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Spatial Diffusion of Innovation
A Spatial Panel Analysis of Electronic Toll Collecting Transponders in Japan

Yutaka Hamaoka*

Abstract

The spatial panel model is applied to a new data set: monthly data of the number of ETC (Electronic Toll Collecting) transponders newly installed in 47 Japanese prefectures. The model incorporates marketing variables and highway-related variables. Regarding the spatial panel model, this work estimates fixed-effect and random-effect model for spatial-lag model and spatial-error model. For each formulation, four types of weight matrix, geographical adjacency matrix, automobile traffic OD (Origin-Destination) table, telecommunication OD, and the inverse of the geographical distance are employed. Among estimated models, fit of "the fixed effect spatial-lag model with the inverse of distance as the weight matrix" is the best. The positive and significant spatial-lag parameter means diffusion in neighbor area promotes diffusion in other area. In case of the ETC transponder promotions, we find that the promotions at the early stage are effective but promotions at later stages are not. In addition to sales promotion of ETC transponders, the number of ETC gates and highway fee promotion for ETC drivers are also significant.

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Abstract

The spatial panel model is applied to a new data set: monthly data of the number of ETC (Electronic Toll Collecting) transponders newly installed in 47 Japanese prefectures. The model incorporates marketing variables and highway-related variables. Regarding the spatial panel model, this work estimates fixed-effect and random-effect model for spatial-lag model and spatial-error model. For each formulation, four types of weight matrix, geographical adjacency matrix, automobile traffic OD (Origin-Destination) table, telecommunication OD, and the inverse of the geographical distance are employed. Among estimated models, fit of "the fixed effect spatial-lag model with the inverse of distance as the weight matrix" is the best. The positive and significant spatial-lag parameter means diffusion in neighbor area promotes diffusion in other area. In case of the ETC transponder promotions, we find that the promotions at the early stage are effective but promotions at later stages are not. In addition to sales promotion of ETC transponders, the number of ETC gates and highway fee promotion for ETC drivers are also significant.

Keywords. Spatial panel model, diffusion of innovation
JEL classification C21, C23, M31

1.Introduction

Figure 1 summarizes the geographical diffusion pattern of the ETC (Electronic Toll Collection) transponders. The system was introduced March 2001 at Okinawa and Chiba. Since then, as we can see, ETC transponders were first adopted by the Tokyo, Osaka, and Nagoya metropolitan areas and were later distributed to their neighboring areas.

ETC is an acronym of the Electronic Toll Collection System. The E-Z pass system used in the US is one such ETC system. This system enables automatic toll collection at the tollgate. To use this system drivers need to install ETC trans ponders in their automobiles. And the tollgate must be equipped with appropriately.

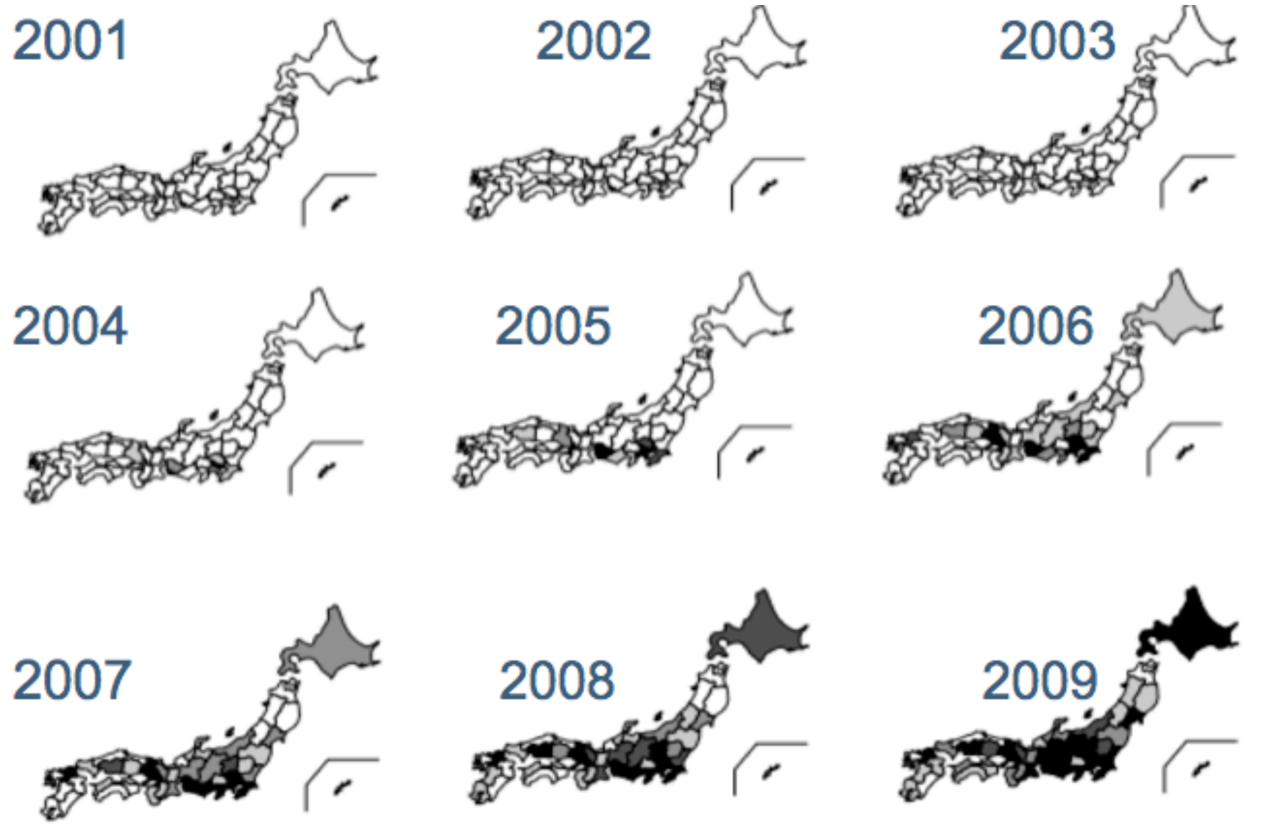

Fig.1 Number of Newly installed ETC (Electronic Toll Collection) Transponders for 47 Prefectures

At the individual level, adoption of ETC transponders is affected by four factors: regional characteristics, ETC-transponder-related variables, ETC-toll-gate-related variables, and Highway fee-related variables. To promote diffusion of ETC, Nippon Expressway Company (NEXCO) and Ministry of Land, Infrastructure, Transportation and Tourism (MLITT) installed ETC receivers to toll gates, conducted rebate promotions for ETC transponder purchasers, and high way fee discount for ETC drivers.

Sales promotion for ETC Transponders

When it was introduced on March 2001, ETC transponder costed 49,000 yen (US$600), and then gradually reduced to 9,500 yen (US$100) until May 2006. To cover this cost partially, 5,000-yen rebate promotion has been conducted since 2001. Due to the budget limitation, it was limited to first

250,000 purchasers for each year.

Sales promotion for ETC drivers

Another type of sales promotion: highway fee discount for ETC equipped drivers were introduced. In July 2002, high way fee discount for pre-paid purchaser was introduced. In November 2004, the late night and commuting discount have been introduced. And on March 2009, the weekend only 1,000-yen (11$) flat rate discount was introduced.

Figure 2 summarizes the major promotions and the number of newly installed ETC transponders in Tokyo, Osaka, Aichi, and Fukuoka prefectures. Some spikes can be observed in the number of installations, corresponding to promotion. For instance, a spike around November 2004 is due to the introduction of the late-night discount for ETC drivers. And a spike around March 2009 is due to the introduction of the weekend only 1,000-yen flat rate discount.

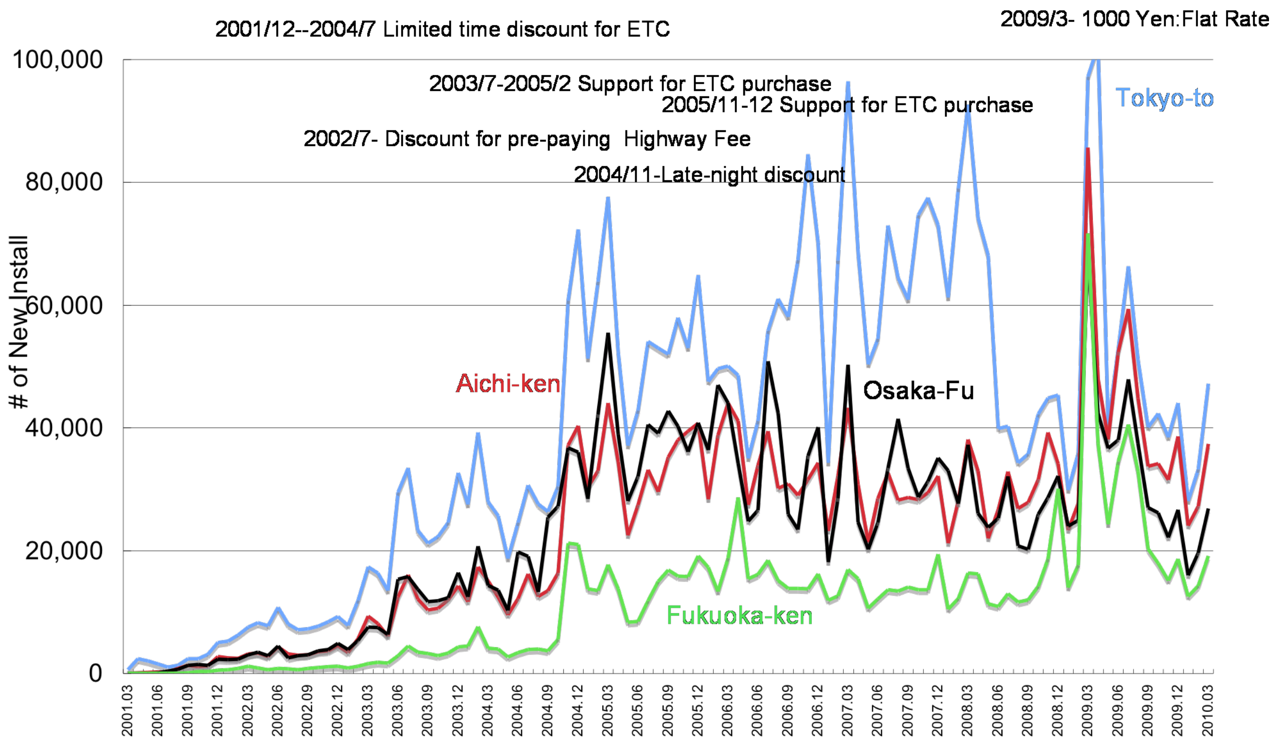

Figure 2 Major Promotion and # of Newly installed ETC in Representative Prefectures

2.Related Research

Geographical diffusion

As mentioned before, The ETC system was expanded from three metropolitan areas to neighboring local areas. Hence, geographical expansion must be taken into account. However, as far as I know, geographical diffusion and adoption has not been investigated considerably. (Mahajan and Peterson 1979) assumed that an innovative state is the first to adopt the innovation. This influences neighboring states; however, the influence reduces with the increase in distance. Their model neglects interaction among lagged states. (Yang and Allenby 2003) developed a choice model that incorporated geographical and social proximity. However, their data is cross section and the diffusion process has not been investigated.

Diffusion model for complementary goods and/or goods with network effect

Why driver purchase the ETC transponders? Transponder itself does not bring significant utility. Drivers install a transponder, because they don't have to stop at the tollgate and they could get some discount for the highway fees. That is to say, diffusion of the ETC transponder depends on, availability of ETC tollgate and highway fee discounts. Some previous studies have focused on interdependence between goods. For example, (Bucklin and Sengupta 1993) have related the diffusion of UPC scanners and barcode readers. In the case of products such as software, people find it convenient to use the same product as it leads to an easy exchange of data. Such an effect is called the "network effect." PCs and software are complementary goods, and software intrinsically promotes a network effect. (Brynjolfsson and Kemerer 1996) and (Stremersch et al. 2007) have also examined these relationships. However, with the exception of (Brynjolfsson and Kemerer 1996), most studies have employed the Bass model (Bass 1969) and neglected the marketing variables.

In other words, previous researches have two limitations. They employ the Bass model and neglect marketing variables. Further, they neglect the geographical interaction. Therefore, in this paper, we focus on the ETC system and incorporate effect of marketing variables and geographical interdependence.

3.Model

Spatial econometrics modes

We employ a spatial econometrics model to analyze the spatial diffusion of ETC transponders. The spatial econometrics model is of two types (Anselin 1988). The first one is a "spatial lag model" that assumes that a dependent variable y of region i am affected by y of other regions and by other regressor: x. Here, the influence of other regions is expressed using a *spatial weight matrix*: W. If we have N regions, this is an N × N matrix. Usually, the diagonal element of this matrix is zero.

$$y = \rho Wy + X\beta + u$$

The second one is a "spatial error model," which assumes error terms that are interdependent among regions.

$$y = X\beta + \lambda W\varepsilon + u$$

Spatial panel models

Previous models assume a cross-sectional data. However, for the ETC system, we obtain monthly data for 47 regions (prefectures). These models can be extended to *spatial panel models*. Assuminng that spatial weight matrix remains constant over time, weight matrix is stacked with Cronecker product of I_T and W. Here, I_T: is Identity matrix dimension of T and T denotes the number of periods (Anselin et al. 2008). We can extend both the spatial lag and spatial error model as follows.

Spatial lag panel model

$$y = \rho(I_T \otimes W\ )y + X\beta + u$$

Spatial error panel model

$$y = X\beta + \lambda(I_T \otimes W\ )\varepsilon + u$$

Due to limitation of availability of spatial panel data, application of spatial panel model is scarce. (Kakamu et al. 2008) analyzed 18 types of crime records in 47 Japanese prefectures and they found positive and significant spatial dependencies. (Moscone et al. 2007) applied spatial lag model for analysis of mental health expenditure in local authorities in England. They also detected positive geographical interdependence.

4. Empirical Setting

Spatial panel model applied to our ETC data. Unit of analysis is Japanese 47 prefectures. Monthly data since its launch on March 2001 to March 2010 is downloaded form homepage of ORSE (http://www.orse.or.jp/). The number of newly installed ETC transponders is the dependent variable. There are four sets of explanatory variables: regional characteristics, ETC-transponder-related variables, ETC-toll-gate-related variables, and highway-fee-related variable (Table2). They are collected from government statistics and firms' news release.

Spatial weight matrix

Spatial weights are very important for the spatial model. (Moscone et al. 2007) employed *geographical adjacency matrices* weighted by population, population density, and political characteristics. They compared model fit and concluded that the fit of model with geographical adjacency weighted by political party is the best. Following their exploratory approach, we employed four spatial weight matrices. The first one is a *geographical adjacency matrix*. This matrix has a set of dummy variables whether region i and j is adjacency. This matrix assumes only the influence of the adjacency region. (Kakamu et al. 2008) employed this matrix. The second one is an *automobile traffic OD* (Origin-Destination) table, which measured the number of automobiles moving between the regions during a certain week in 2000. The third one is a similar table for telecommunication traffic *OD*: including telephone call and data exchange during 2001. This matrix is interpreted as the flow of information. The fourth one is a matrix for the inverse of the geographical distance. This matrix assumes, each region affect each other, however, its strength decays as distance. To avoid endgeneity problem, weight matrix data prior 2001 was employed and assumed to be constant during 2001 to 2010 (Moscone et al. 2007).

Estimation

We estimated both spatial lag and spatial error models. Since this is a panel model, we estimated the fixed effect and random effect models. Parameters are estimated with maximum-likelihood method(Elhorst 2008) with MATLAB routine developed by (Elhorst 2009).

5.Results

Overall fit

Table 1 summarizes the AIC of estimated models. We estimated the fixed and random effect models for spatial-lag and spatial-error models. Among the estimated models, the fit of the “Fixed effect spatial model with the inverse of distance as the weight matrix” is the best. This indicates that adoption of the system by some regions influences other regions.

The fit of the fixed effect model is better than that of the random effect model. This indicates that the diffusion of ETC is affected by region-specific factors, which cannot be explained by introduced variables.

As we mentioned, the selection of the correct spatial weight model is important and we employed four spatial weights matrices. In all columns, the fit of the adjacency matrix is the worst. This implies that regions other than the adjacent ones can influence a region.

Table 1 Comparison of Overall Fit (AIC)

	Spatial lag		Spatial-error Model	
W: Spatial weight	Fixed effect	Random effect	Fixed effect	Random effect
Adjacency	7318.0	7648.1	5573.6	5762.1
Traffic OD	6036.1	6473.1	5155.8	13717.8
Telephone call OD	-	6308.5	-	6529.5
1/Distance	4739.1	4912.4	4768.7	4802.0

-: Cannot be estimated, because of singularity of matrix.

We examined the MAE for 47 prefectures; the error is larger for northern prefectures (Figure 2). In these areas, only one major highway runs from north to south and the highway across these regions is less developed. It means, even the prefectures located close to each other, they do not have access to the highway. Hence, these prefectures have larger deviations. Necessary actions should be taken in this regard.

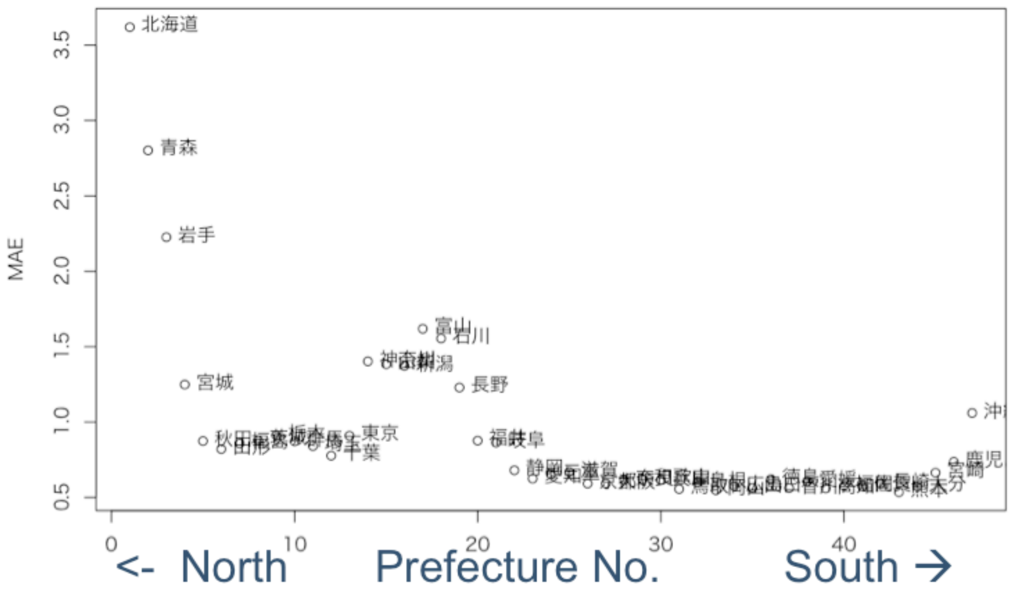

Figure 2. MAE for Each Prefecture

Results

Table 2 summarizes estimates of our best model: fixed effect spatial-lag model with inverse of distance as spatial weights. First, spatial lag parameter is positive and significant that means diffusion in neighbor area promote diffusion of other area.

Coefficient of ETC transponder average price is negative and significant as we expected. And the promotions of ETC transponders at the early stage were effective but promotions at later stages were not. This is because of price reductions from \$500 to \$100 and the discount for ETC to be ineffective. Both the number of ETC gate and installation of ETC for motorcycle are positive and significant. Among highway fee campaign, the late-night discount and the \$10 flat rate discount were effective promotions.

Table 2. Results of Estimation (Fixed Effect Spatial-lag Model with 1/Distance as Spatial Weights)

	Variables		Coefficient	z-value	p-value	
Regional	# of newly registered automobiles		0.472	0.77	0.44	
	Household Expenditure for highway		2.80E-05	8.72	0.00	***
ETC transponder	Average Price		-4.00E-06	-2.30	0.02	**
	Limited time discount for ETC	2001/12-2004/7	0.126	4.45	0.00	***
	Support for ETC purchase	2003/7-2005/2	0.080	3.39	0.00	***
	Support for ETC purchase2	2005/11--12	0.012	0.22	0.83	
	Sweepstakes for ETC Buyers	2007/1---3	-0.030	-0.89	0.37	
ETC gate	# of ETC gate		0.082	2.11	0.03	**
	ETC for Motor Cycle	2006/11-	0.046	2.30	0.02	**
Highway Fee	Discount for pre-paid purchase	2002/7-	-0.011	-0.36	0.72	
	Late-night discount	2004/11-	0.112	2.73	0.01	***
	Commuter-discount	2005/1-	0.067	1.49	0.14	
	Mileage	2005/4-	0.068	1.65	0.10	*
	Prepaid-card for highway fee	2005/11--	0.014	0.37	0.71	
	1,000 yen flat-rate discount	2009/3--	0.077	3.55	0.00	***
March (end of fiscal year)-dummy			0.036	1.84	0.07	*
Spatial Lag			0.932	25.32	0.00	***

Note1) ***: Significant at 1%, **: 5%, and *: 10% level.

2) Variables are monthly data except "Household Expenditure for highway."

6.Conclusion

In this paper, spatial panel mode was applied to new dataset: diffusion of ETC transponders to 47 Japanese prefectures. This model incorporate both marketing variables and geographical interdependence. Analysis confirmed positive spatial dependency: diffusion at other region affects other region.

Managerial implication

In addition to promotion of ETC transponders, the number of ETC gates and highway fee promotion are also significant. This implicates that to promote ETC transponders, we need to develop infrastructures and benefit from using ETC transponders.

In case of the ETC transponder, the promotions at the early stage were effective but promotions at later stages were not. Promotion must be arranged during time period accordingly. Among the highway fee promotion, the late-night discount and the 1,000-yen flat rate discount were effective promotions. Effective management of promotion is also necessary.

Limitation and Future Extension

This research has some limitations that lead to future extension. Firstly, to avoid complexity, our model does not include new installation at t-1. The extension of the model with cumulative number of adaptors is necessary. Secondly, we employed four weight matrices and found reverse of distance matrix is the best. However, the comparison of MAE among 47 prefectures revealed a larger error in the northern prefectures where highway system is less developed. Other weight matrix should be explored to reduce errors in these regions. Thirdly, we applied spatial panel model to ETC transponders. Application of the model to other product category leads to generalization of findings of this research.

Acknowledgement

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Appendix

Table History of ETC

•1997/3/31	Experiment of ETC started at Odawara-Atsugi Road
•2001/3/28	ETC Service started in Chiba and Okinawa area.
•2001/3	Matsushita introduced 3-piece type ETC device (49,000 Yen: $500)
•2001/7/23	Service started in Tokyo, Osaka, and Nagoya metropolitan areas.
•2001/11/30	Service started in nation wide.
•2001/11/30	ETC device limited number discount (5,000 Yen for 250,000 buyers)
•2002/4	Matsushita introduced 2 piece type ETC device (26,000 Yen:$250)
•2002/7/19	Highway fee discount (about 18%) for pre-paid purchase.
•2003/6/	Matsushita introduced 3-piece type ETC device (21,000 Yen: $200)
•2003/7/19	Highway fee discount for long distance drivers.
•2004/3	Most of toll gate installed with ETC enabled.
•2004/11/1	Highway fee discount for late-night drivers.
•2005/1/11	Highway fee discount for commuting and early morning drivers.
•2005/4/1	Highway fee mileage service started.
•2005/11/29	ETC-only card service launched.
•2006/11/1	ETC service for motorcycle launched.
•2006/5	Matsushita introduced 2-piece type ETC device (9,500 Yen: $100)
•2009/3/29	Highway fee flat rate (1,000 Yen, weekend only)

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