Theoretical and Empirical Researches in Urban Management
Volume 10 Issue 1 / February 2015

DETERMINATION OF SPATIAL EXTENT OF LAND USE IN THE FRINGE OF JAKARTA METROPOLITAN: A SEMIVARIOGRAM ANALYSIS

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Abstract
Spatial interaction of land use or commonly associated with externalities of land use is one factor which drives the land use change. A recent study indicates that the significance of land use externalities create sprawl – leapfrogged urban spatial pattern in the fringe of Jakarta Metropolitan. This inefficient development activity gives more pressure to the conservation area and the productive agricultural sites in the southern fringe. Therefore a proper land use policy to protect those important sites should be formulated. The proper formulation however, needs precise information about the extent or the maximum distance in which land use externalities are still affecting the land use change. The development of spatial statistics especially the semivariogram analysis enables the formulation of this distance, which is the aim of this study. Based on the range of the estimated semivariogram function, this study indicates that in the fringe of Jakarta Metropolitan, the furthest distance for interaction between developments is 29.2 km, while the interaction between open space or agricultural uses are still in effect at mostly 29 km. Those results will be useful to predict the future land use change in the area, based on the recent land use pattern within the distances.
Keywords: Land use change, spatial externalities, spatial statistics, semivariogram.

1. INTRODUCTION

The fringe of Jakarta Metropolitan (BoDeTaBek: Bogor, Depok, Tangerang and Bekasi) has experienced sprawl. It is a low density, non contiguous and land intensive development activities. They have scattered across the regions and consumed large areas of prime agricultural land. As a result, the predominantly agricultural activities in the fringe area were transformed into industrial and service based activities (Firman 1997). This type of development is regarded as an inefficient development process, emerging from market forces subject to various market failures (Brueckner 2000; Ewing 2008). Key market failures in this context include the failure to take into account the social value of open space, the failure of an individual commuter to take into account the social costs of congestion, and the failure of the real estate developers to take account of all the public infrastructure costs (Brueckner 2000).

Among some of the negative effects of sprawl, the increased development value of open space (e.g. forest, agriculture land) adjacent to developed land will be the main attention of this study. This situation speeds up the conversion of productive agricultural land, forest or conservation areas in the southern fringe (Bogor and Puncak) (Firman 1997). It endangers the sustainability of agricultural and forestry activities. Moreover, the conversion of the conservation areas has been blamed as the main cause of the severe yearly flood in the area and other environment problems. The existing spatial plan fails to manage the situation properly (Firman 2004).

The traditional monocentric city model (Alonso 1964), in which distance from CBD is the main determinant of land value, does not explain sprawl very well. More recent models (Fujita 1988; Anas 1992; Anas and Kim 1996; Irwin and Bockstael 2002; Caruso, Peeters et al. 2007) provide improved explanations of sprawl through the interaction of spatially distributed agents, emphasising competing externalities. They argue that sprawl (the low density and fragmented residential development, and the emergence of mixed housing farming arrangement in suburban areas) is the result of households' significant appreciation of both neighbourhood open space ('green' externality) and social interaction ('social' externality). The relative importance the households attach to each type of externality determines the spatial pattern of urban development (fragmented – sprawl or compact). The leapfrog development pattern or sprawl occurs when the preference for the 'green' externality is similar to the preference for the 'social' externality.

In response to those interaction models, Fitriani and Harris (Fitriani and Harris 2011) adapted a model of competing externalities, Residential Choice of Location with Externalities, by looking at the direct interaction of 'green' and 'social' externalities rather than looking at them independently, as simultaneous determinants of residential location choice. In particular they analyze the implication of leapfrog development pattern-sprawl-on the predicted city size, and the consequences for development of new land. The analysis indicates that a city with significant household preferences for both types of externalities will be relatively larger than a city with no significant externalities. Their model is tested empirically using three years (1995, 2000 and 2006) of grid-based land use data (i.e. covering two changes in land use) of the fringe of Jakarta Metropolitan area. The empirical study suggests that both types of neigbourhood development externalities determine the observed land use change. The model predicts that in this area, the new development will most likely take place in the proximity of other developed land, which still has enough surrounding open space. It implies that during the observed study, the offsetting externalities have contributed to the non-compact urban development activities, expanding the urban areas such that it might potentially reach the environmentally sensitive land in the southern fringe of the city.

The above findings motivates Fitriani and Harris (2012) to simulate the effect of two policies which intended to reduce the impacts of the social and the green externalities, namely agricultural zoning and maximum lot size zoning respectively, on the urban spatial pattern. The simulations indicate that the combination of those policies can reduce the effect of sprawl on the existing agriculture land, forest and conservation area in the southern fringe (Puncak – Bogor). Therefore with proper policies, the negative effect of sprawl on the sustainability of agricultural activity and environment protection can be reduced.

The two last studies by Fitriani and Harris (2011; 2012) adopt 1×1 mil2 (1 mil ≈ 1.6 km) grid based land use change data of the study area. The particular distance is chosen based on the assumption that the development externalities are still in effect within that radius, following the result of Flemming (Fleming 1999) for the case of land use change in Howard County, Washington DC. Even though the studies in Fitriani and Harris (2011; 2012) indicate that the significance of the competing externalities depends on the chosen distance, they set an a-priori one, without analysing its suitability with the current land use change condition of the study area. Therefore, to increase the accuracy of the test, as well as the accuracy of the land use change prediction in BoDeTaBek, this study will conduct further analysis of the optimal distance. Using semivariogram analysis, the particular distance will be chosen as the furthest distance where the interaction of land value or land use change between locations is still significant. The optimal distance will be useful to reformulate the economic model of land value and land use policy in BoDeTaBek, in the effort to remedy the negative effect of sprawl on the sustainability of agricultural activities, food production and environment protection.

2. SEMIVARIOGRAM ANALYSIS

Semivariogram analysis is a geostatistical method, which was initially developed as a tool for mining exploration. It has recently been adopted for use in other areas of research. Ecological study, epidemilogy, and urban studies, are the main study areas which frequently implement the analysis, due to the involved spatial process. In urban studies particularly, it is commonly applied to analyse the spatial pattern of population density (Wu and Murray 2005), hedonic land value (Fleming 1999), remotely sensed images of urban and land cover/land use change (Brown, Goovaerts et al. 2002). In those studies, semivariogram can be an initial analysis which complements the next stage or another geostatistical analysis. It is fitted to determine the weight for the prediction model, such as in kriging or co-kriging (Wu and Murray 2005). But it can also be combined with another statistical analysis such as spatial econometrics or hazzard model of land use (Fleming 1999; Irwin and Bockstael 2002).

Semivariogram analysis is useful to determine the between-locations-interdependency, in term of (spatial) correlation of observations, as function of distance between them. It is expected that the closer the distance between locations, the more auto-correlated the observations will be. Consequently, there will be a certain distance in which there is no significant correlation between observations seperated by that particular distance(Cressie 1993). When it is applied to analyse the land value, it is useful to determine the radius of neighbourhood land use or the maximum distance in which the spatial interaction of land use is still significant, which will be the main interest in this study. Instead of setting the distance of neighbourhood land use a-priori, it can be estimated empirically based on the observation of land use.

Empirically, the variogram is estimated using sampling points (observed data) as follows:

$$\gamma^*(h) = \frac{1}{2|N(h)|}\sum_{N(h)}[Z(s_i) - Z(s_j)]^2, \qquad (1)$$

where

Z(si) : the observed value at location i

si =(xi, yi) : vector of spasial coordinate (x, y) of location i

h = $|s_i - s_j|$: distance between location si and sj

N(h) : the set of observed values at location si and sj which are seperated by the same distance h.

$|N(h)|$: The number of pairs in N(h)

For a given observations, the shape of the semivariogram can be fitted into one of the possible theoretical semivariogram models. The parameters of the theoretical semivariogram are estimated using Weighted Least Square (WLS)(Cressie 1993). The following variogram models are admissible:

Spherical Model

$$\gamma(h;\sigma^2,r) = \begin{cases} \sigma^2\left[\frac{3h}{2r} - \frac{1}{2}\left(\frac{h}{r}\right)^3\right], \text{for } 0 < h \le r \\ \sigma^2 \qquad\qquad\qquad\quad , \ h > r \end{cases}, \qquad (2)$$

$$\gamma(0) = 0$$

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Exponential Model

$$\gamma(h;\sigma^2,r)=\sigma^2\left[1-\exp\left(\frac{-h}{r}\right)\right], h\geq 0, \quad (3)$$

$$\gamma(0)=0$$

Gaussian Model

$$\gamma(h;\sigma^2,r)=\sigma^2\left[1-\exp\left(-3\frac{h^2}{r^2}\right)\right], h\geq 0, \quad (4)$$

$$\gamma(0)=0$$

Circular Model

$$\gamma(h;\sigma^2,r)=\begin{cases}\sigma^2\left[\frac{2h}{\pi r}\sqrt{1-\left(\frac{h}{r}\right)^2}+\frac{2}{\pi}\arcsin\frac{h}{r}\right], \text{for } 0<h\leq r\\ \sigma^2 \quad , h>r\end{cases}, \quad (5)$$

$$\gamma(0)=0$$

where

σ^2 : sill, the value of semivariogram at which the function levels off as the distance increase

r : range, corresponds to the distance (lag) h at which the semivariogram reaches the sill σ^2. This is the critical distance at which the correlation structure no longer significant.

As the lag h approach zero, the semivariogram does not always go to the origin. It indicates thet there is a component of spatially independent variance in the data, due to the measurement errors. This effect is known as the nugget effect. In addition, the distance where the semivariogram reaches 95% of the sill value is called the effective range (Cressie 1993).

3. THE STUDY AREA AND DATA SPECIFICATION

The study area covers the fringe of the Jakarta Metropolitan Area: Bogor Regency, Bogor Municipality, Depok, Bekasi Regency, Bekasi Municipality, Tangerang Regency and Tangerang Municipality. Each region has some districts at the lower administration level, such that overall the study area covers 87 districts. The spatial information of each district is extracted from the map of the study area provided by BAKOSURTANAL (National Coordinating Agency for Surveys and Mapping) Indonesia.

The land use related variables of the districts are available from "Regions in Numbers" by BPS (Central Statistics Biro) Indonesia. Data from 2006 are used.

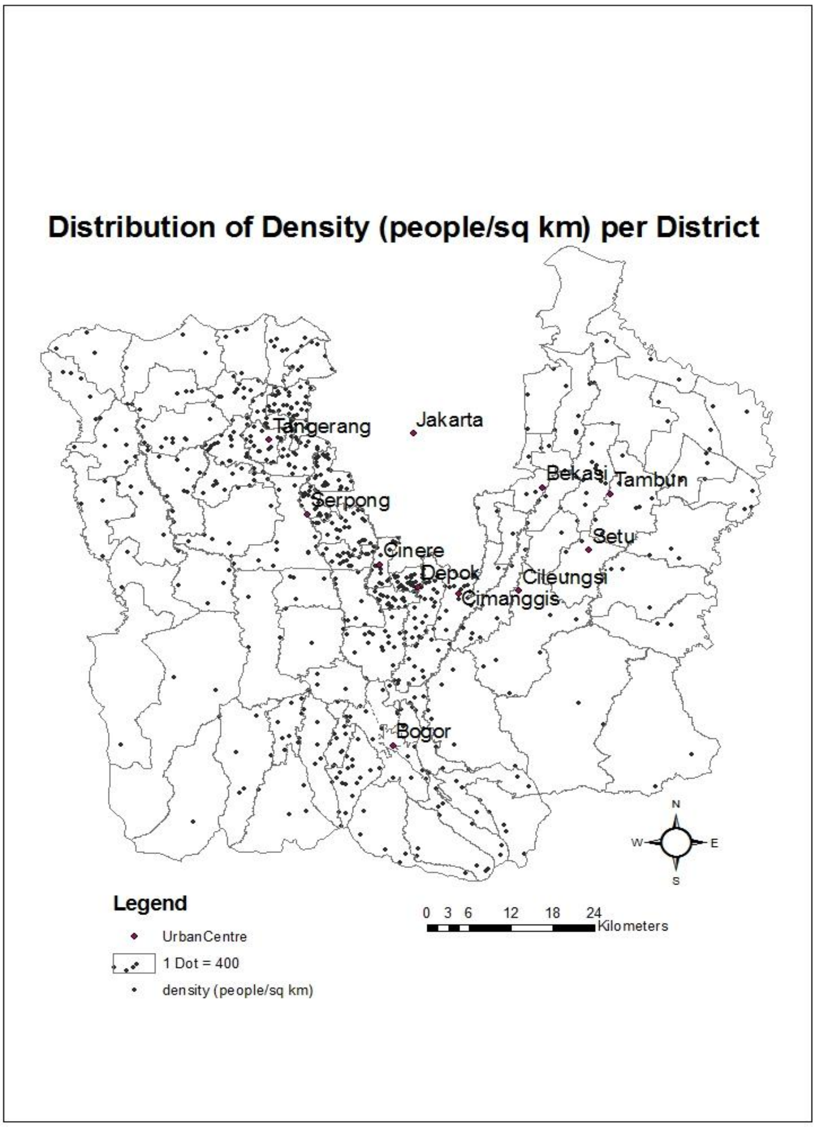

FIGURE 1 - DISTRIBUTION OF DENSITY (PEOPLE/SQUARE KM) PER DISTRICT

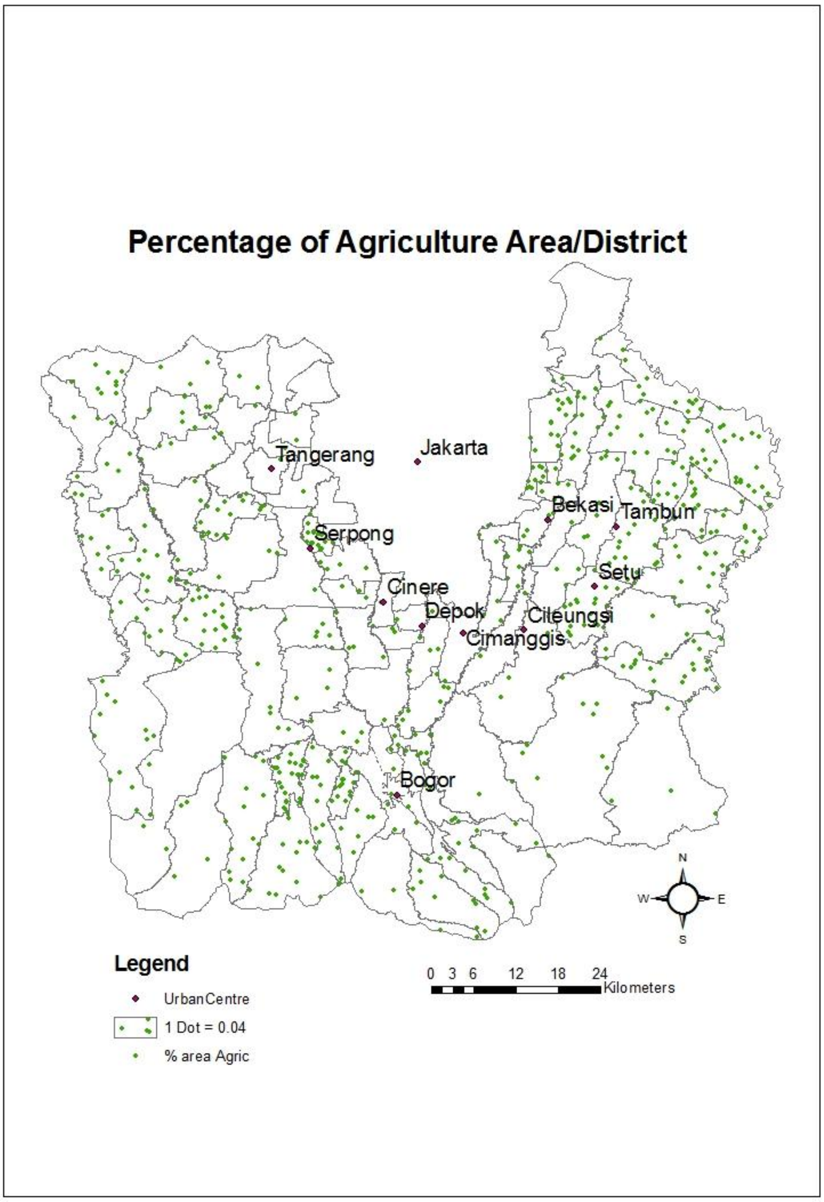

FIGURE 2- DISTRIBUTION OF PERCENTAGE OF AREA FOR AGRICULTURAL USE PER DISTRICT

Two variables are used to capture the competing externalities of land use which is indicated as the cause of sprawl development pattern in BoDeTaBek. They are density (people/km2) per district and percentage of area that is used for agricultural activity per district. The distribution of density and percentage of agriculture area per district, based on 2006 data, are shown in Figure 1 and Figure 2 respectively.

Following the previous studies (Fitriani and Harris 2011), density per district is chosen as a proxy of social type of externalities since it represents the amount of development in a particular district, whereas, the percentage of agriculture area per district defines per district amount of agricultural activity, or available open space. It represents the green type of externalities.

The following definitions are used for data specification:

si =(xi, yi) : vector of spatial coordinate (x, y) of district i, i = 1, ..., 87

ZA(si) : the observed density at district i, i = 1, ..., 87

ZG(si) : the observed percentage of agriculture area at district i, i = 1, ..., 87

4. RESULTS AND DISCUSSIONS

Figure 1 shows that the districts surround the urban centres (and central Jakarta) are the most populated districts. Figure 2 indicates that there are some districts with high area percentage for agricultural activity. Those districts are in proximity of densely populated districts. Comparation of the two figures indicates that most of the districts experience mixed use between development and agricultural activity, which has been identified as sprawl type of development.

The key to test the validity of externalities effect on sprawl is the proper choice of distance defining the neighbourhood. It will be more appropriate if the distance is estimated based on the local characteristic of land use change. Therefore the distance of neighbouring land must be calibrated to yield more accurate results in the analysis of the extent of sprawl, based on the two competing externalities in the fringe of Jakarta Metropolitan. The properties of semivariogram allows for the identification of distance where the spatial (auto) correlation no longer exists. Since there are two variables representing each type of externalities, the semivariogram analysis is conducted for each variable. Locations separated by smaller distance tend to have significant auto-correlated (low variogram value) density or proportion of agriculture area. On the other hand, the further the distance between locations the less auto-correlated (high variogram value) the density or the proportion of agriculture area will be. When the semivariogram levels out at its sill, the practical range can be identified as the furthest distance where the interaction or externalities are in effect. The semivariogram analysis might fit different practical range for each variable, implying the different extent of each type of externalities.

The estimated semivariogram of each variable defining each type of externalities is based on 39 spatial lags, up to half of the maximum possible distance between districts (≈125 km). The size of lag is one mile, to accommodate the chosen distance in the prior studies (Fitriani and Harris 2011). The empirical semivariogram is defined based on (1) in which the observed value is ZA(si) and ZG(si) respectively for the social type and the green type of externalities. Then, the empirical semivariogram is fitted into one of the theoretical semivariogram defined in (2) until (5). For each theoretical semivariogram, the model parameter σ^2 and r are estimated using the WLS method (Cressie 1993). It chooses the value of σ^2 and r to minimize the following weighted sum of square:

$$W(\sigma^2, r) = \sum_{i=1}^{39} N(h_i)\left\{\frac{\gamma^*(h_i)}{\gamma(h_i;\sigma^2, r)} - 1\right\}^2, \quad (6)$$

where

$\gamma^*(h_i)$ is the empirical semivariogram defined in (1) for each of spatial lag I, I = 1, …, 39,

$\gamma(h_i)$ is one of the fitted theoretical semivariogram defined in (2) until (5) for each of spatial lag I, I = 1, …, 39.

For each variable representing each type of externalities, all of the four possible semivariogram models are fitted. The best model is chosen based on the smallest weighted sum of square in (6). The estimated parameters and the weighted sum of square from the models are presented in Table and Table 1 respectively for the social type and the green type of externalities. The plots of the fitted models are presented in Figure 3 and Figure 4 respectively for the social type and the green type of externalities. The weighted sum of squares in Table and Table 1 indicate that the spherical model is the best fitted model for both types of externalities.

TABLE 1 - THE ESTIMATED PARAMETERS AND THE WEIGHTED SUM OF SQUARE OF THE SEMIVARIOGRAM MODELS FOR DENSITY (SOCIAL TYPE OF EXTERNALITY)

Model	σ^2 (sill)	Range (meter)	Effective Range (meter)	Nugget	Weighted SS
Exponential	11897618	13189.26	39511.48	0	104.61
Spherical	**11292486**	**29171.72**	**29171.72**	**0**	**93.801***
Gaussian	10989282	10094.97	17472.57	0	118.32
Circular	11241160	25110.92	25110.91	0	95.403

*the best model based on the smallest weighted sum of square

TABLE 1 - THE ESTIMATED PARAMETERS AND THE WEIGHTED SUM OF SQUARES OF THE SEMIVARIOGRAM MODELS FOR PROPORTION OF AGRICULTURAL AREA (GREEN TYPE OF EXTERNALITY)

Model	σ^2 (sill)	Range (meter)	Effective Range (meter)	Nugget	Weighted SS
Exponential	0.1044	29000	86876.24	0	160.5706
Spherical	**0.0704**	**29000**	**29000**	**0**	**91.2837**
Gaussian	0.2631	29000	50193.73	0	1415.829
Circular	0.0738	29000	29000	0	122.9599

*the best model based on the smallest weighted sum of square

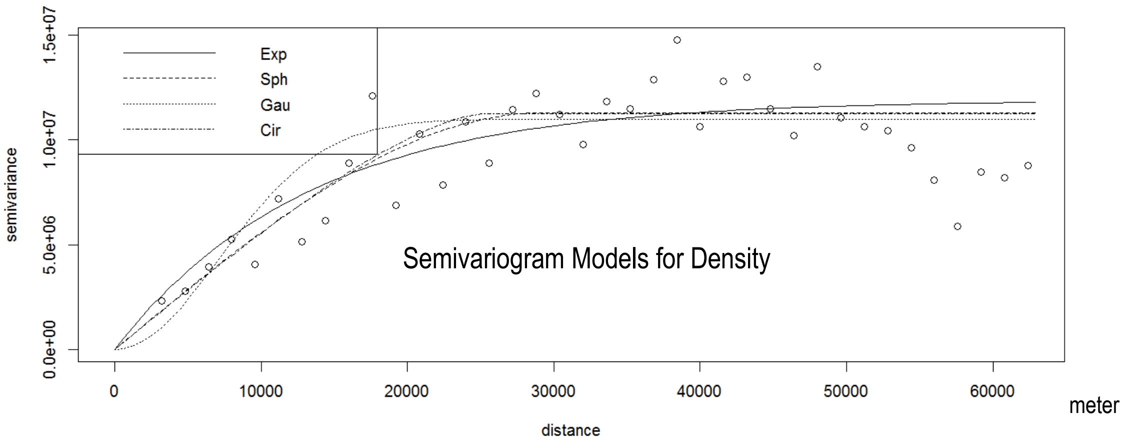

Figure 3 - The Plots of Fitted Semivariogram Models for Density (the social type of externality)

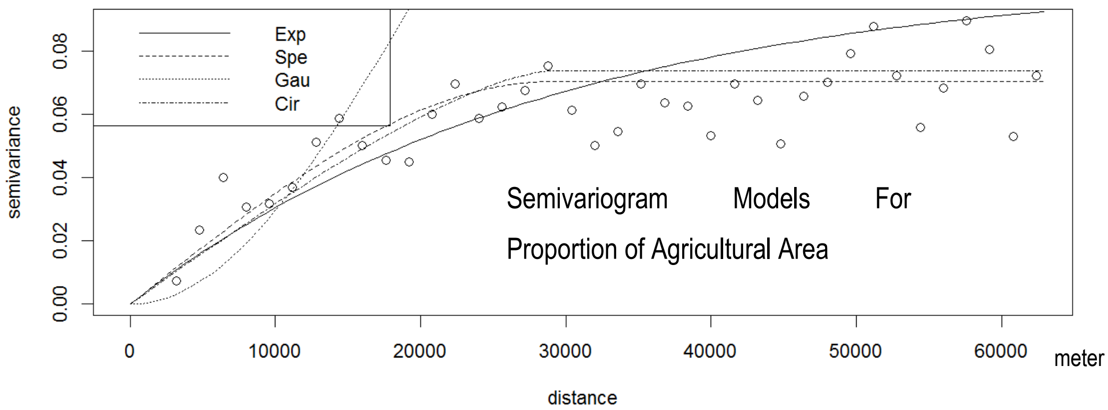

FIGURE 4 - THE PLOTS OF FITTED SEMIVARIOGRAM MODELS FOR THE PERCENTAGE OF AGRICULTURE AREA (THE GREEN TYPE OF EXTERNALITY)

Specifically for spherical model, the estimated parameters in Table 1 and Table 2 indicate that the autocorrelation of density will dissappear at the distance beyond 29.2 km. In term of land use, it can be interpreted that beyond 29.2 km, density or the presence of any social/development activities will have no effect on land use change. Similarly, based on the results in Table 1, also for the spherical model, the autocorrelation of percentage of agriculture area will be insignificant at the distance beyond 29 km. Thus, the presence of agricultural activity will affect any land use change within radius 29 km.

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5. CONCLUDING REMARKS

The indication that sprawl has been dictated by the two competing land use externalities has been the main interest in this study. It is hypothesized that the situation when the preference of neighbourhood development (social type of externalities) is as strong as the preference of available open space (green type of externalities) leads to leapfrogged development pattern. The hypotheses can be tested using a spatial econometric model. In the model, land value is the response, whereas factors affecting the land value such as distance to the CBD, geographical condition and utility are the predictors. In addition to those variables, to accommodate the neighbourhood externalities, variables representing those two competing externalities must be included. It is assumed that these two variables are spatially correlated within certain radius that is called neighbourhood. In a standard spatial econometric model, these variables will be complemented by a spatial lag matrix W which determines the neighbour locations.

The land use condition in the fringe area of Jakarta Metropolitan indicates that based on 2006 data, the two types of externalities will come in effect within radius of 29 km. Therefore any districts/locations within the radius will be defined as the neighbourhood. In other words, only the districts within that radius that are regarded as neighbours. The identification of neighbour districts is important to develop a neighbourhood matrix W, which is needed in a further spatial econometric analysis. The analysis is useful to test the externalities hypothesis as the driver of sprawl, or to predict the future land use change.

It will be more informative if the same analysis is conducted for data from other years. The results in different years will describe the nature of the distance: static or dynamic. This will be the objective of the future research.

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