# Evaluation Method of Optimal Type of High-Speed Rail Lines in Local Regions and a Case Study for Shikoku Shinkansen, Japan

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**Abstract**: In general, it is difficult to develop the full spec high-speed rail (HSR) line in local region where population is small and transportation demand to other regions is also small. In Japan, there is a type of HSR called Mini-Shinkansen for local regions whose construction cost is low compared to the full spec HSR. We propose the method to evaluate the optimal type of HSR in a local region and connecting to other regions. The method consists of a regional econometric model, a model for estimating the number of visitors from other regions, a model for estimating interregional transportation demand of each mode and the cost-effectiveness analysis. We also adopt the method to Shikoku which is one of the four main islands of Japan and has no HSR. As a result, it is indicated that developing HSR in Shikoku is beneficial and the Mini-Shinkansen type is optimal.

*Keywords*: High-speed rail, Regional econometric model, Cost-effectiveness analysis

## 1. INTRODUCTION

Japan has a number of plans to extend or build new high-speed rail lines in the near future, including the Hokuriku Shinkansen (Kanazawa to Tsuruga) at the end of 2022, the Chuo Shinkansen (Shinagawa to Nagoya) in 2027, and the Hokkaido Shinkansen (Shin-Hakodate -Hokuto to Sapporo) in 2030. There are some types of high-speed rail lines in Japan. One is the Shinkansen line with full specification which has dedicated railway line for high-speed rail. Most of existing high-speed rail lines connecting large cities are this type. In some local areas, the Mini-Shinkansen line is adopted in which Shinkansen trains run straight through into the regular railway. The Chuo Shinkansen is using a magnetic levitation (MAGLEV) approach based on superconducting linear technology. Figure 1 shows the current high-speed rail network and future plans in Japan as well as location of Shikoku.

Shikoku is one of the mail four islands of Japan. The population of Shikoku is about 3.7 million in 2000. The master plan of the Shikoku Shinkansen which intended to connect Honshu and Shikoku with a high-speed rail connection over the Seto Ohashi (Great Seto Bridge) was laid out in 1973. However, this project has not begun by 2021. This makes Shikoku the only one of Japan’s four major islands that does not have high-speed rail and puts it increasingly behind the regions that do. The Shikoku Shinkansen, if it is built, has the potential to revitalize and re-energize the region.

Previous research analyzing the impact of high-speed rail networks includes Muto et al. (2001), who estimated changes in the modal share; Tsuchiya et al. (2009), who measured economic impacts using an SCGE model; and Sato (2015), who captured economic impacts using a regional econometric model. However, these studies did not consider the mechanism of high-speed rail networks for shortening the time required for business trips, thus making more time available for work and improving potential productivity of firms. Nor did any of them analyze both of the changes in modal share and economic impact and propose optimal type of high-speed rail lines based on the analyses.

This paper proposes the evaluation method of optimal type of high-speed rail lines in local areas. The method consists of a regional econometric model, a model for estimating the number of visitors from other regions, a model for estimating interregional transportation demand of each mode and the cost-effectiveness analysis. We also develop empirical models for the four prefectures in Shikoku. With the empirical models, we estimate the increases in visitors to the four prefectures and the increases in gross regional product of the four prefectures caused by developing two types of the Shikoku Shinkansen. We also estimate the number of passengers of each type of the Shinkansen. And we carry out the cost-effective analysis for developing each type of the Shikoku Shinkansen and indicate the optimal type.


Figure 1. Current high-speed rail network and future plans in Japan and location of Shikoku

## 2. OUTLINE OF THE EVALUATION METHOD

Figure 2 illustrates the impact of developing high-speed rail in a local region which we assume in this paper.

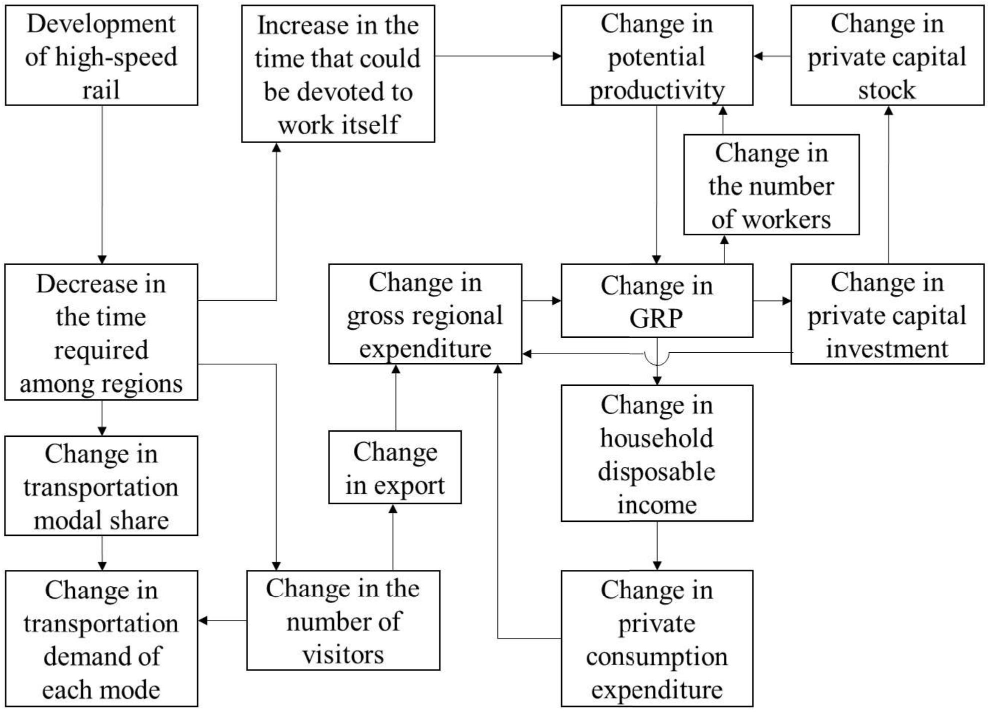


Figure 2. The impact of developing high-speed rail in a local region

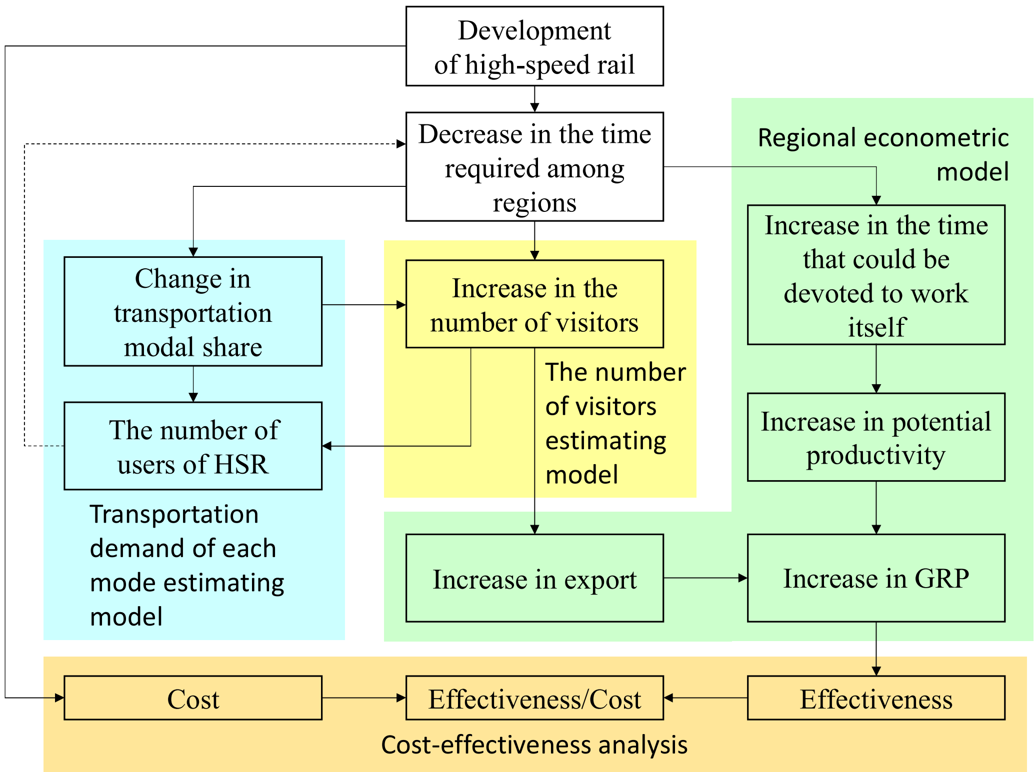


Figure 3. Outline of the evaluation method

Developing high-speed rail lines from a local region to other regions in a country would decrease the time required to travel from the region to other regions. Such a reduction would increase the time that could be devoted to work itself in the region. This would potentially improve regional productivity. Decease in the time required to travel could also lead to changes in the number of visitors to the region and transportation usage patterns into the region. In turn, this could change demand for each transportation mode. Changes in the number of visitors would derive changes in export to other regions. Changes in these could impact gross regional product (GRP). The flow from "decrease in the time required among regions" to "change in the number of visitors" is the same assumption as Sato (2015) and Sato et al. (2020). The flow from "decrease in the time required among regions" to "increase in the time that could be devoted to work itself" is the original assumption of this study. Other flows are based on general macroeconomic theory.

The evaluation method of these impacts consists of a regional econometric model, a model for estimating the number of visitors from other regions, a model for estimating interregional transportation demand of each mode and the cost-effectiveness analysis. Outline of the evaluation method is illustrated in Figure 3.

## 3. REGIONAL ECONOMETRIC MODEL

### 3.1 Theoretical Model

To illustrate the relationship between decrease in the time required to travel from the region to other regions and increase in the time that could be devoted to work itself in the region mentioned above, we offer a new production function which is expressed by Equations (1).

$$X_{r.t} = X_{r.t}\left( ROW_{r.t} \cdot KP_{r.t},\ LHR_{r.t} \cdot NW_{r.t} - \sum_{s}\sum_{m} B_{rs,m,t} T_{rs,m,t} \right) \tag{1}$$

where,

| | |
|---|---|
| $t$ | : year, |
| $r,s$ | : region, |
| $m$ | : transportation mode, |
| $X$ | : regional potential productivity, |
| $ROW$ | : the rate of capital utilization, |
| $KP$ | : private capital stock, |
| $LHR$ | : the average working hours, |
| $NW$ | : the number of workers, |
| $B_{rs}$ | : the number of business trip from r to s, and |
| $T_{rs}$ | : the time required to travel from r to s. |

Gross regional expenditure is expressed by Equation (2) considering change in export caused by increase in the number of visitors.

$$GRE_{r,t} = CP_{r,t} + IP_{r,t} + IHP_{r,t} + G_{r,t} + Z_{r,t} + NE_{r,t} + \Delta E_{r,t} \tag{2}$$

where,

| | |
|---|---|
| $GRE$ | : gross regional expenditure, |
| $CP$ | : private consumption expenditure, |
| $IP$ | : private capital investment, |

- $IHP$ : private housing investment,
- $G$ : public expenditure,
- $Z$ : increase in inventory,
- $NE$ : net export, and
- $\Delta E$ : change in export caused by increase in the number of visitors.

Change in export caused by increase in the number of visitors is expressed by Equation (3) taking account of the difference of expenditure per person between for business and sightseeing.

$$\Delta E_{r,t} = u_{r,b,t} \sum_{s} \Delta V_{sr,b,t} + u_{r,k,t} \sum_{s} \Delta V_{sr,k,t} \tag{3}$$

where,

- $b$ : business purpose,
- $k$ : sightseeing purpose,
- $u$ : expenditure per person, and
- $\Delta V$ : increase in the number of visitors.

For functions other than regional potential productivity (production function) and gross regional expenditure, we basically follow the functions of Sato (2015). Other functions are expressed by Equations (4) – (10).

$$KP_{r.t} = (1-\eta_r) KP_{r.t-1} + IP_{r.t} \tag{4}$$

$$NW_{r.t} = NW_{r.t}\left(NW_{r,t-1}, POP_{r.t}, GRP_{r,t}\right) \tag{5}$$

$$\frac{CP_{r,t}}{POP_{r,t}} = \frac{CP_{r,t}}{POP_{r,t}}\left(\frac{YH_{r,t}}{POP_{r,t}}\right) \tag{6}$$

$$YH_{r,t} = YH_{r,t}\left(GRP_{r,t}\right) \tag{7}$$

$$IP_{r.t} = IP_{r.t}\left(GRP_{r.t-1}\right) \tag{8}$$

$$IHP_{r,t} = IHP_{r,t}\left(POP_{r,t}, YH_{r,t}\right) \tag{9}$$

$$GRP_{r,t} = GRP_{r,t}\left(X_{r,t}, GRE_t\right) \tag{10}$$

where,

- $\eta$ : depreciation rate of private capital stock,
- $POP$ : population,
- $YH$ : household disposable income, and
- $GRP$ : realized gross regional product.

### 3.2 Empirical Model for Shikoku

We constructed the empirical models for four prefectures in Shikoku (Tokushima, Kagawa, Ehime and Kochi) based on the theoretical model. To estimate the parameters of each function, we gathered time series data of the four prefectures in Shikoku for all variables in Equations (1) – (10). As for economic data, we used published data of the economic and fiscal model (Cabinet Office of Japan) for the period 1980–2015. Data of the number of business trip among regions in each year were collected from the Inter-Regional Travel Survey in Japan (Ministry of Land, Infrastructure, Transport and Tourism: MLIT). Data of the time required to travel among regions in each year were calculated using the National Integrated Transport Analysis System (MLIT).

As Maddala (1992) shows, estimation of parameters for each function using time series data requires that data of the explained variable and all explanatory variables are stationary. Therefore, after validating the stationarity of the data using the Augmented Dickey–Fuller (ADF) test, we carried out the estimations with ordinary least squares method (OLS). If the original time series data of all variables are not stationary and the 1st difference data of all variables are stationary, we use the equation with 1st difference variables for each function and each prefecture.

Table 1–7 show the results of parameter estimations of each function for each prefecture. In the tables, the figures in parentheses indicate the t values. ** indicates significance at 1% level and * indicates at 10% level. "d_" accompanied with a variable in each equation indicates taking 1st difference.

Table 1. Parameter estimation results of Equation (1)’

| Prefecture | $\alpha$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | $\alpha_4$ | $\beta$ | Ad-$R^2$ | D.W. | Estimation period |
|---|---|---|---|---|---|---|---|---|---|
| Tokushima | -1.1790<br>(-1.049) | -0.0608<br>(-5.082**) | 0.0381<br>(2.757**) | | | 0.8957<br>(6.847**) | 0.9154 | 2.5909 | 2005-2015 |
| Kagawa | -4.4239<br>(-12.754) | 0.0967<br>(3.757**) | 0.0885<br>(3.465**) | 0.0742<br>(2.880**) | 0.0694<br>(2.666**) | 0.5213<br>(13.273**) | 0.9237 | 1.7125 | 1991-2015 |
| Ehime | -4.6756<br>(-16.799) | -0.0566<br>(-3.096**) | | | | 0.5040<br>(15.774**) | 0.9116 | 1.9092 | 1991-2015 |
| Kochi | -4.3528<br>(-9.317) | -0.0407<br>(-2.369*) | -0.0550<br>(-4.755**) | 0.0596<br>(5.515**) | | 0.5324<br>(10.268**) | 0.9228 | 1.5801 | 1995-2015 |

$$\frac{X_{r.t}}{LHR_{r.t}\cdot NW_{r.t}-\sum_s\sum_m B_{rs,m,t}T_{rs,m,t}}=\alpha_r+\sum_i\alpha_{i,r}D_{i,r}+\beta_r\frac{ROW_{r.t}\cdot KP_{r.t}}{LHR_{r.t}\cdot NW_{r.t}-\sum_s\sum_m B_{rs,m,t}T_{rs,m,t}} \qquad (1)’$$

where,

$D_1$ : 1 in 2006-2008 and 0 in other years for Tokushima, 1 in 2011 and 0 in other years for Kagawa, 1 in 2008-2009 and 0 in other years for Ehime, 1 in 1997 and 0 in other years for Kochi,

$D_2$ : 1 in 2010-2011 and 0 in other years for Tokushima, 1 in 2012 and 0 in other years for Kagawa, 1 in 2006-2008 and 0 in other years for Kochi,

$D_3$ : 1 in 2013 and 0 in other years for Kagawa, 1 in 2013-2015 and 0 in other years for Kochi, and

$D_4$ : 1 in 2015 and 0 in other years for Kagawa.

Table 2. Parameter estimation results of Equation (4)’

| Prefecture | $\beta$ | Ad-$R^2$ | D.W. | Estimation period |
|---|---|---|---|---|
| Tokushima | 0.8936 (310.447**) | 0.9421 | 2.4666 | 2000-2016 |
| Kagawa | 0.9064 (412.305**) | 0.9932 | 0.5664 | 1981-2016 |
| Ehime | 0.9165 (392.495**) | 0.9927 | 0.4138 | 1981-2016 |
| Kochi | 0.8961 (449.324**) | 0.9670 | 0.5268 | 2006-2016 |

$$KP_{r.t} - IP_{r.t} = \beta_r KP_{r.t-1} \quad (4)’$$

Table 3. Parameter estimation results of Equations (5)’ and (5)”

| Prefecture | $\alpha$ | $\alpha_1$ | $\alpha_2$ | $\beta$ | $\gamma$ | $\delta$ | Ad-$R^2$ | D.W. | Equation | Estimation period |
|---|---|---|---|---|---|---|---|---|---|---|
| Tokushima | 45,134.90 (5.128) | | | 0.4972 (7.014**) | 0.1810 (4.587**) | | 0.9951 | 1.7338 | (5)' | 2006-2015 |
| Kagawa | -846.31 (-1.015) | 4,081.03 (1.258) | 4,927.14 (1.513*) | | 0.4766 (2.907**) | 0.0220 (3.533**) | 0.4344 | 1.0581 | (5)" | 1986-2016 |
| Ehime | -2,139.92 (-2.026) | | | 0.3179 (2.008*) | | 0.0128 (1.809*) | 0.1651 | 2.1200 | (5)" | 1982-2016 |
| Kochi | -38,953.37 (-1.061) | | | 0.6009 (2.548*) | 0.2444 (1.598*) | | 0.9543 | 1.6917 | (5)' | 2000-2015 |

$$NW_{r.t} = \alpha_r + \beta_r NW_{r,t-1} + \gamma_r POP_{r.t} + \delta_r GRP_{r,t} \quad (5)’$$

$$d\_NW_{r.t} = \alpha_r + \sum_i \alpha_{i,r} D_{i,r} + \beta_r d\_NW_{r,t-1} + \gamma_r d\_POP_{r.t} + \delta_r d\_GRP_{r,t} \quad (5)”$$

where,

$D_1$ : 1 in 2014 and 0 in other years for Kagawa, and
$D_2$ : 1 in 2015 and 0 in other years for Kagawa.

Table 4. Parameter estimation results of Equation (6)”

| Prefecture | $\alpha$ | $\alpha_1$ | $\alpha_2$ | $\beta$ | Ad-$R^2$ | D.W. | Estimation period |
|---|---|---|---|---|---|---|---|
| Tokushima | 0.0086 (0.633) | | | 0.2266 (1.561*) | 0.1522 | 1.9766 | 2007-2015 |
| Kagawa | | | | 0.2195 (1.836*) | 0.2784 | 2.1912 | 2007-2015 |
| Ehime | | 0.0988 (3.331**) | | 0.2979 (3.392**) | 0.5080 | 2.7755 | 2007-2016 |
| Kochi | -0.0159 (-1.921) | 0.1220 (5.224**) | -0.1618 (-6.817**) | 0.5296 (10.184**) | 0.9641 | 1.6962 | 2007-2015 |

$$\mathrm{d}\_\frac{CP_{r,t}}{POP_{r,t}} = \alpha_r + \sum_i \alpha_{i,r} D_{i,r} + \beta_r \mathrm{d}\_\frac{YH_{r,t}}{POP_{r,t}} \qquad (6)''$$

where,

$D_1$ : 1 in 2012 and 0 in other years for Ehime and Kochi, and

$D_2$ : 1 in 2014 and 0 in other years for Kochi.

Table 5. Parameter estimation results of Equations (7)' and (7)"

| Prefecture | $\beta$ | Ad-$R^2$ | D.W. | Equation | Estimation period |
|---|---|---|---|---|---|
| Tokushima | 0.7317 (254.353**) | 0.8365 | 1.2570 | (7)" | 2006-2016 |
| Kagawa | 0.7483 (106.152**) | 0.9990 | 1.9136 | (7)' | 2006-2016 |
| Ehime | 0.7168 (380.471**) | 0.9315 | 1.3011 | (7)' | 2006-2016 |
| Kochi | 0.7651 (348.645**) | 0.8707 | 1.4357 | (7)' | 2006-2016 |

$$YH_{r,t} = \beta_r GRP_{r,t} \qquad (7)'$$

$$\mathrm{d}\_YH_{r,t} = \beta_r \mathrm{d}\_GRP_{r,t} \qquad (7)''$$

Table 6. Parameter estimation results of Equations (8)' and (8)"

| Prefecture | $\alpha$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | $\alpha_4$ | $\alpha_5$ | $\alpha_6$ | $\beta$ |
|---|---|---|---|---|---|---|---|---|
| Tokushima | 1,553.9 (0.104) | | | | | | | 0.2876 (1.167*) |
| Kagawa | 3,784.1 (0.818) | | | | | | | 0.1241 (2.558**) |
| Ehime | -174,949.2 (-3.710) | 56,954.4 (3.492**) | -87,452.0 (-2.532**) | 88,353.6 (4.213**) | 84,502.2 (2.467**) | 71,135.1 (2.080*) | 93,389.0 (2.721**) | 0.1709 (16.036**) |
| Kochi | 3,273.2 (2.497) | 8,288.0 (3.047*) | -13,147.7 (-5.337**) | 6,604.0 (2.508*) | 19,958.3 (4.808**) | -13,249.6 (-4.853**) | | 0.2045 (5.688**) |

| Prefecture | Ad-$R^2$ | D.W. | Equation | Estimation period |
|---|---|---|---|---|
| Tokushima | 0.1933 | 2.6606 | (8)" | 2006-2016 |
| Kagawa | 0.1402 | 1.6147 | (8)" | 1982-2016 |
| Ehime | 0.9120 | 1.7247 | (8)' | 1981-2016 |
| Kochi | 0.9705 | 2.0156 | (8)" | 2006-2016 |

$$IP_{r,t} = \alpha_r + \sum_i \alpha_{i,r} D_{i,r} + \beta_r GRP_{r,t-1} \qquad (8)'$$

$$d\_IP_{r.t} = \alpha_r + \sum_i \alpha_{i,r} D_{i,r} + \beta_r d\_GRP_{r.t-1} \quad (8)”$$

where,

$D_1$ : 1 in 1986-1991 and 0 in other years for Ehime, 1 in 2006 and 0 in other years for Kochi,

$D_2$ : 1 in 1999 and 0 in other years for Ehime, 1 in 2010-2011 and 0 in other years for Kochi,

$D_3$ : 1 in 2006-2008 and 0 in other years for Ehime, 1 in 2012 and 0 in other years for Kochi,

$D_4$ : 1 in 2011 and 0 in other years for Ehime, 1 in 2013 and 0 in other years for Kochi,

$D_5$ : 1 in 2013 and 0 in other years for Ehime, 1 in 2016 and 0 in other years for Kochi, and

$D_6$ : 1 in 2016 and 0 in other years for Ehime.

Table 7. Parameter estimation results of Equations (9)’ and (9)”

| Prefecture | $\alpha$ | $\alpha_1$ | $\alpha_2$ | $\alpha_3$ | $\alpha_4$ | $\alpha_5$ | $\alpha_6$ | $\beta$ |
|---|---|---|---|---|---|---|---|---|
| Tokushima | -0.0048<br>(-1.368) | | | | | | | 0.0537<br>(1.440*) |
| Kagawa | | 55,155.6<br>(8.919**) | 29,973.3<br>(2.602**) | 28,187.5<br>(2.449*) | 25,687.7<br>(2.232*) | -27,346.7<br>(-4.849**) | -18,558.7<br>(-1.637*) | 0.2331<br>(37.046**) |
| Ehime | -892,323<br>(-7.203) | 48,347.0<br>(5.317**) | -27,200.5<br>(-3.206**) | 14,173.1<br>(0.894) | | | | 0.7265<br>(8.570**) |
| Kochi | -126,244.2<br>(-3.583) | 16,066.1<br>(5.286**) | -9,175.9<br>(-5.207**) | 6,407.9<br>(2.442*) | | | | 0.2407<br>(5.159**) |

| Prefecture | Ad-$R^2$ | D.W. | Equation | Estimation period |
|---|---|---|---|---|
| Tokushima | 0.1184 | 1.5722 | (9)" | 2007-2015 |
| Kagawa | 0.9172 | 2.0347 | (9)' | 1992-2015 |
| Ehime | 0.9077 | 2.3058 | (9)' | 1992-2016 |
| Kochi | 0.9468 | 2.2554 | (9)' | 2006-2015 |

$$IHP_{r,t} = \alpha_r + \sum_i \alpha_{i,r} D_{i,r} + \beta_r POP_{r,t} \quad (9)’$$

$$d\_\frac{IHP_{r,t}}{POP_{r,t}} = \alpha_r + d\_\frac{YH_{r,t}}{POP_{r,t}} \quad (9)”$$

where,

$D_1$ : 1 in 1992-1996 and 0 in other years for Kagawa, 1 in 1993-1996 and 0 in other years for Ehime, 1 in 2006 and 0 in other years for Kochi,

$D_2$ : 1 in 1997 and 0 in other years for Kagawa, 1 in 2008-2011 and 0 in other years for Ehime, 1 in 2009-2011 and 0 in other years for Kochi,

$D_3$ : 1 in 1999 and 0 in other years for Kagawa, 1 in 2013 and 0 in other years for Ehime, 1 in 2013 and 0 in other years for Kochi,

$D_4$ : 1 in 2000 and 0 in other years for Kagawa,
$D_5$ : 1 in 2007-2012 and 0 in other years for Kagawa, and
$D_6$ : 1 in 2014 and 0 in other years for Kagawa.

Value of D.W. (Durbin-Watson ratio) for each function and each prefecture except for Equation (4)' which is larger than 1.0 and less than 3.0 indicates that series correlation of error terms in each estimated equation is very small. Although values of D.W. for Equation (4)' for Kagawa, Ehime and Kochi prefectures are less than 1.0, we use these estimated equations because Equation (4)' is the definition function of private capital stock.

The mean absolute percentage error (MAPE) for actual values and the estimates of gross regional product using all functions for which parameters were estimated for the period 1981–2015 became 1.25% for Tokushima, 1.33% for Kagawa, 1.33% for Ehime, and 2.60% for Kochi.

## 4. THE NUMBER OF VISITORS ESTIMATING MODEL

We assume that the number of visitors for business into a region is affected by the number of workers in origin region and generalized cost from origin to the region, while the number of visitors for sightseeing into a region is affected by population in origin region and generalized cost from origin to the region with reference to the gravity model. The model for estimating the number of visitors is expressed by Equations (11) – (13). Equation (11) indicates that the more workers in origin region, the more the number of visitors for business from the origin. Equation (12) indicates that the more population in origin region, the more the number of visitors for sightseeing from the origin. Equations (11) and (12) also indicate that the less generalized cost from the origin to the region, the more the number of visitors from the origin.

$$\ln V_{b,sr} = \alpha_b + \beta_b \ln NW_s + \gamma_b \ln GC_{sr} + \sum_q \delta_{b,q} D_q \tag{11}$$

$$\ln V_{k,sr} = \alpha_k + \beta_k \ln POP_s + \gamma_k \ln GC_{sr} + \sum_q \delta_{b,q} D_q \tag{12}$$

$$GC_{sr} = F_{sr} + w_s T_{sr} \tag{13}$$

where,

$V_{sr}$ : the number of visitors from $s$ to $r$,
$GC$ : generalized cost,
$D_q$ : region $q$ dummy variable (1 for region $q$ and 0 for other regions),
$F$ : fare amount,
$w$ : value of time, and
$T$ : the time required to travel.

We take the prefectures in Shikoku as destinations, and the other 46 prefectures in Japan are points of departure to estimate parameters of Equations (11) and (12). Parameter estimations of Equations are conducted with ordinary least squares method (OLS). Table 8 shows the result of parameter estimations of Equations (11) and (12).

Table 8. Parameter estimation results of Equations (11) and (12)

| Prefecture | Purpose | $\alpha$ | $\beta$ | $\gamma$ | Ad-$R^2$ |
|---|---|---|---|---|---|
| Tokushima | Business | 12.5498<br>(5.787) | 1.1552<br>(9.686**) | -1.8752<br>(-10.414**) | 0.9622 |
| | Sightseeing | 16.2432<br>(5.876) | 1.0574<br>(8.542**) | -2.1040<br>(-11.514**) | 0.9486 |
| Kagawa | Business | 0.8598<br>(0.422) | 1.6748<br>(17.577**) | -1.4370<br>(-10.083**) | 0.9711 |
| | Sightseeing | 14.7970<br>(5.337) | 0.4669<br>(3.140**) | -1.2667<br>(-4.964**) | 0.9343 |
| Ehime | Business | 5.8506<br>(3.081) | 0.6032<br>(7.649**) | -0.4976<br>(-2.671**) | 0.9705 |
| | Sightseeing | 3.3877<br>(0.794) | 1.2793<br>(8.455**) | -1.2046<br>(-3.748**) | 0.8669 |
| Kochi | Business | 3.9021<br>(0.921) | 1.0062<br>(6.458**) | -0.9006<br>(-2.389*) | 0.9140 |
| | Sightseeing | 20.4488<br>(7.946) | 0.5429<br>(3.923**) | -1.9228<br>(-7.633**) | 0.9568 |

Note: The figures in parentheses indicate the t value.
** indicates signficance at 1% level and * indicates signficance at 10% level.
Parameters of region dummy variables are ommited.

## 5. TRANSPORTATION DEMAND OF EACH MODE ESTIMATING MODEL

Transportation demand of each transportation mode between regions is expressed with the product of transportation demand of all modes and each modal share. It is expressed by Equation (14). Each transportation modal share is expressed with the logit model like Equations (15) – (16).

$$Q_{sr,m} = Q_{sr} P_{sr,m} \tag{14}$$

$$P_{sr,m} = \frac{\exp\left(V_{sr,m}\right)}{\sum_{m} \exp\left(V_{sr,m}\right)} \tag{15}$$

$$V_{sr,m} = \alpha + \beta T_{sr,m} + \gamma F_{sr,m} + \delta L_{sr,m} + \varphi N_{sr,m} + \mu D_{700,sr} + \theta D_{1000,sr} + \sum_{s,r} \zeta_{sr} D_{sr} \tag{16}$$

where,

$Q_{sr}$ : transportation demand from $s$ to $r$,
$P$ : modal share,
$V$ : partial utility,
$L$ : the time of line haul transport,
$N$ : the number of transfers in line haul transport,
$D_{700}$ : 700 km dummy variable (1 for regions pair more than 700 km apart and 0 for other regions pairs),
$D_{1000}$ : 1000 km dummy variable (1 for regions pair more than 1000 km apart and 0 for other regions pairs), and

$D_{sr}$ : regions pair dummy variable (1 for specific regions pair and 0 for other regions pairs).

Here, we consider travel by air and by rail. We estimated parameters of Equation (16) using all prefectures pairs in Japan, both of which have high-speed rail stations and are at least 500 km apart as the origin and destination locations. Table 9 shows the result of parameter estimations of Equations (16).

Table 9. Parameter estimation results of Equation (16)

| $\alpha$ | $\beta$ | $\gamma$ | $\delta$ | $\varphi$ | $\mu$ | $\theta$ | $R^2$ |
|---|---|---|---|---|---|---|---|
| -2.9463<br>(-14.731) | -0.0298<br>(-3.023**) | -0.2580<br>(-6.996**) | -0.0321<br>(-1.552*) | -0.2566<br>(-4.893**) | 1.4275<br>(9.722**) | 3.3261<br>(23.024**) | 0.8098 |

Note: The figures in parentheses indicate the t value.
** indicates signficance at 1% level and * indicates signficance at 10% level.
Parameters of regions pair dummy variables are ommited.

## 6. SIMULATION ANALYSIS AND OPTIMAL TYPE OF SHIKOKU SHINKANSEN

### 6.1 Outline of Simulation Analysis

We assume that the Shikoku Shinkansen which connect Okayama on the existing network of HSR (Sanyo Shinkansen) to capital cities of the four prefectures in Shikoku (Tokushima, Takamatsu, Matsuyama and Kochi) will be open to the public in 2035. Figure 4 illustrates the assumed network of the Shikoku Shinkansen.

We carry out simulation analyses with the empirical models we constructed and cost-effectiveness analyses for two types of new HSR; the Shinkansen with full specification and the Mini-Shinkansen. Data of decreases in the time required from Shin-Osaka to capital cities of the four prefectures in Shikoku and among four capital cities due to introduction of the Shinkansen with full specification are open to the public by the Developing Shikoku Shinkansen Promotion Office. As for the Mini-Shinkansen which is a small-scale bullet train running on both of a Shinkansen line and a conventional railway line, in general, speed-up on a conventional railway line cannot be expected. Here, we assume that decreases in the time required from Shin-Osaka and other cities outside Shikoku to capital cities of the four prefectures in Shikoku are the same as the transfer time from Sanyo Shinkansen to the existing limited express at Okayama station. And we also assume that decreases in the time required among four capital cities in Shikoku equal 0. Table 10 indicates decreases in the time required due to introduction of two types of new HSR.

In simulation analysis with the regional econometric model, we do not measure flow effects during construction. In cost-effectiveness analyses, we use the discounted present value of increase in gross regional product for 40 years after opening as effectiveness. And we use the discounted present value of construction cost, increases in maintenance costs of railways and cable ways and operation cost of trains compared to the existing lines as cost. As for construction cost, we use one-third of the actual cost which four prefectures in shikoku should cover based on the Japanese cost sharing system for Shinkansen in local region. We assume that increase in maintenance cost and operation cost compared to the existing lines of Mini-Shinkansen equals 0 because Mini-Shinkansen will be running on conventional railway lines in Shikoku.

Table 11 indicates the simulation cases and each cost per km of each type.

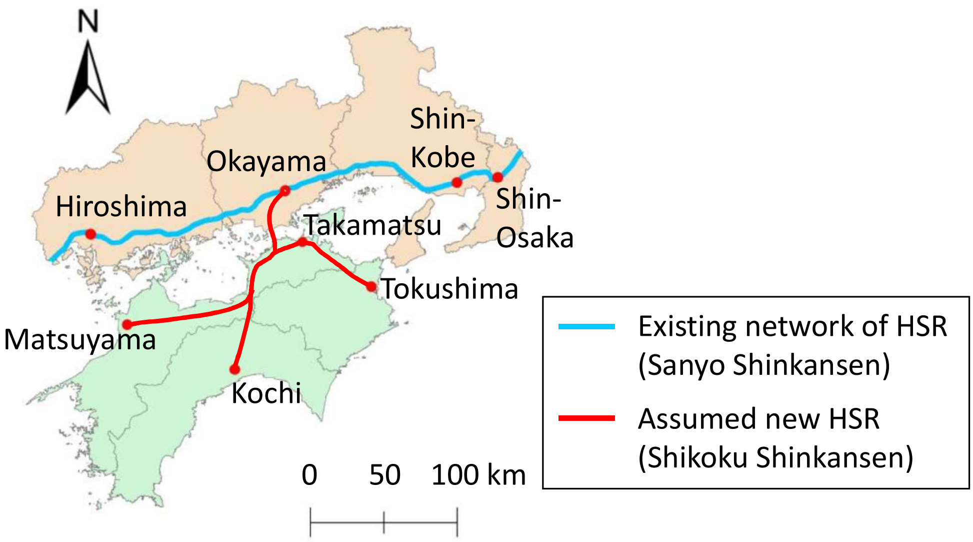


Figure 4. Assumed network of the Shikoku Shinkansen (New high-speed rail)

Table 10. Decreases in the time required due to introduction of two types of new HSR

(min)

| Origin | Destination | Type of HSR | |
|---|---|---|---|
| | | Shinkansen with full specification | Mini-Shinkansen |
| Capital cities outside Shikoku (Via Okayama) | Tokushima | 78 | 42 |
| | Takamatsu | 29 | 27 |
| | Matsuyama | 112 | 42 |
| | Kochi | 104 | 42 |
| Tokushima | Takamatsu | 39 | 0 |
| Tokushima | Matsuyama | 145 | 0 |
| Tokushima | Kochi | 143 | 0 |
| Takamatsu | Matsuyama | 100 | 0 |
| Takamatsu | Kochi | 96 | 0 |
| Matsuyama | Kochi | 193 | 0 |

Table 11. The simulation cases and cost per km of each type

| | | Construction cost (million yen / km) | Increase in maintenace and operation costs (thousand yen / km / year) | | |
|---|---|---|---|---|---|
| | | | Maintenace of railways | Maintenace of cable ways | Operation of trains |
| Case 0 | BAU (without new HSR) | - | - | - | - |
| Case 1 | Developing the Shinkansen with full specification | 1,689 | 1,894 | 873 | 5,835 |
| Case 2 | Developing the Mini-Shinkansen | 274 | 0 | 0 | 0 |

### 6.2 Result of Simulation Analysis

We can simulate time series change in economic variables of each prefecture in Shikoku such as gross regional product in each case using the empirical regional econometric model and the number of visitors estimating model. Table 12 shows estimated gross regional product in the future in each case.

The number of visitors into the four prefectures in Shikoku by train can be calculated with the parameter estimated models for estimating the number of visitors and estimating transportation demand of each mode. Table 13 shows the number of visitors into each prefecture by train after 2035 in each case.

Table 12. Estimated gross regional product in the future

(million yen)

| | Tokushima | | | Kagawa | | |
|---|---|---|---|---|---|---|
| | Case 0 | Case 1 | Case 2 | Case 0 | Case 1 | Case 2 |
| 2020 | 3,413,385 | 3,413,385 | 3,413,385 | 3,734,364 | 3,734,364 | 3,734,364 |
| 2035 | 4,101,849 | 4,108,829 | 4,102,719 | 3,742,235 | 3,746,722 | 3,744,262 |
| 2040 | 4,328,429 | 4,340,169 | 4,329,897 | 3,694,676 | 3,700,473 | 3,697,310 |
| 2045 | 4,548,060 | 4,564,197 | 4,550,085 | 3,636,596 | 3,642,800 | 3,639,429 |

| | Ehime | | | Kochi | | |
|---|---|---|---|---|---|---|
| | Case 0 | Case 1 | Case 2 | Case 0 | Case 1 | Case 2 |
| 2020 | 4,636,961 | 4,636,961 | 4,636,961 | 2,171,403 | 2,171,403 | 2,171,403 |
| 2035 | 4,092,688 | 4,102,900 | 4,093,877 | 1,917,228 | 1,921,213 | 1,917,438 |
| 2040 | 3,884,412 | 3,897,532 | 3,885,939 | 1,825,422 | 1,830,866 | 1,825,712 |
| 2045 | 3,670,962 | 3,684,890 | 3,672,582 | 1,730,450 | 1,736,764 | 1,730,791 |

Table 13. The number of visitors into each prefecture by train after 2035

(thousand / year)

| | Case 0 | Case 1 | Case 2 |
|---|---|---|---|
| Tokushima | 141.3 | 2,184.0 | 465.4 |
| Kagawa | 545.7 | 1,635.7 | 1,129.4 |
| Ehime | 372.9 | 1,848.5 | 778.6 |
| Kochi | 49.1 | 1,792.4 | 174.3 |
| Total | 1,108.9 | 7,460.6 | 2,547.8 |

### 6.3 Result of Cost-Effectiveness Analysis and Optimal Type of Shikoku Shinkansen

Table 14 shows the discounted present values of increases in gross regional product caused by developing the Shikoku Shinkansen of each type for 40 years after opening (from 2035 to 2075). Here, we set the base year 2020 and discount rate 4%.

With the total discounted present value of increase in gross regional product, construction cost, increase in maintenance costs and operation cost, we conducted cost-effectiveness analyses for each type of the Shinkansen. Each cost is calculated with the product of each cost per km shown in Table 11 and total length of Shikoku Shinkansen (302km). Table 15 shows the result of cost-effectiveness analysis for each Shinkansen type.

Table 14. The discounted present values of increases in GRP by developing the Shikoku Shinkansen

(million yen)

| Tokushima | | Kagawa | | Ehime | | Kochi | |
|---|---|---|---|---|---|---|---|
| Case 1 - Case 0 | Case 2 - Case 0 | Case 1 - Case 0 | Case 2 - Case 0 | Case 1 - Case 0 | Case 2 - Case 0 | Case 1 - Case 0 | Case 2 - Case 0 |
| 162,140 | 20,325 | 68,721 | 31,312 | 154,815 | 18,011 | 67,602 | 3,633 |

Table 15. The results of cost-effectiveness analyses

(million yen)

| | The Shinkansen with full specification | The Mini-Shinkansen |
|---|---|---|
| Incease in gross regional product | 453,277 | 73,281 |
| Construction cost | 353,595 | 57,318 |
| Incease in maintenance and operation cost | 32,811 | 0 |
| Effect / Cost | 1.173 | 1.279 |

The results suggest that building the Shikoku Shinkansen with the Mini-Shinkansen type would be the optimal solution for a new high-speed rail system between Honshu and Shikoku and among capital cities in Shikoku.

## 7. CONCLUSION

This paper proposed the method to evaluate the optimal type of high-speed rail (HSR) line in a local region whose population is small and transportation demand is also small. The method consists of a regional econometric model, a model for estimating the number of visitors from other regions, a model for estimating interregional transportation demand of each mode and the cost-effectiveness analysis.

We also adopted the method to Shikoku which is one of the four main islands of Japan and has no HSR, estimated the impact of developing the Shikoku Shinkansen on regional economy and the number of rail passengers and carried out the cost-effectiveness analyses for two types of HSR. Our analyses indicate that any type of HSR would increase the number of rail passengers and boost gross regional product in all the prefectures in Shikoku. Our cost-effectiveness analyses suggest that if a Shikoku Shinkansen is to be built, the Mini-Shinkansen type would be optimal.

When we evaluate developing a new transportation, in general, it is necessary to conduct sensitivity analysis for number of uses, construction cost, etc. The sensitivity analyses for the cost-effectiveness analyses of two types of new HSR in Shikoku are our future work. The future challenge also includes evaluation of other HSRs under planning in local regions in Asian countries with our evaluation method.

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