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Measuring the Containment and Spillover Effects of Urban Growth Boundaries: The Case of the Portland Metropolitan Area

Abstract: Although Urban Growth Boundaries (UGBs) are increasingly used as a containment policy to promote contiguous and compact urban forms, little is known about how UGBs affect development within the designated area or how development is displaced to other cities. This study analyzes the UGB's containment and spillover effects, focusing on the case of the Portland metropolitan area where UGBs have long been implemented. This is accomplished by employing a spatial market disequilibrium framework in which explicit consideration is given to the containment and spillover processes when under the influences of UGBs. The findings suggest that UGBs can promote development within the boundaries, but that cooperation with neighboring municipalities is necessary to effectively attain the policy goals.

Keywords: Urban growth boundaries; Containment; Spillover; Housing market; Disequilibrium

Introduction

While urban expansion can be attributed to decreasing transportation and communication costs enabling people's preference for suburban living environments (Gordon and Richardson 1997), unchecked development is generally considered a cause of many contemporary urban problems (Lamb 1983; Ewing 1996; Burchell et al. 2005). To curb sprawl and induce compact development, many municipal governments have taken action through various growth management programs. Among others, in the United States more than a hundred cities and counties have adopted Urban Growth Boundaries (UGBs) or similar policy initiatives to manage urban expansion (Staley, Edgens, and Mildner 1999). Furthermore, Oregon, Washington, and Tennessee have enacted state laws that mandate local and regional government bodies to establish their own growth boundaries and incorporate UGBs into their comprehensive plans.

As UGBs have been increasingly employed, a growing number of studies have analyzed how the policy affects the implementing communities and regions. Particularly, a great deal of attention has been paid to whether UGBs really induce a more compact urban form, which is assumed to be environmentally and fiscally desirable. A group of prior studies (e.g., Nelson and Moore 1993; Moore and Nelson 1994) examine this issue by analyzing the locational pattern of new development and determining if new development tends to occur within the boundaries. More recent studies test the effectiveness of UGBs in controlling sprawl and promoting compact development through intertemporal comparison (e.g., Kline and Alig 1999; Carlson and Dierwechester 2007) or cross-sectional analysis (e.g., Jun 2004; Nelson et al. 2004).

However, although previous research helps understand the effect of UGBs, little is known about how UGBs affect development within the designated area or how development is displaced to other cities. This study examines the influence of UGBs on development patterns with explicit consideration of the containment and spillover mechanism. More specifically, an investigation is made by employing a spatial market disequilibrium framework, where the displacement process is explicitly handled, with the use of data from the Portland metropolitan area.

The remainder of this article is structured as follows. The following section provides a background discussing the potential effects of UGBs on development patterns. The third section explains the spatial market disequilibrium model, originally developed by Snell (1999) and employed for this study to assess containment and spillover effects in an explicit manner. Then, the section on "Empirical Analysis" describes how the effects of Portland's UGB are empirically analyzed using the model. The fifth section presents the analysis results, followed by a concluding section where the main findings and overall research are discussed.

Background: Development Pattern & Urban Growth Boundaries

An underlying idea of land use regulation is to realize a desirable spatial pattern of various human activities (e.g., residence, leisure, agricultural, commercial, industrial production, etc.) by restricting the corresponding land uses in some areas, while allowing them in other areas. A typical example is provided by UGBs which are increasingly being adopted to control sprawl, by restricting development outside of the boundaries, while allowing land uses for urban purposes within the boundaries (Kim 2011: 36). It is anticipated that unchecked expansion can be controlled and that the constrained demand for urban development can be directed into the designated areas. As a result of this potential development relocation, the implementing city is expected to have a more compact and contiguous urban form.

It is literally possible to prevent any form of development in a certain area, if strict regulations are enforced. However, it is not guaranteed that the constrained demand for development will go to the designated areas, so the regulation attains its goal – i.e., a compact urban form – without any sacrifice. In other words, it may happen that a certain portion of the constrained activities and associated development may relocate outside the implementing city.

In reality, how do UGBs affect development patterns? Does this policy really achieve the expected outcomes – i.e., creating a more compact urban form and mitigating the problems of sprawl? This question has been the core issue in empirical studies of UGBs, with other research concerning UGBs' impacts on real estate and housing markets (Knaap 1985; Nelson 1985, Philips and Goodstein 2000; Dawkins and Nelson 2002; Kim 2010), residents' welfare (Cho 1997; Ding, Knaap, and Hopkins 1999; Bento, Franco, and Kaffine 2006), and congestion problems (Brueckner 2000, 2007; Anas and Rhee 2006, 2007). The literature suggests that UGBs can contribute to controlling sprawl and increasing the density of implementing areas, although some studies (e.g., Jun 2004; Cho et al. 2007; Cho, Poudyal, and Lambert 2008) question the effectiveness of UGBs.[1]

A typical form of research to empirically evaluate this policy is to analyze where new development tends to occur when under the influence of UGBs in the study area. For instance, Nelson and Moore (1993) analyze the location of new residential development (including potential development as revealed by building permit data) in the Portland metropolitan area in late 1980s and find the concentration of development within the growth boundary, which indicates the effectiveness of the UGB. In another study, they investigate the effect of Medford, Oregon MSA's UGB using a broader range of indicators covering residential and commercial-industrial development (Moore and Nelson 1994). Their analysis results suggest that the location and density of new development followed the policy makers' intentions between 1985 and 1989.

As it is difficult to judge whether development patterns are really modified or not without a reference or benchmark, intertemporal comparison with a long range dataset is often conducted. Kline and Alig (1999) use the U.S. Department of Agriculture's (USDA) Forest Inventory and Analysis dataset that compiles land use changes since 1961 to investigate the effectiveness of Oregon's UGBs. Employing a probit model, they analyze the locational pattern of a particular type of land use change indicating new development (i.e., land use changes from forest or farmland to urban uses) and find that the UGBs in the state of Oregon seem to direct development into designated areas. More recently, Carlson and Dierwechester (2007) analyze the case of Pierce County, Washington using geo-coded building permit data that enable researchers to detect the location of new development more accurately than spatially less explicit zonal information, such as U.S. Census data. The dataset here also covers not only a post-UGB-implementation period (1995~2002) but also a few years before the enforcement of the UGB (1992-1995). Using the data, the authors compute the kernel density and show the increasing density within the UGB after the policy adoption, which is in contrast to the declining development outside the UGB. Gennaio, Hersperger and Burgi (2009) investigate the effectiveness of UGBs implemented by four municipalities in Switzerland. Using compactness measurements, they assess how the development patterns of the four cities have changed between 1970 and 2000. They find empirical evidence suggesting that the growth boundaries have been effective in inducing compact development, namely increasing densities within the building zone boundaries. This density increase is clearly contrasted to the density declines outside the boundaries.

Recent years have also seen cross-sectional studies comparing the implementing region(s) with others in terms of relevant indicators such as density changes and/or the locational distribution of development. Nelson et al. (2004) analyze whether various urban containment policies, including UGB programs, are effective in inducing central city revitalization by modifying the locational pattern of development as intended. From an interregional comparison using data for 144 central cities in the United States, they find that central cities in regions with urban containment programs prior to 1985 had attracted a greater number of real estate construction projects between 1985 and 1995 than those within uncontained metropolitan areas, although there was no considerable difference in terms of the central city's share of the entire region. In particular, containment policies seem to effectively direct construction of multi-family housing units and remodeling/addition of commercial buildings into central areas, rather than suburban or exurban areas. Wilson and Song's study (2009) is also notable, although it is not a formal evaluation of a UGB. They compare Portland, OR and Charlotte, NC in a consistent setting for development pattern assessment (i.e., "apples to apples" comparison, rather than "apples to oranges") that they create by employing a cluster analysis technique. In Portland, they find that single family residential development tended to locate in inner or middle-ring suburbs between 2000 and 2002, whereas approximately 75% of total development in Charlotte occurred in outer suburbs or rural greenfields. This finding suggests that the Portland UGB may be successful in modifying the pattern of new development.

Overall, existing research has extensively examined the effect of UGBs on the spatial pattern of development and suggests that UGBs often work. It appears that UGBs are likely to contribute to controlling sprawl and increasing the density of implementing areas, although the outcomes seem to differ by context and implementation strategies. However, in the previous studies, little attention has been paid to the detailed mechanism of containment and spillover when under the influence of UGBs, although the underlying logic of UGBs is to pull development into the boundaries. As summarized above, the studies typically focus on the manifested pattern of development with and without UGBs, rather than tracing how potential development is relocated, if restricted at a location point, and how the resultant pattern evolves.

It should be noted that some potential development may relocate away from the implementing city rather than stay within the boundaries due to regulations, as suggested by Shen (1996), Levine (1999), and Byun, Waldorf, and Esparza (2005). *How* is the potential development contained or displaced, if regulated by UGBs? Do UGBs contain the demands for development as much as expected or push them out? An examination of the containment and spillover mechanism will provide a better insight into the consequences of UGBs and lead to a more meaningful discussion on the policy.

Spatial Market Disequilibrium Framework

To measure the containment and spillover effects of UGBs, this study employs a spatial market disequilibrium framework developed by Snell (1999). In spite of some difficulties of disequilibrium modeling that arise from denying the assumption of market equilibrium, this kind of framework is useful to better describe the housing supply – demand interaction in small areas where supply constraints are likely to exist. In particular, this approach is needed to analyze the relocation process under the influence of a UGB or other types of supply restriction.

Basically, the present application of the framework to a spatial housing market system is designed to estimate the hidden original housing demand (i.e., U_1U_1' and U_2U_2' in Figure 1), based upon

- satisfied, thus observable demand (i.e., O_1O_1', $M'O_2'$, and $O_2'O_2$ in Figure 1)
- information about whether a particular location is constrained (i.e., supply shortage and unmet demand) or not
- a priori knowledge about the basic rule of the demand relocation (i.e., r_{ij} in the formulation, presented below).

<< Figure 1 about here >>

Figure 1. Hidden Original Demand & Observed Development Pattern

The applied formulation slightly modifies Snell's (1999) framework and is explained as follows. First, the expected housing demand of zone *i*, which indicates the level of demand without any supply constraints, can be expressed as below.

$$\overline{D_i} = X_i \cdot \beta + \varepsilon_i \qquad (1)$$

where X is a vector of determinants of housing demand; β is a column vector of corresponding parameters; and ε_i is *i.i.d.* error.

However, in reality, the expected housing demand cannot be obtained for many reasons and is thus unobservable. For instance, if development is not allowed in a zone, such as the case of $M'O_2'$ in Figure 1, the empirical data will exhibit a much lower number of housing units than the expected demand in the area. In contrast, what we can observe in unconstrained zones (e.g., O_1O_1' and $O_2'O_2$) will be greater than the original demand, as the unmet demand from the constrained zones will be relocated to the areas. The observation in such unconstrained zones can be called "effective demand" (D_i), which is different from the initially expected level; it is the sum of the expected demand of zone i (i.e., $\overline{D_i}$) and spillovers to the zone from all other zones in the study region.[2] In other words,

$$D_i = \overline{D_i} + \sum_j r_{ij} \cdot (D_j - Q_j) \tag{2}$$

r_{ij} are known values, representing the proportion of demand spillover from zone j to zone i (i.e., displacement), when demand is unmet in j. r_{ij} is equal to zero, when $i = j$. The column sum (i.e., $\sum_j r_{ij}$) is equal to one. As a result, r_{ij} are analogous to the elements of the well-known spatial weight matrix.

In the equation (2), Q_j represents the quantity of satisfied demand, which is

$$Q_j = \min(D_j, S_j) \tag{3}$$

Here, S_j is the effective housing supply in zone j, in which a natural vacancy rate in the housing market is considered. Most simply, S_j can be expressed:

$$S_j = (1 - v) \cdot HU_j \tag{4}$$

where v is a natural or inevitable rate of vacancy; and HU_j is the stock of housing units in zone j.

It should be stressed that we assume to know whether residential development in each small zone is constrained by the UGB or other types of restrictions (constrained zone), or not (unconstrained zone). Otherwise, this kind of disequilibrium market model cannot be estimated. How to determine whether the current state of a market is with an excess demand over supply capacity is the most critical issue of disequilibrium modeling and will be explained in the next section.[3]

As well presented in Snell (1999), the framework provides the following model with the two groups of samples: 1) constrained zones and 2) unconstrained zones.

$$\begin{bmatrix} D_1 \\ D_2 \end{bmatrix} = X \cdot \beta + \begin{bmatrix} R_{11} & 0 \\ R_{21} & 0 \end{bmatrix} \cdot \begin{bmatrix} D_1 - S_1 \\ D_2 - S_2 \end{bmatrix} + \varepsilon \qquad (5)$$

where D_1 and D_2 represent the demand vectors of constrained and unconstrained zones, respectively. S_1 and S_2 indicate the housing supply provided in the two groups of small zones. R_{11} and R_{21} are the matrices with r_{ij}, representing the logic of demand spillover from constrained zones to other zones.

The model suggests that the housing supply (S) does not necessarily meet the original demand ($\overline{D} = X \cdot \beta + \varepsilon$) in each small area (i.e., a disequilibrium state). In the case of the constrained zones, housing units could not be supplied as much as demanded, due to physical and/or regulatory constraints on development. In contrast, the level of housing supply in unconstrained zones would be greater than their original demand, as these areas need to accommodate the demand spillovers from constrained zones in addition to the demand originally arising in the areas.

It is somewhat difficult to estimate this model due to unobservable demand in the cases of the constrained areas and its spatial autoregressive form. However, a maximum-likelihood estimation technique with a set of special treatments can work for the estimation. The maximum likelihood estimates will show the most probable hidden demand function, namely equation (1), given available information.

Once the hidden demand function is revealed, it is possible to identify how the actual development pattern in the region differs from an unregulated situation lacking constraints on housing supply outside of the boundary. Furthermore, the containment and spillover effects of the UGB can then be quantified. In other words, we can have a better sense of how much constrained demand (i.e., $MM'U_1'$) is transferred to the designated areas within the implementing city, as opposed to relocating to adjacent municipalities (i.e., $O_1O_1'MU_1$ vs. $O_2O_2'U_2'U_2$ in Figure 1). In the next section, attention will be given to the empirical analysis of the case of the Portland metropolitan area, including the process of model estimation.

Empirical Analysis

Study Area

The spatial market disequilibrium model presented in the previous section is applied to the Portland metropolitan area where a UGB has long been implemented. This study considers the urbanized and surrounding areas within the 30 mile buffer from the central business district (CBD) of the city of Portland. The region stretches over nine counties in two states: Clackamas, Columbia, Multnomah, Marion, Multnomah, Washington, and Yamhill counties in Oregon, and Clark, Cowlitz, and Skamania counties in Washington (Figure 2).

<< Figure 2 about here >>

Figure 2. Study Region: Portland Metropolitan Area

In the study area, there are more than fifty local municipalities (besides census designated places) with a broad range of sizes. Two major cities in this area are Portland and Vancouver that represent the two parts of the region – the state of Oregon and the state of Washington. Whereas many central cities in the United States have shown no growth or population decline through the trend of rapid suburbanization, Portland and Vancouver have grown over the last three decades (Table 1). Particularly, in the 1990s, Vancouver experienced a dramatic population increase. This may be partly attributable to the early and relatively strict implementation of UGB programs in the Oregon part of the region, although large annexations that occurred during the time period are important contributors to the population increase (Bae 2001). In other words, the UGB is regarded as a strong force to shape the spatial structure of the region that induces significant relocations of development in this area.

<< Table 1 about here >>

Table 1. Population Growth of the City of Portland and the City of Vancouver

As well documented by previous studies, such as Knapp and Nelson (1992), Nelson and Moore (1993), and Jun (2004), the Oregon part of this region is one of the pioneering and exemplary cases of UGB implementation in the United States. In this part of the study area, a UGB was first established in 1979 based upon state-wide proactive growth management initiatives adopted in early 1970s (Knaap and Nelson 1992). Since then, Portland's UGB has been recognized as a good model for anti-sprawl efforts, even though the implementation with a requirement to have developable land for 20 years is sometimes perceived as too loose to attain significantly compact development (Bae 2007).

One thing to be noted is that the UGB in the Oregon part of the region is managed by *Metro*, a regional government body responsible for a wide range of planning activities for three counties in the state of Oregon (Clackamas, Multnomah, and Washington counties). This regional planning system can ensure the implementation of the policy in a more coordinated manner, rather than leaving municipalities to their own affairs. As clearly stated on its website (http://www.oregonmetro.gov/index.cfm/go/by.web/id=277 accessed June 4, 2011), *Metro* is required to review land supply every five years, identify suitable areas for future development, and, if necessary, expand the boundary to keep developable land supply for 20 years inside the boundary. By doing this, it attempts to realize more efficient uses of land and infrastructure, to protect valuable farmlands and environmentally sensitive areas, and to encourage more compact and contiguous development patterns.

In contrast, until 1995, no UGB existed in the Washington part of the region, so constrained development on the Oregon side could easily spillover to the Washington side (Bae 2001). However, Washington enacted state-wide growth management legislation in 1990.[4] Then, as a part of the 1995 comprehensive plan, a UGB was introduced in Clark County where the city of Vancouver and the majority of areas in the Washington part of the study area are found.

Similar to the case of Oregon, the UGB program is an essential part of Washington's growth management initiatives. Under the state growth management act, "the cities and counties with a population of 50,000 or more, or a 17% increase in population within the past ten years, are required to prepare and adopt comprehensive plans for 20 years of growth [in which the urban growth areas should be designated], and to update those plans every seven years, [while others can voluntarily] choose to plan under the [requirements]" (League of Women Voters of Washington 2006: 13). Clark County and the city of Vancouver analyze and monitor the appropriateness of the growth boundary in a regular and extensive manner.[5] Based upon the analysis, their UGB was updated in 2004 and 2007 (City of Vancouver – Clark County 2007).

Variables & Data

To analyze the detailed containment and spillover effects of UGB program in the region, this study uses a grid system with one square mile sections. The study area consists of 2,832 sections, the unit of analysis in this study, as shown in Figure 3. These regular shapes make the analysis easier because otherwise special consideration would need to be given to areas of land in each unit, on which housing supply and demand largely depend.

<< Figure 3 about here >>

Figure 3. Spatial Unit of Analysis: 1 mile × 1 mile Section

Regarding the time periods, consideration is given to two periods: 1990-2000 and 2000-2010. In other words, the hidden demand of housing in year 2000 and 2010 are estimated using previous decennial year's conditions and other available information, based upon the grid system.

Urban growth area shapefiles (i.e., growth boundaries) are obtained from the U.S. Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing) /Line system. Only 2010 growth boundary information is available for the state of Washington so information presented in local plans is also used to fill this data gap. The number of households and housing units in each section is computed by transforming the census block group level numbers through an area-based spatial interpolation technique, since decennial Census is tabulated along with Census boundaries rather than the section.[6] Furthermore, a wide range of geographic information is compiled from the U.S. Census Bureau and the U.S. Geological Survey (USGS), to consider various factors of housing demand in different locations. In accomplishing this, lagged variables (i.e., the values measured in earlier years) are mainly used to minimize possible endogeneity problems. For instance, 1990 Census and 1992 USGS National Land Cover Dataset are utilized to construct explanatory variables to estimate the housing demand in year 2000.

Table 2 summarizes the variables and data sources used in this empirical analysis. The descriptive statistics are presented in Table 3.

<< Table 2 about here >>

Table 2. Variables & Data Sources

<< Table 3 about here >>

Table 3. Descriptive Statistics

The data show that both sides of the study region have maintained substantially increasing densities in central cities as demonstrated by the household density curves (Figure 4 and 5). This pattern of the changes in urban spatial structure, which is unusual in American cities undergoing rapid suburbanization, may be evidence of the effect of UGB.

<< Figure 4 about here >>

Figure 4. Household Density Curve in the Oregon Part of the Region

<< Figure 5 about here >>

Figure 5. Household Density Curve in the Washington Part of the Region

Estimation

First, to estimate the spatial disequilibrium housing market model, the characteristics of the individual sections – i.e., whether a particular small area is constrained or not – needs to be determined. This determination was conducted using the available information about the UGB and other natural constraints. More specifically, a certain section is regarded as a *constrained zone* if more than three fourths of the section's total area falls in any of the following constraints: 1) outside the UGB, 2) water, or 3) national forests or conservation areas (e.g., Mt. Hood National Forest). Both 100 and 500 year flood plains are not included in this process of determination, as land cover data suggest that development for urban uses often occurs in these areas, if the zones are not excluded from the growth boundary.

Then, r_{ij}, the logic of the containment and spillover, needs to be specified using a priori knowledge. Following Snell (1999), this analysis makes only a fundamental assumption that the spillover of the unmet demands is determined by the distance. This can be expressed:

$$r_{ij} = \frac{1}{d_{ij}^{k} \cdot \sum_{j,j \neq i} \left(\frac{1}{d_{ij}^{k}} \right)} \tag{6}$$

where r_{ij} is the elements of R_{11} and R_{21}, as explained in the section on “Spatial Market Disequilibrium Framework.” d_{ij} is the distance between section *i* and *j*. *k* is the distance decay rate, which is uncertain and thus needs to be determined. For this purpose, this study estimates the model with a wide range of *k* values. Then, the estimation outcomes based upon a particular *k* value that shows the best fit is chosen.

Even if we identify the status of each zone and specify r_{ij}, the estimation of the model is challenging, primarily because D in constrained zones cannot be observed. The autoregressive characteristic of the model adds another layer of difficulty. To deal with such issues, the maximum-likelihood estimation combined with the Expectation-Maximization (EM) technique is applied, like Snell’s (1999) application of the disequilibrium model to a school system. The EM technique was developed by Dempster, Laird, and Rubin (1977) and widely used for estimating models with incomplete data, including disequilibrium models (e.g., Atanasova and Wilson 2004) or spatial discrete choice models (e.g., McMillen 1992). In brief, the EM algorithm is an iterative two step (expectation step + maximization step) process to find out maximum likelihood estimates – convergence point through the iteration. As derived by Snell (1999: 600), in this case, the log likelihood function to be maximized is

$$\ln L = -\frac{n}{2} \cdot \ln \sigma_{\varepsilon}^{2} - \frac{1}{2\sigma_{\varepsilon}^{2}} \cdot \sum_{i} \left(D_i - \breve{R}_i \cdot D_i - X_i \cdot \beta + \breve{R}_i \cdot S_i\right)^2 + \sum_{i} \ln(1 - \omega_i) \tag{7}$$

where $\breve{R}_i$ and ω_i represent the rows and eigenvalues of $\begin{bmatrix} R_{11} & 0 \\ R_{21} & 0 \end{bmatrix}$ matrix in equation (5), respectively.

In most cases, it is found that all estimates converge within 15 iterations, when 0.1% level of tolerance is applied. Because the estimation outcomes with different *k* values need to be compared, a fixed number of iterations (thirty) are conducted in every estimation work to ensure the consistency.

Analysis Results

Using the EM approach, the model is first estimated with a range of *k* values from 0.1 to 3.0 with an increment of 0.1 to reveal the hidden demand of housing in the two time periods: 1990-2000 and 2000-2010. Figure 6 presents how the value of log likelihood function varies by *k* in each case. As shown in the figure, the likelihood values are generally higher with low *k* values; the maximums are found at *k*=0.8 and *k*=1.2. This finding may suggest that the distance decay rate in the process of demand relocation is unlikely to be large, although nearby zones are still more likely to get a larger amount of demand spillover. In other words, city centers as well as edge areas can get the benefits from the UGB restricting development out of the city edges.

<< Figure 6 about here >>

Figure 6. Likelihood by *k*

The estimation outcomes with the *k* values showing the maximum likelihood are summarized in Table 4.

<< Table 4 about here >>

Table 4. Hidden Housing Demand Estimation Result

First, it is found that the existing demand for housing units in the previous decennial year (i.e., HH1990 and HH2000) shows the strongest explanatory power. The estimated coefficients of other variables show how the demand for housing changes for the decade once this fundamental determinant is controlled.

In the case of 1990-2000, the distances to both the Portland's and Vancouver's CBDs exhibit statistically significant positive coefficients. The positive estimates may imply that hidden new demand for housing is likely to increase in the areas far from the CBDs. This finding indicates the force of dispersed development and further suggests that compact urban form is rarely attained without UGBs.

Other variables generally show significant effects in expected directions. For instance, significant positive effects are found for *EDU1990* and *MHOHINC1989*, meaning that demand tends to grow in the zones with existing residents with higher educational and income level. The negative coefficients of *OLDHU1990* and *PROPTAX1992* are also consistent with our expectation that areas with old housing units and/or larger property tax burdens are less attractive than areas with newly developed housing and/or other sources of tax revenues. It should be noted that *WHITE1990* shows a negative effect. This result may reflect the fact that the neighborhoods with relatively higher non-white population ratios had experienced more rapid growth for this period of time in the Portland metropolitan region. Regarding infrastructure, light rail stations are found to increase demand, whereas railroads seem to have negative effect on housing demand. The presence of arterial roads is less significant than public rail variables in this case.

The estimation outcomes for hidden demand in year 2010 are similar to the case of 2000, explained above. Most explanatory variables, including educational attainment, median household income, percentage of old housing units, presence of light rail transit stops, and presence of rail roads, exhibit significant effects in the same expected directions. Furthermore, the distance to the Portland's CBD again shows a significant positive influence indicating the force of expansion. However, the distance to the Vancouver's CBD now turns out to have a negative effect. This may be associated with the vital growth of the city center between 2000 and 2010 – on average, each section within a two-mile radius from the CBD attracted approximately 100 new households in this decade, whereas it had received only about 60 additional households between 1990 and 2000.

This study is particularly interested in the containment and spillover effects of the UGB that can be identified by comparing actual development (i.e., O_1O_1', $M'O_2'$, and $O_2'O_2$ in Figure 1) against the estimated hidden demand (i.e., U_1U_1' and $U_2'U_2$ in Figure 1). Figures 7 thru 10 demonstrate this for each part of the region for each time period, based upon the estimation result with *k* values resulting in the highest likelihood. For the illustration's purpose, the average density along the distance from the CBD (with 1 mile increment) is computed and displayed.

<< Figure 7~10 about here >>

Figure 7. UGB's Effect (Original vs. Actual): Oregon Part in 2000

Figure 8. UGB's Effect (Original vs. Actual): Washington Part in 2000

Figure 9. UGB's Effect (Original vs. Actual): Oregon Part in 2010

Figure 10. UGB's Effect (Original vs. Actual): Washington Part in 2010

It is apparent that central areas within the UGB have a greater number of households than the level of hidden original demand in the areas, whereas actual development is smaller than the original demand in the edge zones. Particularly, it appears that the Washington part of the region had attracted a significant amount of the constrained demand for housing between 1990 and 2000.

One remaining issue is development transfer over the state boundaries. As noted in the previous section, the earlier implementation of the UGBs in the Oregon part of the region is sometimes conceived of as a cause of large growth in the Washington side of the region particularly during 1990s (Bae 2001). Given the estimated hidden demand function, the original total housing demand in each side of the region can be calculated and compared with the real number of households in the Oregon and Washington study areas.

As summarized in Table 5, the analysis results suggest that Oregon experienced a net loss in housing demand in the case of 1990-2000. The estimated magnitude of demand loss is approximately 3,400. This may be attributable to the fact that the UGB had not been implemented in the Washington side of the region until 1995, so the constrained demands in Oregon were likely displaced toward the relatively unregulated side of the region. In the next time period, however, the policy had occurred in both sides of the region throughout the entire decade, and thus the relocation over the state boundaries would not matter a great deal. As expected, the estimation results of 2010 shows a much smaller amount of transfer (now from Washington to Oregon).

<< Table 5 about here >>

Table 5. Demand Transfer under the Influence of the UGB

In order to verify the found pattern of development transfer over the state boundaries and address some potential limitations of the separate analyses for the two time periods, an additional round of model estimation is conducted with the pooled data. In this pooled data analysis, the following three dummy variables are used to see the fixed effects – 1) *Dummy9000*, indicating the time period 1990-2000, as opposed to 2000-2010, 2) *DummyWA*, indicating the zones in the state of Washington, as opposed to Oregon, and 3) *Dummy9000WA*, derived from the multiplication of the above two dummy variables. If the constrained demands were displaced from Oregon to Washington between 1990 and 2000, the third dummy variable (i.e., *Dummy9000WA*) will show a positive coefficient greater than the second one (i.e., *DummyWA*).

The estimation result (with k=1.0, showing the maximum likelihood in the case of the pooled data analysis) suggests that this may be the case. As shown in Table 6, although not significant, *Dummy9000WA* shows a positive estimated coefficient, and the magnitude of the coefficient is much larger than that of *DummyWA*, which is applied to the zones in Washington in both time periods. In other words, the Washington part of the region had received demands in the first time period (i.e., 1990-2000) rather than the second decade (i.e., 2000-2010). The estimation with the pooled data also exhibits the effects of many explanatory variables in expected directions, consistent with the separate analyses presented above.

<< Table 6 about here >>

Table 6. Pooled Data Estimation Result

Summary and Discussion

The present study attempts to assess the effect of UGBs on the spatial pattern of development with explicit consideration of the displacement processes. To examine how UGBs affect development within the designated area or how development is displaced to other cities, this study applies a spatial market disequilibrium framework to the Portland metropolitan area, and measures the containment and spillover effects caused by the UGB in the area. The empirical analysis estimates the hidden original demand and shows how the UGB might modify development patterns in the study area.

Some methodological issues exist in this application of the disequilibrium model. The present analysis focuses on the quantity (supply and demand) balances and/or imbalances without explicit consideration of the land and housing prices. In addition, it is uncertain that the assumption made to characterize the demand transfer logic (i.e., distance-based relocation of unmet demands) is credible. In the literature, particularly in the studies on the housing sub-market, it has been suggested that the substitutability in urban housing markets may depend not only on locational proximity but also on other structural attributes (e.g., Galster 1996; Bourassa, Hamelink, and Hoesli 1999). Also, it is probable that the spillover is not uniform in all directions. These methodological issues imply that consideration may need to be given to other factors in addition to the distance, when r_{ij} is specified. Another issue is the linear fashion of the model, adopted to formulate the demand transfer in a logical manner, which may not be a true form of the causal relationship. The computational requirement for the spatial disequilibrium model estimation is also relatively heavy as it involves special treatments such as the EM algorithm for a spatial model. Limited availability of disaggregated-level data is another challenge that prevents us from considering a full set of factors of housing demand changes in small areas.

In spite of such issues, this study presents a useful approach to investigating the detailed mechanism of the demand relocation, which is an essential part of many land use regulations but attracts little attention. From the estimation results, it is found that a force for dispersed development seems to exist and that the UGB can direct housing demands emerging in the edge areas into the more central zones (i.e., the UGB can contribute to realizing a more compact urban form.) In addition, it is suggested that the constrained demands can be displaced to adjacent cities, rather than being contained in the boundaries, particularly if nearby communities do not participate in the growth management efforts. These findings imply that the implementation of UGBs without systematic cooperation among neighboring municipalities may not be able to attain the main goal of the policy, namely realizing a regional spatial structure that is environmentally and fiscally desirable, even though the policy is somewhat promising. It seems that urban development can be effectively contained only when the possibility of the leakages is systematically controlled. In this sense, it can be argued that implementation strategy and institutional structure are critical in attaining the policy objectives.

NOTES

[1] Jun (2004) analyzes the effect of Portland's UGB, adopted in 1980, by using several methods, including comparison with other thirty-one metropolitan areas and a regression analysis. He could not find a better performance of Portland from the comparison based upon the indicators of suburbanization and infill development. The regression analysis, focusing on the location of new housing construction, also does not show a statistically significant effect of the UGB. Cho and

others (Cho et al. 2006, 2007; Cho, Poudyal, and Lambert 2008) conduct a series of empirical analyses measuring the effects of UGB in Knox County, Tennessee by applying econometric techniques. In an early study (Cho et al. 2006), a pooled dataset is used and suggests that the UGB is effective in controlling sprawl. However, in recent analyses (Cho et al. 2007; Cho, Poudyal, and Lambert 2008), they conclude that the UGB may accelerate the fringe development rather than inducing infill or compact development within urban areas. According to their interpretation, this finding may be attributable to Knoxville City government's annexation power (i.e., the parcels within the growth boundary can be easily incorporated by the city government. Thus, developed properties within the boundary hardly avoid a higher property tax, and this discourages the development in these designated areas).

[2] Snell (1999) includes an additional parameter ρ, recognizing the possibility of demand loss of the entire region through the relocation process. However, when estimated, the value of ρ is often invalid (e.g., greater than 1). Therefore, in this study, such a parameter is not included, assuming that all constrained demands for housing are relocated into somewhere in the large region, but not necessarily within the implementing municipality.

[3] See Fair and Jaffee (1972) and Maddala and Nelson (1974) for the explanations about how the states of markets are typically determined for different types of disequilibrium models.

[4] Washington is one of the states having a long history of growth management in the United States. "Washington's Shoreline Management Act, [which established the state government's authority of reviewing and judging local programs], was passed by the Legislature in 1971 and

adopted by the public in a 1972 referendum." (Washington Department of Ecology 2003: 1). This earlier effort, however, was not very successful, so that Washington had not been included in the list of growth management states until it passed the Washington State Growth Management Act of 1990 through two phases (Weitz 1999).

[5] The analysis has been well presented in a series of buildable lands and monitoring reports available on their website, http://www.clark.wa.gov/planning/comp_plan/monitoring.html (accessed June 5, 2011).

[6] For the transformation, an areal interpolation technique, explained in Goodchild, Anselin, and Deichmann (1993: 386), is used. The same technique is repeatedly applied to 1990, 2000, and 2010 census data to keep the consistency and minimize the influence of the transformation on estimation outcomes.

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Table 1. Population Growth of the City of Portland and the City of Vancouver

Year	City of Portland, Oregon		City of Vancouver, Washington		United States	
	Population	Growth Rate	Population	Growth Rate	Population	Growth Rate
1960	372.7		32.5		179,326	
1970	380.0	2.00%	41.9	28.90%	203,210	13.30%
1980	366.4	-3.60%	42.8	2.30%	226,546	11.50%
1990	437.3	19.40%	46.4	8.30%	248,710	9.80%
2000	529.1	21.00%	143.6	209.50%	281,422	13.20%
2010	583.8	10.30%	161.8	12.70%	308,746	9.70%

Unit: thousand people

Data source: Decennial Census, U.S. Census Bureau

Table 2. Variables & Data Sources

Variable	Description	Data Source
D	Effective demand; Observable only in unconstrained zones	Decennial Census
S	Effective supply of housing units	Decennial Census
HH	Number of households living in the section; *HH=D* in the case of unconstrained zones	Decennial Census
DistCBD1	Distance to the CBD of Portland, OR; The CBD location is determined based upon Census tract-level employment density using the data source.	Census Transportation Planning Package
DistCBD2	Distance to the CBD of Vancouver, WA; The CBD location is determined based upon Census tract-level employment density using the data source.	Census Transportation Planning Package
WHITE	Ratio of White Population	Decennial Census
EDU	Educational attainment level of the residents, defined as a percentage of 25+ population, whose educational attainment is Bachelor's degree or above.	Decennial Census
MHOHINC	Median household income level	Decennial Census
OLDHU	Percentage of old housing units (over age 50)	Decennial Census
PROPTAX	Percentage of property tax revenue to the total revenue in the municipality containing the zone	Census of Governments
WATER	Presence of water	USGS National Land Cover Dataset
AGG	Developable land (Agricultural and grassland) area in the section	USGS National Land Cover Dataset
RC1	Presence of interstate highway (Functional class: 01)	National Highway Planning Network Data
RC2	Presence of other expressway (Functional class: 02)	National Highway Planning Network Data
LrtStop	Presence of light rail transit stops	Portland’s Metro Data Resource Center
Rail	Presence of rail roads	Census TIGER/Line

Table 3. Descriptive Statistics

Variable	Mean	Standard Deviation	Min	Max	Remark
D2000	994	922	13	8,695	Only unconstrained zones are considered.
D2010	1,099	1,007	13	10,851	
S2000	272	626	0	9,411	
S2010	318	715	0	12,221	
HH1990	204	516	0	7,792	
HH2000	257	592	0	8,695	
DistCBD1	20.0	7.1	0.5	30.0	
DistCBD2	21.1	8.4	0.4	37.8	
WHITE1990	0.952	0.045	0.279	0.990	
WHITE2000	0.909	0.068	0.372	0.975	
EDU1990	0.171	0.096	0.021	0.709	
EDU2000	0.234	0.119	0.027	0.781	
MHOHINC1989	35.178	7.151	10.079	81.621	The unit is current thousand dollars.
MHOHINC1999	54.724	11.876	17.138	127.518	
OLDHU1990	0.156	0.095	0.000	0.767	
OLDHU2000	0.183	0.114	0.000	0.849	
PROPTAX1992	0.287	0.072	0.051	0.474	
PROPTAX2002	0.262	0.049	0.028	0.471	
WATER	0.696	0.460	0.000	1.000	
AGG1992	0.372	0.278	0.000	0.997	
AGG2001	0.383	0.280	0.000	0.999	
RC1	0.057	0.232	0.000	1.000	
RC2	0.080	0.271	0.000	1.000	
LrtStop	0.020	0.140	0.000	1.000	
Rail	0.167	0.373	0.000	1.000	

Table 4. Hidden Housing Demand Estimation Result

Variable	Y: Demand in 2000		Y: Demand in 2010	
	Estimated Coefficient	Standard Error	Estimated Coefficient	Standard Error
C (intercept)	439.91 ***	54.11	160.19 ***	33.61
HH1990	1.02 ***	0.01		
HH2000			1.07 ***	0.01
DistCBD1	2.39 ***	0.68	4.90 ***	0.57
DistCBD2	1.41 **	0.47	-0.88 *	0.39
WHITE1990	-412.44 ***	54.32		
WHITE2000			-220.5 ***	34.88
EDU1990	200.99 ***	33.36		
EDU2000			70.78 **	22.73
MHOHINC1989	1.52 ***	0.41		
MHOHINC1999			0.25	0.24
OLDHU1990	-403.94 ***	24.95		
OLDHU2000			-176.62 ***	18.41
PROPTAX1992	-228.20 ***	32.30		
PROPTAX2002			-20.00	42.98
WATER	-13.64 **	5.05	-9.10 *	4.48
AGG1992	-51.27 ***	9.46		
AGG2001			5.10	8.57
RC1	0.95	9.86	6.23	8.80
RC2	11.68	8.27	6.29	7.37
LrtStop	135.21 ***	17.02	145.28 ***	15.18
Rail	-56.12 ***	6.54	-29.88 ***	5.86
Log-likelihood	-14,809.3		-14,486.3	
R-squared [a]	0.934		0.959	

***: 0.1% level significant | **: 1% level significant | *: 5% level significant

[a] This is a pseudo r-squared that is often used to show the preciseness of the predicted values, generated by maximum likelihood estimates. Like the case of ordinary least squares, it is defined as 1–(sum of the errors/sum of the variation). Since *D* can be observed only in unconstrained zones, the statistic is calculated using the data only for the unconstrained zones.

Table 5. Demand Transfer under the Influence of the UGB

		Year 2000			Year 2010		
		Original Demand	Actual House -holds	Gap	Original Demand	Actual House -holds	Gap
Oregon Side	Constrained zones (Restricted only by UGB)	137.3	73.7	-63.7	113.5	74.2	-39.3
	Constrained zones (Restricted by other factors) [a]	3.3	1.0	-2.3	2.5	1.2	-1.3
	Unconstrained zones	462.1	524.7	62.6	571.1	613.0	41.9
	Net gain			-3.4			1.2
Washing -ton Side	Constrained zones (Restricted only by UGB)	40.7	22.1	-18.5	41.6	24.5	-17.1
	Constrained zones (Restricted by other factors) [a]	2.8	0.4	-2.3	1.9	0.6	-1.2
	Unconstrained zones	81.4	105.6	24.2	117.2	134.3	17.1
	Net gain			3.4			-1.2

Unit: thousands

[a] A group of zones constrained by natural factors, such as water and national forests, are classified into this category, even if those areas are located outside the growth boundaries.

Table 6. Pooled Data Estimation Result

Variable	Y: Demand(T)	
	Estimated Coefficient	Standard Error
C (intercept)	296.61 ***	29.04
HH(T-1)	1.04 ***	0.00
DistCBD1	2.39 ***	0.52
DistCBD2	0.57	0.39
WHITE(T-1)	-240.82 ***	30.19
EDU(T-1)	133.42 ***	19.31
MHOHINC(T-1)	-0.34	0.21
OLDHU(T-1)	-271.49 ***	15.81
PROPTAX(T-1)	-157.01 ***	25.10
WATER	-13.1 ***	3.52
AGG(T-1)	-31.91 ***	6.49
RC1	3.35	6.74
RC2	9.04	5.65
LrtStop	128.11 ***	11.63
Rail	-42.86 ***	4.48
Dummy9000	16.59 **	5.58
DummyWA	0.92	6.01
Dummy9000WA	8.49	6.88
Log-likelihood	-29,425.4	
R-squared [a]	0.946	

***: 0.1% level significant | **: 1% level significant | *: 5% level significant

[a] This is a pseudo r-squared that is often used to show the preciseness of the predicted values, generated by maximum likelihood estimates. Like the case of ordinary least squares, it is defined as 1–(sum of the errors/sum of the variation). Since *D* can be observed only in unconstrained zones, the statistic is calculated using the data only for the unconstrained zones.

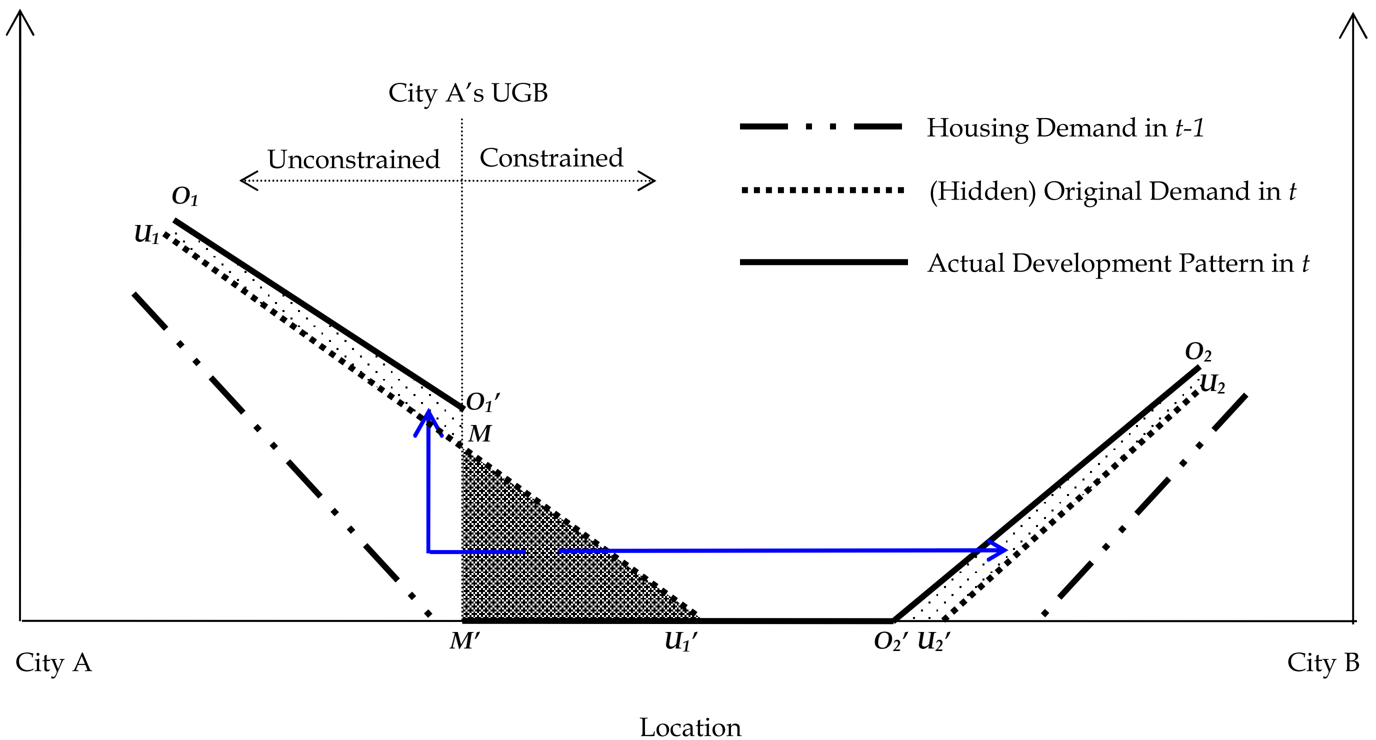

Figure 1. Hidden Original Demand & Observed Development Pattern

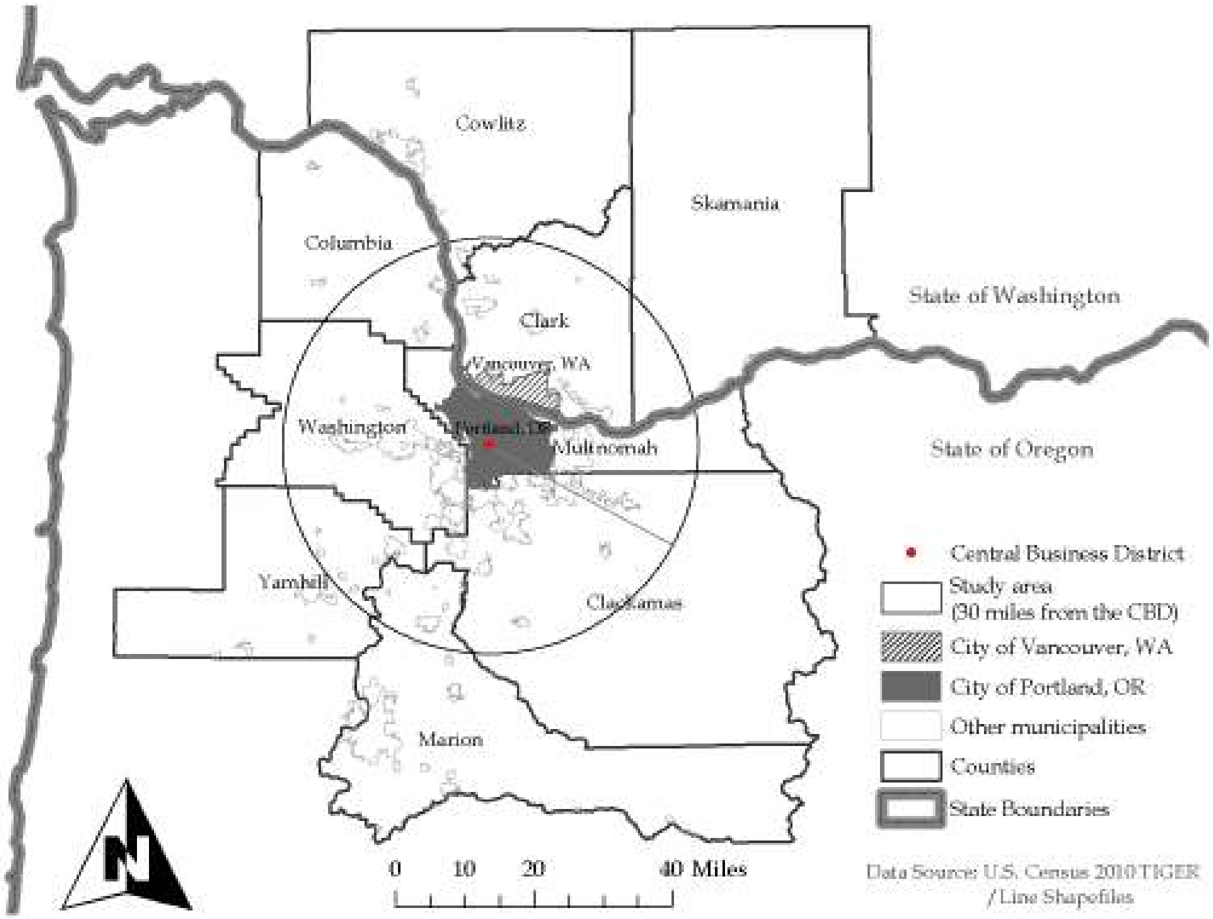

Figure 2. Study Region: Portland Metropolitan Area

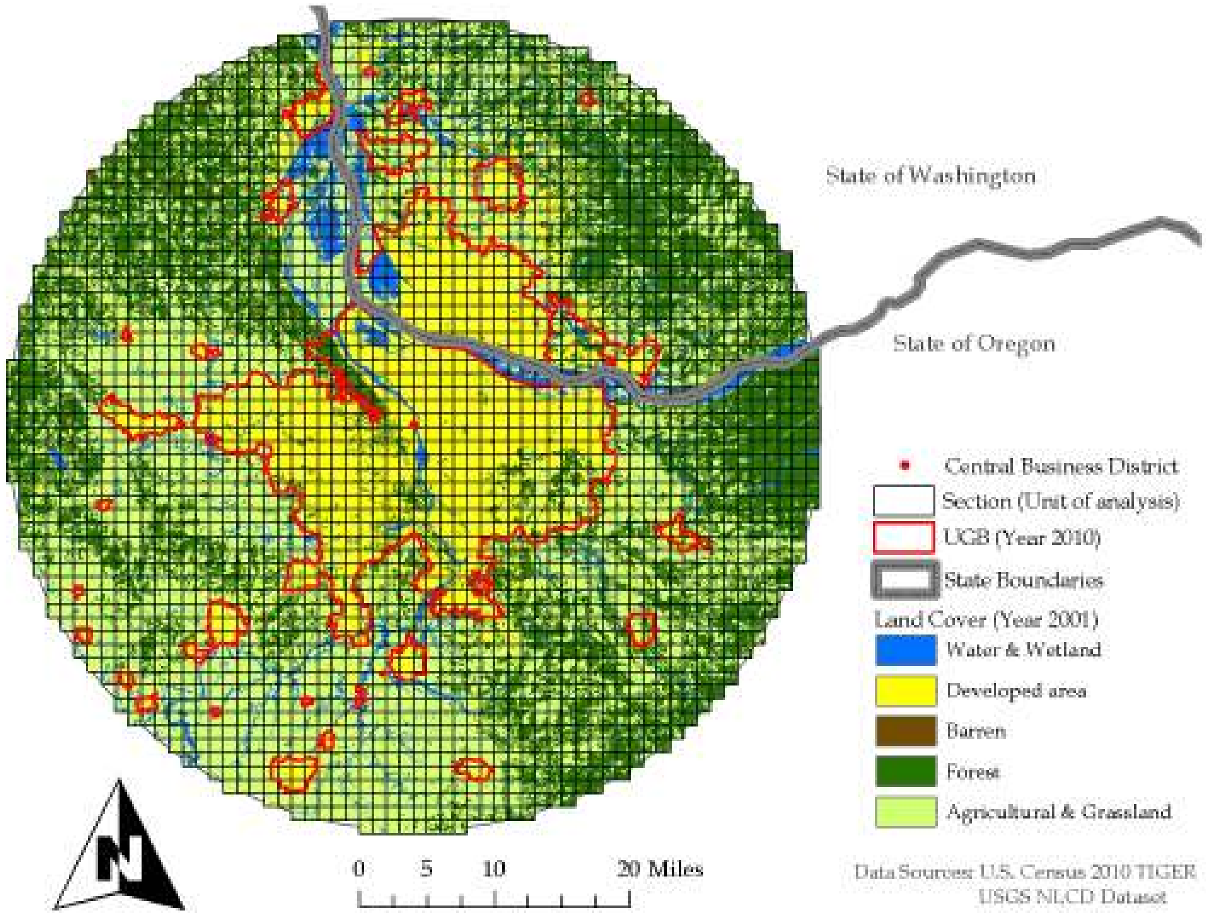

Figure 3. Spatial Unit of Analysis: 1 mile × 1 mile Section

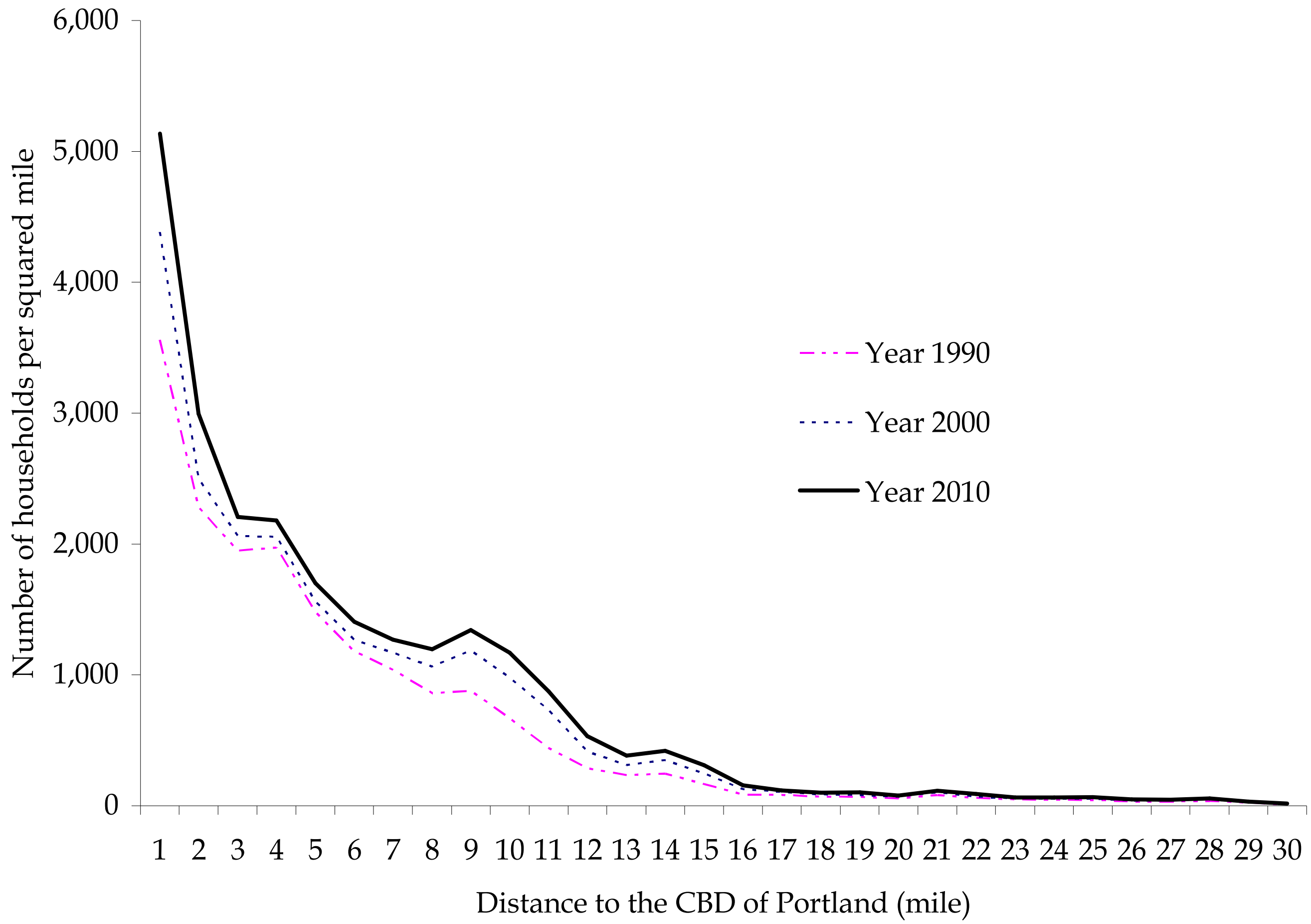

Figure 4. Household Density Curve in the Oregon Part of the Region

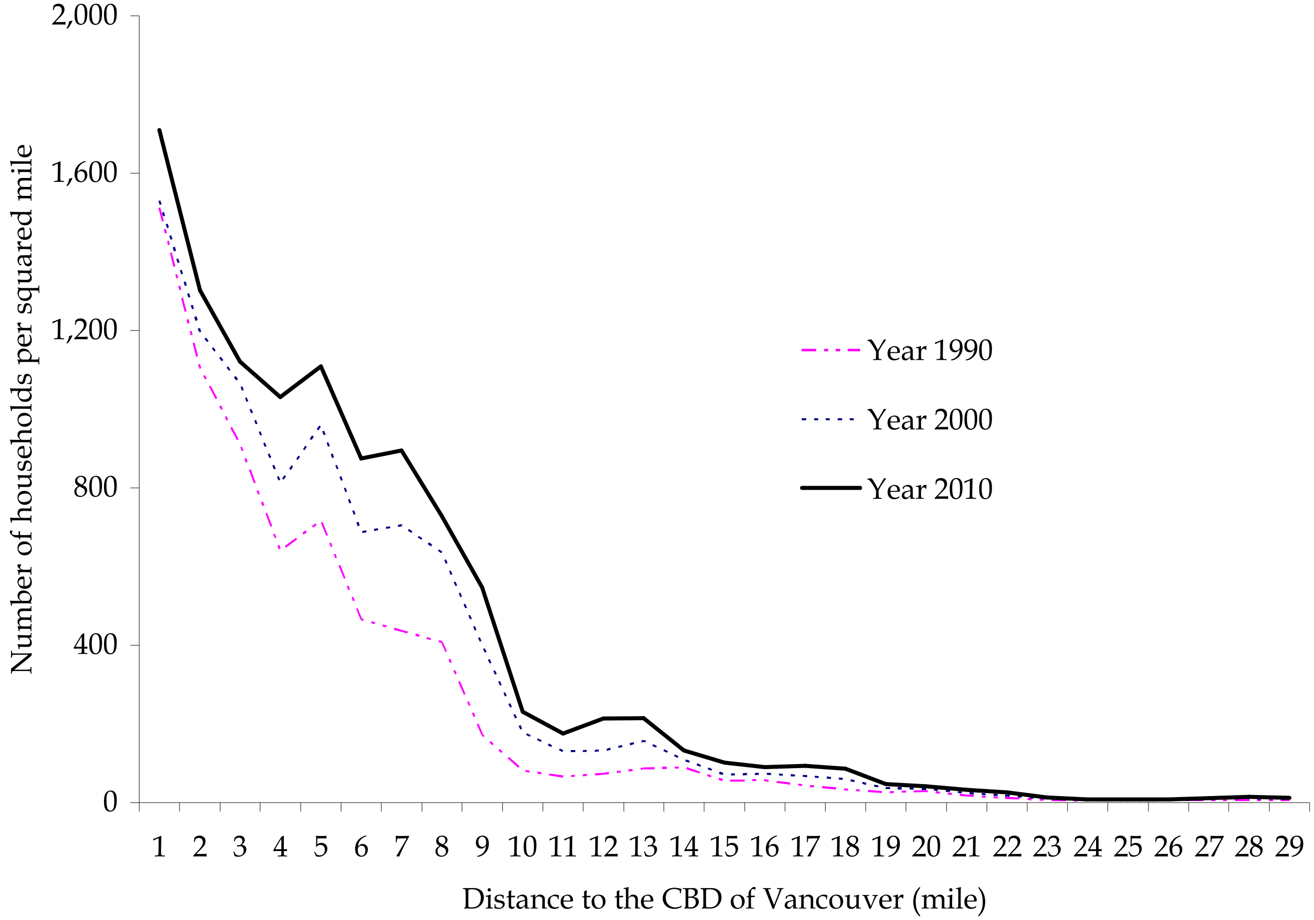

Figure 5. Household Density Curve in the Washington Part of the Region

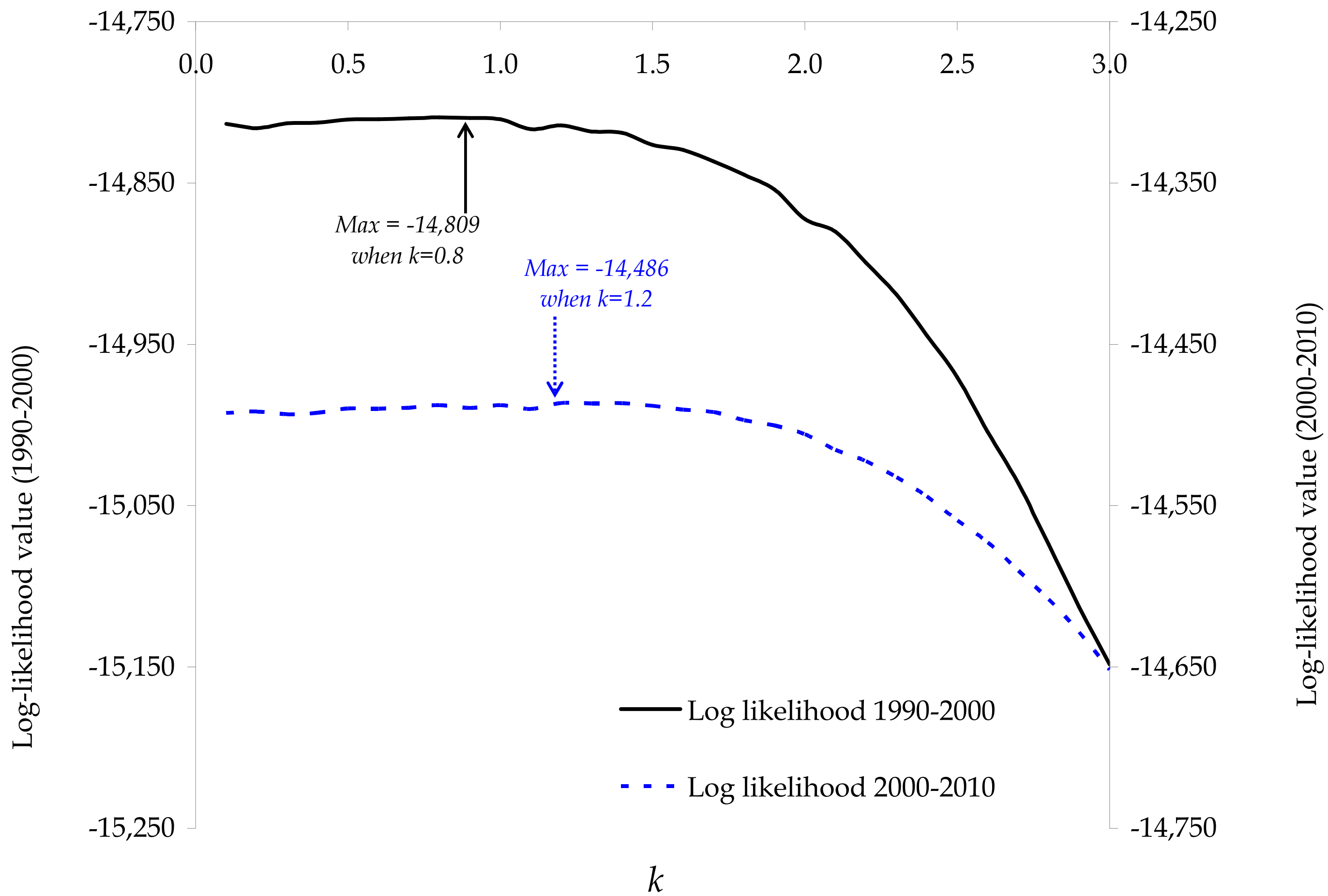

Figure 6. Likelihood by *k*

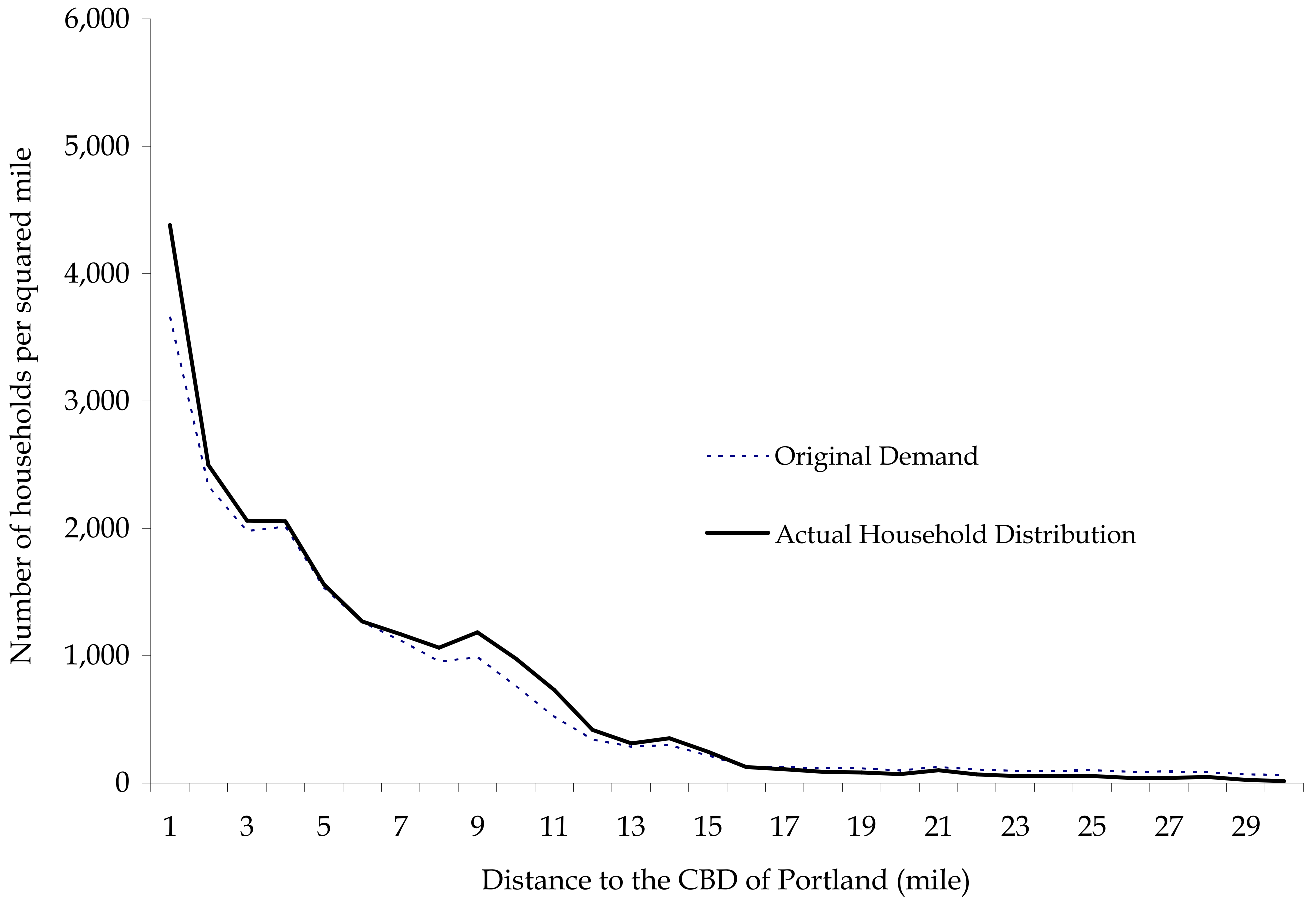

Figure 7. UGB's Effect (Original vs. Actual): Oregon Part in 2000

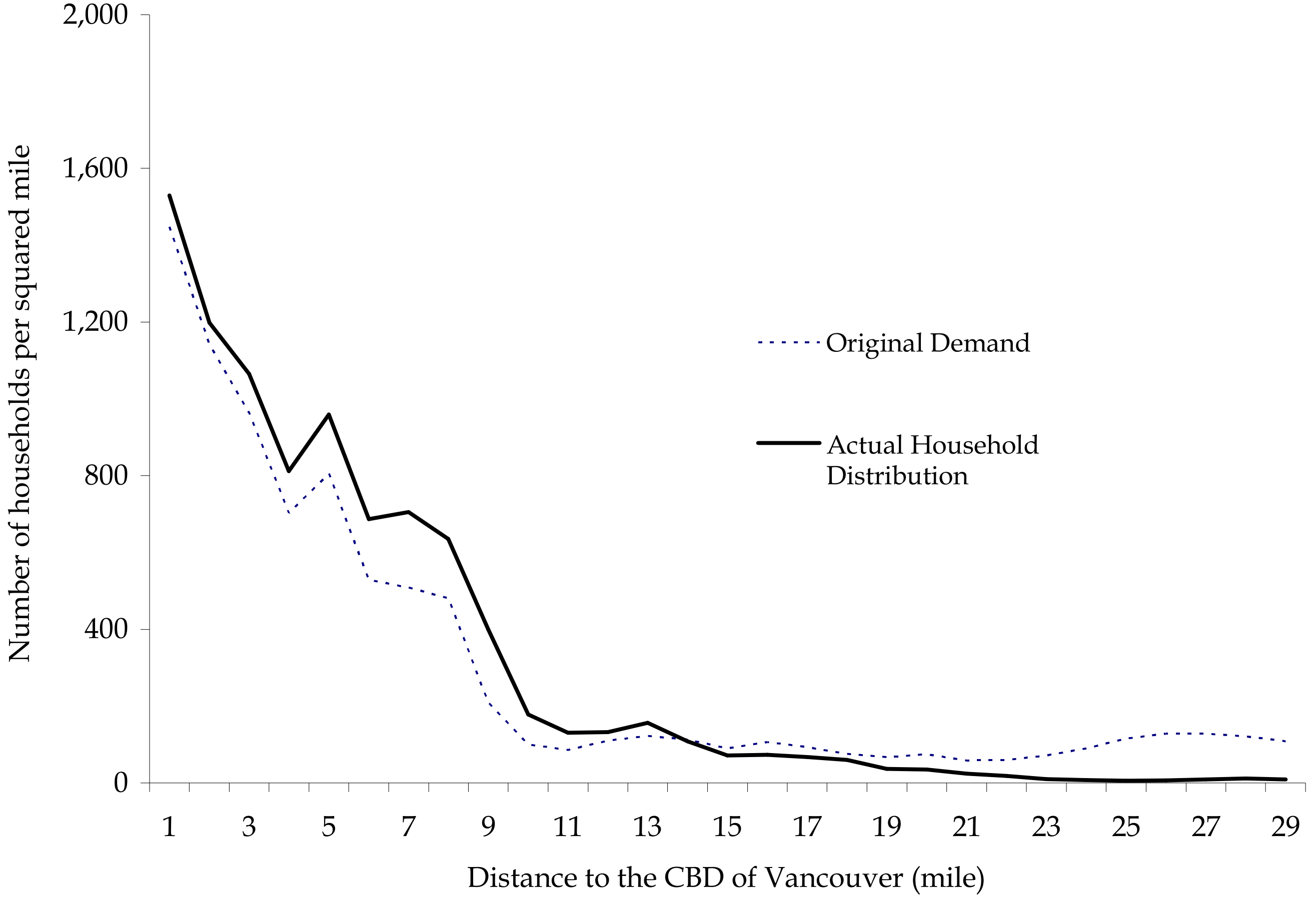

Figure 8. UGB's Effect (Original vs. Actual): Washington Part in 2000

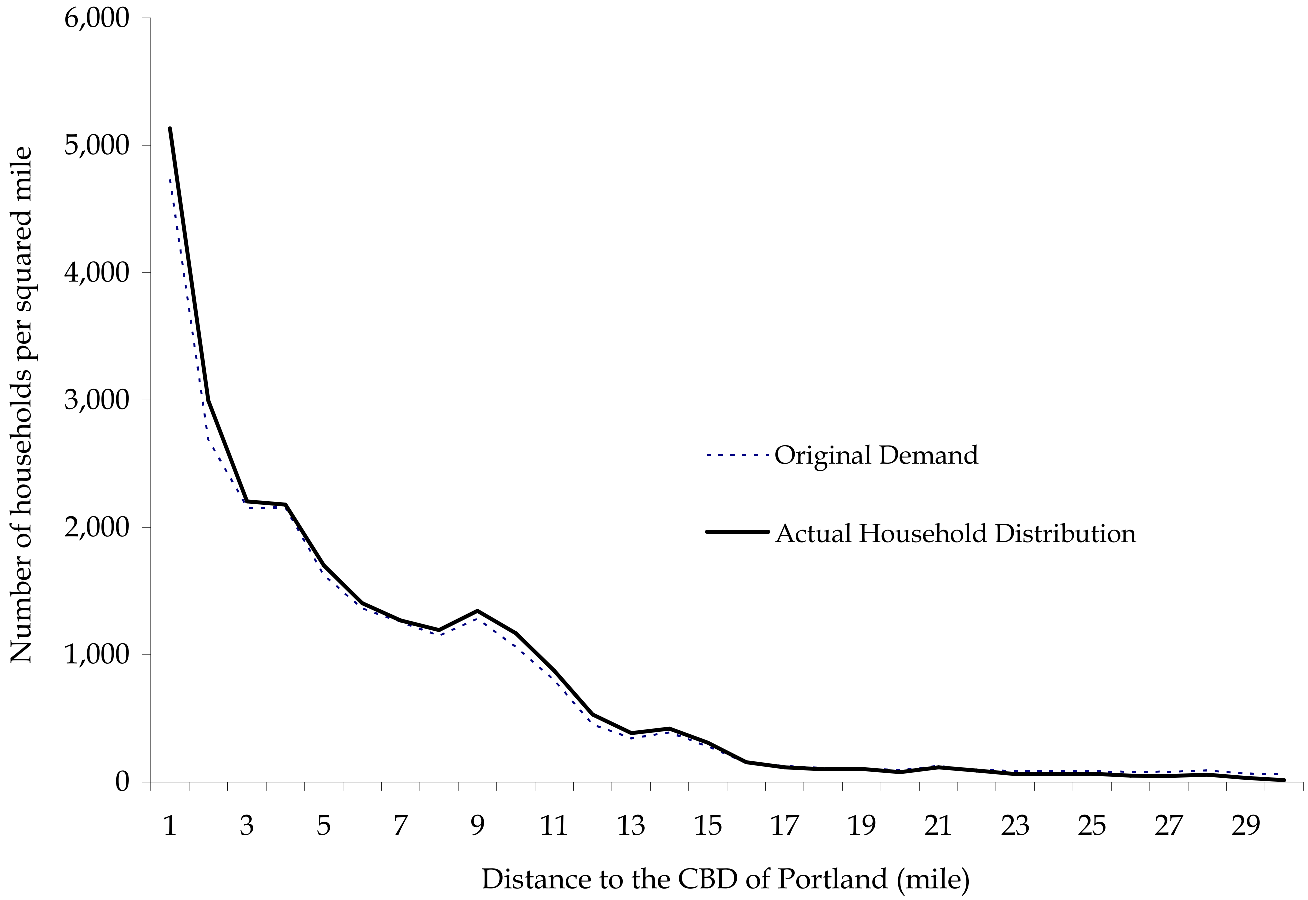

Figure 9. UGB's Effect (Original vs. Actual): Oregon Part in 2010

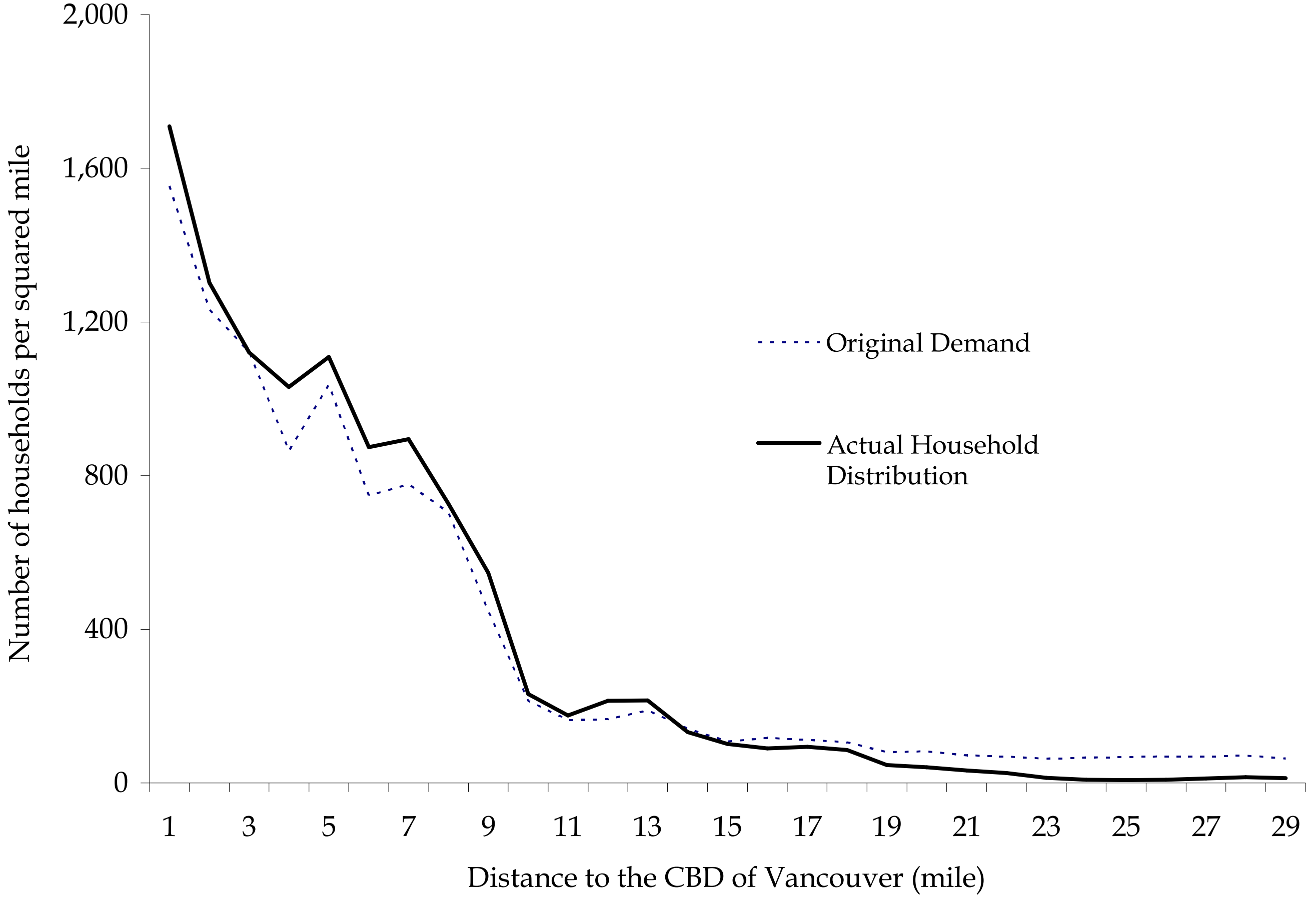

Figure 10. UGB’s Effect (Original vs. Actual): Washington Part in 2010