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Geographical Patterns of Urban Residential Development

1. Introduction

In an urbanized environment, the geographical pattern of residential development is a complex phenomenon to model quantitatively. This is because it is a comprehensive and dynamic phenomenon that involves a wide spectrum of social, economic, cultural, and geographical variables. Conventional approaches to studying this phenomenon have been focusing on using one or just a few variables, while holding others constant, to obtain a sketchy impression of how the development of urban residential land use has changed over space and in time. Some examples can be found in Morcombe (1984), Donovan and Neiman (1993), Hitt (1994), Fulford (1996), Fader (2000), and Levia and Page (2000). As such, results from the research and literature on this topic offer only partial understandings of how urban residential lands develop geographically and temporally. For practical application, we would need to develop integrated models with definable quantitative measures.

Urbanization expands the size of a city or a population settlement until the city becomes too crowded for further development at its core. At that time, sub-urbanization occurs. Both population and economic activities move from the city's core to its peripheral areas. With advancement in transportation technology, sub-urbanization actually expands urbanized areas and connects the surrounding scattered developments into metropolitans. During such process, the development of residential lands takes a variety of geographic patterns at different stages of urbanization.

In the early stage of urbanization, residential lands develop in a more compact form, as new developments tend to occur adjacent to existing ones within and surrounding the urban core. During sub-urbanization, the population settlement continues to expand, new residential developments may occur in a more haphazard manner and at faster rate – a phenomenon often referred to as urban sprawl. The sprawling of urbanized area surrounding its core typically occurs by first spilling new developments over peripheries and then followed by in-filling those vacant lands in between. As peripheries become saturated, the next stage of expansion begins to ignite another cycle.

We illustrate here a set of models that can be used to measure the geographical patterns of how residential lands develop spatially and temporally. The actual pattern can be measured to fit into one of the defined models to see if it is closely related to a compact expansion, a sprawling growth, or an in-fill process.

B. Boots et al. (eds.), Modelling Geographical Systems, 13–31.

Specifically, we use Join-Count Statistics, a simple spatial statistic, to measure the geographical patterns of the development of residential lands. Coupled with temporal trends, these models can be used to quantitatively study residential developments.

The parcel-level data from Geauga County, Ohio, USA, were used to show how a simple statistical method could be applied to quantitatively model the geographical pattern of residential development over time. With similar data at parcel level, modeling of urbanization process can be carried out in other regions in the same way.

2. Join-Count Statistics as a Measure of Geographical Patterns

We suggest that the Join-Count Statistics can be used to measure quantitatively the clusterness and dispersion of the geographical patterns of residential lands. Join-Count Statistic is the simplest form of spatial autocorrelation. While not being the most powerful statistic for measuring spatial patterns, it is appropriate for this study because of its ability to handle polygonal binary nominal data.

In statistical concepts, autocorrelation is the relationship between successive values of residuals along a regression line. In most cases, a strong autocorrelation indicates successive values are strongly related, which implies that data values being regressed may have a systematic trend among them. Spatial autocorrelation is a simple extension of the autocorrelation concept into two dimensions:

- A strong, positive spatial autocorrelation means that the characteristics of geographic objects are very similar to those of nearby objects. This is normally referred to as a *clustered* pattern.
- Alternatively, a strong negative (or inverse) spatial autocorrelation suggests that geographic objects may have very distinctive properties between adjacent objects. This is often known as a *dispersed* or *uniform* pattern.
- When there is no measurable spatial autocorrelation, the geographic objects are said to be in a *random* pattern.

The three patterns, clustered, random, and dispersed, serve as three mileposts on a spectrum along which many other possible patterns may exist. Because of this, a value of spatial autocorrelation coefficient by itself is not useful unless it is tested for its statistical significance of how different it is from a coefficient value indicating a particular pattern. For example, a spatial autocorrelation coefficient measured from an observed pattern will need to be tested to see if it is statistically significantly different from the coefficient value of a random pattern – giving the same spatial structure of the geographic objects.

Join-Count statistics provides a simple and efficient way of quantitatively measuring the degree of clusterness or dispersion among a set of spatially adjacent polygons. It bases its measurements on how different the geographical pattern being observed is different from a theoretically constructed random pattern, given the same number of geographical areas and the same spatial structure. This statistic allows users to measure and test if a geographic pattern is statistically significantly different from a random pattern, and if so, whether the geographic pattern is more clustered than a random pattern or it is more dispersed than a random pattern.

Join-Count Statistics only work with binary nominal data associated with polygons. Given a geographic phenomenon with a yes/no, presence/absence, black/white, or other forms of dichotomy characteristics, each geographic area, or termed as a *polygon*, is associated with either one of the two possible characteristics. In our case, a land parcel can be classified as built or vacant. A *built* parcel is one where it has been built with a construction unit while a *vacant* parcel is without one and is available for future development.

Once the polygons of land parcels are defined as either built or vacant, the Join-Count Statistic counts the numbers of various types of Joints between adjacent polygons. These numbers are then compared with those of a random pattern to determine if the pattern being observed is significantly different from a random pattern or if it is more clustered or dispersed than a random pattern.

A *joint* is a segment of shared boundary between two adjacent polygons. It can be a *BV* joint if the joint connects a built polygon and a vacant polygon. A joint can be a *BB* joint if it is shared by two adjacent polygons that both have been built for residential use. Similarly, a *VV* joint is one that is shared by two vacant parcel polygons.

Following Lee and Wong (2001, pp. 147–156; also in Cliff and Ord, 1981; Upton and Fingleton, 1985; Goodchild, 1986; Griffith, 1987), let O_{BV} be the number of observed *BV* joints, E_{BV} be the number of expected *BV* joints from a random pattern, and σ_{BV} be the estimated standard deviation of E_{BV}, a Z score can be calculated as:

$$Z = \frac{O_{BV} - E_{BV}}{\sigma_{BV}} \quad (1)$$

If the observed number of *BV* joints is greater than the number of expected *BV* joints, it means that the observed pattern has more *BV* joints than that of a random pattern with same polygonal structure. In this case, the observed pattern is likely more dispersed than a random pattern because it has more occurrences of built polygons adjacent to vacant polygons. Alternatively, a pattern whose number of *BV* joints is less than that of a random pattern would imply that it is a more clustered pattern because the built polygons tend to be located next to built polygons. A word of caution should be given here regarding the appropriate use of Z score in testing the statistical significance of Join-Count Statistics. There should be at least 30 (or more) parcels in each data set and that the ratio between built and vacant parcels should not be too close.

A graphic example for a clustered pattern (Figure 1a), a random pattern (Figure 1b), and a disperse pattern (Figure 1c) is shown in Figure 1. In this

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