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MUNICIPAL SOLID WASTE ILLEGAL DUMPING AND IT'S SPATIAL AUTOREGRESSION: THE CASE OF THE REPUBLIC OF KOREA

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Abstract

We reviewed the data pertaining to the illegal dumping of municipal solid waste in the Republic of Korea for the year 2011 to check for the presence of spatial autoregression of illegal dumping among 224 basic autonomous units with reference to the “Broken Windows Theory.” We found that a pure neighborhood effect exists even after controlling for conventional variables that explain illegal dumping behavior. Interestingly, however, the neighborhood effect is largely offset by so-called relative price effect such that the number of illegal dumping reported in one region is in fact decreased as the price of vinyl bag for MSW in neighboring regions increases, which is seemingly against the implication of the “Broken Windows Theory.”

Keywords: Illegal Dumping, Spatial Econometrics, Municipal Solid Waste

1. Introduction

If a house in the city has broken windows for a long time, it would easily become a breeding ground for crimes, resulting in the windows of the neighborhood being broken eventually as well. Wilson and Kelling (1982) called this the “broken windows theory” (hereafter BWT). In the 1980s, in New York City, the war against crime started with preventing small crimes rather than the big and violent ones. This has been successful in keeping the overall level of crimes under control. The understanding for this successful prevention of crimes lies in the improvement of the general crime environment first and the subsequent use of this virtuous circle of good environment to prevent crimes altogether, which is an application of the BWT in the opposite direction. We attempt to apply a similar logic for the municipal solid waste (hereafter MSW) illegal dumping behavior. According to the BWT, one illegal dumping in a region might attract another, undermining a “sense of community”, thus leading us to hypothesize that illegal dumping is spatially autoregressive.

The “pay-by-the-bag” system (unit pricing), which was introduced in the ROK in 1995, is an economic instrument for managing MSW by giving a direct price signal to households. However, imposing a price on legal discharge increases the benefit of illegal dumping at the same time. Kim *et al.* (2008) has indicated that there is a statistically significant relationship between the price of a vinyl bag and the number of citizens' reports on illegal dumping in the 16 provinces of the ROK for the period 2001 to 2003. However, if illegal dumping is spatially correlated as suggested by BWT, then the analysis by Kim *et al.* (2008) is incomplete in the sense that dependent variables (or error terms) are not independent of each other and the estimates should be statistically biased and inconsistent (LeSage and Pace, 2009). To address these problems, we introduce a spatial autoregressive regression model, test the presence of spatial autoregression in illegal dumping, and estimate the illegal dumping behavior more accurately.

Analyzing the data of basic administrative units in Japan, Ichinose and Yamamoto (2011) argues that the deficiency of waste treatment facilities is the main cause of illegal dumping. Yamamoto and Yoshida (2012) extends this idea to claim that the Nimby area is a center of illegal dumping because Nimby behavior drives out treatment facilities to other areas; thereby, attracting illegal dumping. They have found that this was the case for England during 2010 to 2011. Usui *et al.* (2013), using the data of 3,000 basic administrative units of Japan, argues that unit pricing, especially two tier pricing, is the main cause of illegal dumping and the implementation of two tier pricing on one unit attracts in the main area and its neighborhood.

This paper proceeds as follows. In the next section, we explain the methodology we adopt. In the third section, we discuss the data and empirical results. Then, we conclude the paper by making some remarks on the limitations of our study and its contribution to the existing literature.

2. Methodology

Suppose a dependent variable y is completely explained by two explanatory variables x and z as follows,

$$y = x\beta + z\theta \tag{1}$$

but z is not observable, like the undermined "sense of community" caused by illegal dumping, and spatially correlated as implied by the BWT. We can describe this situation by the following equation.

$$z = \rho W z + r \tag{2}$$

where W stands for a $n \times n$ spatial weight matrix. We assume that $W_{ij} > 0$ when j is a direct neighbor of i, and $W_{ij} = 0$ otherwise. For instance, $W_{12} = 0.3$ means that region 1 and 2 are each other's direct neighbors and a unit change of a variable in region 2 affects the variable in region 1 by 0.3 unit. In addition, we assume that each row sums to unity, which means that a variable in one region is influenced by the weighted average of the same variables in its neighboring regions. ρ represents the average level of spatial dependence of the dependent variable. Here, ρ is not just a conventional correlation coefficient, but the average strength of spatial dependence that is determined in a cumulative way as a steady-state after a long chain of simultaneous interactions among regions (LeSage and Pace, 2009). The fact that z is spatially correlated means that the observations on the dependent variable are not independent. Thus, if we run an OLS regression without considering this, we would end up with biased and inconsistent estimates of the regression coefficients as well as an omitted variable bias. This justifies the following spatial econometric model.

Assuming the existence of the inverse matrix, $(I_n - \rho W)^{-1}$, Eq. (2) can be solved for z as follows.

$$z = (I_n - \rho W)^{-1} r \tag{3}$$

Substituting (3) into (1) yields,

$$y = x\beta + (I_n - \rho W)^{-1}(\theta r) \quad (4)$$

Now, we define $\theta r = u$ and assume that x and u are correlated as follows.

$$u = x\gamma + v \quad (5)$$

where v represents white noise. Here, u (or r) stands for variables determining the "sense of community"; say, various indices for social capital like trust towards the government or others, and so on (refer to Eq. (2) or Eq. (3)). We might imagine that the level of social capital in one region is determined by the kind of people residing in that region by the "vote of foot." For instance, high-income and aged people naturally gather in one region. Then, the resulting level of income and age distribution in one region determines the level of social capital in that region. Thus, conventional explanatory variables directly affect the amount of illegal dumping and at the same time, they indirectly exert influences through social capital. The data generating process can be described as follows.

$$y = x\beta + (I_n - \rho W)^{-1}(x\gamma + v) \quad (6)$$

Expanding the second term in the RHS of Eq. (6), we get the following.

$$y = x\beta + (I_n - \rho W)^{-1}x\gamma + (I_n - \rho W)^{-1}v \quad (7)$$

Multiplying both sides by $(I_n - \rho W)$, we have

$$(I_n - \rho W)y = (I_n - \rho W)x\beta + x\gamma + v \quad (8)$$

Separating y on the LHS, we have

$$y = \rho Wy + x(\beta + \gamma) + Wx(-\rho\beta) + v \quad (9)$$

Eq. (9) is the final equation we adopt as our econometric model. Anselin (1988) has called this the Spatial Durbin Model (LeSage and Pace, 2009). The equation includes spatially lagged dependent variable as an explanatory variable and spatially lagged explanatory variables.

3. Data and Empirical Results

3.1. Data

The cross-sectional data for 224 basic autonomous administrative units of the Republic of Korea (ROK) for the year of 2011 is used in our empirical analysis. However, the analysis excludes Jeju and Ulung Islands as they are surrounded by no other region. Moreover, two more regions are omitted because of the absence of any reports of illegal dumping. The dependent variable is the number of citizens' reports on illegal dumping under the ROK bounty system, which is a proxy for the amount of illegal dumping that is not easily observable. As the number of reports is count data, we transform it into its logarithmic values (ldil). Explanatory variables are classified into two groups. One represents the households' economic and demographic characteristics that directly affect the propensity for illegal dumping and the other group represents the reporting behavior. The first group includes variables such as per capita income (pcrgdp) and population (pop); however, the most important variable in the first group is the price of vinyl bags (pl). We expect the number of reports of illegal dumping increases as the price of vinyl bag and the population increases, but decreases as the level of income increases (Kim *et al.* 2008). The second group of variables includes the size of the bounty (pz), the population density (popden), and average age (aage). We expect that the number of reports increase as the size of the bounty and the population density increases, but it may increase or decrease as the average age increases. The following table summarizes the data used.

Table 1. Summary Statistics

Variable	Mean	Standard Deviation
ldil	5.4	2.05
pl	323.36	125.92
pcrgdp	29.03	23.37
pop	211.57	204.94
pz	44	481
popden	3.91	6.12
aage	41.56	5.45

As one focus of this paper is the spatial dependence of our dependent variable, illegal dumping, we would like to take a glimpse at its general tendency using the following Moran Scatter Plot before formally estimating the various coefficients for our regression model. The horizontal axis represents the amount of illegal dumping in one region and the vertical axis represents the weighted average of illegal dumping in the neighboring regions. The variables are all normalized to deviations from respective means. We can clearly observe the general tendency for a positive relationship between those two variables in the figure. This implies a strong spatial dependence of illegal dumping among the regions.

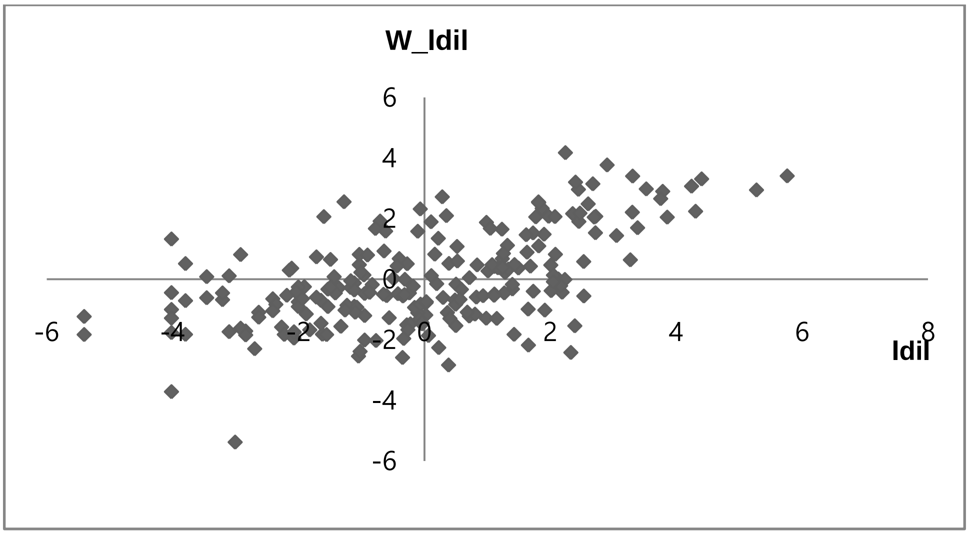

Figure 1. Moran Scatter Plot for Citizens' Reports on Illegal Dumping in the ROK (2011)

3.2. Empirical Results

We have estimated the coefficients of our regression model by the maximum likelihood method and displayed the results in Model (3) of Table 2 below. We would first like to review the results of the simple OLS regression in Model (1) of Table 2 that regresses the dependent variable, the number of reports of illegal dumping in one region, against the weighted average of the number of reports of illegal dumping in the neighboring regions. In a way we have measured the average level of spatial dependence among the regions, as identified in Figure 1. The coefficient for Wldil is estimated to be 0.77664 at the 1% significance level. As we run a log-log regression, the estimation gives us the elasticity value. That is, a 1% increase in the weighted average of illegal dumping reported in neighboring regions would lead to a 0.77% increase in the illegal dumping reported in the region under study. However, Model (1) is an over-simplification that does not consider other important explanatory variables.

Table 2. Empirical Results

Model Variable	(1)	(2)	(3)
Intercept	1.22646*** (2.995)	8.1416529*** (6.293)	8.027*** (2.810)
Wldil	0.77664*** (10.600)		0.2796** (2.003)
Pl		0.0006457 (0.765)	0.004782*** (3.155)
Pop		0.0023247*** (3.595)	0.002432*** (3.779)
Popden		0.1358212*** (7.834)	0.06650** (2.241)
Aage		-0.1010325*** (-4.034)	-0.08153*** (-3.031)
Pcrgdp		0.0074207 (1.830)	0.007200* (1.692)
Pz		0.0002688 (1.421)	0.0003369* (1.852)
Wpl			-0.006219*** (-3.578)
Wpop			-0.002557** (-2.167)
Wpopden			0.09052** (2.061)
Waage			-0.02488 (-0.487)
Wpcrgdp			-0.0003315 (-0.054)
Wpz			-0.00009761 (-0.274)
R squared (Adjusted R squared)	0.3361 (0.3331)	0.5834 (0.5663)	0.6262 (0.603)

Notes: 1.The numbers in parentheses are t-values. 2. *, **, *** stands for 10%, 5%, 1% level of significance, respectively.

For the purpose of comparison with our main model, we also run an OLS regression with conventional explanatory variables, the result of which is depicted in Model (2) of Table 2. The coefficient for the price of vinyl bag is estimated to be positive as expected, but it is not statistically significant. The coefficient for the size of bounty also conforms to our expectation that it is positive, but it is statistically insignificant too. Furthermore, the data generating process assumed in our main model implies that the simple OLS estimates are biased and inconsistent (LeSage and Pace, 2009). In contrast, Model (3) has controlled for spatially correlated and unobservable factors to measure the net effect of conventional variables on illegal dumping. We have estimated ρ, $\beta+\gamma$, $-\rho\beta$ which can use to get the estimates for β and γ (see Eq. (9). The results are summarized in Table 3 below.

The coefficients for the price of vinyl bags and the size of bounty are estimated to be positive and greater than the corresponding ones in Model (2). In particular, the one for the price of vinyl bag is much greater. As the dependent variable is in logarithmic form, these estimates represent the rate of change in the number of illegal dumping reported due to one unit change in the explanatory variables. Thus, the result says that one unit change in the price of vinyl bags would lead to a 2.2% increase in the number of reports of illegal dumping, which is starkly greater. Similarly, one unit change in population density would lead to a 32.4% decrease in the number of reports of illegal dumping. Further, in comparison to Model (1), the estimate for ρ has dropped to 0.2796, which means a 1% increase in the number of reports of illegal dumping in neighboring regions would lead to a 0.28% increase in the number of reports of illegal dumping in the region under study. This estimate represents the net effect of illegal dumping in neighboring regions after controlling for other explanatory variables. The coefficient ρ represents the spatial dependence of the unobservable "undermined sense of community" like z also. (see Eq. (2)) Thus, we can interpret that the "sense of community" is spatially contagious and if degraded in one region, it would affect its neighboring regions in the form of frequent illegal dumping. This can be called the BWT effect.

Table 3. Decomposition of Coefficients

Variable	β	γ
pl	0.022242	-0.017460
pop	0.009145	-0.006710
popden	-0.323750	0.390248
aage	0.088984	-0.170510
pcrgdp	0.001186	0.006014
pz	0.000349	-1.20E-05

It is interesting to note in Table 2 that all the lagged explanatory variables, except Wpopden, are estimated to be negative. For instance, one unit increase in the price of vinyl bags in the neighboring regions would lead to a 0.62% decrease in the number of reports of illegal dumping in the region under study. The coefficient for WX is –ρβ (see Eq. (9)). Thus, the data has conformed to the theory that states the sign of β (coefficient for X) is the opposite of the sign of –ρβ (coefficient for WX), when ρ>0. The data has confirmed this. For example, the weighted average of vinyl bag prices in neighboring regions have had a negative impact on the illegal dumping reported in the region under study. However, this fact is seemingly controversial because the increase in vinyl bag price in neighboring regions increases the illegal dumping in their regions and in the region under study through the BWT effect. We might be able to reconcile this conflict by the understanding that the increase in the price of vinyl bags in neighboring regions has lowered the relative price of vinyl bags in the region under study and this so-called relative price effect offsets the BWT effect.

It must be emphasized that in our model, β, coefficients for conventional explanatory variables, represent much less than the marginal effects of the explanatory variables in OLS. To clarify this, Eq. (9) can be rewritten as follows (LeSage and Pace, 2009).

$$(\mathrm{I_n} - \rho \mathrm{W})\mathrm{y} = \mathrm{X}(\beta + \gamma) + \mathrm{WX}(-\rho\beta) + \mathrm{v}$$

$$\mathrm{y} = \sum_{r=1}^{k} \mathrm{S_r}(\mathrm{W})\mathrm{x_r} + \mathrm{V}(\mathrm{W})\mathrm{v} \qquad (10)$$

$$\mathrm{S_r}(\mathrm{W}) = \mathrm{V}(\mathrm{W})\left(\mathrm{I_n}(\beta_r + \gamma_r) + \mathrm{W}(-\rho\beta_r)\right)$$
$$\mathrm{V}(\mathrm{W}) = (\mathrm{I_n} - \rho\mathrm{W})^{-1} = \mathrm{I_n} + \rho\mathrm{W} + \rho^2\mathrm{W}^2 + \rho^3\mathrm{W}^3 + \cdots$$

Here, $\mathrm{S_r}(\mathrm{W})$ is a $\mathrm{n} \times \mathrm{n}$ matrix. The marginal effect of the $\mathrm{i^{th}}$ observation for $\mathrm{r^{th}}$ explanatory variable on the $\mathrm{i^{th}}$ observation for dependent variable, $\partial y_i / \partial x_{ir}$ is $\mathrm{S_r}(\mathrm{W})_{ii}$, which is more than β_r. It includes a series of cumulative interaction, $\rho\mathrm{W}, \rho^2\mathrm{W}^2$, and so on. The change in an explanatory variable, say, the price of vinyl bag, in one region affects the amount of illegal dumping in the neighboring regions as well as in the region under study. The changes in the neighboring regions have a feedback mechanism that affects the main region and are simultaneously transmitted to their neighbors. The changes in the neighbors are transmitted to their respective neighbors, which is in turn transmitted to their respective neighbors, and so on.

The original region has impacts on all the other regions in this manner and simultaneously receives feedback from all of them. We add the impacts the original region makes on its own region, which we call direct impact. Direct impact includes the feedback effects from all the other regions. Moreover, we add the impacts the original region has on all the other regions, which we call indirect impact. Indirect impact, similarly, includes the feedback effects from the neighbors on their respective neighbors. However, direct and indirect impacts vary depending on the location of the original region. Thus we take the average of all the regions. In mathematical terms, direct impact is $S_r(W)_{ii}/n$, while indirect impact is $\imath' S_r(W)\imath$. where ı represents a vector of ones (LeSage and Pace, 2009). We summarize these direct and indirect impacts for various explanatory variables in Table 4 below.

With reference to Table 3, we realize that the overall impacts of the explanatory variables are weakened through cumulative spatial interaction. For example, one unit change in the price of vinyl bag leads to only 0.4% increase in the illegal dumping (the net effect is 2,2% in Table 3) Another observation is that the overall, indirect impacts are negative. This may be because the opposite effect of WX is much stronger and offsets the BWT effect ($\rho > 0$). We have explained the case for the price of vinyl bag previously.

Table 4. Direct and indirect impact summary

Variable	Direct Impact	Indirect Impact	Total Impact
pl	0.0047364	-0.0000210	0.0047153
pop	0.0024115	–0.0000107	0.0024007
popden	0.0665430	–0.0003084	0.0662345
aage	-0.0812570	0.0003704	-0.0808866
pcrgdp	0.0071657	-0.0000324	0.0071332
pz	0.0003349	-0.0000015	0.0003334

4. Concluding Remarks

Despite controlling for traditional explanatory variables such as vinyl bag price, population-related variables, income, and bounty, we are still left a statistically significant spatial autoregression of illegal dumping of MSW among the 224 basic autonomous units in the ROK for the year 2011. By neglecting this spatial dependence, the existing literature is incomplete with biased and inconsistent estimates (Kim *et al.* 2008). We have contributed to the existing literature by positing a plausible hypothesis on spatial dependence of illegal dumping and more accurately estimating the coefficients of the conventional variables that explain illegal dumping behavior. Moreover, we have calculated the effect that the change in one region has on the original regions as well as the other regions in a cumulative interaction perspective. For example, one unit change in the price of vinyl bag in one region would lead to a 0.474% increase in the illegal dumping in that region and a 0.002% decrease in the illegal dumping in the other regions on an average. This result seems to be controversial because the increase in the price of vinyl bags in neighboring regions increases the illegal dumping in their regions as well as in the region under study through the BWT effect. However, we can interpret this in terms of the relative price effect wherein the increase in the price of vinyl bags in the neighboring regions lowers the relative price of vinyl bags in the region under study, thus offsetting the BWT effect.

The spatial contagion of illegal dumping that occurs with the increase in the unit price for vinyl bags and the resulting increase in illegal dumping in the region has important policy implications. Thus, considering the vinyl bag price only for fiscal revenue is to be refrained. In addition, public campaign and environmental education for improving the “sense of community” or culture are as important in waste management as the traditional enforcement policy instruments of monitoring and imposing a penalty. Finally, we have to note that the channel or mechanism by which the “sense of community” or social capital is spatially correlated needs to be more clearly specified. This is left for our future study.

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