Assessing Urban Sprawl

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Abstract

Human interaction with nature has been always an interesting study in the field of social sciences. Since most of the ancient cities were planned to deal with the population of that era, the cities have been having a hard time coping with additional burden. In this paper, I study the causes of the urban sprawl and how variables like rail network and roads add up to this sprawl. For my analysis, I incorporated laws from theoretical physics such as inverse square law and Kirchhoff's law to define how these models fit the urban context and spatially relate to the cities we live in. I also came up with an hypothesis that relates the house price with the distance between the station and the house.

Introduction

It's a natural characteristic of a human being to flock to places where there is abundance of resources. Needless to say, these resources are the key that help us grow and create new things to move our civilization forward. Ever since industrialization, our society has witnessed drastic changes in people's movement pattern. When the industries started setting up, people flocked to city centers from where they could easily commute their workplace. At this time in history, the only option for transit were the carriages and so the working class preferred to live in close vicinity of the industrial areas and they couldn't possibly afford the carriage rides. As our society grew, we developed new modes of transportation and with every new invention, our city scape changed substantially. With the advent of railway system, people could who couldn't afford to live far away because of commute and had to pay higher rent for industrial areas, had an option to move to outskirts and commute via trains. As technology made its way in the society, people started using cars for commute thereby shortening their travel time to work. Urban migration has been a phenomenon for decades, as the cities started flourishing, people from rural and less developed areas move towards the cities and settle in the low-income areas. This creates havoc for city officials as they have to manage limited resources with increased number of citizens in the city. In order to solve these problems, one has to analyze the city quantitatively and understand how city centers interact with other facilities that city provides to its citizens. Urban sprawl could be a result of (Vaz & Nijkamp, 2014):

a) Excessive city growth
b) Population dispersion
c) Disconnection between infrastructure and buildings
d) Creation of new core developments in sub-urban areas of the cities

Our current models however, fail to analyze the interaction between the city centers and the new suburban developments which is in fact the part of the same city area. This is due to the assumption based on two criteria (Vaz & Nijkamp, 2014):

- Centrality: In urban context, urbanization follows distance decay where the allocation of urbanization is led by proximity of previously constructed areas, and
- Cellular Neighborhoods: the weights calculated for future urbanization for urban growth models are the result of the neighboring cell, and not the result of an entire system of regional dynamics, that is, the reality of an urban spatial structure, which is by far more complex (A. Anas, 1998)

Assessing Urban Sprawl is particularly important because, although moving away from the city center would help decrease the population density, but may cause other problems such as farmland depletion, displacing wildlife, increased traffic as more and more people would be using their private vehicles. 'Because sprawl occurs on the urban fringe and is piecemeal in its development, sites within sprawling areas tend to be located at distances from the urban core and also from each other; consequently, journeys for residents of these areas become unnecessarily long and there may be associated social and environmental consequences' (Torrens & Alberti, 2000).

Literature Review

One of the previous studies I found interesting regarding Urban Sprawl was Eric Vaz and Peter Nijkamp's analysis of Gravitational forces in the spatial impacts of urban sprawl (Vaz & Nijkamp, 2014). They test their hypothesis in Veneto, Italy for two different years i.e. 2000 and 2006 to see how population density and land use pattern differs over a period of 6 years. They also considered neighboring cities of Padua, San Dona di Piave, Treviso, Chioggia, Schio, Venice, Rovigo, Bassano del Grappa, Vicenza and Verona for their analysis to test for spatial contiguity. Bringing their law of gravitation to urban context, 'a' was considered as urban change witnessed in urban land-use during a given time t, affecting the regional dynamic of intra-city growth. The force F is defined as the relation to spatial proximity of the main cities in Veneto in Italy while the mass is considered to be the population density of the city. They feel that "an intercity gravitational model could help to better understand urban sprawl at the regional level. Such a model offers an understanding of changes between all urban footprints in the region, as they respond to change according to the force of a gravitational pull, a process previously not considered in urban and geographical literature as an independent force, which exerts pressure over the entire regional environment rather than being limited just to the city fringe". The results show that Verona, Padua and Trevisso generate per mass the urban sprawl, which is then validated by defining a buffer that assesses this change. "The assessment of urban sprawl in the entire region of Veneto leads to the conclusion that the intensity of urbanization is proportional to the increasing gravitational pull in the area, and suggests the need to integrate the spatial dynamics in the context of cities that have a definable spatial proximity."

Another such study conducted by Mischa Young, Georges A. Tanguay and Ugo Lachapelle analyzed the transportation cost and urban sprawl in Canadian metropolitan areas (Young, Tanguay, & Lachapelle, 2015). Since most of the official buildings in Canada offer free parking, people tend to use their cars for commute more often. In order to test their hypothesis, the authors studied two very important dependent variables, proportion of low-density housing and proximity using the median commuting distance traveled while considering independent variables such as gasoline price, parking price, population, agriculture land cost and household income. With reference to an older study that used natural evolution theory, on average, a 1% increase in the price of gasoline caused a decrease in low-density housing by 0.60% and an increase in the population living in the inner city by 0.32% (Travisi, Camagni, & Nijkamp, 2010). The authors hypothesize that as commuters recognize that they will have to absorb the additional increase in transportation costs brought upon by a rise in off-street and on-street parking prices, they may reconsider their choice of living in suburban neighborhoods and potentially decide to move closer to the city center in order to benefit from better public transit infrastructures and active transportation routes. From their results, it was clear that both off-street parking prices and gasoline prices had an effect on urban sprawl, but their effects were modest and gasoline prices had a greater effect on sprawl than off-street parking prices. Also in their regression model, total population and median household income offer statistically significant coefficients and present a small negative relationship and a strong positive relationship to low-density housing respectively.

A study on Interaction between Road Network Connectivity and Spatial Pattern was interesting and resonated well with my analysis premise. The authors Sreelekha.M.G., Krishnamurthy.K., Anjaneyulu. M.V.L.R. studied the road network pattern in Calicut, India to come up with the relationship between the level of road network development and the network spatial structure (Sreelekha.M.G., Krishnamurthy.K., & M.V.L.R., 2016). Their objective was to understand the existing road network of the city in terms of connectivity and development, and characterize the spatial structure of the road network in terms of fractal dimension. After running their model, the authors inferred that Fractal Dimension had the highest correlation with the Network Density, that is 0.877. They also found that the R square value for their regression was highest in case of linear regression model, 0.794. Their analysis reveals that road network fractality is directly varying with respect to connectivity and coverage of the study area. In conclusion, the quantitative relationship between spatial patterns and road network provides an empirical guide for city officials and policymakers.

Theory

As a result of Urban Sprawl, the city needs to manage its public transportation for the suburban areas as commute is major aspect that could affect the sprawl. For my analysis, I consider the road network and railway network because these are the modes of commute that is used extensively when people move to the peripheral areas of the city. The road network can be considered as a network of nodes and links where every intersection can be considered as a node and the path leading to the node can be considered links. The flow of traffic at these nodes can be better understood by the following formula:

$$\sum_{k=1}^{n} I_k = 0$$

where, I_k represents the number of incoming or outgoing vehicles at a node

In theory, if we consider our road network to be a closed network, then at each node the number of incoming vehicles is equal to the number of outgoing vehicles. The incoming vehicles are represented by a positive sign whereas outgoing vehicles are represented by negative sign. More famously, this law is known as Kirchhoff's Current Law(KCL) in analog electronics which states "The algebraic sum of current into any junction is zero " (Jones, 2017). This kind of analysis is particularly interesting when we want to study certain junctions at any given time that experience tremendous amount of traffic. This equation is universal for nodal analysis of closed networks and can be applied to any given node in the city. The method can be easily applied to GIS as we can consider a subset of our test region known as sample region and for every node in the sample region, we can analyze the traffic flow.

For any given polygon in the city center, the ratio of rate of change of footfall in that polygon to the rate of change of footfall on similar polygon in suburban areas is given by a constant. Mathematically,

$$\frac{\lim_{c\to\infty}\frac{d\phi_c}{dt}}{\lim_{s\to\infty}\frac{d\phi_s}{dt}} = \mathrm{K}$$

where, ${d\phi_c}/_{dt}$ is the rate of change of footfall in a given polygon in city center where as ${d\phi_s}/_{dt}$ is the rate of change of footfall in the similar shaped polygon in the suburban area and K is a numerical value.
If K>1, the rate of change of footfall in city center is greater than that in suburban area and vice versa. This method is useful to identify if for a particular shaped polygon, the rate of change of footfall is greater in city center or not which in turn gives us the information about the population density of the two areas. Multiple polygons can be tested for correlation with this method based on contiguity and we can determine how different parts of the city, sharing common edges, correlate with each other in terms of density. The size of polygon can be set anything depending on the type of problem under consideration.

As the railway network became prominent, the residents of the city conveniently moved to outskirts as they had an option to commute back and forth to the city using the trains and keep themselves away from high rent burdened areas of the city center. Although, it could be thought of as one of the reasons that caused urban sprawl, there are some logistic assumptions we need to look into. For a person moving to suburban areas, their commute is a priority and therefor the dwellings closer to train stations witness higher housing price. To formulate this hypothesis:

$$P \propto \log\left(\frac{1}{d^2}\right)$$

$$\text{or, } P = \log\left(\frac{K}{d^2}\right)$$

where, P is the housing price and d is the Euclidean distance between the station and the house. K is any other factor that plays pivotal role in deciding the price of the house and it's kept constant because those factors may or may not spatially affect urban sprawl. One can assume that after a particular distance from the station, the house price does not increase exponentially and rather gets a steady state, so taking logarithm of the distance would help us make better predictions. The scope of this method is essentially broad and can be applied to a number of areas as the distance can be calculated between any two physical entities. We can also find correlation between different houses of different areas having similar attributes but different distance from station using inverse distance parameter. Since the spatial construct is very strong for this method, we can easily use GIS as we have multiple regression, autocorrelation tools built-in.

In conclusion, the methods discussed gives us some vital information on urban sprawl. The things that would make a person leave the city center is high rent burden, more traffic on the road in exchange of shorter commute time. If the suburban areas get connected to the city centers efficiently, we would see drastic change in movement patterns as people would prefer to live outside the city with comparatively cheaper and bigger houses. This popularity can also bring about competition in the housing market in suburbs where the property next to transit access would get more expensive than the others. As discussed earlier, urban sprawl although helps a lot of investors and citizens who want to move out, but also create imbalance in the ecology and land use. Therefore, the city officials need to assess the pros and cons of the urban sprawl and how it spatially impacts the different elements of our society.

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