THE COMPLEX INTERACTION OF AGENTS AND ENVIRONMENTS: AN EXAMPLE IN URBAN SPRAWL

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ABSTRACT

We present and evaluate a foundational agent-based model of land use change at the rural-urban fringe within the context of a larger project that will link to surveys of the environmental and community preferences of residents with historical data on patterns of development. In this paper, we focus on the dynamics arising from a model of residential location resulting from preferences for services, density, and aesthetics focusing on the relationship between micro level preferences and policy relevant macro phenomena such as scattered development, largest city size, and the number of residential clusters. We consider two representations of agents' utility functions – one additively separable and one multiplicative – to see if functional form has any impact on the dynamics of the system, and find that they produce similar results. Our analysis includes both representative agent runs, in which all agents have identical preferences, as well as runs in which the agents have diverse preferences. We find that diversity can increase sprawl through feedbacks associated with the spatial locations of services and agents. In addition, we examine cases in which the agents' location decisions affect the aesthetic quality of neighboring sites and find that these feedbacks further exacerbate the sprawl effect.

INTRODUCTION

The goal of our project is to use an agent-based model to evaluate the ecological effects of alternative plans and designs for urban development. Development at the urban-rural fringe has been linked to a variety of negative ecosystem impacts, including habitat and migration corridor destruction [Johnson, 2001]. In the modeling portion of our research agenda, we focus on how agent level preferences alter land use change in this fringe region. Our immediate goal is to

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understand how residential agents make decisions on where to live and which dimensions of that decision making process influence settlement patterns on the urban rural fringe. If we have a better understanding of this process then we can design policy instruments to control the patterns of urban development to improve ecological performance.

Our project encompasses a suite of models that extends from very simple analytical models all the way up to a full blown agent-based models with heterogeneous types and spatio-temporal feedbacks. In this paper, we present some of the results of our agent-based models. Our study focuses on modeling land use change at the urban-rural fringe in the Detroit Metropolitan Area, USA, but our analysis here involves a hypothetical area. In our experiments we use preference distributions designed to test archetypal or extreme cases. This allows us to analyze the verisimilitude of our assumptions in a controlled manner, and thus test the limits of our model. In future experiments, the assumptions driving our model will be linked to empirical data.

Our agent-based model extends the traditional land use and settlement models in several directions. First, we include feedback on several dimensions simultaneously. Residential choices affect services, density, and aesthetic quality, all of which influence the decisions of other agents. Second, our model includes heterogeneous agents. We find that heterogeneity matters. Just knowing the mean preferences of the agent population is insufficient to predict land use patterns. These changes – multiple feedbacks and heterogeneity – would be difficult if not impossible to include in an analytic model. Our agent-based approach enables us to include in our model both of these important, empirically validated features [Irwin and Bockstael, 2001][Ewing, 1997][Chin, 2002].

In this paper, we explain our approach, its various parameters, and its potential. We then present some results from this model and discuss how those results compare to other models. We conclude with a discussion of future explorations. Our long range goal is to use an extension of this model to address normative and descriptive questions.

EXPLANATION OF MODEL

The simplified model we present here was developed in SWARM using agents who have locational preferences. These agents exist on a heterogeneous two dimensional landscape, which can be defined using data stored in a geographic information system (GIS) or set to a hypothetical landscape. The model generates dozens of outcome variables of both a spatial and quantitative nature and even more can be added. We call this model SLUCE (**S**patial **L**and **U**se **C**hange and **E**cological effects). The model is composed of three primary parts, the environment, the agents, and the agents interaction with the environment. We describe each in turn.

Environment

We represent geographic space with a two-dimensional square lattice. The results presented below all take place on an 80 by 80 lattice. For purposes of calibration, each site can be interpreted as one half mile by one half mile so that the entire lattice is forty miles by forty miles. Each location on the landscape has two exogenous characteristics: a natural beauty score in the interval $[0, 1]$ and the presence or absence of an initial service center. In the model presented here there is only one initial service center in the center of the lattice. We then compute the distance to services for location (x, y), sd_{xy} by taking the sum of the inverse Euclidean distances (for simplicity) to the nearest eight service center locations from that cell. Thus, a cell that is surrounded by service centers would receive a score of 8. Because it seems reasonable that the residents of a cell would not receive additional benefit from more than about 2 immediately adjacent service centers, we set the service center score to a maximum of 2 and normalize the value. Thus,

$$sd_{xy} = max[1, \frac{(\frac{1}{||sc_1||} + \ldots + \frac{1}{||sc_8||})}{2}] \quad (1)$$

where $\|sc_i\|$ is the Euclidean distance to the $i-th$ nearest service center from x, y. Service center distance will change over time as new service centers arise. The other variables that will affect agents' choices are endogenous, such as density, and will also change as the time progresses.

The Agents

The basic agent types are residents and service centers (e.g., retail firms). Residents and service centers enter the world at each time step and each takes up one cell in the lattice. Both agents and service centers have the capacity to include heterogeneous attributes and behaviors, but at present service centers do not have any attributes themselves. They might be more accurately called proto-agents. However their presence greatly affects how residents determine where to live.

In the most basic model, residents have two attributes: (1) *Beauty Preference* ($\alpha_{nb} \in [0, 1]$), the weight that an agent gives to the natural beauty of an area. The natural beauty of an area can be generated from a distribution or set to a particular value exogenously. The beauty value of a cell x, y to an agent i is $nb_{xy} \times \alpha_{nb,i}$; and (2) *Service Center Preference* ($\alpha_{sd} \in [0, 1]$), the weight that an agent gives to the nearness of an area to service centers. The service value of a cell x, y to an agent i is $sd_{xy} \times \alpha_{sd,i}$.

The distribution of the attributes across agents can be set at normal, uniform, or homogeneous. With the normal distribution, the variance must also be chosen.

Agent Behavior

The agents choose locations on the lattice and this in turn influences how other agents choose locations resulting in a settlement pattern. Each iteration of the model, a group of new residents enters the map. The rate at which residents move into the landscape is determined exogenously. For the experiments below, we set the rate to 10 per step. Residents use a hedonic utility calculation to make their decisions about where to live, which currently takes into account some or all of the landscape variables. We endow the service centers with much less intelligence. Every time some number of residents (arbitrarily set to 100) is created, a service center is created in an empty cell near the last resident to enter the model. There is also an initial service center that is located in the middle of the map.

To select a cell, a new resident r looks at some number of randomly selected cells (10 for all runs presented here) and moves into the cell that has the highest utility for r, or selects randomly among tied cells. In the results presented we calculate the utility in two different ways The first is an additive model, which assumes that the preferences are separable from each other:

$$u_{xy} = \alpha_{nb} \times nb_{xy} + \alpha_{sd} \times sd_{xy} \tag{2}$$

The second is a multiplicative model, which assumes that the preferences are dependent, i.e. being near a service is irrelevant if there is no natural beauty:

$$u_{xy} = nb_{xy}^{\alpha_{nb}} \times sd_{xy}^{\alpha_{sd}} \tag{3}$$

ALTERNATIVE MODEL STRUCTURES

We start with our standard model as described above and then alter the model to examine alternative structural assumptions. Our goal is to determine what effect different modeling choices have on the output and results of the system. By doing this we hope to make recommendations about issues that must be taken into account when looking at questions of urban sprawl and those features that can be ignored, in order to gain a simpler understanding of the general dynamics of the system. We start by looking at how modifying the distribution and use of preferences in the system affect the outcome. Then we move on to adding feedbacks between the agents and the environment.

Preferences and Utility Functions

We first examine whether the form of the utility function affects the outcome of the model and whether representative agent models are sufficient to capture settlement patterns or heterogeneous agent models are necessary. We find that both matter with regards to quantitative measures. When agents have diverse preferences, we see much more sprawl. Moreover, when we change agents' preferences from separable to non-separable, we see less extreme residential choices.

Heterogeneous Preferences We begin with a model where all agents have the same preferences, i.e. all agents value distance to services and natural beauty equally. However our model also allows for agent preferences to be drawn from a distribution of preferences. In most of our experiments this distribution was a normal distribution with the same mean and different levels of variance. This allows us to examine how having heterogeneous agents can change the outcome of the model. The variances are increased equally for all preferences. This allows us to characterize how varying levels of heterogeneity affect the system, as opposed to looking at the separate question of how the positive or negative correlation of preferences affects the system.

Feedbacks

Another area of interest is how the agents' locational choices influence future agents' decisions. For instance, an agent's development decision may change the natural beauty of the location around it, and make that area less desirable for future agents. In this case, it is the interaction of the agents and the environment that determines the course of development in a run of the model. Thus we examine two ways that this interaction might occur: (1) *Neighborhood Density*, where agents can prefer to live in areas of higher or lower density, and (2) *Land Use Affects Beauty* where agents moving into a location decreases the natural beauty of the area around them.

Neighborhood Density The first feedback that we added to the model was to give agents a preference for a neighborhood density. In other words, an agent determines what the density of a neighborhood will be if it moves into it and it compares that to its ideal value for the density of the area in which it wants to live. This value is then used as part of the utility function similar to the distance to services and natural beauty.

The neighborhood density function around cell C is a weighted average of the fraction of Moore (8) neighbors that are inhabited and whether C is also inhabited (when this is being used in the locational decision, C is always considered to be inhabited). The neighbors fraction is worth $\frac{1}{2}$ the value and C is worth $\frac{1}{2}$ the value. For example for a non-edge cell C, if 2 neighbors are developed in a square and C is developed, the result is $\frac{\frac{2}{8}+1}{2} = \frac{5}{8}$. Thus,

$$nd_{xy} = \frac{\frac{DevelopedNeighbors_{xy}}{Neighbors_{xy}}}{2} + \frac{Developed_{xy}}{2} \quad (4)$$

where $DevelopedNeighbors_{xy}$ is the number of developed neighbors cell x, y has, $Neighbors_{xy}$ is the number of possible neighbors x, y has, and $Developed_{xy}$ is 1 if x, y is developed and 0 otherwise. Since the agent always calculates what the value of the neighborhood density would be if they moved in, the minimum value is 0.5 and the maximum value is 1.

This adds two more attributes to the agents: (1) *Neighborhood Density Ideal Value* ($\beta_{nd} \in [0,1]$), the density that the agent prefers in their neighborhood, and (2) *Neighborhood Density Preference* ($\alpha_{nd} \in [0,1]$), the weight that an agent gives to living in a location that has a density near its ideal density value. The density value of a cell x, y to an agent i is $(1 - |nd_{xy} - \beta_{nd,i}|) \times \alpha_{nd,i}$ where the nd_{xy} is calculated as if the agent was already living in the cell. Thus, the greater the difference between the ideal and the actual value of neighborhood density, the lower the utility derived from locating at x, y.

This results in the following modified utility functions, first the additive:

$$u_{xy} = \alpha_{nb} \times nb_{xy} + \alpha_{sd} \times sd_{xy} + (1 - |nd_{xy} - \beta_{nd,i}|) \times \alpha_{nd,i} \tag{5}$$

then the multiplicative:

$$u_{xy} = nb_{xy}^{\alpha_{nb}} \times sd_{xy}^{\alpha_{sd}} \times (1 - |nd_{xy} - \beta_{nd,i}|)^{\alpha_{nd,i}} \tag{6}$$

Land Use Affects Beauty The second feedback that we incorporated was to have land use decrease natural beauty of surrounding locations. Specifically, as an area becomes more and more developed we decrease the natural beauty of neighboring cells by a proportional amount. The modified natural beauty landscape simply takes the neighborhood density, subtracts that value from one and multiplies the result by the original natural beauty in order to come up with a new natural beauty measure.

Thus,

$$mnb_{xy} = (1 - nd_{xy}) \times nb_{xy} \tag{7}$$

where nb_{xy} is the original natural beauty at cell x, y.

In determining a location the resident calculates what the mnb of a cell will be if they move into it and then uses that value in the utility function. This results in new utility functions, first the additive:

$$u_{xy} = \alpha_{nb} \times mnb_{xy} + \alpha_{sd} \times sd_{xy} \tag{8}$$

Then the multiplicative:

$$u_{xy} = mnb_{xy}^{\alpha_{nb}} \times sd_{xy}^{\alpha_{sd}} \tag{9}$$

Of course this interaction can be used with or without the neighborhood density preferences and ideal values described above.

Separable versus Non-separable Preferences Our final comparison involves changing the functional form of our utility function and rerunning our entire suite of experiments. In our original model, preferences are additively separable. This implies that agents may choose locations that have extremely high values on one attribute but low values on another. If instead, we assume that preferences are multiplicative, so that the utility from natural beauty and distance to services equals their product not their sum, then agents will choose locations that better balance beauty with distance to services. For example, suppose that one location has a natural beauty value of 1.0 but a distance to services value of 0.1 and that another location has a natural beauty value of 0.4 and a distance to services value of 0.5. Moreover assume that the agent has preferences such that $\alpha_{nb} = \alpha_{sd} = 1.0$. Using an additive utility function, the first location is preferred since $1.1 > 0.9$. But, using a multiplicative utility function, the latter is preferred because $0.2 > 0.1$. This tendency for choosing locations with more extreme attribute values can cause more sprawl, as agents choose locations of high natural beauty that are far from service centers, and may at the same time cause bigger central clusters as agent who do not care about natural beauty choose locations near service centers.

EXPERIMENTS AND RESULTS

Experiments were run starting with the two base models, corresponding to the additive and multiplicative value functions described above. The natural beauty of each cell was derived from a normal distribution ($\mu = 0.5, \sigma^2 = 0.5$) between 0 and 1, and then a local filter was applied to create spatial autocorrelation[1]. Results for each experiment were averaged over a minimum of 30 runs. These models were subsequently modified to add heterogeneous preferences, the effect of neighborhood density preferences, and the link between land use and natural beauty.

Our model generates dozens of output measures. Two that closely track sprawl are the size of the largest cluster ($LRGECLUS$) and development beyond a 30 cell radius of the center ($DEV + 30$). The first measure is used to estimate the size of the main development. Clustered development is generally considered to result in less ecological impact because it reduces the amount of area directly affected by development. In addition, such development pattern increases accessibility to urban amenities, reducing commuting distances, and consequently energy consumption and pollution [Ewing, 1994][Beatley and Manning, 1997]. A larger central cluster, compared among patterns with the same amount of area developed, usually means less scattered

[1] The samples in all normal distributions in this paper are drawn with the given μ and σ^2 but if the result is outside the bounds, a new sample is drawn until the sample is within the bounds.

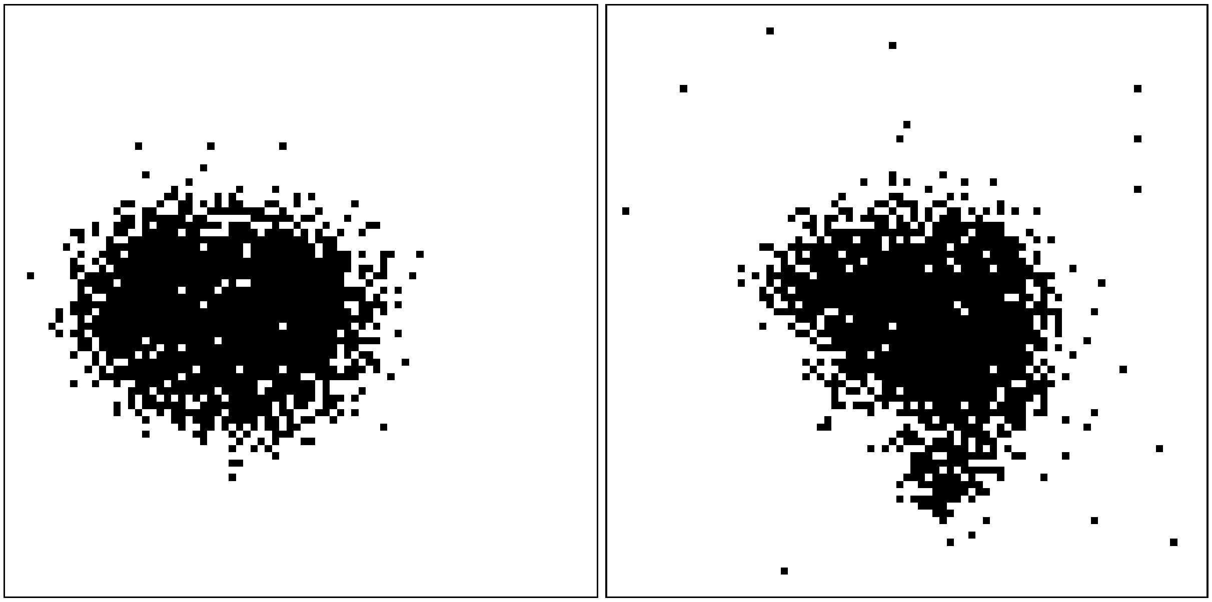

Figure 1. Homogeneous Agents (left) and Heterogeneous Agents (right)

development in outlying areas, therefore, less impact. $DEV + 30$ provides a good measure of how much leapfrogging or scattered development we see. All measures were averaged over time steps 95 to 105 to give us an average measure at time step 100. After 100 time steps, 1000 agents and 10 service centers have located in the world.

Heterogeneous Preferences

The first set of experiments were run keeping the mean value of all α-parameters at 0.5 while sweeping the variance between 0.0 and 0.4, at 0.05 intervals. Land Use Affects Beauty and Neighborhood Density were not included. The results for this experiment as well as others are listed in Tables 1 and 2. This set of experiments allowed us to examine the effect of heterogeneous preferences. These results were averaged over 100 runs. We find that including heterogeneity ($\sigma^2 = 0.25$) increases the amount of sprawl according to the (DEV+30) measure by 31 units. This should have been expected given that their are now agents who care relatively more about natural beauty and are willing to move away from service centers. The effect on the size of the largest cluster was harder to predict prior to running the model. Those agents that want to be relatively close to services should make the cluster larger, but what was less clear was whether these agents could fill in all of the gaps created by the agents who want high natural beauty. In the model, we found that the largest cluster ($LRGCLUS$) decreased by 33 units when we included heterogeneity ($\sigma^2 = 0.25$). This indicates a larger amount of sprawl, which shows that these agents were not able to fill in all of the gaps.

The inclusion of diversity created more sprawl as well as more clustering behavior. These two effects can be seen in screen captures of the model in Figure 1 (black indicates development).

	$DEV+30$	$LRGCLUS$
Basic Model	123 (8)	800 (3)
Diversity	131 (7)	761 (5)
Land Use Affects Beauty	251 (9)	475 (12)
Density	96 (10)	771 (9)
Land Use Affects Beauty and Diversity	303 (8)	371 (10)
Density and Diversity	124 (11)	760 (9)
Land Use Affects Beauty and Density	65 (5)	814 (7)
Land Use Affects Beauty, Density and Diversity	109 (9)	740 (9)

Table 1. Observed Results – Additive Case
(Mean and Standard Deviation of the Mean)

With high levels of diversity, we see dark patches in the center where the early service centers locate. We also see isolated agents jumping far from the service centers to locations of great natural beauty fairly early on in the run of the model. Interestingly, while we found that diversity mattered, we also found that the level of diversity was less important. Our measures did not vary much once the variance was increased to 0.25. Thus when we state that we are using heterogeneous agents we mean that they had preferences with a variance of 0.25 and a mean of 0.5. This regularity proves useful in running other scenarios as we were able to work with only two diversity levels when exploring other changes in the model.

Land Use Affects Beauty

The next set of experiments included feedbacks on the natural beauty. This had a much larger effect than including diversity (Tables 1 and 2). The results were averaged over a 100 runs. We found huge increases in the ($DEV+30$) parameter and much larger decreases in the size of the largest cluster ($LRGCLUS$). The reason for this is straightforward. The decrease in natural beauty caused subsequent agents in search of natural beauty to leapfrog out into undeveloped territory, increasing $DEV+30$. The destruction of beauty decreased $LRGCLUS$ by making locations near the largest cluster less attractive.

Neighborhood Density

Our next set of experiments included preferences for density in the agents' utility functions (Tables 1 and 2). The results are averaged over 30 runs, and agents are sampling 10 cells at each time step. The mean value of the parameter for ideal density (β_{nd}) was swept from 0.5 to 1.0 at 0.1 intervals. As a crude benchmark we first ran a model where agents only cared about density, turning off preferences for service centers and beauty. When density preference was set to 0.0, the development pattern resembled a perfectly spaced splattering of points. When the parameter was set to 1.0, we obtained a collection of randomly placed clusters of agents. These effects played out

	$DEV+30$	$LRGCLUS$
Basic Model	123	800
Diversity	+8	-39
Land Use Affects Beauty	+128	-325
Density	-27	-29
Land Use Affects Beauty and Diversity	+44	-65
Density and Diversity	+20	+28
Land Use Affects Beauty and Density	-159	+368
Land Use Affects Beauty, Density and Diversity	-123	+349

Table 2. Independent and Interaction Effects – Additive Case

when the density preference were just a part of preference as well. We present the results here for agents whose β_{nd} is set to 1.0, which means that they prefer areas that are densely inhabited. Also when we discuss heterogeneity in preferences now we also mean that the variance of the α_{nd} is set to 0.25. As should be expected a high density preference causes sprawl to decrease. However it is not as great a change as the land use affects beauty change is in the other direction.

Interactions of Feedbacks and Diversity

In addition to providing the raw numbers, we unpack the data to show the individual and linear effects of each of our variations. We do this by showing the marginal contribution to each output variable from each variation. For example, $DEV+30$ has a value of 123 in the base model, but a value of 131 in the model with diversity. Therefore, the marginal contribution of diversity equals $+8$. Similarly, the marginal contribution of Land Use Affects Beauty equals $+128$. To approximate the interaction effect, we compute the total expected contribution of each change separately and assign to the interactive term the difference between that value and the data. For example, with Diversity and Land Use Affects Beauty without any interactive effect we would obtain

$$DEV+30 \;=\; 259 = \; 123+8+128$$

But instead, we get a value of 303. Therefore, we assign a value of $+44$ to the interactive effect. We perform similar calculations for the other interactive effects. To capture the effect of all three variations, we calculate the expected value using all three pairs of interactive effects plus the individual effects and allocate the difference between that variable and the data to the interactive effect. When we included both the effect of land use on natural beauty and preference heterogeneity (set the variance to be 0.25), we found that the two effects reinforced one another and we got even more sprawl than we would have had just by summing the two effects. This reinforcement effect occurs because with diverse preferences, we have some agents who care greatly about natural beauty. When development destroys natural beauty they have to go even further out than they would have were this effect not in place. Thus, diversity plus natural beauty feedback creates an even larger effect than the two would separately.

	$DEV+30$	$LRGCLUS$
Basic Model	84 (5)	814 (3)
Diversity	111 (7)	799 (3)
Land Use Affects Beauty	218 (8)	600 (6)
Land Use Affects Beauty and Diversity	227 (6)	514 (8)
Density	67 (9)	828 (6)
Density and Diversity	82 (7)	822 (5)
Land Use Affects Beauty and Density	139 (15)	771 (7)
Land Use Affects Beauty, Density and Diversity	131 (12)	695 (8)

Table 3. Observed Values – Multiplicative Case

	$DEV+30$	$LRGCLUS$
Basic Model	84	814
Diversity	+27	+15
Land Use Affects Beauty	+134	-214
Density	-17	+14
Land Use Affects Beauty and Diversity	-18	-71
Density and Diversity	-12	+9
Land Use Affects Beauty and Density	-62	+157
Land Use Affects Beauty, Density and Diversity	-97	+96

Table 4. Independent and Interaction Effects – Multiplicative Case

Note that whereas diversity tends to increase sprawl, a preference for density should decrease it. Moreover it appears that the preference for density decreases the effect that diversity in preferences has on the system. This is because once agents want to live near the center, it causes more service centers to choose central locations. This process decreases the effect that a strong preference for natural beauty has on agents who still have some preference for service centers.

Combinations of Feedbacks

In our final set of experiments we see what effect the two feedbacks have when they interact with each other (Tables 1 and 2). There is an interesting feedback here that density has a greater effect on the results than land use and diversity of preferences. In fact as shown in the last case, the density preference may turn the diversity of preferences from a positive sprawl feedback to a negative sprawl feedback. Land use affects beauty can only serve to increase sprawl but apparently its effect is not great enough to overcome the preference for higher density.

Separable versus Non-separable Preferences

Tables 3 and 4 show our findings from the same scenarios as before but with multiplicative utility functions. For the most part, the results are similar. The linear effects are directionally nearly identical: diversity increases sprawl as does having land use affect beauty and preferences for density tend to decrease sprawl. The only difference is that density preferences appear to lead to a smaller largest cluster with linear preferences but not with multiplicative preference. The only difference in magnitude of note relates to the effect of diversity. It is more pronounced in the multiplicative case. This was to be expected given that in order to get people to locate far from service centers preferences must be diverse in the multiplicative case but not in the linear case. This is verified by the fact that with diversity there is less sprawl under multiplicative preference than there is with homogeneous linear preferences.

When we turn to the interaction effects, we begin to observe differences between the models. The interaction effect between diversity and land use affecting beauty is positive in the separable case but not significant or even smaller in the multiplicative case. Again, this results from people who care more about natural beauty being willing to move far from service centers with linear preferences but being held closer with the more moderating multiplicative preferences. This same effect is even more pronounced when we look at the interaction between preferences for density and land use affecting beauty. In the multiplicative case, the interactive term is negative but moderately so. In the linear case, the interactive term is so negative that development beyond the radius of thirty is lower than the base case. This paradoxical result occurs because the agents with linear preferences are willing to sacrifice one attribute for another. As agents move to regions of high natural beauty, they destroy the natural beauty around them. Therefore, agents who locate later choose to move into dense central regions that have almost no natural beauty but that have high density. In a cursory investigation of screen shots, we found that agents with additive preferences left very few holes in the largest cluster, while agents with multiplicative preferences left holes in locations that had high density but almost no natural beauty. Further, agents with additive preferences who located outside the central region were predominantly isolated, while the agents with multiplicative preferences tended to form little population clusters around areas that had high natural beauty initially.

DISCUSSION

In this paper, we have shown some preliminary results from an agent-based model that can be used to explore development patterns on the urban rural fringe and their ecological impact. Our findings suggest that diversity and feedbacks matter independently and jointly, but that the separability of the utility function is qualitatively unimportant for the parameters we are examining. The scientific and policy implications of these findings are provocative. On the scientific end, the fact that heterogeneity matters so much means that the empirical focus on means of variables may be misplaced. Perhaps variances are as or more important than means. Similarly, the importance of feedbacks on natural beauty for sprawl suggests that their extent should be measured empirically, but doing so may be difficult. Third, the feedbacks support the Schelling-inspired possibility that preferences may be inconsistent in that people's micro level preferences may lead to macro level development patterns that generate low levels of utility [Schelling, 1978].

From a policy standpoint, the implications are obvious. The interaction between higher preferences for density and natural beauty feedbacks can lead to significant effects on reducing sprawl, even when heterogeneous preferences are played out. Changing the ecological and aesthetic quality of development can modify the perception that dense development precludes access to privacy, quiet and open areas away from congestion. Education on the environmental impacts of development, and supporting alternative modes of transportation can also change the attitudes toward density. In addition, facilitating the location of urban amenities in central areas can reinforce the clustering effect of density preferences. More generally speaking, the policy instruments can be seen as "motivators", i.e. as tools which change the agents' preferences. Agent-based models, like the one presented here, can then show how those new preferences will aggregate, sometimes in unintended ways.

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