E C O N O M I C S   B U L L E T I N

Simulation Studies on the CO2 Emission Reduction Efficiency in Spatial Econometrics: A case of Japan

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Abstract

In this paper, we estimate the CO2 emission function based on the production function, taking into account the interregional spillover effect in Japan. Using the estimated result, we propose suitable means of simulation using spatial econometrics and simulate which prefecture can reduce the CO2 emission most efficiently. Our results indicate that prefectures that are located in urban areas reduce CO2 emissions more efficiently than do those located far from urban spaces.

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1 INTRODUCTION

Carbon dioxide gas (CO_2) is a cause of global warming. Since the Kyoto Protocol in 1997, the provision of rules to reduce emissions of Green House Gases (GHG), including chiefly CO_2, has been implemented in each participating signatory. These countries having confirmed the Kyoto Protocol have made efforts to reduce their levels of CO_2 emission. Japan itself has also confirmed the Kyoto Protocol and striven to attain the target CO_2 emission reduction. As far as companies are concerned, certain methods to reduce CO_2 have been introduced, for example, emission allowances, Clean Development Mechanisms (CDM) and Joint Implementation (JI), which are actively being utilized. On the other hand, on a regional level, there are also further attempts to reduce CO_2, for example, energy saving, educating citizens, handing out pamphlets and events to discuss global warming (Symposium of Society of Environmental Science (2004)). However, these attempts appear to have less impact since failure to obtain any CO_2 emission reduction in these cases does not incur any penalties.

There is another problem associated with attaining the goal of reducing CO_2 emissions by 6 percent from the level present in 1990 in Japan, despite an overall increasing trend in emissions since this time. While CO_2 emissions were recorded at 1122 million tons in 1990, they reached a total of 1249 million tons in 2002, meaning that a practical reduction of 11 percent in real terms is necessary to meet the target. It is very difficult to achieve this CO_2 emission reduction level without reducing production.

In this paper, we estimate the CO_2 emission function based on the production function, taking into account the interregional spillover effect in Japan.[1] Empirical studies have been performed using the spatial lag model (Kim, Phipps and Anselin (2003), Kakamu (2006), Kakamu, Polasek and Wago (2007) and so on), however, there are few simulation studies using spatial econometrics. In this paper, we propose simulation methods using such a method of spatial econometrics and present the results of the simulations to show which prefectures can reduce the CO_2 emission most efficiently.

The remainder of this paper is organized as follows. In the next section, we construct the CO_2 emission model taking into account the spatial lag term, while in Section 3, we estimate the spatial lag model. In Section 4, we simulate which prefecture can reduce the CO_2 emission efficiently and finally, in Section 5 we present concluding remarks.

2 MODEL

Most industries emit CO_2 during the production process, especially in manufacturing industries. For example, factory production of goods necessarily consumes a lot of electric power. Thermal power generation, using fossil fuel, involves the emission of CO_2 under the production process. Therefore, we assume that the CO_2 emission is the function of the product as follows:

$$CO_2 \equiv CO_2(Y), \tag{1}$$

where the CO_2 emission is the function of production, Y.

[1] This type of model is known as a spatial lag model.

We also assume this relation based on the studies of the Environmental Kuznets Curve. The Environmental Kuznets Curve resembles an inverted U shape when displaying the relationship between economic growth and pollution emissions (i.e., CO_2, SO_2, SPM and so on). There are many theoretical and empirical studies covering this and indeed, in many of the empirical studies, most of the contaminations support the Environmental Kuznets Curve (Panayotou (2000), Strazicich and List (2003)). However, in the case of CO_2, the quadratic term is not statistically significant, and the CO_2 is specified by the linear function of the production. Therefore, we specify the following relationship:

$$CO_2 = \gamma Y, \tag{2}$$

where γ is an unkown parameter.

We consider the production function of the prefecture under the assumption that all companies have the same production function. Most CO_2 emissions are caused by the use of capital such as the burning of fossil fuels, e.g. oil, coal, natural gas and so on. Therefore, in this paper, we specify the Romer (1986) type production function as follows:

$$Y_i = A_i K_i^{\beta}, \qquad i = 1, 2, \dots 47, \tag{3}$$

where A and K represent technological progress and capital respectively. In this model, we also assume a zero rate of population growth. [2]

Traditionally, the production of an individual region is assumed independent to all other regions. However, as mentioned by Kakamu (2006), the results of the R & D activity of the individual company or university present in one region are not confined to that region alone. Therefore, in this paper, we specify the technical progress and introduce the interregional spillover effect based on Kakamu (2006) as follows:

$$A_i = A_0 \Pi_{j \neq i} (Y_j)^{\lambda w_{ij}}, \tag{4}$$

where w_{ij} is the spatial weight[3]. We introduce the above equation into the overall Equation (4) and obtain the following equation:

$$Y_i = A_0 \Pi_{j \neq i} (Y_j)^{\lambda w_{ij}} K_i^{\beta}. \tag{5}$$

Then, when introducing Y of Equation (5) into Equation (2), we obtain the following equation:

$$\begin{aligned} CO_{2i} &= \gamma Y_i, \\ &= A_0^* \Pi_{j \neq i} (CO_{2i})^{\lambda w_{ij}} K_i^{\beta}, \end{aligned} \tag{6}$$

where $A_0^* = A_0 \times \gamma / \gamma^{\lambda \Sigma_{j \neq i} w_{ij}} (\Sigma_{j \neq i} w_{ij} = 1)$. We take a logarithm into the above equation as follows:

$$log(CO_2)_i = log(A_0^*) + \lambda \Sigma_{j \neq i} (w_{ij} log(CO_2)_i) + \beta log(K_i). \tag{7}$$

This equation is represented by the vector form as follows:

$$\mathbf{Y} = \lambda \mathbf{W} \mathbf{Y} + \mathbf{X} \beta + \mathbf{e}, \tag{8}$$

[2] We use the cross sectional data in the empirical study. Therefore, this assumption is valid.

[3] w_{ij} is a dummy variable, which is used in the field of Spatial Econometrics usually in the analysis of geographical data. If two prefectures have a common border of non-zero length, they are considered to be contiguous, and a value of 1 is assigned and 0 otherwise. See Anselin (1988) and Banerjee, Carlin and Gelfand (2003). for further details

where $\mathbf{e}$ is a disturbance vector which is assumed to be distributed as $N(\mathbf{0}, \sigma^2\mathbf{I})$. The elements of the Equation (9) are given by:

$$\mathbf{Y} = \begin{pmatrix} log(CO_2)_1 \\ \vdots \\ log(CO_2)_j \\ \vdots \\ log(CO_2)_J \end{pmatrix}, \quad \mathbf{X} = \begin{pmatrix} 1 & logK_1 \\ \vdots & \vdots \\ 1 & logK_j \\ \vdots & \vdots \\ 1 & logK_J \end{pmatrix}, \quad \beta = \begin{pmatrix} A_0 \\ \beta \end{pmatrix}, \tag{9}$$

where λ is a scalar. The model which includes the spatial lag term $\lambda\mathbf{WY}$ is called a Spatial Lag model (Anselin (1988) and Banerjee, Carlin and Gelfand (2003)).

Because the model of Equation (9) include the spatial lag term, Ordinary Least Square estimator does not become a consistent estimator. Therefore, we follow Ord (1975) and estimate the model of Equation (9) with the Maximum Likelihood estimation. We specify the disturbance term as follow:

$$\begin{aligned} \mathbf{e} &= (\mathbf{I} - \lambda\mathbf{W})\mathbf{Y} - \mathbf{X}b, \\ &= \mathbf{AY} - \mathbf{X}b. \end{aligned} \tag{10}$$

We use above form, and obtain the following likelihood function:

$$\begin{aligned} L &= |\mathbf{A}| \frac{1}{\sigma^n (2\pi)^{\frac{n}{2}}} e^{-\frac{\mathbf{e'e}}{2\sigma^2}}, \\ &= |\mathbf{A}| \frac{1}{\sigma^n (2\pi)^{n/2}} e^{-\frac{(\mathbf{AY}-\mathbf{Xb})'(\mathbf{AY}-\mathbf{Xb})}{2\sigma^2}} \end{aligned} \tag{11}$$

The log likelihood function is given by:

$$lnL = ln|\mathbf{A}| - \frac{n}{2}ln(2\pi) - \frac{n}{2}ln(\sigma^2) - \frac{1}{2\sigma^2}(\mathbf{Y'A'AY} - 2\mathbf{b'X'AY} - \mathbf{b'X'Xb}). \tag{12}$$

As we choice the parameter which maximize this log likelihood function, we can obtain the consistent estimator.

3 EMPIRICAL ANALYSIS

We used the CO_2 emission data of each prefecture calculated by Hasegawa (2004). He calculates the CO_2 emission data by multiplying the individual prefectural fuel energy from the "Input-Output Analysis" and CO_2 transformation factor. The capital data are obtained from the Census of Manufactures prepared by the Ministry of International Trade and Industry (MITI) of Japan in 1995. We use the same weight matrix with Kakamu et al. (2007).[4]

Table 1 shows the estimation result. The coefficient of the spatial lag term becomes negative and statistically significant at the 5 percent significance level. Therefore, it appears that an

[4] All except one (Okinawa) Japanese prefectures are situated on the four major islands, Hokkaido, Honshu, Shikoku and Kyushu. But these four islands are connected by train and roads, despite the fact that islands are separate geographical entities. But for example, the most northern island Hokkaido is connected by the Seikan railway tunnel to Honshu. And Honshu is connected by the Awaji and Seto Bridge to Shikoku, and the southern island of Kyushu is also connected by the Kanmon Tunnel and Bridge to Honshu. Therefore, Okinawa is the only prefecture which is independent of all other prefectures.

interregional spillover effect does exist in Japanese prefectures. In the next section, we propose simulation studies based on this estimation result in order to find the region, specifically the prefecture, where CO_2 emissions can be most efficiently minimized.

Table 1

The Estimation Result of the Spatial Lag Model				
coefficient	estimate	standard error	t-statistics	p-value
constant	-6.763	1.778	-3.804	0.000
α	0.856	0.097	8.848	0.000
λ	-0.168	0.068	-2.453	0.018
σ^2	0.337	0.07	4.846	0.000

Number of observations = 47
Log likelihood = -41.2945

4 SIMULATION STUDY

This sections presents our simulation method to locate the prefecture best able to reduce CO_2 emissions efficiently. In the previous section, the coefficient of the spatial lag model became statistically significant, demonstrating the interregional spillover effect present within Japanese prefectures. In this section, we propose a method for the simulation studies as follows.

1. From Equation (7), we use the estimation coefficients and calculate the sum of the CO_2 emission estimate for the 47 prefectures. We describe it as $\hat{CO_2}$.

2. In the particular prefecture i, we take the 10 % reduction of capital K_i. From Equation (7), we calculate the sum of CO_2 emission reduction from the individual prefecture and some other prefectures related to the prefecture i. We describe it as $\tilde{CO_2}_i$, and calculate $Rate(CO_2)_i = \tilde{CO_2}_i / \hat{CO_2}$.

3. We calculate the $Rate(K)_i$ which is the rate of the capital reduction in the prefecture i and the sum of the total capital in Japan.

4. The efficiency of the CO_2 reduction of prefecture i is represented by the following formula:

$$\frac{Rate(CO_2)_i}{Rate(K)_i}, \qquad i = 1, 2, \ldots, 47. \tag{13}$$

The standard value of Equation (9) is 1. If this value exceeds 1, the prefecture can attain the CO_2 reduction efficiently, but should it be lower than 1, the prefecture will be unable to do so.

Table 2 shows the result of the simulation studies and describes the top 10 best and worst prefectures respectively. Figure 1 shows the distribution of each level of prefectural efficiency, showing the number of prefectures depending on the prefecture in parentheses. We find most of the efficient prefectures located in urban areas, for example, Tokyo, Aichi and Osaka, distinguished by the darkest colors on Figure 1. These prefectures have a high output level and are placed in favorable locations, since expansion of technology is easier in urban areas. However,

Table 2

Results of the Simulation Study			
Rank	Prefecture	Rank	Prefecture
1	Aichi (46)	47	Nagasaki (43)
2	Kanagawa (40)	46	Okinawa (1)
3	Chiba (46)	45	Kagoshima (46)
4	Shizuoka (46)	44	Iwate (43)
5	Osaka (40)	43	Kochi (29)
6	Saitama (39)	42	Ehime (29)
7	Ibaragi (45)	41	Miyazaki (46)
8	Hyogo (40)	40	Hokkaido (32)
9	Nagano (39)	39	Shimane (28)
10	Mie (44)	38	Saga (38)

The parenthesis represents the number of prefectures which depend on prefecture i

most of the inefficient prefectures are far from such urban areas and distinguished by the lightest color shades on Figure 1. Figure 2 shows the absolute value of the CO_2 emission reduction in the prefectures of Aichi and Nagasaki, respectively the best and worst prefectures based on the value of Equation (9) when the capital is reduced by 10 percent. The interregional spillover effect of Aichi prefecture is bigger than in the case of Nagasaki. The results of the above simulation studies enable us to determine which prefectures are able to attain efficient CO_2 emission reductions based on the value of Equation (9).

In general, the idea of spillover is an approximation for capturing unobservable factors that can not be completed in own area (Anselin (1988) and Banerjee et al. (2003)). Our estimatation result shows a negative (but absolute value is under zero) spatial correlation in Japanese prefectures. This relationship means that if one prefecture is imposed to reduce CO_2 emission, adjacent prefectures increase the emission that are parts of the reduction of original prefecture. This is a similar situation with a real example that if the emission regulation imposed on developed countries, they relocate their factories to adjacent countries or developing countries (like a relationship between China and Japan). In consequence, CO_2 emissions reduction which we anticipate initially will be offset partially by this increased emission. Under this circumstances, this paper shows the prefectures where CO_2 emission can be reduced efficiently.

However, our estimated result is based on the data of 1995. Recently, people's awareness of the global environment is raising, and most of companies compete to embark on reducing CO_2 emission. Therefore, our negative spatial correlation may change to positive over time.

5 CONCLUSION

Since the Kyoto Protocol in 1997, the provisions for CO_2 emission reductions have been implemented in each participating country. In Japan, however, the regional provisions are inefficient.

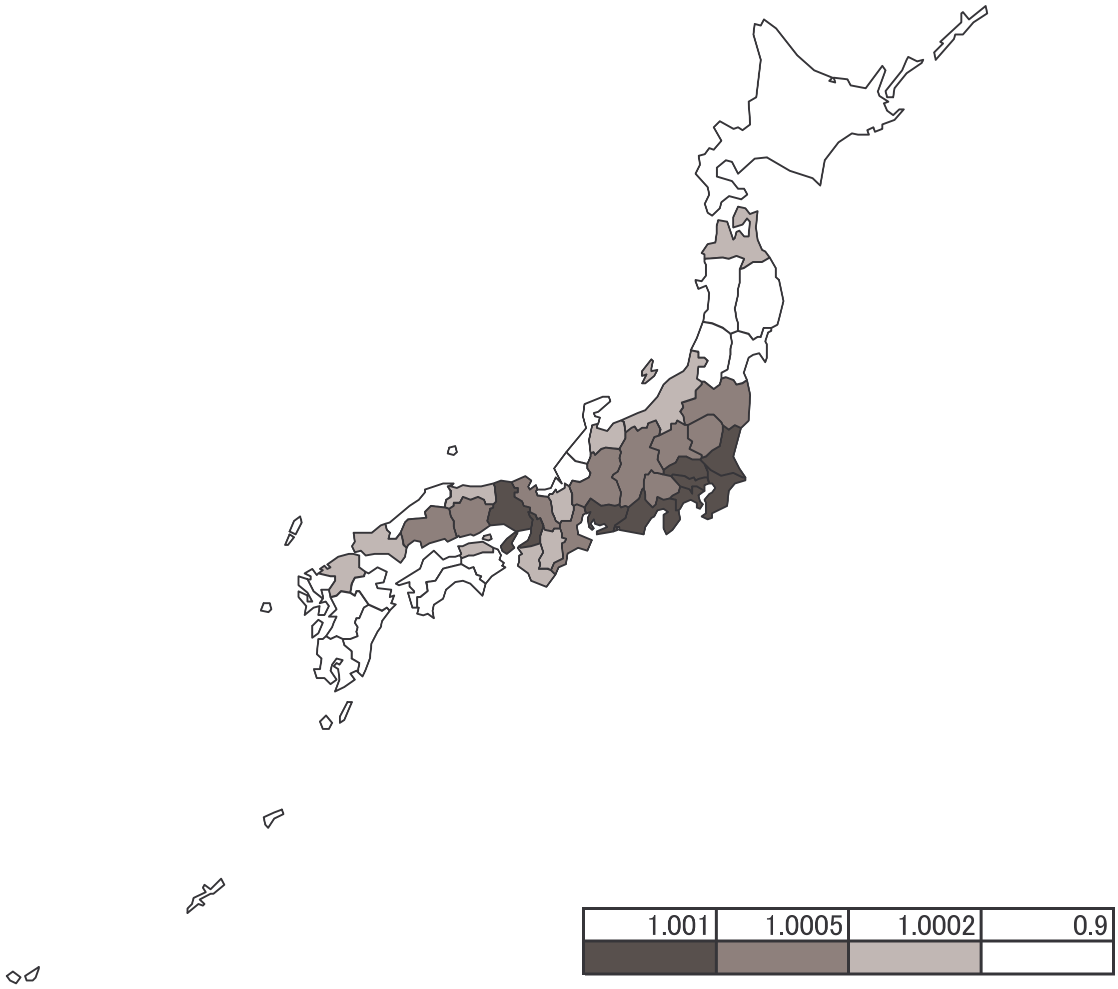

Figure 1: Geographical Distribution of Efficiency

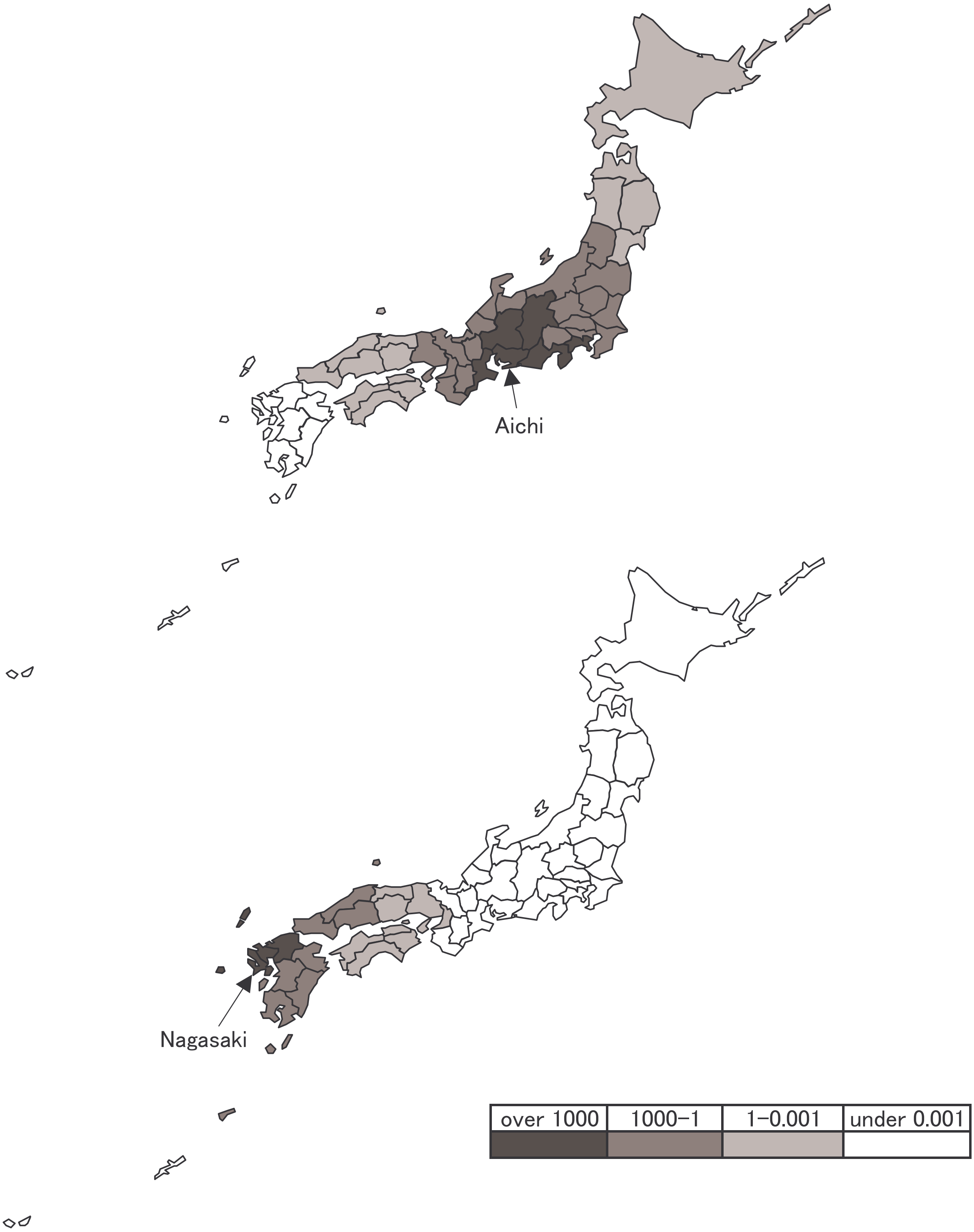

Figure 2: Simulation Study (Aichi and Nagasaki) [kg–C]

In this paper, we propose simulations to show the prefectures where CO_2 emission reductions can be efficiently obtained. In order to conduct the simulation study, we constructed a spatial lag model of CO_2 emissions using data from the 47 prefectures in Japan and constructed an index of efficiency using the estimation results. The simulations show that prefectures located in urban areas tend to attain CO_2 emission reductions more efficiently than those prefectures located far from such urban spaces.

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