	0.15	0.40
Share of employees in construction industry		0.08	0.02	0.04	0.09
Share of employees in wholesale & retail industry		0.26	0.02	0.22	0.29
Share of employees in finance & insurance industry		0.03	0.01	0.01	0.04
Share of employees in services industry		0.21	0.05	0.15	0.33
Price of gasoline (per 1 liter)	JPY (2005 prices)	198.9	81.3	95.2	521.7

Note: Data are yearly data for Tokyo Metropolis (Tokyo-*to*) from 1920 to 2010, excluding the data for 1935-49.

The urban rail supply is represented by rail service-kilometers in Tokyo Metropolis. The rail network considered in this study includes urban railways, subways, monorails, and automated guideway transit, which are operated by private companies or public authorities. Although intermediate outputs of urban rail service, such as seat-kilometers of rail service (*23*), may be an ideal indicator of urban rail supply, the urban rail service-kilometer can also represent the service capacity well for Tokyo. The service kilometer is measured on a double-track basis. When quadruple tracks are used in some sections of the rail network, the service kilometers for such sections are doubled for converting it into double-track-based data. Note that many rail operators have installed quadruple tracks to enhance the rail capacity in Tokyo.

The urban rail demand is represented by ridership or the number of passengers of urban railways, subways, monorails, and automated guideway transit in Tokyo Metropolis. Note that the statistical data assumes that multiple train ridings in a single journey owing to transfer at stations are counted as a single ridership when the transfer is done in a rail network operated by the same operator, while they are counted as the multiple ridership when the transfer is among different rail operators.

The level of urban rail service is represented by the average travel speed of representative urban rail services in Tokyo Metropolis. The average speed is estimated using the scheduled travel speeds of representative urban railway and subway services by weighting their ridership in each year. The scheduled speed of the representative urban railway service is assumed to be the speed of a local train running from *Tachikawa* station to *Shinjuku* station (27.2 km in length) in the JR *Chuo* Line during the morning hours until 1970 or earlier, while it is assumed to be the average speed of local, rapid, and special rapid trains in the same section during the morning hours for the period after 1970. The scheduled speed of the representative subway service is assumed to be the speed of a train running on the *Ginza* Line during the morning hours for the period until 1961, while it is assumed to be the average speed of trains on the *Ginza*, *Marunouchi*, and *Hibiya* Lines during the morning hours for the period after 1961.

The level of bus/tram service is represented by the average travel speed of bus and tram services in Tokyo Metropolis. The average travel speed is estimated using the scheduled travel speed of the tram until 1950 or earlier, while it is estimated using the scheduled speeds of buses and trams by weighting their ridership in each year for the period after 1950. All the scheduled speeds are collected from the services of *Toei* Lines, which are operated by the Tokyo Metropolitan Government.

The availability of automobiles is measured in terms of car ownership, which is defined as the vehicle stock of passenger cars and four- and three-wheeled vehicles in the category of light vehicles in Tokyo Metropolis. Vehicles used as taxis are excluded from car ownership. Because the definition of car as per the classification in the statistical reports has changed over time, car ownership in the period before 1960 are modified to maintain consistency in the definition of cars.

The socio-economic data include the Gross Regional Product (GRP) in 2005 prices, population, age distribution, the share of male population in the total population, the share of employees in the population aged 15 years or older, and the share of employees in the total number of employees by industry in Tokyo Metropolis. The industries comprise manufacturing, construction, wholesale & retail, finance & insurance, and services. The population, age distribution, and the share of male population were obtained from the national census data throughout the period. However, other data are not available throughout the study period, particularly before 1950s. Because the GRP data are available only after 1955, the data for 1955 and earlier years are estimated using the growth rate of Gross Domestic Product in Japan. The shares of employees in the population aged 15 years or older are available only after 1950; hence, the data for 1950 or earlier are estimated using the national data. Similarly, the shares of employees by industry are available only after 1960, and hence, the data for 1960 or earlier are estimated using the national data. For example, the data show that, in terms of the growth rate of GRP, the values of mean, standard deviation, maximum, and minimum are 0.048, 0.028, 0.11, and 0.008, respectively.

Finally, the gasoline price is defined as the annual average gasoline price per liter in Tokyo Metropolis. The nominal price in each year is converted into 2005 prices by using the consumer price index of Tokyo Metropolis.

In the estimation, dummy variables for representing each year are also introduced to capture the effects that are specific for each year. In total, the model contains 65 annual dummy variables.

EMPIRICAL ANALYSIS

Estimation Method

The BMA method was applied for the model estimation. Although parameters in the supply model could be estimated consistently even with the ordinary least squares (OLS) approach, the OLS approach was not applied in our study. This is because it is generally difficult to obtain a robust estimation result with multivariate time-series data owing to the high multi-collinearity. The BMA has been applied in many fields such as economics, biology, ecology, and public health research (*24*). For instance, a growth regression with the BMA intensively examined the determinants of differences in the levels of per capita income between countries, using many hypothetical determinants proposed by theorists (e.g., *21*, *25*). These studies generally use cross-sectional or cross-sectional time-series data of countries. Meanwhile, using data such as multivariate time-series data, the BMA was utilized to forecast GDP and inflation (*26*) and exchange rate (*27*).

The basic structure of the BMA is presented following Zeugner (*28*). Further detailed presentation of the BMA is available in Hoeting *et al.* (*29*) and Raftery *et al.* (*30*). Consider a linear model $\gamma,\ M_\gamma;\ y = \alpha_\gamma + X_\gamma\beta_\gamma + \varepsilon, \varepsilon \sim N(0, \sigma^2 I)$ where y is a dependent variable; X is a vector of explanatory variables; $\alpha_\gamma,\ \beta_\gamma$ are the coefficients; and ε is a normal error term with variance σ^2. Then, the posterior distributions of parameters $p(\theta|y, X)$ are obtained by averaging the posterior distributions of parameters in each model $p(\theta|M_\gamma, y, X)$ with the posterior model probability $p(M_\gamma|y, X)$ over all possible models 2^K, where K is the number of explanatory variables. This is expressed as follows:

$$p(\theta|y, X) = \sum_{\gamma=1}^{2^K} p(\theta|M_\gamma, y, X)p(M_\gamma|y, X) \tag{3}$$

The posterior model probabilities $p(M_\gamma|y, X)$ are derived from Bayes' theorem as shown below:

$$p(M_\gamma|y, X) = \frac{p(y|M_\gamma, X)p(M_\gamma)}{p(y|X)} = \frac{p(y|M_\gamma, X)p(M_\gamma)}{\sum_{s=1}^{2^K} p(y|M_s, X)p(M_s)} \tag{4}$$

where $p(y|X)$ denotes likelihood; $p(y|M_\gamma, X)$ denotes marginal likelihood; and $p(M_\gamma)$ denotes prior model probability. The marginal likelihood is obtained in each model M_γ.

We should set the prior model probability $p(M_\gamma)$ though this study has no prior information. Ley and Steel (*31*) suggested that beta-binomial model priors can reflect non-prior information and proposed using them instead of uniform priors, in which case, the model prior is the binomial prior and the inclusion probability of each parameter is taken randomly from the beta-distribution. We use the beta-binomial model priors under the condition that the prior expected model size is 10 and that the hyperparameter on Zellner's g-prior is K^2. After 1,000 iterations for burn-in, 1,000,000 iterations were carried out for a Markov chain Monte Carlo simulation.

Estimation Results

TABLE 2 lists the estimation results of the BMA for the average growth rate of the urban rail supply in Tokyo. It lists the explanatory variables, from with the highest Posterior Inclusion Probability (PIP) to lowest PIP. The PIP of a variable is the sum of the posterior model probabilities for all models including that variable; that is, it is a ratio of the number of models that are expected to include the variable out of the total number of possible models. The posterior mean and SD show the average and standard deviation over the coefficient estimates that are obtained in each model. The sign certainty is the ratio of positive coefficient estimates for a variable out of all the coefficient estimates that are obtained in the models including that variable. In summary, the sum of PIPs over all explanatory variables (i.e., 81 variables) is 6.555. This implies the mean number of regressors in the models. Then, the mean number of regressors divided by the number of explanatory variables (i.e., 6.555 / 81 = 0.080) shows the average inclusion probability. This implies that the variables having a larger PIP than the average inclusion probability may be more robustly related to the dependent variable. The data in TABLE 2 shows that 12 variables have PIPs higher than the average.

TABLE 2 shows that 96.0%, 86.1%, and 14.5% of all possible models include the urban rail ridership, bus/tram travel speed, and urban rail travel speed, respectively, as the explanatory variables; the table also lists the elasticities of the urban rail supply with respect to these variables: 0.18, –0.29, and –0.12, respectively. However, car ownership is not robustly related to the urban rail supply. All potential models include the share of population aged 65 years and older, and an increase in this share corresponds to a 0.38% increase in the urban rail supply.

Discussion

The results support demand-responsive investment in urban rail in two ways. On one hand, the urban rail supply in Tokyo reacted positively and directly to the urban rail ridership. This would be the direct evidence indicating the demand-driven or demand-following development of the urban rail network in Tokyo as pointed out by Yasoshima (*16*) and Yoshida (*17*). The transportation planner's view of Tokyo was simple: "the rail capacity is currently saturated and rail demand is increasing, then let's plan a new rail line" (*16*). In practice, the urban rail supply may be the most realistic and desirable to accommodate increasing urban rail demand. There was no choice but to do so, and investing in roads to accommodate the increasing urban rail demand was never in their minds. This link seems a component of positive feedback processes to the rail-orientation in Tokyo, which might be further investigated in relation to the regulation and subsidy for urban rail. This link might also relate to the topics of long-run analysis such as a path-dependence in the urban transportation market as discussed in Barter (*32*). On the other hand, the urban rail travel speed influenced the urban rail supply negatively. Further, as a negative effect of urban rail ridership on the rail travel speed is assumed in FIGURE 1, there could be a positive indirect effect of rail ridership working through the rail travel speed. This is also the demand-responsiveness of urban rail supply. It should be noted that the negative effect of the urban rail demand on rail travel speed may be significant in Tokyo, where the in-vehicle congestion leads to an increase in the dwell time at stations for getting on and off trains. The sensitive reactions of Tokyo's urban rail operators to in-vehicle congestion is frequently observed (*33*).

TABLE 2 Estimation Results for the Growth Rate (Annual Average in Ten-Year Intervals) of Urban Rail Supply

Explanatory Variable	Posterior Inclusion Probability (PIP)	Posterior Mean	Posterior SD	Sign Certainty (1: positive; 0: negative)
Share of population aged >65	1.000	0.383	0.099	1.000
Growth rate of urban rail ridership (Lag)	0.960	0.177	0.057	1.000
Growth rate of bus/tram travel speed (Lag)	0.861	–0.287	0.162	0.000
Share of manufacturing industry	0.749	0.118	0.072	0.999
Growth rate of gasoline price	0.724	–0.068	0.044	0.000
Share of employees in the population >15	0.292	0.158	0.262	1.000
Growth rate of population	0.283	0.204	0.339	0.997
Share of employees in construction industry	0.195	–0.125	0.267	0.007
Share of population aged 15–64	0.193	–0.034	0.072	0.005
Growth rate of urban rail travel speed (Lag)	0.145	–0.115	0.305	0.001
Share of employees in services industry	0.124	–0.031	0.085	0.005
Share of male population	0.083	0.123	0.438	0.990
Share of employees in wholesale & retail industry	0.014	–0.001	0.017	0.307
Growth rate of car ownership (Lag)	0.008	0.000	0.002	0.930
Share of employees in finance & insurance industry	0.005	–0.001	0.025	0.271

Note: The mean number of regressors is 6.555. The number of observation is 66. The number of explanatory variables is 81. Year-dummy variables are not listed in the table.

The results also revealed that the urban rail supply is influenced by alternative transportation modes. The urban rail supply reacted negatively to the travel speed of buses and trams. This effect was clear during the 1950–60s when the travel speeds of trams was lower in Tokyo owing to serious traffic congestion under rapid motorization. Note that the then-traffic regulation in Japan allowed cars to enter tram tracks on roads, and this considerably reduced the travel speed of trams making it almost comparable to walking speed (*34*). However, the urban rail supply is not strongly influenced by the car ownership. This means that the decision of urban rail investment was virtually independent of car availability in Tokyo. One possible reason for this is that motorization started much later than the development of the urban rail network in Tokyo. This may imply that urban rail did not follow the car, but rather, the car followed the urban rail in Tokyo. This fact was a good luck for the rail-orientation in Tokyo rather than a result of active transit-oriented planning (*5*).

The results showed that the urban rail supply correlated with exogenous factors of the urban transportation market. The urban rail supply was positively correlated with population or employment. In Tokyo, population or employment growth was accompanied by suburbanization, which resulted in an increase in the travel demand for commuting from suburban areas to the Central Business District (CBD) and a longer travel distance per capita. This led to the necessity for a faster, and higher-capacity transportation mode, which in turn led to investment in the urban rail service.

Unexpectedly, the gasoline price negatively correlated with the urban rail supply. For example, decreases in the gasoline price generally increase the car travel demand. Then, given the predicted decrease in the gasoline price, planners might predict a higher car travel demand in the planning process, based on the assumption that planners could precisely predict the gasoline price. Nevertheless, they planned even higher urban rail supply. This might not be straightforward. We here relax that assumption, which might be too strict for the gasoline price. One explanation is that the planners have predicted the future gasoline price to be higher than the price that actually realized. In actual, Japanese gasoline prices have continuously decreased over time as the overall trends. In this case, planners wrongly predicted a smaller car travel demand than the actual demand over the years. This produces an increase in urban rail supply regardless of an increase in car travel demand.

The urban rail supply is also correlated with other demographic factors. The share of the elderly positively and strongly correlated with the urban rail supply. Senior individuals are typically expected to support public-transit patronage, which might be translated into a higher predicted patronage in the planning process. Note that the share of the elderly has been increasing from 3% in 1950 to 16% in 2000. The share of employees in the manufacturing industry also positively correlated with the urban rail supply. The employment in the manufacturing industry is mainly located in one of the CBD areas and its neighboring areas in Tokyo. The larger employment in the manufacturing industry might be translated into a larger predicted patronage in the planning process through a larger predicted employment growth in the CBD. Note that in Tokyo, the share of employees in the manufacturing industry has been decreasing from 35% in 1950 to 15% in 2000.

CONCLUSION

In this study, the factors that have affected the urban rail supply in Tokyo were investigated. The results revealed the demand-response of the urban rail supply to the urban rail demand. The reaction of the urban rail supply to the bus/tram travel speed and the weak reaction to car ownership were observed. The gasoline price negatively correlated with the rail supply, while the urban growth factors, including population and employment, positively correlated with it. The results help understand a series of supply-side actions for public-transit over time conducted in transit-oriented cities.

What are major lessons from Tokyo? The experiences in Tokyo could be useful for future urban rail investment particularly in developing cities. For instance, we found that the urban rail supply in Tokyo reacted strongly to the service level of road public transit. In many large cities in developing Asian countries, the travel speed of urban bus service has deteriorated owing to escalating road congestion. This condition might be one of the best for urban rail investment, and travelers may easily switch from buses to urban rails. We also found the rail supply in Tokyo correlated with its population or employment. Population growth with suburbanization may require an investment of high-capacity, fast, and reliable transportation stocks connecting the suburban area with the central district. This also may be a good time for urban rail investment.

It is true that uncertainty is always one of risks for transportation investment. Even from the perspective of risks, however, Tokyo may not be a special case. As Watts (*35*) expressed it, the rail investment in Tokyo was not promising at the stage of investment, though it seems promising in hindsight. A notable supply-side action in Tokyo may include the policy decision of a large-scale investment in subways in 1956 (*36*). The subway supply has been rapidly increasing after this notable decision. Although now we find obviously that the decision was made at the excellent timing, some transportation planners at that time raised questions particularly about financial sustainability, wondering "[still poor] Tokyo may not financially maintain such a complete subway network" (*37*). This concern may be similar to the concerns in developing countries. How the decision-makers' perceptions of uncertainty influences the urban rail supply may be one of matters to be investigated.

Other topics for future research are summarized as follows. First, in this study, the service-kilometer was used for representing the urban rail supply, but this parameter has limitations; the service-kilometers cannot distinguish the capacity added by the construction of a new rail line and by updating the existing line from a double- to a quadruple-track. In addition, the parameter cannot represent the capacity added by improvements in the rail operating system per service-kilometer. Similarly, the supply measure is also discussed from the viewpoint of road investment (typically measured in lane-miles); however, none of the parameters actually measured the supply in terms of the true outcomes (*38*). Next, it may be an interesting topic to consider whether or not urban rail demand had a direct positive effect on urban rail supply in another city.

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