Does Distance Make Good Neighbors? The Role of Spatial Externalities and Income in Residential Development Patterns

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Short Abstract: Scattered residential development is explained using a theoretical model of residential location in which household interactions generate externalities that determine location choices. Results demonstrate the role of income and heterogeneous preferences in generating this form of sprawl. Among our findings is that rising income generates only temporary increases in sprawl.

Introduction

Urban sprawl is a catch-all phrase that is often used to refer to various aspects of changing urban form characterized by low density, scattered, or mixed use development. Within economics, sprawl has been largely conceived of and analyzed as two complementary urban land use patterns: decentralization of cities and leapfrog (or scattered) development.[1] Rising household incomes, along with population growth and declining transportation costs, have been hypothesized to be a primary driving force of decentralization (Mieszkowski and Mills). With increasing incomes, households are hypothesized to consume more housing services, which leads to an expansion of the overall city size (Brueckner). In addition, to the extent that households substitute land consumption for proximity to the city, rising incomes will redistribute population towards the suburbs and away from the central city. Finally, because suburbs are often perceived as having superior public goods and services, increases in income are hypothesized to spur households to engage in Tieboutian moves to suburban locations in search of these superior goods and services (O'Sullivan). Empirical evidence supports these theoretical hypotheses. For example, Brueckner and Fansler find that sprawl, as proxied by city size, is positively influenced by average household income levels. Based on empirical results from a model of household location, Margo estimates that about 40% of the increase in suburbanization between 1950 and 1980 is attributable to increases in household income.

While evidence supports a broad connection between rising incomes and sprawl in terms of population decentralization, theoretical motivations and empirical evidence regarding the role of income in generating sprawl at a finer spatial scale, e.g., in the form of scattered or leapfrog development, are much more limited. The standard income effect that links rising incomes to increased consumption of housing and land, both normal goods, implies that increases in income will lead to a more dispersed or scattered pattern of development. Other than this hypothesis, which is implicit in Brueckner's discussion of sprawl and city size, the closest explanation linking

[1] Both trends capture relevant aspects of sprawl, but at different spatial scales. Decentralization (or suburbanization) is typically used to refer to metropolitan-wide shifts in population away from central cities towards suburban locations whereas leapfrog (or scattered) development typically refers to a finer scale pattern of development that is characterized by intervening plots of vacant land.

income and leapfrogging is from Mills. He extends the basic intertemporal efficiency model of leapfrog development (e.g., Ohls and Pines) by incorporating economic growth into a two-period model of land development. He shows how uncertainty over future returns and heterogeneity among land developers' expectations can lead to permanent scattered and mixed use patterns of development. More recent explanations of leapfrogging focus on the role externalities, e.g., externalities from public parks that attract residents (Wu and Plantinga) and, for the case of scattered development, externalities from neighboring land uses (Irwin and Bockstael, 2002; Parker and Metersky, Turner).

To explore the role of income in generating sprawl at a finer spatial scale, we develop a theoretical model of scattered residential development,[2] in which spatial interactions among households generate a set of locational features that are hypothesized to be the primary determinants of household location. For example, spatial clustering of households can generate both local benefits, e.g., the provision of public infrastructure and the availability of neighborhood networks, as well as costs, e.g., neighborhood congestion and the loss of open space amenities. Thus, rather than defining space exogenously in terms of distance to an exogenously located central city, space is defined endogenously by the relative proximity of households to each other and the spatial externalities that result are treated as the primary determinant of a household's location choice. This approach is consistent with some of the more recent models of scattered development (Parker and Metersky, Turner), in which endogenous land use externalities from neighboring plots of land influence household choice, and is similar in spirit to the approach taken by some theoretical models of suburban subcenter formation (e.g., Fujita and Ogawa). In addition, it is consistent with the empirical evidence on spatial externalities and residential patterns, which indicates that such local externalities are a significant determinant of these patterns (Carrion-Flores and Irwin, Irwin and Bockstael, 2002, 2004). This approach is in contrast

[2] By scattered development we mean low-density, dispersed development with intervening vacant land that is typical of urban-rural fringe landscapes in the U.S. and refer interchangeably to this as scattered development, leapfrog development, or sprawl. While some researchers associate leapfrog development explicitly with an urban distance gradient, we treat is as a more generic land use pattern that is not necessarily defined with respect to the city center.

to the majority of theoretical models of leapfrog development, which have been developed within the framework of the monocentric model and explain leapfrogging as the result of distance to the city center, as well as heterogeneous expectations among landowners (Mills, 1981) or publicly provided open space (Wu and Plantinga).

In developing such a model, we depart from the traditional monocentric framework and define space as the average distance between a household and neighboring households. Thus, this approach is applicable for describing residential patterns for cases in which distance to a central location is not a primary factor.[3] Both positive and negative spatial externalities are assumed to decay continuously with average distance to a maximum point, at which point they disappear. Positive externalities generate benefits to nearby households and encourage agglomeration, e.g., people may find it beneficial to live close enough to others so as to reap social benefits from neighbors. In addition, there may be positive effects associated with a critical density of residents in an area that attracts public or private services. Negative externalities create disutility among neighboring households and encourage dispersion, e.g., due to congestion of local public goods, including environmental goods, lack of neighboring open space, pollution, or simply the desire of living in relative isolation from others. By incorporating these effects into a model of household location choice, we are able to describe the household's bid curve as a function of the optimal average distance between a household and its neighbors. From this we derive the household's demand for distance and examine the effects of spatial externalities and household preferences and income on the regional pattern of scattered development. Results show that increases in household income will increase the optimal distance among households, but that this effect diminishes with further increases in income and eventually goes to zero. This is due to the fact that distance to other households is not always a normal good and thus income effects in a model of spatial externalities are not always positive. The result is that continual increases in household

[3] For example, this approach is applicable for describing patterns within a smaller area, e.g., a neighborhood, for which all locations are relatively equi-distant from the employment center or for areas located relatively far from the urban center (e.g., exurban areas), such that differences in distance to the city are small across locations. Alternatively, this model applies to cases in which transportation costs are sufficiently low or employment is more uniformly distributed throughout the region such that distance to a single employment center is not a primary factor.

income over time are predicted to generate only temporary increases in scattered residential development. We also consider the influence of heterogeneous households, as distinguished by their preferences over the spatial externalities, on the effect of income on scattered development. Although the total amount of scattered development is clearly increasing in the proportion of households that have strong preferences for more isolated locations, we find that the *rate* of increase in scattered development due to rising household incomes is greater the higher the proportion of "average" households[4] in the region.

Explaining Scattered Residential Development

Theoretical models of leapfrog or scattered development have suggested different causes of leapfrogging, including efficient intertemporal decisionmaking, heterogeneous expectations among land developers under uncertainty, heterogeneous preferences among households, and spatial externalities. The traditional explanation of leapfrogging is that it is a temporary process that results from intertemporal efficient decisionmaking by land developers. For instance, Ohls and Pines develop a two period model in which households trade-off living space and accessibility and demonstrate that under certain conditions, discontinuous development will be efficient. They argue that if households prefer lower densities (or if lower costs are associated with lower densities), then lower density housing further from city center will be built initially to accommodate this desire for low density, while leaving the skipped-over land to be filled with higher-density residential buildings during later stages of development. Fujita (1976) uses a dynamic version of the monocentric model to compare the efficiency of the competitive outcome, in which vacant land is skipped over for a period of time, with the optimal equilibrium growth path and finds that the competitive path with leapfrog development is efficient. In a later work, Fujita (1983) differentiates households by income in which differences in incomes drive differences in buildings and activity types. He shows that, under conditions of perfect foresight, a "sprawl-fashioned urbanization" process is more efficient. The spatial growth of the city is characterized

[4] Average households are defined as those that have moderated preferences over the positive and negative externalities that are generated by proximity of a household to others.

by a pattern of leapfrog and mixed development, which is shown to be an intertemporal efficient process of land development.

Mills develops an extension of these models by incorporating multiple types of development (residential and industrial) and alternative assumptions about economic growth relative to landowners' expectations in a two-period analysis. When landowners are uncertain about future returns, they must speculate in the first period because they cannot know for certain how much land to be withheld and preserved for future industrial expansion. A permanent pattern of leapfrog development results when actual growth is insufficient to fill the vacant land with industrial expansion. When extending his model to include heterogeneous expectations, Mills finds that either scattered development occurs if actual growth in the second period is less than landowners' expectations or mixed development occurs if actual growth in the second period is greater than expected growth.

Alternatively, Bar-Ilan and Strange explain leapfrogging as the result of uncertainty combined with temporal lags in development. As described by Capozza and Helsley (1989), uncertainty over future returns to development introduces an option value to delaying development (i.e., a growth premium). Findings from Capozza and Helsley's (1990) model show that, although the presence of uncertainty and irreversibility delay development, they cannot cause leapfrogging. Bar-Ilan and Strange consider the role of development lags in this model. They find that in a non-lag scenario, uncertainty increases with distance and thus so does the option value. Therefore, leapfrogging does not occur as landowners at the edge of a city will exhibit more caution than central owners and wait. However, when development lags are incorporated into the model, leapfrog development can occur because lags reduce the option value and thus uncertainty is less a deterrent to development.

Heterogeneity in agent preferences or incomes has been shown to generate leapfrog development. Fujita (1982) develops a model to examine the spatial dynamics of residential development and shows that, while leapfrog development does not occur when all households have homogeneous income levels, it is the general development pattern in the suburbs if there are multiple income classes and housing is a non-neutral good. Page analyzes city formation using an agent location model where agents' preferences depend on location's population and its separation (its average distance from other agents). Given their preferences on population at their own location and the average distance from their location to other agents, individual agent's decision about where to locate result in different "macro" spatial configurations.

Leapfrog or scattered pattern of residential development has also been explained as an outcome of public policies, e.g., zoning, public open space preservation, or publicly provided infrastructure, e.g., roads and sewer lines. Turnbull examines the effect of zoning on the pace and pattern of residential development using a dynamic open city model. Zoning, which is specified as a minimum lot size restriction, is shown to temporarily halt development at some locations while inducing leapfrog development at others, both phenomena that in the absence of zoning would not occur. Wu and Plantinga, investigate the impact of public open space on residential land use patterns in a city. They use an open city monocentric model, but, in contrast to the traditional model, residential sites are differentiated by their proximity to open space, which generates distance-dependent amenities for residents. After solving for the spatial market equilibrium, they use a series of simulations to examine the conditions under which public open space causes leapfrog development when placed outside the city by spurring development of nearby land before land closer to the city is developed.

Finally, leapfrog development has been explained as the result of spatial externalities that arise from interactions among households that cause households to locate apart from each other. Turner develops a game theoretic model of residential location choice in which people choose to immigrate to a city and derive utility from their proximity to open space. In a static framework, the equilibrium development outcome consists of three regions: An urban region near to the old city that is solidly occupied, a more extreme suburban region where only alternate spaces are occupied, and an unoccupied frontier. Any immigrant at a suburban location who does not obtain open space benefits is strictly better off in an alternate city and therefore, no adjacent occupied spaces are possible in the suburbs. When incorporating a dynamic component, Turner finds that an equilibrium location profile has the same basic form as the static games. In addition he show that if proximity to open space is sufficiently valuable and player are sufficiently patient, then at least some suburban locations must be occupied before all urban locations are occupied, generating leapfrog development. In both the static and dynamic games, he finds that the competitive equilibrium is not efficient: it will contain too many people too close together because the external open space effects are not considered. In addition, in the dynamic game, the equilibrium development path deviates from the optimum because suburban locations are developed earlier than they should be and thus generate leapfrog development. Parker and Meteresky develop an agent-based model of urban and agricultural land use in which transport costs pull urban uses to the center of the city, negative externalities between agricultural and urban users encourage separation and negative externalities between urban users encourage dispersal of urban activity. They simulate this model and show that the negative externalities associated with urban land generate a fragmented pattern of development on the urban fringe, which surrounds a contiguous urban core.

The vast majority of the papers reviewed above explain leapfrog development within the framework of the monocentric model, which assumes that proximity to the city center is a primary determinant of urban land use patterns. Leapfrog development is explained either as the result of dynamic efficiency decisions, made under conditions of either perfect foresight or uncertainty, that are driven by the urban land rent gradient or as the result of additional sources of exogenous heterogeneity. A limitation of this approach is that it fails to consider how leapfrog development may arise endogenously from a process of interdependent household decisionmaking about location or land use. In contrast are the models by Turner and Parker and Meteresky, in which leapfrogging is posited as the result of spatial externalities generated by other households' location or land use decisions. However, both these papers focus only on externalities that create repelling effects that cause development to disperse. Positive externalities that cause residential land to cluster are of course also quite plausible. Such household interaction effects have been incorporated into previous urban economic models that have explained urban spatial structure as the result of social interactions (e.g., Beckman, Page) and there is some empirical evidence of both positive and negative effects associated with neighboring residential development (e.g., Carrion-Flores and Irwin, Irwin and Bockstael, 2002, 2004). Thus a more general model would consider the role of both agglomerative and repelling effects that are generated from proximity of households to each other and how the tension between these effects influences leapfrog or scattered development.

A Model of Household Location with Spatial Externalities

We begin with a model in which households are assumed to maximize utility by choosing residential location and the amount of a composite good. To focus on the role of endogenous interactions among households, we assume that residential location is defined solely in terms of the location of households relative to one another. Proximity of households to one another generate externalities that yield both positive (agglomerative) and negative (repelling) spatial externalities. Households have preferences over these effects and thus, in choosing a location, households choose the optimal levels of positive and negative externalities generated by the relative proximity of neighboring households. To simplify a measure of neighboring household proximity, we assume that all nearest neighbors (i.e., houses on lots that share a common border) are equi-distant, so that the distance between a house and its nearest neighbor is the same for all nearest neighbors and thus is equal to the average distance the nearest neighbors.[5] To capture the effects of heterogeneous households, we allow for different types of households who vary in their preferences over the agglomerative and repelling effects. As a result, a household's optimal distance to neighbors will characterize and distinguish each type of household; some households enjoy living in neighborhoods that are within close proximity to

[5] Because we assume a lattice structure, this distance measure corresponds exactly to a measure of residential density around each house and thus we refer interchangeably to average distance and neighborhood density.

others (i.e., higher density neighborhoods) while others prefer to live in much more isolated places (i.e., lower density neighborhoods). A representative household of type *j* will maximize the following utility function:

$$U_j = X_j^{\theta_1}\left(\alpha_{0j}G^{\alpha_{1j}} - \beta_{0j}R^{\beta_{1j}}\right)^{\theta_2} \quad (1)$$

where *X* is a composite good, *G* is a scalar that represents the net positive externalities (agglomerative effects) from neighboring households and *R* is a scalar that captures the net negative externalities (repelling effects) from neighbors. In this version of the model we suppress the household's choice of the amount of housing services that it consumes and assume that the quality of housing services, as determined by the relative proximity of the house to neighboring houses, is the only characteristic that distinguishes houses.[6]

We assume that the physical decay over distance (*d*) of both effects is the same and that this relationship is linear:

$$G = R = \gamma_0 - \gamma_1 d \quad (2)$$

Equation (2) says that both effects (*G* and *R*) decrease with distance at the same rate, γ_1, and that as distance approaches a maximum distance cut-off, $\frac{\gamma_0}{\gamma_1}$, the effects of positive and negative externalities go to zero. Substituting equation (2) into (1) yields:

$$U_j = X_j^{\theta_1}\left(\alpha_{0j}\left(\gamma_0 - \gamma_1 d_j\right)^{\alpha_{1j}} - \beta_{0j}\left(\gamma_0 - \gamma_1 d_j\right)^{\beta_{1j}}\right)^{\theta_2}. \quad (1')$$

Equation (1') shows a Cobb-Douglas utility function where parameters θ_1 and θ_2 reflect the weight households give to the composite good and to the net effect of distance on their utility ($0 \le \theta_1, \theta_2 \le 1$). Agglomeration effects are assumed to generate diminishing marginal returns and thus utility is assumed to increase at a decreasing rate in agglomerative effects. Conversely, we treat repelling effects like congestion effects, which are very low or non-existent for low levels of the congestible good and typically increase at an increasing rate for higher levels of the good.

[6] Including the amount of housing services would allow us to take account of how households trade-off quantity of house with proximity to others, but the basic results with respect to how spatial externalities influence household decision-making hold irrespective of this trade-off.

Thus repelling effects are assumed to generate disutility at an increasing rate. These assumptions imply that $0 \leq \alpha_1 \leq 1$ and $\beta_1 \geq 1$. Household types are distinguished by their preferences over agglomerative and repelling effects and thus by the specific values assigned to α_0 and β_0, both of which are assumed to be non-negative. These assumptions guarantee the following concavity conditions for the households' utility function:

$$\frac{dU^j}{dX^j} \geq 0; \quad \frac{dU^j}{dG} \geq 0; \quad \frac{dU^j}{dR} \leq 0; \quad \frac{dG}{dd^j} \leq 0; \quad \frac{dR}{dd^j} \leq 0$$

$$\frac{d^2U}{dX^2} \leq 0; \quad \frac{d^2U}{dG^2} \leq 0; \quad \frac{d^2U}{dR^2} \leq 0$$

Taken together with the linear distance-decay process specified in (2), these assumptions imply that utility is affected non-linearly by distance due to the trade-off that households make between agglomerative and repelling forces when choosing their optimal distance.

Households are assumed to maximize utility subject to their budget constraint:

$$I_j = pX_j + r^*(d), \qquad (3)$$

where I is income, $r^*(d)$ is the market price of a house at distance d, and p is the price of the composite good. Housing price $r^*(d)$ it is determined in the market by both the distributions of consumer tastes and producer costs and thus is exogenous to individual households. Because it is a function of housing characteristics (in this case, average distance to neighboring houses), we treat $r^*(d)$ as a hedonic price function from which the implicit price for distance can be derived (Rosen).[7] The household's maximization process yields the following first order conditions:

$$\frac{dL}{dX} = \theta_1 X_j^{\theta_1 - 1}\left(\alpha_{0j}(G)^{\alpha_{1j}} - \beta_{0j}(R)^{\beta_{1j}}\right)^{\theta_2} - \mu p = 0, \qquad (4)$$

$$\frac{dL}{dd_j} = \theta_2 X_j^{\theta_1}\gamma_1\left(\alpha_{0j}(G)^{\alpha_{1j}} - \beta_{0j}(R)^{\beta_{1j}}\right)^{\theta_2 - 1}\left(\beta_{0j}\beta_{1j}(R)^{\beta_1 - 1} - \alpha_{0j}\alpha_{1j}(G)^{\alpha_1 - 1}\right) - \mu\varphi^* = 0, \qquad (5)$$

[7] The hedonic price function is a double envelope of households bid curves and developers offer curves and therefore it depends on the determinants of demand and supply. For all firms and households to be in equilibrium, all bid and offer curves for distance, for each participant in the market, must be tangent to the hedonic price function. For more details, see Rosen or Freeman.

where *L* represents the Lagrangian and $\varphi_j^* = \frac{dr^*(d)}{dd_j}$ is the marginal implicit price for distance. Equations (4) and (5) indicate that at the optimum households will equate the marginal utilities and marginal costs of the composite good and distance respectively. Interpreted jointly they say that at the optimum, the marginal utility of the last dollar spent in the composite good should be equal to the marginal utility from the last dollar spent in distance:

$$\frac{\theta_1\left(\alpha_{0j}G^{\alpha_{1j}} - \beta_{0j}R^{\beta_{1j}}\right)}{p} = \frac{\theta_2 X_j \gamma_1\left(\beta_{0j}\beta_{1j}R^{\beta_1 - 1} - \alpha_{0j}\alpha_{1j}G^{\alpha_1 - 1}\right)}{\varphi_j^*}. \qquad (6)$$

Considering the household's optimal choice of distance, *d**, it is clear that the household will never choose values of *d* for which the net spatial externality effect is negative. This is because the household can always choose to locate at $d \geq \frac{\gamma_0}{\gamma_1}$, at which point the spatial externality effect is zero. Thus for any *d**, it will always be the case that $\alpha_0 G^{\alpha_1} - \beta_0 R^{\beta_1} \geq 0$. Given this, the household's choice of *d* is influenced by the trade-off between the marginal disutility of distance due to agglomerative effects and marginal utility of distance due to repelling effects:

$$\begin{aligned} \frac{dU}{dG}\frac{dG}{dd} &= -\gamma_1\alpha_{0j}\alpha_{1j}\theta_2 X_j^{\theta_1}\left(\alpha_{oj}(G)^{\alpha_{1j}} - \beta_{0j}(R)^{\beta_{1j}}\right)^{\theta_2 - 1} G^{\alpha_{1j}-1} < 0 \\ \frac{dU}{dR}\frac{dR}{dd} &= \gamma_1\beta_{0j}\beta_{1j}\theta_2 X_j^{\theta_1}\left(\alpha_{oj}(G)^{\alpha_{1j}} - \beta_{0j}(R)^{\beta_{1j}}\right)^{\theta_2 - 1} R^{\beta_1 - 1} > 0 \end{aligned} \qquad (5'); (5'')$$

The household derives disutility from a marginal increase in distance due to the loss of agglomeration benefits that an increase in distance implies (5'), but derives utility from the decline in congestion externalities that accompanies an increase in distance (5''). The trade-off between these two effects determines the optimal distance among neighbors, which varies across types of households.

Household Demand for Distance

From (4) and (5) we can obtain the household's (uncompensated) bid rent function for distance, $r_u(d)$, which is a function of distance, income, and the equilibrium implicit price for distance, φ*:

$$r_{uj} = I - \frac{\theta_1\left(\alpha_{0j}(\gamma_0 - \gamma_1 d)^{\alpha_{1j}} - \beta_{0j}(\gamma_0 - \gamma_1 d)^{\beta_{1j}}\right)\varphi_j^*}{\theta_2\gamma_1\left(\beta_{0j}\beta_{1j}(\gamma_0 - \gamma_1 d)^{\beta_{1j}-1} - \alpha_{0j}\alpha_{1j}(\gamma_0 - \gamma_1 d)^{\alpha_{1j}-1}\right)}. \tag{7}$$

The household's bid rent function reflects the household's willingness to pay for a house at every distance, while the hedonic price function, *r*(d)*, is the minimum price that households must pay in the market. Thus household utility is maximized at the point at which the household's bid equals the market price: $r_j^*\left(d_j^*\right) = r_{uj}\left(d, I_j, \varphi_j^*\right)$, where *d** is the optimal distance. At this optimal point, the bid curves have the same slope and are tangent to the hedonic price function and thus the marginal bid and the marginal implicit price of distance are equal:

$$\varphi_j^* = \varphi_{uj}\,. \tag{8}$$

Combining (7) and the equality from (8) that holds in equilibrium allows us to derive an expression for the uncompensated demand function for distance that holds for the optimal value *d**: (Freeman):

$$\varphi_{uj}\left(d^*\right) = \left(I - r_j^*\right)\frac{\theta_2\gamma_1\left(\beta_{0j}\beta_{1j}R^{\beta_{1j}-1} - \alpha_{0j}\alpha_{1j}G^{\alpha_{1j}-1}\right)}{\theta_1\left(\alpha_{0j}G^{\alpha_{1j}} - \beta_{0j}R^{\beta_{1j}}\right)}\,. \tag{9}$$

Equation (9) is the household's marginal willingness to pay for distance, which is the household's uncompensated inverse demand for distance. It depends positively on the rate of decay of externalities with distance, γ_1, the relative preference weighting of externalities in the utility function, θ_2/θ_1, and negative externalities (*R*) and negatively on positive externalities from neighbors (*G*). Simulations of (9) for specific parameter values, described in more detail in the following section, reveal that the demand for distance is positive and decreasing over ranges of *d* over which utility is increasing and negative for ranges of *d* over which utility is decreasing (see figure 3).

Income and Scattered Development

In order to examine how household location choices influence scattered development, we focus on how the household's choice of optimal distance changes with changes in income and with heterogeneity in households' preferences over the agglomerative and repelling effects generated by proximity to neighbors. As a household's choice of optimal distance from its neighbors increases, so does the degree of scattered or leapfrog development in the region and thus factors that increase optimal distance will increase this form of sprawl. Given this, we are interested in testing whether this form of sprawl is increasing in income, as is suggested by previous models, and whether increases in income affect heterogeneous households differentially in terms of their optimal location decision. The latter allows us to investigate the interaction between heterogeneous preferences and income and whether the income effect associated with households that have stronger preferences for more isolated locations contributes more to sprawl than the income effect associated with those with weaker preferences for isolated locations.

The effect of income changes on optimal distance

Comparative statics is used to examine the effect of an exogenous change in income on the household's equilibrium bid function (equation 7), where the marginal implicit price of distance, φ^*, is equal to the household's marginal willingness to pay for distance, φ_{uj}, at the equilibrium point:

$$\frac{dd_j}{dI_j} = \frac{\theta_2}{\varphi_{uj}\theta_1 Z_j}, \tag{10}$$

where $Z_j = 1 + \frac{\left(\alpha_{0j} G^{\alpha_{1j}} - \beta_{0j} R^{\beta_{1j}}\right)\left(\beta_{0j}\beta_{1j}\left(\beta_{1j}-1\right)R^{\beta_{1j}-2} - \alpha_{0j}\alpha_{1j}\left(\alpha_{1j}-1\right)G^{\alpha_{1j}-2}\right)}{\left(\beta_{0j}\beta_{1j}R^{\beta_{1j}-1} - \alpha_{0j}\alpha_{1j}G^{\alpha_{1j}-1}\right)^2} > 0$ for any positive value of utility function.[8] Therefore, the sign of $\frac{dd_j}{dI_j}$ depends on the sign of φ_{uj}. From equation (9) we know that the sign of φ_{uj} changes with distance such that, for $d_{0j} < d_j < \hat{d}_j$, φ_{uj}

[8] Remember that $G = R = \gamma_0 - \gamma_1 d$.

> 0 and $\frac{dd_j}{dI_j} > 0$, where $d_{0j} = \frac{\gamma_0}{\gamma_1} - \frac{1}{\gamma_1}\left(\frac{\alpha_{0j}}{\beta_{0j}}\right)^{\frac{1}{\beta_{1j}-\alpha_{1j}}}$, which is the minimum distance that generates a positive utility for household *j* and $\hat{d}_j = \frac{\gamma_0}{\gamma_1} - \frac{1}{\gamma_1}\left(\frac{\alpha_{0j}\alpha_{1j}}{\beta_{0j}\beta_{1j}}\right)^{\frac{1}{\beta_{1j}-\alpha_{1j}}}$, which is the distance at which household *j* maximizes its utility. Thus, for $d_{0j} < d_j < \hat{d}_j$, utility is positive and increasing over d_j and distance behaves as a normal good. On the other hand, for $\hat{d}_j < d_j < d_{1j}$, $\varphi_{uj} < 0$ and $\frac{dd_j}{dI_j} < 0$, where $d_{1j} = \frac{\gamma_0}{\gamma_1}$ is the distance at which agglomerative and repelling effects vanish. In this case, utility is positive and decreasing over d_j and distance behaves as an inferior good.

As discussed earlier, the market equilibrium is defined by a set of tangencies between the households' bid functions and the offer curves of the sellers (in this case assumed to be housing developers). Although we refrain from developing an explicit model of the supply side, we assume that developers can achieve economics of scale in housing production when houses are within sufficient proximity of each other and thus, that developers' offer curves are non-decreasing over distance. On the other hand, as discussed above, household bid functions are increasing over distance only for distances that are less than or equal to their unconstrained optimal distance, $\widehat{d}_j$, and are decreasing with distances that are greater than this. Given these conditions, a market equilibrium implies that households will be located at distances that are less than or equal to $\widehat{d}_j$ since an offer curve can only be tangent to that portion of the bid curve that correspond to this distance range. In this case, increases in income will cause a household to increase its optimal distance from neighbors so long as households are not already located at their unconstrained optimum (i.e., so long as $d_j^* < \hat{d}_j$). However, once a household reaches $\hat{d}_j$, further increases in income will have no effect on distance decisions and additional income will be allocated to the consumption of other goods, *ceteris paribus*. These results lead us to conclude that, keeping population constant, scattered development that is driven by spatial externalities is a process that is driven only *temporarily* by increases in income. This process is the result of households looking, over time, for a location that satisfies their preferences over proximity to others. Once households have reached their unconstrained optimum, $\hat{d}_j$, increases in income will not be reflected in greater distances, *ceteris paribus*, because distance becomes an inferior good over the range $\hat{d}_j < d_j < d_{1j}$. If we accept that income increases over time, we can assert that distance among households reaches a static equilibrium point and that increases in income only generate temporary increases in scattered development due to spatial externalities, other things equal.

Income effects with heterogeneous households

While the comparative statics tell us something about how the household's optimal distance changes with income, we cannot readily compare the magnitude of this change across different household types (as differentiated by their preferences over proximity to neighbors). To obtain this, we compute household type *j*'s income elasticity of demand for distance:

$$\eta_j = \left[\frac{\theta_2 r_j}{\theta_1 \varphi_{uj}} - \frac{\left(\alpha_{0j} G^{\alpha_{1j}+1} - \beta_{0j} R^{\beta_{1j}+1} \right)}{\gamma_1 d \left(\beta_{0j} \beta_{1j} R^{\beta_1} - \alpha_{0j} \alpha_{1j} G^{\alpha_{1j}} \right)} \right] Z_j, \tag{11}$$

where Z_j is defined as in equation (10). The sign of income elasticity depends of the sign of φ_{uj}. Household *j*'s income elasticity is positive for $d < \hat{d}_j$ and negative for $d > \hat{d}_j$, where $\hat{d}_j$ is the optimal distance to neighbors for household type *j*. The magnitude of the percentage change in distance due to a change in income varies among households and depends, among other things, on the values of the parameters governing preferences over proximity to neighbors.

To further examine how heterogeneous preferences influence the income elasticity of demand for distance, a simulation is performed for three types of households that have identical incomes, but heterogeneous preferences over their proximity to neighbors. We refer to these three types as gregarious, average, and loner households. Gregarious households value the benefits from living within close proximity to their neighbors, but also perceive some of the negative effects from congestion. Average households perceive a relatively balanced mix of benefits and costs associated with proximity to neighbors and thus do not like locating too close or too far from others. Loner households primarily perceive the costs from congestion generated by neighbors and only a few of the potential benefits from proximity and thus try to locate relatively far from neighbors. To define each type of household, variations in the values of some parameters are allowed (namely, we vary α_0 and β_0), while the other parameters remain constant across households.[9]

Figures 1 to 4 report the results of the simulation, including the optimal distance, compensated bid function,[10] uncompensated marginal willingness to pay for distance, and income elasticity of demand for distance for each type of household. We use these results to discuss the optimal choices of each household type and the implications of this heterogeneity for scattered residential development. Gregarious households have a positive utility over the relevant distance range (from zero to γ_0/γ_1), but their utility is increasing only for a portion of this range, $0 < d < \widehat{d}_g$ (figure 1). Their maximum willingness to pay for a house is at $d = \widehat{d}_g > 0$ (figure 2) and their demand for distance is positive only for the range $0 \leq d_g < \hat{d}_g$ (figure 3). On the other hand, the range of distances for which average households' utility is increasing is much greater than the gregarious households (figure 1) and therefore, its marginal willingness to pay for distance is positive for a greater range of *d* (figure 3). Lastly, loner households maximize utility at $d = \widehat{d}_l$, which is very close to the distance at which agglomerative and repelling effects vanishes, γ_0/γ_1.

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[9] Specifically, we vary the following parameters as follows for the gregarious, average, and loner households: $\alpha_0 = 14$, 20, and 40 respectively and $\beta_0 = 0.75$, 2, and 20 respectively. The following parameters are held constant at the following values: $\theta_1 = 0.5$; $\theta_2 = 1$; $\alpha_1 = 0.5$; $\beta_1 = 1.5$; $\gamma_0 = 10$; and $\gamma_1 = 1$.

[10] We graph the compensated bid function since the uncompensated function in (9) is a function of the marginal implicit price of distance, φ^*, which is an endogenous variable. The compensated bid function is derived by substituting (3) into (1'), holding utility constant and solving for *r(d)* as a function of distance.

This type of household faces a small distance range for which their utility is positive and small range for which it is increasing (figure 1). Its willingness to pay for a house within its relevant distance range is the steepest of all types of households (figure 2) and these households have the highest demand for housing that is located at further distances (figure 3).

Figure 4 illustrates the differences in the income elasticity of demand for distance across household types. In each case, households' demand for distance is more or less income elastic depending on distance. Households' income elasticity of demand for distance is zero at the household's unconstrained optimum and is the most inelastic and positive (negative) for distances that are just less than (greater than) this value. Thus, at the unconstrained optimum, income changes do not alter the household's optimal choice of distance. For all households, the income elasticity goes to zero at distances that are at or beyond the maximum distance for which externalities are generated ($d = \gamma_0/\gamma_1$).

Households' income elasticity varies in sign and magnitude by household type. Gregarious and average households exhibit an income elasticity of demand for distance that is positive and highly elastic for distances that are substantially less than their respective unconstrained optimal distances. Distances that are farther than this point reduce utility and therefore the income elasticity is negative for these distances. The gregarious households' demand for distance is highly income elastic for shorter distances, but their income elasticity is positive only for a relatively narrow range of distances before reaching their unconstrained optimum. On the other hand, the income elasticity for average households is less elastic, but is positive for a greater range of distances. Finally, loner households are the most inelastic of all types as the range of distances for which their utility (as well as their demand for distance) is positive and increasing is very short and close to the distance at which the externalities vanish.

Taken together, these results indicate that the effect of income on household location will depend on both the household's initial location and their particular set of preferences over the spatial externalities generated by proximity to neighbors. As discussed earlier, the market equilibrium will force households to locate at distances that are either less than or equal to their unconstrained optimal distance, $\hat{d}_j$. If $d_j^* < \hat{d}_j$, then increases in income will increase the optimal distance, but the magnitude of this effect will depend on the household's preferences over distance.[11] Gregarious households' demand for distance is highly elastic to income, but at the same time they only consider a small range of plausible locations. Thus, increases in income will generate relatively little increase in the amount of scattered development among these households. On the other hand, the demand for distance among loner households is the most inelastic to income changes. In addition, because they choose a location that is relatively far away (but not beyond the point at which the externalities vanish), they also have a small range of plausible distances from which they are willing to choose. In contrast, the average households' demand for distance is moderately elastic and these households have the greatest range of distances over which they are willing to choose. Consequently, changes in income are likely to affect these households the most in terms of the magnitude of their increase in optimal distance and thus, the rate at which scattered development increases as a result of rising incomes. This leads us to conclude that, while the absolute amount of scattered development obviously increases in the proportion of loner households in the region that have strong preferences for more isolated locations, the *rate* at which scattered development increases as the result of rising incomes will be driven by the proportion of *average* households in the region. Holding population constant, the rate at which scattered development increases due to rising incomes will be greater the higher the proportion of average households in the region.

Summary and Conclusions

We develop a theoretical model to explain scattered development at the urban fringe, as characterized by dispersed development with intervening vacant land. The central feature of the model is a set of spatial externalities that arise from the relative proximity of neighboring

[11] It will also depend on the nature of the economies of scale that determine the developers' offer curves, but we abstract from this consideration here.

residential development and that influence households' location decisions. Both positive and negative externalities are hypothesized to exist that generate benefits (agglomerative effects) and costs (repelling effects) respectively, which influence a household's decision regarding its optimal average distance from nearest neighbors. The cumulative result of households' location choices determines the extent of scattered development or sprawl in the region.

Based on a utility-maximizing framework in which households choose distance and a composite good, we derive the household's bid rent function and their demand for distance, which describes the households' implicit price of distance as a function of distance. We use the basic model to examine the impact of economic growth on the scattered development that results from the externalities. Our two main findings are that (1) rising household income generates only *temporary* increases in scattered development due to spatial externalities, holding population constant and (2) the rate at which scattered development increases due to rising incomes will be greater the higher the proportion of average households in the region. The first result is driven by the fact that distance behaves as a normal good only up to a certain distance threshold, the household's unconstrained optimal distance, $\hat{d}_j$. Beyond this point, distance is an inferior good and thus further increases in income once the household has reached $\hat{d}_j$ will not be reflected in greater distances, *ceteris paribus*. The second result is due to the fact that, given our assumptions about the heterogeneous preferences of households over distance, households with moderated preferences over the positive and negative externalities that are generated by distance (i.e., average households), are the most responsive to income changes in terms of having both a moderately elastic income elasticity of demand and a relatively large range of distances over which their utility is increasing. Thus, while the absolute amount of scattered development will depend on the proportion of households that have strong preferences for more isolated locations (loner households), the rate at which scattered development increases as the result of rising incomes is driven by the proportion of average households in the region.

These results are subject to several important caveats. First, this model ignores the household's choice over the amount of housing or land that is consumed and thus we do not account for the standard income effect associated with housing and land consumption. Assuming that housing and land are both normal goods, this effect would generate an ever-increasing amount of scattered development, which is in contrast to the income effect associated with distance that we analyze here. Because the consumption of both the quantity of housing (or land) and its location (in terms of distance) are likely to drive observed household behavior, the net effect of these two income effects is an empirical question. Second, we assume that population and preferences over spatial externalities are constant. Clearly the amount of scattered development will increase with population as additional households locate in a region. If the population is homogeneous in their preferences, then additional population will simply increase in the geographical extent of the developed area in the region. However, if new households entering the region have different preferences—namely, stronger preferences for proximity to neighbors—or if the preferences of the existing population change such that there is a larger proportion of more gregarious households, then this "temporary" process of increasing sprawl could easily become permanent. For example, as new households with stronger preferences for proximity fill up intervening vacant land, then these locations will become sub-optimal for existing residents with stronger preferences for more distant locations. In a dynamic setting, such households would choose to relocate to more distant locations, thus expanding the geographical extent of sprawl in the region. So, with increases in population or even with a constant population, but heterogeneous and changing preferences, a stationary state may never be reached.

Despite these limitations, our results are of interest in terms of highlighting the role of spatial externalities in generating scattered development and have implications for the efficiency of development patterns. Contrary to the traditional models of leapfrogging, a model in which scattered development is driven by spatial externalities implies that the competitive outcome is unlikely to be efficient. In our case, household are both the victims and generators of externalities as their location decisions are driven by externalities that are generated by others, but these decisions also generate externalities that impact others' utility and cause a divergence between the private and social optima. This is akin to Turner's result that the competitive outcome is characterized by not enough intervening open space since individual agents do not take into account the impact on others' utilities of the loss of open space that is generated by their action. Here we hypothesize that household interactions lead to both positive and negative externalities and thus, depending on the net effects, the competitive outcome will be characterized either by houses that are too close (if the net externality is negative) or not close enough (if the net externality is positive). Thus, unlike Turner's results in which the competitive process always leads to overdevelopment of a given area, the competitive outcome in our model may lead to either too much or too little development for a given area, depending on the net effect.

Our results have potential implications for the evolution of scattered residential development and policies that seek to manage this form of sprawl. To the extent that spatial externalities drive household location, policies that seek to make this form of development more efficient are warranted. However, because both positive and negative externalities may exist, it is unclear what the desired policy goal should be. If there are net positive externalities generated by household interactions, then policies that seek to encourage more spatially clustered development are warranted. On the other hand, if negative externalities are stronger, then this would suggest that policies should seek to spread development out further and to retain larger areas of intervening open space. Thus, to draw more substantial policy implications from such a model, a better understanding is needed of the types of externalities that are generated from household proximity, their magnitudes and spatial extents, and the underlying processes that generate these effects.

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Figures 1-4: Comparison of household types as distinguished by heterogeneous preferences over proximity to neighbors

Figure 1. Utility

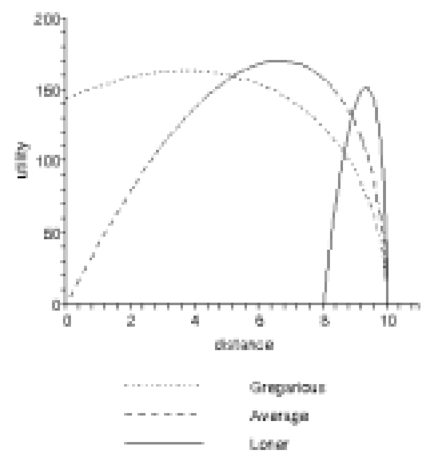

Figure 2. Compensated Bid Curve

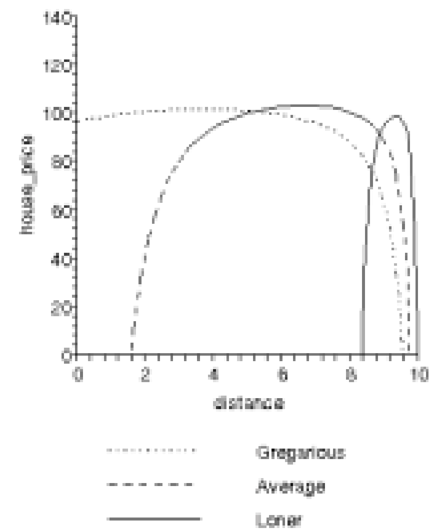

Figure 3. Willingness to Pay for Distance

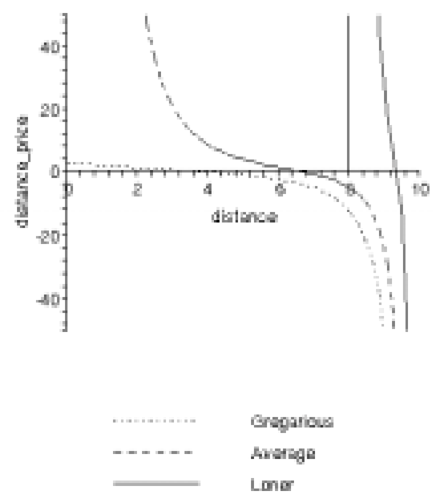

Figure 4. Income-elasticity