EFFECT OF HIGH-SPEED RAIL DEVELOPMENT ON THE PROGRESS OF REGIONAL ECONOMY

Xuesong FENG
Research Fellow
Graduate School of Environmental Studies, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
Fax: +81-52-789-1454
E-mail: charles.x.feng@gmail.com

Quan YUAN
Master Student
Graduate School of Environmental Studies, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
Fax: +81-52-789-1454
E-mail: yuanquan0127@hotmail.com

Peng JIA
Research Fellow
Graduate School of Environmental Studies, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
Fax: +81-52-789-1454
E-mail: jiapeng1979@gmail.com

Yoshitsugu HAYASHI
Professor
Graduate School of Environmental Studies, Nagoya University
Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan
Fax: +81-52-789-1454
E-mail: yhayashi@genv.nagoya-u.ac.jp

Abstract: Considering system efficiency and spatial interdependence, this study proposes an analysis approach to study the effect of High-Speed Rail (HSR) development on regional economy, by utilizing the development cases of the Japanese Shinkansen. The stochastic frontier analysis and spatial auto-regressive study are applied in this research. It is confirmed that the proposed approach can make rationally accurate explorations of HSR development’s impact on regional economy. It is found that HSR development will improve the economy of each city along HSR line, and the more the city’s travel impedance to the nearest HSR station decreases, the more its economic progress is distinct. However, the proportions of the contributions to regional economy from the cities originally near to HSR stations decrease in comparison to the increase of the contribution shares of the cities which HSR lines newly extend to.

Key Words: High-Speed Rail, Regional Economy, Stochastic Frontier Analysis, Spatial Auto-Regressive, Shinkansen

1. INTRODUCTION

To date, much attention has been paid to the development of High-Speed Rail (HSR) as an efficient and sustainable transport mode (Arduin and Ni, 2005) with comprehensive spatial and social-economic impacts on regional development (Banister and Berechman, 2001; Blum, et al., 1997; Bonnafous, 1987; Froidh, 2005; Vickerman, 1997). However, though has been frequently being asked, it has never been fairly answered in theoretically precise manners that e.g. in what exact degree constructing some HSR line contributes to the economic growths of the cities in the region along the HSR line. It is argued that system efficiency study in support
of convincing theories to analyze the HSR effect in spatial viewpoint is indispensable in the decision-making process of HSR development especially for the benefit of regional economy (Banister and Berechman, 2001; Garmendia, et al., 2008; Sasaki, et al, 1997). Therefore, this paper proposes a study approach with system efficiency analysis in consideration of spatial effect to explore regional-wide economic impacts of HSR development, which is explained by utilizing the Shinkansen development cases in Japan, with its application accuracy computationally proved.

As for the analysis of system efficiency, Stochastic Frontier Analysis (SFA) (Kumbhakar and Lovell, 2000) and Data Envelopment Analysis (DEA) (Ray, 2004) are two dominating tools. The DEA can calculate the efficiency even in case of very small sample size, but the calculation results are very sensitive to the set of input variables; in contrast, SFA has an advantage of allowing for random shocks and measurement errors, also with the assumption of specific statistical distribution of both random shocks and error terms (Cullinanea, 2006; Liao, et al., 2007; Worthington, 2001). As a result, SFA is adopted in this research and integrated into the Spatial Auto-Reggressive (SAR) study (Anselin, 1988; Getis, et al., 2004) to investigate the effect of HSR development on both systematic and spatial perspectives of regional economy. The following parts of this paper are organized as follows. Section 2 explains the framework of the proposed analysis approach with the application of SFA and SAR study. Next, the SFA and SAR models established to be applied in the proposed approach is estimated with the software Stata 9.0 in Section 3. Then, the effect of HSR development on regional economy is analyzed by making use of the cases of the Shinkansen development in Japan in Session 4, with the application of the SFA and SAR models estimated in Section 3. Finally, Session 5 summarizes the findings and points out the future research issues.

### 2. PROPOSED ANALYSIS APPROACH

Despite the apparent multitude of factors influencing the performance of regional economy, the Travel Impedance to the nearest HSR station (Vickerman, 1998; Vickerman, et al., 1999) is acknowledged to be one of the key elements to make a crucial effect on the economic prosperity of each city in a certain region with a HSR line passing through. Any change of such travel impedance of some city will first directly influence the frontier of this city’s urban economic product which will systematically decide the product outcome, as explained by the SFA model shown in equation (1) from an output-oriented perspective (Kumbhakar and Lovell, 2000).

\[
\ln y = \beta_0 + \beta_1 \ln TI + \sum_k \beta_k \ln x_k + \nu - u
\]  

(1)

Where,

- \( y \) : output variable, i.e. outcome of urban economic product,
- \( TI \) : travel impedance to the nearest HSR station,
$x_k$ : the $k^{th}$ input variable, e.g. number of households,
$v$ : the two-sided “noise” component,
$u$ : the nonnegative technical inefficiency component, and
$\beta_0, \beta_1, \beta_k$ : coefficients to be estimated.

Moreover, $v \sim \text{iid } \mathcal{N}(0, \sigma_v^2)$; $u \sim \text{iid exponential; } v$ and $u$ are distributed independently of each other, and of the regressors.

Because of the uncertainties of the random errors of the SFA model shown in equation (1), the value of urban economic outcome ($y$) based on the product frontier can be measured from the perspective of mathematical expectation, as shown in equation (2).

\[
\ln y = \beta_0 + \beta_1 \ln TI + \sum_k \beta_k \ln x_k - E(u)
\]

Any change of the outcome of any city’s urban economic product will spatially affect the urban economic products of all the other cities within a certain region, according to the theory of spatial autocorrelation (Anselin, 1988; Getis, et al., 2004). The outcomes of the urban economic products of all the cities within a certain region will make spatially interdependence on each other, which is explained here as the first-order SAR model (LeSage and Pace, 2009) shown in equation (3).

\[
Y = \rho W Y + \varepsilon
\]

Where, $Y$ is the $n \times 1$ vector of $y$ in equation (2) ($n$ is the number of the cities within the assumed region), and $W$ is the spatial weight matrix composed of the standardized reciprocal values of the Shortest Intercity Travel Time. The parameter $\rho$ is the SAR parameter on the dependent variables. Moreover, the error term $\varepsilon$ follows the normal statistic distribution, i.e. $\varepsilon \sim \mathcal{N}(0, \sigma^2 I)$ ($I$ is the identity matrix).

Along with the changes of urban economic products because of the above-explained systematic and spatial effect, the contributions from each city within the decided regional area to the economy of regional wide will be accordingly changed, which can be simultaneously measured by equation (4), equation (5) and equation (6) in comprehensive viewpoints.

\[
P^i = \frac{y^i}{\sum_{j=1}^{n} y^j} \times 100\%
\]

Where, $P^i$ means the percentage of the contribution to the economy of region $m$ from city $i$, and $y^i$ represents the afore-explained outcome of urban economic product of city $i$. 
\[ P_{imp}^i = \left( \frac{y_{imp}^i - y_0^i}{y_0^i} \right) \times 100\% \]  \hspace{3cm} (5)

Where, \( P_{imp}^i \) is the percentage of the improvement of urban economy of city \( i \), \( y_{imp}^i \) represents the improved outcome of urban economic product of city \( i \), and \( y_0^i \) means the original outcome of urban economic product of city \( i \).

\[ P_{imp}^m = \left( \frac{\sum_{i=1}^{m} y_{imp}^i - \sum_{i=1}^{m} y_0^i}{\sum_{i=1}^{m} y_0^i} \right) \times 100\% \]  \hspace{3cm} (6)

Where, \( P_{imp}^m \) is the percentage of the improvement of the economy of region \( m \).

3. ESTIMATION TO THE SFA AND SAR MODELS

According to the data from the works of JTBF (2005) and SBMIAC (2007), the Total Income of Urban Taxpayers (TIUT) (here representing the outcome of urban economic product) of each city is firstly studied as the dependent variable of equation (1). The explaining variable of Travel Impedance takes the product of travel time and travel cost by public travel modes from each of the more than 700 cities in Japan to the nearest stations of Shinkansen which is the longest-running HSR system in the world. Moreover, as another representation of economic prosperity, the Number of Households (Rivera-Batiz, 1988; Crampton, 1999; Luk, 1993) in each of these cities is also imported into the SFA model as another explanatory variable. Table 1 shows the results of the estimation to the SFA model and it can be seen that the statistical indices shown in this table are satisfactory.

| Variables                  | Coefficients | Std Err. | z-statistics | p>|z| |
|----------------------------|--------------|----------|--------------|-----|
| Constant                   | 1.3909 (\( \beta_0 \)) | 0.0985   | 14.12        | 0.000 |
| Travel Impedance           | -0.0327 (\( \beta_1 \)) | 0.0030   | -10.85       | 0.000 |
| Number of Households       | 1.0317 (\( \beta_2 \))  | 0.0080   | 129.26       | 0.000 |
| **Model Log-Likelihood**   |              | 196.3093 |              |     |

Next, the expected outcomes of the TIUT of each city is able to be obtained according to equation (2) and further adjusted in accordance with the mechanism of the spatial interdependence explained as the first-order SAR model shown in equation (3) estimated based on the Shortest Intercity Travel Time provided in the work of JTBF (2005). The estimation results of the SAR model described by equation (3) are reasonably and satisfactorily shown in Table 2.
### Table 2 Estimation to the first-order SAR model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>$T$-Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$</td>
<td>$3.8200e-0001$</td>
<td>2.1939</td>
</tr>
<tr>
<td>Log-Likelihood</td>
<td>71.3922</td>
<td>$R$-Squared 0.8733</td>
</tr>
</tbody>
</table>

4. ANALYSIS OF HSR DEVELOPMENT EFFECT

With the SFA and SAR modes estimated, the effect of HSR development is able to be analyzed in systematic as well as spatial manners. By referring to the development case of the Sanyo Shinkansen Line in Japan in 1970s, the accuracy of the study of HSR development’s impact on the general performance of regional economy is investigated in the first place. As the second line of the HSR system in Japan, the Sanyo Line starts from Osaka, i.e. the terminal of the Tokaido Line which is the first Shinkansen line opened in 1964 from Tokyo to Osaka for the Tokyo Olympic Games (Hatheway, et al., 2005). As shown in Figure 1, the Sanyo Line was initially put into operation in 1972 only between Osaka and Okayama (Richards, 1975) and fully opened with its extension to Fukuoka in 1975 (Kikuchi, 1988; Ohta, 1989).

![Figure 1. Development of the Sanyo Line of the Shinkansen in Japan](image_url)
In order to reflect the economic improvement of the region along the Sanyo Line before and after its extension from Okayama to Fukuoka as introduced in Figure 1, the values of the indices decided by equation (4), equation (5) and equation (6) for some main cities along this HSR line in 1970s are estimated according to the values of TIUT studied successively by equation (1), equation (2) and equation (3) based on the afore-explained variables of Travel Impedance, Number of Households and the Shortest Intercity Travel Time with their surveyed data supplied in the works of JACM (1974; 1976; 1977) and JTBF (1972; 1975). The estimation results are presented in Table 3, where the index values in parentheses are the actual results calculated directly base on the surveyed values of TIUT of these cities along the Sanyo Line in 1972 and 1975 (JACM, 1974; 1976; 1977). It is clearly shown in Table 3 that the maximum errors of the estimated values compared with their real values are smaller than 1.00%, which computationally confirms that the proposed analysis approach considering the efficiency of system frontier and the effect of spatial autocorrelation is able to roundly in reasonable accuracy explore the efficacies of HSR development to improve regional economy.

Table 3 Economic improvements of the region along the Sanyo Line from 1972 to 1975

<table>
<thead>
<tr>
<th>City</th>
<th>(P_i) 1972</th>
<th>(P_i) 1975</th>
<th>(P_{imp}) 1972</th>
<th>(P_{imp}) 1975</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osaka</td>
<td>40.3280% (40.2470%)</td>
<td>36.1549% (36.1538%)</td>
<td>39.6681% (40.2853%)</td>
<td></td>
</tr>
<tr>
<td>Kobe</td>
<td>20.6361% (20.5982%)</td>
<td>19.6978% (19.6982%)</td>
<td>48.7058% (49.3439%)</td>
<td></td>
</tr>
<tr>
<td>Okayama</td>
<td>6.1536% (6.1832%)</td>
<td>6.6016% (6.6017%)</td>
<td>67.1297% (66.7378%)</td>
<td></td>
</tr>
<tr>
<td>Hiroshima</td>
<td>9.6509% (9.6384%)</td>
<td>12.7218% (12.7217%)</td>
<td>105.3610% (106.1265%)</td>
<td></td>
</tr>
<tr>
<td>Kitakyushu</td>
<td>11.9060% (11.9833%)</td>
<td>12.4175% (12.4178%)</td>
<td>62.4818% (61.8306%)</td>
<td></td>
</tr>
<tr>
<td>Fukuoka</td>
<td>11.3253% (11.3500%)</td>
<td>12.4064% (12.4068%)</td>
<td>70.6608% (70.7084%)</td>
<td></td>
</tr>
</tbody>
</table>

\(P_{imp}\) 55.7892% (56.1677%)

With the confirmation of the application accuracy of the proposed analysis approach, it is the time to study the effect of the HSR development. Figure 2 shows all the Japanese Shinkansen lines in operation now. As shown in this figure, the first section of the Hokuriku Line from Takasaki to Nagano was opened in 1997 (Nakagawa and Hatoko, 2007) and the whole line is going to be put into operation with its successive extensions to Jōetsu, Toyama, Kanazawa, etc., in 2014 (Muro, 2009). According to the afore-estimated SFA and SAR models based on the data in 2005 (JTBF, 2005; SBMIAC, 2007), the indices defined by equation (4), equation (5) and equation (6) are calculated to forecast the general performance of the economies of some main cities in the region along the Hokuriku Line in 2014, in only the consideration of the changes of the travel impedances of these cities to the nearest Shinkansen stations. The prediction results about the development effect of the Hokuriku Shinkansen Line are shown in Table 4.

As can be concluded from the contents presented in both Table 3 and Table 4, the extensions of HSR Lines will first improve the economic performance of each city in the region along HSR lines. And the more a city’s travel impedance to the nearest HSR station is decreased, the more its economic progress is distinct. Consequently, though all the cities’ economic
products increase, the shares of the contributions to the general development of regional economy from the cities originally near to HSR stations will decrease in comparison to the increases of the contributions from the cities HSR lines newly extend to. In addition, simultaneously by referring to the illustrations in Figure 1 and Figure 2 about the changes of the transport accessibility of the cities to the nearest HSR stations, it is clearly shown that the more the transport accessibility of a city to the nearest HSR station is improved, the more its economic weight in the regional economy is increased.

Table 4 Economic improvements of the region along the Hokuriku Line from 2005 to 2014

<table>
<thead>
<tr>
<th>City</th>
<th>2005</th>
<th>2014</th>
<th>( P_{\text{imp}}^{i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takasaki</td>
<td>17.6217%</td>
<td>17.1827%</td>
<td>3.9046%</td>
</tr>
<tr>
<td>Nagano</td>
<td>20.9102%</td>
<td>18.0130%</td>
<td>3.8009%</td>
</tr>
<tr>
<td>Jōetsu</td>
<td>10.5425%</td>
<td>10.7698%</td>
<td>8.8568%</td>
</tr>
<tr>
<td>Toyama</td>
<td>23.9024%</td>
<td>24.6206%</td>
<td>9.7611%</td>
</tr>
<tr>
<td>Kanazawa</td>
<td>27.0232%</td>
<td>29.4138%</td>
<td>15.9863%</td>
</tr>
</tbody>
</table>

\( P_{\text{imp}}^{m} \) 6.5603%

Figure 2. Development of the Hokuriku Line of Shinkansen in Japan
5. CONCLUSIONS AND FUTURE RESEARCH ISSUES

With the explanation by utilizing the development cases of the Shinkansen system in Japan, this paper proposes an analysis approach to study the effect of HSR development on regional economy, in consideration of the systematic change of urban economic frontier and spatial autocorrelation of urban economic interdependence. It is computationally proved that the proposed approach can truly explore in reasonable accuracy the comprehensive impact on the regional economy owing to HSR development. It is concluded that HSR development will improve the economic performance of each city along HSR line. The more the city’s transport accessibility to the nearest HSR station is improved, the more its economic progress is able to be distinctly found. As a result, despite the increases of all the cities’ economic products, the shares of the contributions to the development of regional economy from the cities originally near to HSR stations will decrease in comparison to the increases of the contributions from the cities HSR lines newly passes through. Moreover, it is also able to be found that the more the accessibility is improved, the more its contribution to regional economy is increased. However, it is found that the spatial analysis in the proposed study approach applies only the basic spatial autocorrelation model which cannot fully explain the complicated spatial effect and need to be further improved in the future research. In addition, the proposed analysis approach should also be further applied to analyze the development effect of other HSR systems to check its applicability in general.

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