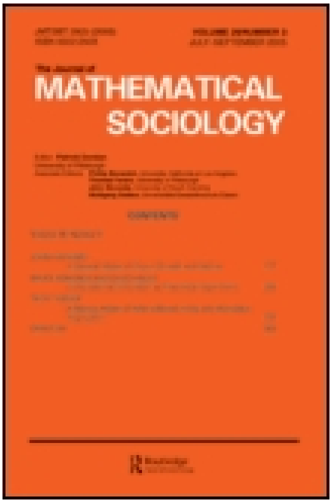


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# Generative Models of Segregation: Investigating Model-Generated Patterns of Residential Segregation by Ethnicity and Socioeconomic Status

MARK FOSSETT [a]
[a] Department of Sociology , Texas A&M University, College Station , Texas, USA
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# Generative Models of Segregation: Investigating Model-Generated Patterns of Residential Segregation by Ethnicity and Socioeconomic Status

**Mark Fossett**
Department of Sociology, Texas A&M University, College Station, Texas, USA



*This article considers the potential for using agent models to explore theories of residential segregation in urban areas. Results of generative experiments conducted using an agent-based simulation of segregation dynamics document that varying a small number of model parameters representing constructs from urban-ecological theories of segregation can generate a wide range of qualitatively distinct and substantively interesting segregation patterns. The results suggest how complex, macro-level patterns of residential segregation can arise from a small set of simple micro-level social dynamics operating within particular urban-demographic contexts. The promise and current limitations of agent simulation studies are noted and optimism is expressed regarding the potential for such studies to engage and contribute to the broader research literature on residential segregation.*

*[An appendix to this article is featured as an online supplement at the publisher's website.]*

**Keywords:** agent-based modeling, race and ethnicity, segregation

In this study I explore how micro-level social dynamics can combine with urban and demographic structures to produce complex patterns of residential segregation along racial and ethnic lines in urban areas. To pursue this goal I draw on an agent-simulation model that represents constructs relevant to urban-ecological perspectives on

The development of the SimSeg program used in this study was supported in part by NIH Grants R43-HD38199 (Simulating Residential Segregation Dynamics: Phase I) and R44-HD038199 (Simulating Residential Segregation Dynamics: Phase II). I also acknowledge the helpful comments of anonymous reviewers and the editors of this special issue.

Address correspondence to Mark Fossett, Department of Sociology, Texas A&M University, College Station, TX 77843-4351. E-mail: m-fossett@tamu.edu

residential processes and urban-demographic structures, and I examine how segregation outcomes vary when selected model parameters are varied in different combinations. The exercise generates a wide range of distinctive and substantively interesting patterns of residential segregation and illustrates the potential for simulation studies to contribute to extending our understanding of residential segregation. Based on this I encourage future simulation studies of segregation to give attention to understanding how multiple mechanisms operating together can generate complex patterns of segregation seen in U.S. urban areas.

The past decade has seen increasing use of agent simulation models to investigate urban phenomena (e.g., Batty, 2005; Benenson and Torrens, 2004; Portugali, 2000). The literature focusing on segregation dynamics has been recently been particularly active (e.g., Bruch and Mare, 2006; Clark and Fossett, 2008; Fossett, 2006; Fossett and Dietrich, 2009; Fossett and Waren, 2005; Laurie and Jaggi, 2003; van de Rijt, Siegel, and Macy, 2009; Wasserman and Yohe, 2001; Zhang, 2004a; 2004b).[1] Most of these explore themes first raised and explored in depth in Schelling's (1971) landmark article in this journal and then later popularized for broader audiences in Schelling (1978). This influential and celebrated study marked the first use of agent models to explore effects of ethnic preferences on residential segregation and today, some 40 years after its initial introduction, is still seen as a compelling exemplar of how relatively simple micro-level behavior can produce nonobvious emergent structure at the aggregate level (Macy and Willer, 2002; Krugman, 1997; Young, 1998). I extend this literature here by investigating whether elaborations of Schelling-style agent models can produce complex patterns of residential segregation based on incorporating generating mechanisms suggested by urban-ecological theory.

I begin by briefly reviewing basic features of segregation patterns in U.S. urban areas and the central ideas urban-ecological perspectives have offered to account for them. I then describe the elements of the computational model used in the analyses noting how constructs and processes from urban-ecological theory are represented in the model. I also comment on recent points of debate and controversy relating to agent simulations of segregation. I then review the results of approximately 35,000 simulation experiments based on 1,250 separate trials for each of 28 different simulation scenarios. I conclude by considering the implications of these results for future research and

[1]An extended version of this article includes a more comprehensive listing of relevant studies pertaining to this topic, and also to other topics, that were omitted here to save space.

argue that agent simulations have good potential to contribute to our understanding segregation dynamics. Finally, I suggest that simulation studies will have greater impact on the "mainstream" literature on residential segregation as they give greater attention to engaging the broader audience of segregation researchers in constructive dialog and to explore models capable of generating complex patterns of segregation observed in U.S. urban areas.

## 1. COMPLEX PATTERNS OF RESIDENTIAL SEGREGATION IN U.S. URBAN AREAS

Urban-ecological studies of residential segregation in U.S. metropolitan areas span more than eight decades.[2] They document and seek to understand the "urban mosaic"—the complex differentiation of residential neighborhoods that stands as a fundamental fact of urban life. This perspective observes that segregation occurs along many axes—race/ethnicity, socioeconomic position, age, stage of family life cycle, nativity, life style, etc.—producing a highly variegated urban spatial fabric. It posits that segregation emerges in part as households compete for location in urban housing markets while seeking to satisfy differing residential goals. For example, differences in needs, interests, and capacities associated with lifestyle and stage of the life cycle are invoked to help account for why young, single professionals are overrepresented in condominium apartments near downtown districts while middle-class, married couples with young children are overrepresented in single-family housing in quiet neighborhoods near parks and good schools. One hallmark of the urban-ecological perspective is that it acknowledges and seeks to understand the full array of segregation patterns that comprise the urban mosaic.

Two patterns of residential segregation in urban areas are striking and have received particularly close attention. One is that ethnic majority groups are spatially separated from ethnic minority groups (Taeuber and Taeuber, 1965; Massey and Denton, 1993). Another is that high-status households are highly separated from low-status households (Farley, 1977; Jargowsky, 1997). Other established patterns of segregation by ethnicity and status include, but are not limited to the following: the clustering of ethnic populations into ghettos—that is, expansive regions of ethnic homogeneity (Massey and Denton, 1988); "zonal" patterns of status segregation wherein inner-city, working-class neighborhoods transition into middle-status

[2]See Fossett (2005) for a recent systematic review of this extensive literature.

neighborhoods in mid-town and inner suburbs which in turn transition into high-status neighborhoods in outer suburbs (Burgess, 1925; Guest, 1984); "sector" patterns wherein ethnic clusters divide status zones and align axially to extend outward spanning multiple status zones (Hoyt, 1939); centralization of ethnic minority groups (Massey, 1985); and the uneven distribution of minority ethnic groups from each other as well as from the majority ethnic group (Massey, 2000). When several such patterns occur together, Massey and Denton (1989) term the result "hyper-segregation."

Urban-ecological theory holds that multiple micro-level dynamics are implicated in these complex macro-level patterns of segregation. Urban-ecological theories of status segregation emphasize social distance dynamics wherein high-status households seek residential separation from lower-status households to minimize contact and consolidate status position. In the United States this is thought to have had historical expression in zonal patterns of status segregation that arise when urban growth and technical change concentrate newer, higher-quality housing in outer suburbs and older, lower-quality housing in the central city. Urban-ecological theories of ethnic segregation emphasize multiple dynamics. One is congregation dynamics resulting from attraction to co-ethnic presence rooted in ethnic solidarity (i.e., ethnic-based mutual support), benefits of ethnic institutions and community structures, and ethnic-based chain migration. Another is social distance dynamics resulting from ethnic prejudice and antagonism exacerbated by competition among ethnic groups for housing and jobs. In addition to expression in antipathy, aversion, and avoidance, it also is manifest in discrimination, especially discrimination by majority ethnic groups against minority ethnic groups. Finally, urban-ecological theory posits that status dynamics and ethnic dynamics may interact and their consequences interweave; for example, status zoning can combine with minority-majority differences in status to produce majority-minority differences in centrality.

It is difficult to assess these ideas solely by examining aggregate-level patterns of segregation or by performing in-depth analyses of individual micro-level dynamics alone; at some point, the two must to be considered together. This is rarely feasible using conventional observational data. Agent-simulation methodology provides a means for exploring the connection between microdynamics and aggregate residential patterns based on implementing "generative experiments" as follows:

> Situate an initial population of autonomous heterogeneous agents in a relevant spatial environment; allow them to interact according to simple

local rules, and thereby generate—or "grow"—the macroscopic regularity from the bottom up. (Epstein, 2006 p. 7)

The macroscopic regularity of interest here is residential segregation in its complex manifestations. The spatial environment and local rules are the urban-demographic conditions and generating mechanisms set forth in urban-ecological theory.

I use the SimSeg computational model to pursue this task. Because it has been introduced and discussed elsewhere (e.g., Fossett and Waren, 2005; Fossett, 2006; Fossett and Dietrich, 2009), I describe it only briefly here. I first provide an overview of the general aspects of the model relevant for all simulations conducted for this study. I next discuss the model parameters of special interest that are manipulated in the experiments and then conclude the review by briefly discussing the segregation outputs used in the empirical analyses.

## 2. BASIC ELEMENTS OF THE SIMSEG MODEL

### 2.1. Agents and Their Social Characteristics

The agents in the model are virtual households with the ability to search and make residential choices within a spatial housing market. In some cases, agent search and movement may be constrained by discrimination. Households possess two social characteristics—ethnic status and socioeconomic status. Each household is a member of one of three ethnic groups—Blues, Reds, and Greens. In addition, each household is assigned a socioeconomic score ranging from 1 to 99 that establishes both its status standing and its purchasing power.

### 2.2. Agent Preferences

Households hold three separate and distinct preferences regarding residential outcomes. These concern housing quality, neighborhood status, and neighborhood ethnic mix with each one receiving equal weight in households' evaluations of alternative residential locations. The *housing quality preference* is specified as a desire on the part of each household to reside in the highest-quality housing unit it can afford. The *neighborhood status preference* is specified as a desire on the part of each household to seek higher-status neighborhoods over lower status neighborhoods with neighborhood status being assessed based on the average of the status scores for the area's residents. The *ethnic preference* is specified as a desire on the part of each household to reside in neighborhoods with a certain minimum level of co-ethnic ethnic presence. Households experience higher levels of satisfaction as neighborhood ethnic mix comes closer to satisfying their goal, but after the goal is met, they are indifferent to further considerations of area ethnic mix. Preferences for housing quality and neighborhood status are active in all simulations. Preferences for neighborhood ethnic mix are not active in all simulations; how they vary across simulations is discussed in more detail below.

## 2.3. Housing Units and the City Landscape

Households reside in *housing units* found at fixed locations in a two-dimensional grid, or "city landscape." Housing units differ in housing "quality" or value measured on a scale of 1–99 corresponding to the scores for household socioeconomic status. Housing units possess no other characteristics in these simulations. For this study the city landscape consists of a collection of 177 small "bounded areas" arranged in a roughly circular area on a "neighborhood" grid. Each bounded area contains 49 housing units arranged in a $7 \times 7$ square housing grid within the neighborhood. These are roughly comparable to census blocks or small census block groups. The full city landscape contains 8,673 housing units. Of these, 6% are vacant, a figure comparable to levels observed in many urban areas. The setting for city size and the use of bounded areas in place of point-specific or "site-centered" neighborhoods reduces computational burden, making it feasible to examine more scenarios and perform more simulation trials for each scenario. These settings also facilitate visual inspection of graphical depictions of city landscapes for qualitative patterns.

Observers sometimes raise concerns that results of segregation simulation may hinge critically on choices for city scale or neighborhood implementations (e.g., Goering, 2006). To date, however, available evidence provides no support for such concerns. To the contrary, direct study of these issues indicates that simulation results of the type reported here are robust over wide variations in implementing city size and neighborhoods (Fossett and Dietrich, 2009). Specifically, findings have been found to be robust over varying specifications of city size (small, medium, and large), city shape (square vs. circular), city form (finite vs. a torus), neighborhood shape (square, diamond, circle), and neighborhood type (bounded area vs. site-centered). Studies have found that the size of the neighborhood agents examine can impact some aspects of simulation outcomes (Laurie and Jaggi, 2003; Fossett and Waren, 2005; Fossett and Dietrich, 2009). Accordingly, the simulations here implement bounded-area neighborhoods roughly on the scale of census blocks and small block groups, a size appropriate for investigating *residential* segregation.

## 2.4. City Ethnic Demography

I implement a multiethnic demography involving three groups as follows: "Blues" are a numerical majority ethnic group comprising 60% of the city population, and the remaining two groups, "Reds" and "Greens," are numerical minority ethnic groups each comprising 20% of the city population, respectively. This multiethnic specification is appropriate for three reasons. First, multiethnic populations are increasingly common for U.S. metropolitan areas; for example, the ethnic diversity adopted here is roughly comparable to that seen for metropolitan areas such as Chicago, Houston, and Los Angeles. Second, as reported below, certain substantively interesting consequences of key segregation dynamics are revealed in multiway segregation patterns. Third, simulations should consider empirically plausible city ethnic demographic structures because the ethnic demography of the city strongly conditions the effects of ethnic preferences (Schelling, 1971; Fossett and Waren, 2005; Fossett, 2006).

To expand on this last point, it is unfortunate that many agent simulation studies have focused on a stylized, two-group, 50/50 ethnic mix. This is a questionable choice because it is rarely observed in real urban areas and because it also is *optimal* for achieving integration in agent simulations where preferences for co-ethnic contact are low or moderate. This creates potential for misleading generalizations about preference effects. For example, studies by Laurie and Jaggi (2003) and Bruch and Mare (2006, 2009) describe ethnic preferences for 50% same-group presence as potentially *compatible* with integration but fail to note that, while this characterization is appropriate for the special case of the two-group, 50/50 ethnic mix used in their studies, it is not generally accurate. Preferences for 50% same-group presence are not compatible with integration in two-group cities with imbalanced ethnic mixes (e.g., 15/85, 10/90, etc.) or in multiethnic cities of *any* demographic structure. Since ethnic demographies of these sorts are the rule, not the exception, in real urban areas, studies seeking to clarify real-world segregation dynamics should consider empirically plausible demographic structures as this study does.

## 2.5. Intra-Group Status Inequality

I set *intra*-group status inequality to a moderate level relative to that observed in most metropolitan areas. Specifically, I draw status scores from a unimodal beta distribution with positive skew (i.e., an extended right-hand tail).[3] The distribution of status scores has a range of 1–99, a mean of 25, and a gini index of 35.

## 3. MOTIVATION AND IMPLEMENTATION OF RELEVANT GENERATING MECHANISMS

I next discuss elements of the SimSeg model that are varied over the simulation experiments. I note both how they relate to urban-ecological perspectives as well as how they are implemented in the model and are varied over simulation experiments.

### 3.1. Urban Structure—Area Stratification (Low-High)

*Area stratification* implements urban structure in the form of a city-suburb gradient in average housing values. When set to low, housing values are distributed randomly over the city landscape. When set to high, high-quality housing is overrepresented in the outlying neighborhoods of the city and low-quality housing is overrepresented in central neighborhoods.[4] This kind of zonal gradient in housing values is noted in urban-ecological studies dating to Burgess (1925) who observed that status segregation emerges on a suburban-central city continuum when newer, higher-quality housing stock is built on the periphery of growing cities. Area stratification also is integral to Hoyt's (1939) "sector model" of ethnic segregation in which ethnic sectors extend radially across status zones (Berry and Kasarda, 1977; Guest, 1984).

### 3.2. Minority Status Disadvantage (Low-High)

When minority status disadvantage is low, all three groups have the same mean for socioeconomic status. When minority status disadvantage is high, the status means for Reds and Greens are set to be 35% lower than the status mean for Blues.[5] When combined with area stratification, minority status disadvantage is relevant for urban-ecological predictions that lower-status segments of minority

[3]Beta distributions generate scores in the bounded range 0–100 and are flexible in terms of the shapes they can assume. The parameters for the beta distribution that yield a mean of 25 and a gini index of intra-group inequality of 35 are $\alpha = 2.999$ and $\beta = 5.570$.

[4]When area stratification is high, distance from the city center explains 80% of variation in housing values. The figure is 0% when area stratification is low.

[5]The gini index for intra-group inequality is fixed at 35 for each group.

populations will be centralized in the older, lower-cost housing stock of the central city (Massey, 1985). Nonspecialists often presume that when area stratification is substantial minority status disadvantage will produce uneven distribution of minority and majority populations, but urban-ecological research consistently finds the impact is modest (e.g., Farley, 1977; Massey and Fischer, 1999; Iceland and Wilkes, 2006).

## 3.3. Majority Discrimination Dynamics (Low-High)

Minority households' efforts to move can be subject to discrimination in the form of a minority-exclusion dynamic. When this dynamic is active, Red and Green households that attempt to move to predominantly Blue neighborhoods are blocked at a rate of up to 95%. This can support interpretations for multiple majority discrimination dynamics including seller discrimination by majority households and "steering" of minority households away from majority neighborhoods. When discrimination is set to "low," minority households that seek to move to a house in a predominantly Blue neighborhood are never blocked. When discrimination set to "high," minority households are blocked up to 95% of the time and must turn to the next best available housing option. For perspective, the discrimination dynamic implemented here is strong compared to patterns of net discrimination reported in recent housing audit studies (e.g., Turner and Ross, 2005). Majority households' moves are not subject to discrimination.

## 3.4. Preferences for Same-Group Presence—Overview

Ethnic preferences are implicated in several urban-ecological theories of segregation. One is the dynamic of ethnic congregation (McKenzie, 1925) based on ethnic solidarity and mutual support. Another is the dynamic of attraction based on practical advantages and cultural benefits associated with ethnic community institutions (Breton, 1964). Another is the dynamic of out-group aversion rooted in high social distance (i.e., ethnic prejudice), often heightened by intergroup competition and conflict for residential location (Cressey, 1938; Hawley, 1944; Ford, 1950). Ethnic preferences also are central to theories of discrimination dynamics which hold that majority discrimination against minority populations is rooted in majority aversion to minority groups which becomes consequential because majority groups have the capacity to directly or indirectly exclude minority populations from majority residential areas.

### 3.5. Majority Preferences for Same-Group Presence Promote Segregation (No-Yes)

When set to no, the majority group's (i.e., Blues') goals for same-group presence are set to zero. When set to yes, Blues' seek at least 80% same-group presence, an amount that is 20 points higher than the group's representation in the population.[6] Fossett and Waren (2005) and Fossett (2006) note that city ethnic demography must be considered before any particular preference for same group presence can be characterized as either segregation-promoting or compatible with integration. When active, majority preferences for same-group presence are segregation-promoting because the typical (e.g., the median) goal for same-group presence exceeds the majority group's representation in the city population. Thus, when active, Blues' preferences for same-group presence are predicted to promote majority-minority segregation (i.e., Blue-Red and Blue-Green segregation).

### 3.6. Minorities' Preferences for Same-Group Presence Promote Segregation (No-Yes)

When set to no, minority group goals for same-group presence are fixed at zero. When set to yes, Red and Green households seek at least 50% same-group presence, an amount similar to levels commonly documented for ethnic minority groups in surveys.[7] While moderate in absolute terms, this setting is 30 points above each group's 20% representation in the population and thus is not compatible with even distribution of ethnic groups. Based on this, it is predicted to foster majority-minority segregation. In addition, it also is predicted to promote *minority-minority* segregation (Fossett, 2006). This is a possible "signature" outcome because minority-minority segregation is not a predicted consequence of any other generating mechanism considered in these simulations.

### 3.7. Adjacency Concerns (No-Yes)

Laurie and Jaggi (2003) use the term "agent vision" to refer to the neighborhoods households "see" when searching. It is delimited in

[6]Following Fossett (2006), the value of 80% is the median of a distribution of preference goals that is dispersed around this value based on a "logit-normal" distribution. The shape of the resulting preference distribution is similar to those documented in surveys.

[7]Following Fossett (2006), the value of 50% is the median of a distribution of preference goals that is dispersed around this value based on a "logit-normal" distribution. The shape of the resulting preference distribution is similar to those documented in surveys.

two ways here. In one, agent vision is restricted to the immediate "bounded area." In the other, households also consider adjacent bounded areas when evaluating the neighborhoods ethnic mix of a neighborhood. Satisfaction with the ethnic mix in adjacent areas is then averaged with satisfaction with the immediate bounded area with the latter counting twice as much as the former. Adjacency concerns are a computationally efficient way to implement a "distance-proximity" component of agent vision. Regarding motivation, research indicates households may be sensitive to proximity both for its own sake and/or out of concerns about future neighborhood change (Ellen, 2000). Urban-ecological theory predicts that this dynamic fosters ethnic clustering—the formation of ghettos or broad regions of ethnic homogeneity.



## 4. SEGREGATION OUTCOMES

Segregation is a multidimensional phenomenon (Massey and Denton, 1988; Stearns and Logan, 1986). Accordingly, SimSeg calculates a variety of quantitative indices measuring different aspects of segregation including uneven distribution, isolation, clustering, and centrality. SimSeg also produces graphical "city landscapes" that convey qualitative information about segregation patterns. Here I present only summary data documenting segregation patterns quantitatively. However, I reviewed representative city landscapes to gain insight into qualitative differences segregation patterns. Examples of these can be found in an expanded version of this article.

I assess uneven distribution using the separation index (S), a refinement of the variance ratio (V) which has been widely used and reviewed favorably in methodological studies (e.g., Duncan and Duncan, 1955; Stearns and Logan, 1986; White, 1986; Zoloth, 1976). S tracks V closely in conventional applications (e.g., measuring segregation using census tract data). But it has special appeal for simulation studies because, unlike conventional indices, it is not distorted by upward bias when segregation is measured at small spatial scales. Instead, it has an expected value of zero under random assignment regardless of neighborhood size (Fossett, 2011).[8] In addition, S is attractive because, like V, its expected value under random

[8]Conventional measures of uneven distribution take positive values under random assignment (Winship, 1977). This bias is a potential concern when segregation is measured at small spatial scales as is typical in simulation studies (e.g., Goering, 2006). See the Appendix of the extended version of this paper for a more detailed discussion of the properties of S.

assignment does not vary with ethnic ratios as is the case for most indices.[9]

S has a substantive interpretation that is attractive to specialists and at the same time easy to convey to nonspecialists; it is a difference of mean contact scores. Thus, S registers the difference between one group's contact with another group and that group's contact with itself when considering only the two groups involved in the comparison.[10] For example, in the case of White-Black segregation, S indicates the White-Black difference in average contact with white households. S ranges from 0 to 100. Under random residential distribution, both groups will have the same expected average level of contact with White households and thus the expected value of S is zero. Under complete residential segregation, Whites' average contact with other White households increases to 100%, Blacks' average contact with White households falls to zero, and the value of S is 100. S, like V, consistently takes lower values than the more widely used index of dissimilarity (D). So findings of segregation obtained using S are *conservative* relative to findings obtained using D.

I assess ethnic *isolation* using the $_{X}P_{X}$ measure of same-group contact introduced by Bell (1954) and later popularized by Lieberson (1981).[11] High scores indicate that an ethnic group is isolated based on the fact that members of the group reside primarily with other members of their own group. I assess ethnic *clustering* using Bell's (1954) revised index of isolation, which expresses $_{X}P_{X}$ as a percentage of its logical range, computed using only the areas *adjacent* to each household's immediate residential area. High scores on this index can obtain only when ethnically homogeneous areas form expansive regions on the city landscape. I assess ethnic group *centrality* based on each group's average location in distance from the city center based on assigning scores of 0 for mid-town, 100 for the center point of the city landscape, and $-100$ for the outer perimeter of the city.

The SimSeg program calculates a wide variety of indices of uneven distribution, isolation, clustering, and centralization. The findings reported here are robust across alternative choices for measuring

[9]The index of dissimilarity (D) is widely used in conventional segregation studies. But using D in simulation studies is highly problematic; its expected value under random assignment (E[D]) is high when segregation is measured at small spatial scales, particularly when group size is imbalanced (Winship 1977).

[10]Contact scores are computed with the focal household excluded. This adjustment eliminates positive bias in V when measuring segregation at small spatial scales.

[11]I use a refined version $_{X}P_{X}$ that excludes the focal household from the contact calculation. This eliminates bias when measuring isolation at small spatial scales.

the different dimensions of segregation. An extended version of this paper includes an appendix, omitted here to save space, that discusses the indices used here in more detail.

## 5. RECENT DEBATES RELATING TO SCHELLING'S INSIGHTS

Here I comment on several themes in the ongoing debates regarding Schelling's (1971) insights about the macro-level implications of micro-level preference dynamics. The first is that skeptics of preference effects sometimes speculate that findings from Schelling-style agent simulations may depend critically on various aspects of model specifications including: city size (Goering, 2006), neighborhood size and shape (Laurie and Jaggi, 2003), heterogeneity of preferences (Yinger, 1996), and preference evaluation functions (Bruch and Mare, 2006). To date, none of these concerns is empirically supported. Fossett and Dietrich (2009) find that preference effects are robust over varying specifications of city size, shape, and form and varying specifications of neighborhood shape and form. Fossett and Waren (2005) similarly find that Schelling effects are robust when choices for agent vision (i.e., neighborhood context) are relevant for investigating residential dynamics. Fossett (2006) finds that preference effects are robust to the specification of either homogeneous or heterogeneous preference distributions. While it is difficult to conclusively prove a negative, concerns relating to these issues have not received empirical support and the basis for objection at this point is weak.

The issue of whether Schelling-style preference effects may depend critically on the form of the function evaluating neighborhood ethnic mix warrants separate discussion. Bruch and Mare (2006) reported preference effects are weaker when continuous evaluation functions are used instead of step-functions similar to that used in Schelling (1971). Van de Rijt, Siegel, and Macy (2009) conclude that Bruch and Mare's finding is erroneous and arises from mistakes in their implementation of the simulation model. Van de Rijt and colleagues state

> "[T]he errors in [the Bruch and Mare] model led them to the wrong conclusion. Schelling did not overstate the tendency toward segregation. Populations with linear preferences also segregate, as do those with more empirically plausible preferences. If anything, Schelling *understated* the tendency toward segregation, which can emerge not only in a population that tolerates diversity (as Schelling demonstrated), but even among multiculturalists who actively seek diversity, so long as they

are also sensitive to small changes in ethnic composition." (p. 1180, emphasis in original)

Bruch and Mare (2009) acknowledge their original error and also the correctness of van de Rijt and colleagues' (2009) finding that models implementing continuous preference functions move to high levels of segregation more rapidly. This is consistent with findings from many studies that support Schelling's (1971) insights based on results of agent simulations that use continuous evaluation functions (e.g., Laurie and Jaggi, 2003; Fossett and Waren, 2005; Fossett, 2006; Fossett and Dietrich, 2009; Clark and Fossett, 2008; Zhang, 2004a, 2004b; Wasserman and Yohe, 2001).

A third issue, concerns when, and with what degree of generality, particular preferences can be characterized as integration-promoting or segregation-promoting. As noted earlier, confusion can arise when discussions do not bear in mind that even distribution requires the ethnic mix of neighborhoods to match that of the city. This simple but crucial fact makes it *impossible* to characterize the implications of preferences for segregation without considering the ethnic demography of the city. Thus, for example, a universal preference for 50% same-group presence is potentially compatible with integration in a city with a two-group, 50/50 ethnic mix. But in situations with three or more groups or any two-group situation that departs from a 50/50 ethnic mix—the preference is incompatible with integration and is segregation promoting since *all* members of at least one group will be unsatisfied under even distribution and will seek neighborhoods where their group is overrepresented relative to even distribution. The point is fundamental, not esoteric, because multiethnic demography and imbalanced ethnic mixtures are common and the potential consequences of achieving 50% same-group presence in such situations are not trivial. For example, in a two-group city with an 85/15 ethnic mix, if all households in the smaller group strategically congregate to reside in neighborhoods with exactly 50% same-group presence (no more, no less), it will produce an index of dissimilarity above 80 which is considered a high level of segregation (Fossett, 2006).

This raises a fourth and related issue; the need to distinguish between when a given preference *promotes* an outcome or is merely *compatible* with it. For example, while observers sometimes characterize preferences for 50% same-group presence as "integration-promoting," this is misleading even for the optimal special case of the two-group, 50/50 city. The preference is *compatible* with integration, but it also is analytically compatible with complete segregation and will not inhibit the influence of any dynamic that drives the system toward segregation. For ethnic preferences to *promote*, rather than simply *permit*, integration, they must cause households to specifically seek *even distribution*. This requires households to avoid both overrepresentation *and* underrepresentation *with equal vigor*. Schelling's (1971) insights take on greater relevance in light of this because surveys indicate that no ethnic group holds preferences that specifically promote the residential outcome of even distribution. To the contrary, surveys indicate that, in relation to the ethnic demography of typical cities, all ethnic groups seek same-group presence at or well above levels associated with even distribution and all ethnic groups are more averse to underrepresentation than to overrepresentation. Based on this, it is appropriate to describe all empirically documented ethnic preference distributions as segregation promoting in relation to the typical ethnic demography of U.S. metropolitan areas.

The last issue I take up before concluding this section concerns the impact of stochastic dispersion on residential distributions in agent models. It is obvious that models exploring *any* single segregation-promoting dynamic—discrimination effects, ethnic preference effects, life-cycle effects, status effects, life-style effects, and so on—will yield integration as an outcome if a sufficiently consequential stochastic dynamic in residential location is incorporated into the model. In view of this, I share the concerns of van de Rijt, Siegel, and Macy (2009) regarding the fact that stochastic dispersion appears to play a central role in Bruch and Mare's (2006) study exploring the effects of ethnic preferences. When an agent model implements a direct mechanism of consequential stochastic dispersion in the relationship between the factor of interest—ethnic preferences in this case—and household residential location outcomes, concern arises that integration may be preordained by the setting for stochastic dispersion. The simulations would likely be more informative if they investigated how effects of ethnic preferences vary when the mechanism of stochastic dispersion is set at different levels (e.g., weak, moderate, and strong). If integration results under all settings, it suggests the preferences considered cannot produce segregation. If integration results under some, but not all settings, it prompts debate about the basis for, and substantive interpretation of, specifying particular levels of stochastic dispersion in residential outcomes.[12] However, if the mechanism of stochastic dispersion is set only to a relatively high level, concern

[12]Possible motivations could include agent error, inaccurate information, compromises in location choices required to satisfy competing preferences, etc.

arises that the simulation demonstrates the unsurprising result that consequential randomness in household residential locations will not produce segregation.

The urban mosaic is a compelling fact of urban life. It does not arise from household location dynamics governed primarily by stochastic dispersion. With this in mind, studies that suggest that any single factor *does not* generate systematic patterns of segregation will be more compelling when they at the same time and using the same model demonstrate how alternative mechanisms *can* generate the familiar segregation patterns of the urban mosaic. To accomplish this, studies must move toward assessing the effects of particular factors in the context of multifactor models that can generate interesting aspects of the urban mosaic. The present study is a modest step in that direction.



## 6. OVERVIEW OF INDIVIDUAL SIMULATION EXPERIMENTS

The first step in each simulation experiment is to implement the city housing stock. The settings for the status distribution of the population are used to establish the distribution of housing values. The setting for area stratification then determines the spatial distribution of low- and high-quality housing on a city-suburb continuum. The next step is to generate the city's population of households assigning characteristics of ethnicity and socioeconomic status consistent with the settings for city ethnic demography, overall socioeconomic inequality, and minority status disadvantage. Individual households are then assigned preference goals for housing quality, neighborhood status, and neighborhood same-group presence. Households also are designated as having "agent vision" per model settings. Once the population is constructed, the individual households are assigned randomly to housing units subject to the lone provision that the quality score for the housing unit matches the household's socioeconomic status score.

When the simulation begins households are sampled at random and given the opportunity to search for housing. A searching household is presented a random selection of a dozen (12) available (i.e., vacant) housing units screened based on the household's "purchasing power." The searching household evaluates each of the available housing units it sees in relation to the household's multiple preferences. This is implemented by computing separate dissatisfaction scores for housing quality, neighborhood socioeconomic status, and neighborhood ethnic mix and summing the three scores to obtain an overall score. The individual dissatisfaction scores are simple linear functions of the degree to which the residential option falls short of the household's preference goal. If the score for the most attractive available unit is higher than that for the household's current residence, the household attempts to move. If discrimination dynamics are active, a minority household's attempt to move may be blocked. If so, it will turn to the next best alternative. Otherwise, the household moves to the new location leaving a vacancy at its original residential location.

Households are sometimes required to move even if they would prefer to remain in their current residence. This occurs on all first searches to ensure that all households reside in a location they have chosen through search. After a household has moved once, it is then subject to forced moves based on a low random probability. This mimics fundamental dynamics of residential turnover such as mortality, household formation and dissolution, job transfers, out-migration, and so on. Fossett and Waren (2005) note that this dynamic is well justified on substantive grounds and protects against pathological outcomes that models can produce when they do not have a mechanism for producing regular vacancies as occur in real neighborhoods. Macy and van de Rijt (2006) endorse this specification as valuable for investigating the expression of segregation dynamics.

Individual experiments proceed by "cycles"—periods of activity during which households engage in housing search and possible movement. A cycle continues until 25% of households have engaged in search. This typically produces residential movement comparable to that observed in "real" cities over a period of 6–18 months. Experiments run for 30 cycles, a duration that is sufficient to reveal the segregation patterns generated by the scenarios explored here. Each experiment draws on a unique random seed to initiate the random number sequence for the simulation trial. Hence each experiment follows a unique pathway to its final residential distribution.

## 7. GENERATIVE MODELS AND TYPOLOGIES OF RESULTING SEGREGATION PATTERNS

I considered 28 different simulation scenarios exploring varying combinations of settings on the generating mechanisms discussed above. For each scenario, I performed 1,250 simulation experiments. Table 1 presents means for the values of different segregation indices at the end of the simulation experiment (after 30 cycles) to document variation in segregation patterns across scenarios quantitatively. Table 2 presents standard deviations that document that variation in segregation outcomes over the simulation trials for a given scenario is low for all scenarios. This low within-scenario variation, along with the combined with the sample size 2,500 for any two scenarios,

**TABLE 1** Mean Values of Selected Segregation Indices over 1,250 Trials for Different Simulation Scenarios

| | Scenario N and active factors* | | | | | SES segregation | | | Uneven distribution | | | Isolation ($_XP_X$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | U | S | P | A | D | Blues | Reds | Greens | Blues-Reds | Blues-Greens | Reds-Greens | Blues | Reds | Greens |
| 1 | – | – | – | – | – | 1.0 | 0.9 | 0.9 | −0.0 | −0.0 | −0.0 | 60.0 | 20.0 | 20.0 |
| 2 | X | – | – | – | – | 90.8 | 91.5 | 91.4 | −0.0 | −0.0 | −0.1 | 60.0 | 20.0 | 20.0 |
| 3 | – | X | – | – | – | 1.1 | 0.9 | 0.9 | 0.0 | 0.1 | −0.0 | 60.0 | 20.0 | 20.0 |
| 4 | X | X | – | – | – | 91.3 | 90.5 | 90.5 | 4.9 | 4.9 | −0.1 | 62.6 | 21.9 | 21.9 |
| 5 | – | – | X | – | – | 1.0 | 1.6 | 1.7 | 98.4 | 98.4 | 98.3 | 99.2 | 98.0 | 98.0 |
| 6 | X | – | X | – | – | 88.6 | 87.7 | 87.7 | 97.6 | 97.6 | 93.5 | 98.9 | 95.2 | 95.2 |
| 7 | – | X | X | – | – | 1.9 | 7.9 | 8.0 | 88.8 | 88.8 | 92.8 | 94.8 | 89.7 | 89.7 |
| 8 | X | X | X | – | – | 93.0 | 78.5 | 78.5 | 95.8 | 95.7 | 96.6 | 98.0 | 95.4 | 95.4 |
| 9 | – | – | X | X | – | 1.3 | 1.9 | 1.9 | 97.4 | 97.4 | 96.0 | 98.7 | 96.2 | 96.2 |
| 10 | X | – | X | X | – | 90.2 | 90.2 | 90.1 | 92.4 | 92.4 | 84.3 | 96.5 | 87.4 | 87.4 |
| 11 | – | X | X | X | – | 4.3 | 10.9 | 10.7 | 84.7 | 84.6 | 90.5 | 92.8 | 85.9 | 85.8 |
| 12 | X | X | X | X | – | 91.6 | 85.9 | 85.9 | 91.2 | 91.1 | 90.6 | 95.9 | 89.6 | 89.4 |
| 13 | – | – | – | – | X | 0.8 | 3.6 | 3.6 | 85.4 | 85.3 | −0.0 | 93.8 | 45.3 | 45.3 |
| 14 | X | – | – | – | X | 85.6 | 93.4 | 93.8 | 82.9 | 83.0 | −0.1 | 92.6 | 44.4 | 44.4 |
| 15 | – | X | – | – | X | 2.5 | 9.5 | 9.4 | 66.8 | 66.8 | −0.0 | 87.5 | 40.6 | 40.6 |
| 16 | X | X | – | – | X | 90.0 | 88.7 | 88.8 | 74.1 | 74.0 | −0.1 | 89.7 | 42.3 | 42.2 |
| 17 | – | – | – | X | X | 1.7 | 5.3 | 5.3 | 78.1 | 78.1 | −0.0 | 91.4 | 43.5 | 43.5 |
| 18 | X | – | – | X | X | 88.7 | 93.7 | 93.8 | 70.0 | 74.0 | −0.1 | 89.7 | 42.3 | 42.2 |
| 19 | – | X | – | X | X | 3.1 | 9.4 | 9.5 | 62.8 | 62.8 | −0.0 | 86.2 | 39.6 | 39.6 |
| 20 | X | X | – | X | X | 91.8 | 88.8 | 88.8 | 66.3 | 66.3 | −0.1 | 86.9 | 40.2 | 40.2 |
| 21 | – | – | X | – | X | 1.1 | 1.3 | 1.4 | 99.8 | 99.8 | 98.6 | 99.9 | 99.2 | 99.1 |
| 22 | X | – | X | – | X | 90.8 | 87.6 | 87.6 | 99.6 | 99.6 | 94.2 | 99.8 | 96.8 | 96.8 |
| 23 | – | X | X | – | X | 1.4 | 11.4 | 11.3 | 89.5 | 89.6 | 81.4 | 95.5 | 85.8 | 85.8 |
| 24 | X | X | X | – | X | 94.9 | 74.2 | 74.4 | 98.8 | 98.8 | 94.9 | 99.4 | 96.6 | 96.6 |
| 25 | – | – | X | X | X | 1.8 | 2.0 | 2.1 | 99.2 | 99.2 | 95.9 | 99.6 | 97.4 | 97.4 |
| 26 | X | – | X | X | X | 91.4 | 90.6 | 90.6 | 97.3 | 97.3 | 84.9 | 98.9 | 90.9 | 90.9 |
| 27 | – | X | X | X | X | 4.3 | 14.1 | 14.0 | 85.5 | 85.5 | 79.9 | 93.6 | 82.9 | 82.9 |
| 28 | X | X | X | X | X | 93.8 | 82.8 | 83.0 | 96.5 | 96.4 | 87.9 | 98.4 | 91.8 | 91.7 |

(*Continued*)

**TABLE 1** Continued

| | Scenario N and active factors* | | | | | Clustering | | | Centrality | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N | U | S | P | A | D | Blues | Reds | Greens | Blues | Reds | Greens |
| 1 | – | – | – | – | – | −0.0 | −0.0 | −0.0 | 0.1 | −0.0 | 0.0 |
| 2 | X | – | – | – | – | −0.0 | −0.0 | −0.0 | −3.8 | −1.9 | −1.9 |
| 3 | – | X | – | – | – | −0.0 | 0.0 | −0.0 | −0.0 | 0.1 | 0.0 |
| 4 | X | X | – | – | – | 2.8 | 2.3 | 2.3 | −32.5 | 20.7 | 20.7 |
| 5 | – | – | X | – | – | −1.3 | −0.7 | −0.5 | −0.3 | 0.3 | 0.2 |
| 6 | X | – | X | – | – | −2.2 | −1.1 | −1.2 | 0.3 | 2.0 | 2.2 |
| 7 | – | X | X | – | – | −1.6 | −0.4 | −0.4 | 0.1 | 0.4 | −0.4 |
| 8 | X | X | X | – | – | 2.9 | 3.2 | 3.1 | −38.1 | 30.2 | 30.1 |
| 9 | – | – | X | X | – | 56.2 | 53.3 | 53.4 | 4.5 | −3.8 | −3.8 |
| 10 | X | – | X | X | – | 55.3 | 49.2 | 49.1 | 1.1 | 1.9 | 1.8 |
| 11 | – | X | X | X | – | 54.7 | 51.7 | 51.6 | 4.2 | −2.9 | −3.2 |
| 12 | X | X | X | X | – | 50.8 | 49.8 | 49.7 | −33.8 | 28.3 | 28.3 |
| 13 | – | – | – | – | X | −1.2 | −0.1 | −0.1 | −0.1 | 0.2 | 0.1 |
| 14 | X | – | – | – | X | 0.2 | −0.3 | −0.3 | 10.4 | −7.6 | −7.6 |
| 15 | – | X | – | – | X | −1.5 | −0.0 | −0.0 | 0.4 | −0.3 | −0.3 |
| 16 | X | X | – | – | X | −1.6 | 2.6 | 2.5 | −27.2 | 20.3 | 20.3 |
| 17 | – | – | – | X | X | 35.1 | 12.7 | 12.7 | 2.7 | −1.8 | −1.8 |
| 18 | X | – | – | X | X | 31.2 | 10.9 | 10.9 | 9.6 | −7.1 | −7.1 |
| 19 | – | X | – | X | X | 31.7 | 11.3 | 11.3 | 1.4 | −0.4 | −0.4 |
| 20 | X | X | – | X | X | 24.5 | 11.2 | 11.2 | −28.3 | 21.7 | 21.7 |
| 21 | – | – | X | – | X | −1.0 | −0.6 | −0.6 | 0.0 | −0.2 | 0.3 |
| 22 | X | – | X | – | X | −1.5 | −1.4 | −1.2 | −5.4 | 3.3 | 3.3 |
| 23 | – | X | X | – | X | −1.6 | −0.5 | −0.4 | −0.5 | 0.5 | 0.2 |
| 24 | X | X | X | – | X | 7.2 | 4.3 | 4.3 | −45.2 | 35.5 | 35.4 |
| 25 | – | – | X | X | X | 42.9 | 44.3 | 44.2 | 1.5 | −1.8 | −1.2 |
| 26 | X | – | X | X | X | 39.4 | 39.4 | 39.3 | −2.3 | 2.5 | 2.6 |
| 27 | – | X | X | X | X | 47.6 | 44.1 | 44.0 | 2.7 | −3.3 | −1.6 |
| 28 | X | X | X | X | X | 38.6 | 41.2 | 41.4 | −39.9 | 31.9 | 31.9 |

*Factors: U = Urban structure-area stratification in housing values; S = Minority SES disadvantage; P = Segregation-promoting ethnic preferences; A = Adjacent areas considered for preferences; D = Majority group prejudice and discrimination.

**TABLE 2** Standard Deviations of Selected Segregation Indices over 1,250 Trials for Different Simulation Scenarios

| | Scenario N and active factors* | | | | | SES segregation | | | Uneven distribution | | | Isolation ($_{X}P_{X}$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N | U | S | P | A | D | Blues | Reds | Greens | Blues-Reds | Blues-Greens | Reds-Greens | Blues | Reds | Greens |
| 1 | – | – | – | – | – | 0.78 | 2.24 | 2.22 | 0.29 | 0.29 | 0.61 | 0.09 | 0.19 | 0.19 |
| 2 | X | – | – | – | – | 0.85 | 1.61 | 1.64 | 0.29 | 0.29 | 0.59 | 0.10 | 0.19 | 0.19 |
| 3 | – | X | – | – | – | 0.80 | 2.36 | 2.44 | 0.29 | 0.30 | 0.61 | 0.10 | 0.19 | 0.19 |
| 4 | X | X | – | – | – | 0.84 | 2.01 | 2.04 | 0.38 | 0.39 | 0.59 | 0.14 | 0.22 | 0.23 |
| 5 | – | – | X | – | – | 0.72 | 1.36 | 1.31 | 1.13 | 1.11 | 1.39 | 0.49 | 0.98 | 0.95 |
| 6 | X | – | X | – | – | 1.47 | 2.50 | 2.57 | 0.89 | 0.86 | 2.42 | 0.34 | 1.20 | 1.21 |
| 7 | – | X | X | – | – | 0.63 | 2.17 | 2.19 | 1.89 | 1.84 | 1.47 | 0.61 | 1.55 | 1.51 |
| 8 | X | X | X | – | – | 1.09 | 4.03 | 3.96 | 1.23 | 1.20 | 1.54 | 0.50 | 1.07 | 1.02 |
| 9 | – | – | X | X | – | 0.75 | 1.39 | 1.45 | 1.00 | 1.04 | 1.77 | 0.33 | 1.10 | 1.07 |
| 10 | X | – | X | X | – | 1.09 | 2.02 | 2.06 | 1.95 | 1.87 | 4.82 | 0.63 | 2.51 | 2.45 |
| 11 | – | X | X | X | – | 0.83 | 2.45 | 2.44 | 2.29 | 2.36 | 2.45 | 0.63 | 2.01 | 2.11 |
| 12 | X | X | X | X | – | 1.10 | 2.73 | 2.66 | 2.12 | 2.13 | 3.42 | 0.72 | 1.98 | 2.00 |
| 13 | – | – | – | – | X | 0.66 | 1.87 | 1.94 | 1.95 | 1.90 | 0.58 | 0.60 | 0.68 | 0.66 |
| 14 | X | – | – | – | X | 1.44 | 1.57 | 1.56 | 1.34 | 1.31 | 0.62 | 0.46 | 0.64 | 0.62 |
| 15 | – | X | – | – | X | 0.68 | 2.33 | 2.47 | 1.62 | 1.63 | 0.63 | 0.53 | 0.64 | 0.66 |
| 16 | X | X | – | – | X | 1.09 | 2.31 | 2.27 | 1.99 | 2.04 | 0.63 | 0.62 | 0.70 | 0.73 |
| 17 | – | – | – | X | X | 0.80 | 1.99 | 2.10 | 2.28 | 2.27 | 0.59 | 0.72 | 0.73 | 0.72 |
| 18 | X | – | – | X | X | 1.10 | 1.47 | 1.50 | 1.74 | 1.76 | 0.61 | 0.57 | 0.67 | 0.69 |
| 19 | – | X | – | X | X | 0.80 | 2.53 | 2.55 | 1.75 | 1.73 | 0.61 | 0.55 | 0.67 | 0.65 |
| 20 | X | X | – | X | X | 0.90 | 2.21 | 2.17 | 2.19 | 2.17 | 0.59 | 0.75 | 0.77 | 0.77 |
| 21 | – | – | X | – | X | 0.70 | 1.31 | 1.31 | 0.33 | 0.33 | 1.32 | 0.15 | 0.69 | 0.69 |
| 22 | X | – | X | – | X | 1.47 | 2.76 | 2.79 | 0.30 | 0.30 | 2.17 | 0.12 | 1.13 | 1.13 |
| 23 | – | X | X | – | X | 0.64 | 2.41 | 2.47 | 1.55 | 1.55 | 2.65 | 0.58 | 1.82 | 1.81 |
| 24 | X | X | X | – | X | 0.95 | 4.27 | 4.18 | 0.71 | 0.71 | 2.02 | 0.30 | 1.10 | 1.09 |
| 25 | – | – | X | X | X | 0.85 | 1.60 | 1.54 | 0.48 | 0.48 | 1.88 | 0.18 | 1.01 | 1.02 |
| 26 | X | – | X | X | X | 1.04 | 2.17 | 2.22 | 0.90 | 0.89 | 4.39 | 0.30 | 2.26 | 2.22 |
| 27 | – | X | X | X | X | 0.83 | 2.67 | 2.61 | 1.89 | 1.78 | 2.95 | 0.56 | 1.99 | 1.93 |
| 28 | X | X | X | X | X | 1.00 | 3.63 | 3.35 | 1.16 | 1.16 | 3.81 | 0.42 | 1.97 | 1.94 |

(*Continued*)

**TABLE 2** Continued

| Scenario N and active factors* | | | | | | Clustering | | | Centrality | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| N | U | S | P | A | D | Blues | Reds | Greens | Blues | Reds | Greens |
| 1 | – | – | – | – | – | 0.22 | 0.12 | 0.12 | 1.40 | 1.62 | 1.60 |
| 2 | X | – | – | – | – | 0.20 | 0.11 | 0.11 | 0.63 | 0.71 | 0.71 |
| 3 | – | X | – | – | – | 0.24 | 0.13 | 0.12 | 1.49 | 1.58 | 1.57 |
| 4 | X | X | – | – | – | 0.30 | 0.15 | 0.16 | 0.63 | 0.70 | 0.72 |
| 5 | – | – | X | – | – | 4.31 | 3.77 | 3.88 | 8.55 | 10.06 | 9.83 |
| 6 | X | – | X | – | – | 3.86 | 3.52 | 3.50 | 2.41 | 2.16 | 2.19 |
| 7 | – | X | X | – | – | 3.83 | 3.25 | 3.22 | 8.76 | 9.76 | 9.80 |
| 8 | X | X | X | – | – | 3.49 | 3.54 | 3.59 | 1.93 | 2.21 | 2.20 |
| 9 | – | – | X | X | – | 6.74 | 7.49 | 7.47 | 22.75 | 25.91 | 22.65 |
| 10 | X | – | X | X | – | 6.74 | 7.48 | 7.74 | 1.86 | 1.85 | 1.79 |
| 11 | – | X | X | X | – | 5.72 | 6.72 | 6.60 | 24.54 | 26.31 | 25.16 |
| 12 | X | X | X | X | – | 6.08 | 7.32 | 7.45 | 1.61 | 1.90 | 1.85 |
| 13 | – | – | – | – | X | 3.65 | 1.34 | 1.33 | 8.09 | 5.87 | 5.81 |
| 14 | X | – | – | – | X | 3.22 | 1.21 | 1.24 | 1.70 | 0.97 | 0.98 |
| 15 | – | X | – | – | X | 3.09 | 1.09 | 1.11 | 7.83 | 5.25 | 5.30 |
| 16 | X | X | – | – | X | 2.82 | 0.98 | 1.01 | 1.27 | 0.89 | 0.89 |
| 17 | – | – | – | X | X | 5.53 | 2.15 | 2.15 | 18.77 | 12.53 | 12.46 |
| 18 | X | – | – | X | X | 5.49 | 2.11 | 2.11 | 1.54 | 0.98 | 1.02 |
| 19 | – | X | – | X | X | 4.50 | 1.83 | 1.82 | 18.93 | 11.57 | 11.54 |
| 20 | X | X | – | X | X | 4.84 | 1.76 | 1.77 | 1.44 | 0.99 | 0.96 |
| 21 | – | – | X | – | X | 4.21 | 3.95 | 3.80 | 8.56 | 10.61 | 10.44 |
| 22 | X | – | X | – | X | 3.85 | 3.78 | 3.81 | 2.69 | 2.48 | 2.48 |
| 23 | – | X | X | – | X | 3.76 | 3.17 | 3.07 | 9.04 | 9.28 | 9.63 |
| 24 | X | X | X | – | X | 3.49 | 3.69 | 3.62 | 2.02 | 2.47 | 2.52 |
| 25 | – | – | X | X | X | 7.53 | 8.41 | 8.37 | 19.35 | 23.01 | 23.79 |
| 26 | X | – | X | X | X | 7.53 | 8.07 | 7.98 | 1.70 | 1.88 | 1.96 |
| 27 | – | X | X | X | X | 6.16 | 6.72 | 6.77 | 21.60 | 23.54 | 24.19 |
| 28 | X | X | X | X | X | 6.32 | 7.25 | 7.50 | 1.57 | 2.12 | 2.06 |

*Factors: U = Urban structure-area stratification in housing values; S = Minority SES disadvantage; P = Segregation-promoting ethnic preferences; A = Adjacent areas considered for preferences; D = Majority group prejudice and discrimination.

yields statistical power sufficient to readily establish the statistical significance of all substantively interesting differences in means for segregation outcomes.[13] In view of this, *I do not systematically comment on the statistical significance of comparisons of means beyond this point because all differences I discuss are significant at the 0.001 level*. The SimSeg program also produces city landscape images that depict segregation patterns qualitatively based on visual patterns. I do not present these here due to space limitations, but I examined them to help interpret segregation patterns. Representative examples are presented in the extended version of this article.

Scenario S1 is a "baseline" scenario in which all "generating" mechanisms are set to values that urban-ecological theory predicts will generate little residential segregation by ethnicity or status. As expected, ethnic and status segregation are extremely low: measures of uneven distribution between high- and low-status households within ethnic groups are near zero, measures of uneven distribution between ethnic groups are near zero, measures of ethnic isolation (i.e., same-group contact) closely mirror each group's population representation; measures of clustering are near zero; and the measure of centrality is near zero for all ethnic groups and so groups do not differ on centrality.

Scenarios S2, S3, and S4 explore the impact of activating various status dynamics. Scenario S2 activates area stratification by itself. Qualitatively, this generates a "zonal" pattern in the distribution of housing values in city landscapes with high-quality housing being more common in suburban areas and low-quality housing more common in central areas. This is manifest quantitatively in high levels of uneven distribution between low- and high-status households *within* ethnic groups. Significantly, segregation *between* ethnic groups remains low on all dimensions. Scenario S3 activates minority status disadvantage by itself. This produces no meaningful changes in patterns of segregation by ethnicity or status. Scenario S4 activates area stratification and minority status disadvantage together. This generates high levels of status segregation *within* ethnic groups as seen previously in S2. In addition, and consistent with urban-ecological theory, S4 generates high levels of majority-minority differences in centralization. However, uneven distribution between ethnic groups, ethnic group isolation, and ethnic clustering are very low. This indicates

[13]Even small, unimportant differences tend to be significant at conventional levels. For example, $t$ tests are statistically significant *at least* at 0.001 for differences of 0.8 or higher for comparisons on uneven distribution, isolation, and clustering and for differences of 2.5 or higher for comparisons on centrality.

that status dynamics and majority-minority status disadvantage do not produce important levels of ethnic segregation except for majority-minority differences in centralization.

Scenario S5 actives ethnic preferences with other factors set to values used in the baseline scenario (S1). As noted earlier, majority and minority preferences for same-group presence are set at 80% and 50%, respectively, levels that roughly correspond to those documented for Whites, Blacks, and Hispanics in multiethnic surveys such as the Multi-City Study of Urban Inequality (Charles, 2000, 2001; Clark, 1992, 2002). Unsurprisingly, given the absence of status dynamics, status segregation is low. In contrast, ethnic preferences generate high levels of ethnic segregation on the two most widely studied dimensions of segregation—uneven distribution and isolation. But ethnic clustering and ethnic differences in centralization are low. City landscapes indicate a qualitative pattern of ethnic "checkering" wherein ethnic groups live separately in ethnically homogeneous neighborhoods that are scattered randomly around the city and do not coalesce into large clusters or "ghettos."

Perhaps the most intriguing finding in the results for this scenario (S5) is that minority-minority uneven distribution is high. This particular segregation outcome is not widely studied, but studies that do examine it (e.g., Massey, 2000) document that it is never low and it often reaches high levels. Why does it arise under scenario S5? Under random distribution Blues live in areas that are 60% Blue and their preference for 80% same-group presence will lead them to make congregating moves to form predominantly Blue neighborhoods. Owing to what Fossett (2006) terms the "paradox of weak minority preferences" (p. 201) minority households also make congregating moves because they cannot satisfy their goal of 50% same-group presence under even distribution. The combination of congregating moves of both majority and minority households produces high levels of majority-minority segregation. However, since Reds and Greens seek only 50% same-group presence, it is logically possible for Reds and Greens to coreside in 50/50 neighborhoods producing minority-minority integration. This does not happen because minority households are averse to less than 50% same-group presence but are not averse to same-group presence above 50%. As a result, most neighborhoods "tip" at some point and become either predominantly Red or predominantly Green. "Tipping" is triggered when Red-Green balance randomly departs from 50/50 balance—something that is likely to occur occasionally in small areas—and the area becomes less attractive to one of the two minority groups. Neighborhoods that drift far enough in one direction or the other are susceptible to tipping into ethnic homogeneity. Once this occurs, the neighborhood tends to remain in that state.

Scenarios S6, S7, and S8 retain ethnic preferences as implemented in S5 and in addition activate area stratification and minority status disadvantage in the sequence seen previously in scenarios S2, S3, and S4. Activating area stratification with ethnic preferences in S6 essentially additively combines segregation patterns for S2 and S5 yielding high levels of status segregation within ethnic groups seen previously when area stratification was active alone (S2) and the same patterns of ethnic segregation seen previously when ethnic preferences were active alone (S5). Activating minority status disadvantage with ethnic preferences in S7 also essentially combines segregation patterns for S3 and S5 in an additive way; minority status disadvantage operating alone (S3) had no important segregation patterns so the results here are fundamentally similar to the results seen when ethnic preferences were activated alone (S5). Finally, activating area stratification and minority status disadvantage in combination to ethnic preferences in S8 also serves to effectively combine segregation patterns for S4 and S5 in an additive way. S8 generates high levels of status segregation within ethnic groups and large majority-minority differences in centrality as seen previously when area stratification and minority disadvantage operated together in S4. S8 also generates high levels of uneven distribution between ethnic groups and high levels of isolation for ethnic groups, but no ethnic clustering.

Scenarios S9–S12 repeat Scenarios S5–S8 with the following modification; they activate adjacency concerns wherein households consider the ethnic mix for adjacent areas as well as that for the immediate bounded area. The impact is relatively straightforward; in all these scenarios, adjacency concerns generate high levels of ethnic clustering (i.e., ghetto formation) not seen for any scenario previously considered. Otherwise, all segregation patterns seen previously are carried forward. Thus, area stratification generates high levels of status segregation *within* ethnic groups in S10 and S12 (as seen before in S2, S4, S6, and S8). Similarly, the combination of area stratification and minority status disadvantage generates large majority-minority differences on centralization in S12 (as seen before in S4 and S8). Finally, ethnic preferences generate high levels of uneven distribution between all ethnic groups and high levels of ethnic isolation (as seen before in S5–S8).

The results for S12, which involves four main dynamics (area stratification, minority status disadvantage, and ethnic preferences with adjacency concerns) are interesting because they produce a highly crystallized pattern of hyper-segregation. In this pattern, minority groups experience segregation on four dimensions—a high level of uneven distribution from the majority ethnic group, high ethnic isolation, high ethnic clustering (ghetto formation), and disproportionate representation in central neighborhoods with lower housing values. This pattern also has the interesting feature of a high level of uneven distribution for the minority-minority comparison.

Scenarios S13–S16 repeat scenarios S5–S8 with the following modification; the ethnic preference dynamics implemented in scenarios S5–S8 are replaced with discrimination dynamics. The discrimination dynamic implemented gives the majority ethnic group a preference for 80% same-group presence and also implements a mechanism of minority exclusion in which minority households seeking to enter areas where the majority ethnic group predominates are blocked up to 95% of the time. Effects of area stratification and minority status disadvantage are similar to those seen before. Thus, high levels of uneven distribution by status within ethnic groups is seen when area stratification is active (in S14 and S16), and large majority-minority differences in centralization are seen when minority status disadvantage is active in combination with area stratification (in S16). When discrimination dynamics are active alone in S13, high levels of uneven distribution between the majority ethnic group and the minority ethnic groups are observed and so too are high levels of majority group isolation. Note, however, that uneven distribution between minority groups is low and ethnic isolation for minority groups is low-to-moderate rather than high. In the main, the impact of discrimination dynamics seen in S13 carries forward in S14–S16. Similarly, status segregation outcomes produced by status dynamics also carry forward.

Scenarios S17–S20 repeat scenarios S13–S16 with one modification; an adjacency dynamic is activated for majority ethnic preferences. Most segregation patterns seen previously in S13–S16 are carried forward. The main changes are moderate increases in ethnic clustering. The increases are markedly greater for the majority ethnic group than for the minority ethnic groups. The two minority groups experience lower clustering for the same reason they experience lower isolation; they are residentially mixed together because minority-minority uneven distribution is low.

Scenarios S21–S24 include both ethnic preference dynamics previously active in scenarios S5–S8 and discrimination dynamics previously active in scenarios S13–S16. Adjacency dynamics are not active. One finding is that the consequences of status dynamics for segregation are the same here as seen before. Another is that ethnic segregation patterns that were previously seen both under scenarios where ethnic preference dynamics were active alone (i.e., without discrimination dynamics) and also under scenarios where discrimination dynamics were active alone (i.e., without minority ethnic preferences being active) are seen here as well. These patterns include high levels of uneven distribution between majority and minority ethnic groups, high ethnic isolation for the majority group, and low levels of ethnic clustering for all ethnic groups. A third finding is that two segregation patterns seen previously for scenarios involving ethnic preference dynamics, but not seen for scenarios involving discrimination dynamics, also are observed here. These are high levels of uneven distribution for the minority-minority comparison and high levels of ethnic isolation for minority groups.

Finally, scenarios S25–S28 add adjacency dynamics to scenarios S21–S24. All patterns seen for scenarios S21–S24 carry forward. In addition, ethnic clustering increases to high levels for all groups.

The results of these experiments support several general conclusions about model generated patterns of ethnic segregation. Majority-minority differences in centrality occur only when area stratification and minority status disadvantage are active together. Otherwise, status dynamics do not contribute in important ways to other dimensions of ethnic segregation. High levels of uneven distribution for majority-minority comparisons and high levels of majority isolation occur when either form of ethnic dynamics—ethnic preferences or discrimination—is active. High levels of uneven distribution for the minority-minority comparison and high levels of minority group isolation occur only when ethnic preferences are active. Ethnic clustering, that is, ghetto formation, occurs only when ethnic dynamics—whether preferences or discrimination—include adjacency concerns. Ethnic clustering is more pronounced when ethnic preferences are active in comparison to when discrimination is active, especially for ethnic minority groups. Ethnic sectoring, that is, the formation of ethnic ghettos that span status zones, occurs only when ethnic dynamics—whether preferences or discrimination—are active in combination with adjacency concerns and area stratification; otherwise, ethnic segregation is manifest in checkering patterns. Like ethnic clustering, ethnic sectoring is more pronounced when ethnic preferences are active in comparison to when discrimination is active, especially for ethnic minority groups.

## 8. OVERVIEW OF IMPLICATIONS OF SIMULATION RESULTS

The results here document that a relatively small set of model parameters can generate a wide array of qualitatively distinct segregation outcomes that in some cases resemble complex, multidimensional patterns seen in real cities. This suggests that key aspects of complex urban patterns could potentially emerge from the interaction of a small set of relatively simple microdynamics and familiar urban-demographic conditions. It also suggests that complex patterns of segregation cannot be attributed to the roles of any single dominant factor. They instead depend on the joint incidence of multiple conditions and dynamics that individually cannot generate the full pattern.

The results here also illustrate how agent models can help refine understanding of segregation dynamics by giving researchers the ability to systematically manipulate generating mechanisms and observe the consequences. This creates new opportunities to clarify points of similarity and difference in the implications of different segregation theories. One case in point is the role of status dynamics in ethnic segregation. The results here support conclusions in the broader segregation literature that minority status disadvantages do not directly foster high levels of uneven distribution between majority and minority ethnic groups. However, the results also suggest that status dynamics are a necessary but not sufficient factor for two aspects of hyper-segregation—majority-minority differences in centrality and ethnic sectoring patterns.

Another area where the approach is helpful is in clarifying points of contrast between the implications of preference dynamics and discrimination dynamics. Discussions in the literature sometimes strain to suggest that an either or choice is required. The two dynamics are not mutually exclusive, however, and can potentially be operating simultaneously in contemporary urban areas as in some of the simulations here. The results here provide support for the view that both may contribute to ethnic segregation in important ways. The results also suggest that it may not be easy to advance simple conclusions about their relative impact. When either of the two ethnic dynamics is added to any scenario in which no ethnic dynamic is active, it leads to large increases in some aspects of ethnic segregation. From that point of view, both are important. But, when either of the two ethnic dynamics is removed from any scenario in which both ethnic dynamics are active, declines in ethnic segregation are modest. From that point of view, both are less important than the first comparison would suggest.

The sociological literature on segregation generally discounts the potential impact of ethnic preference and social distance dynamics. But the results here raise questions about whether discrimination dynamics alone, at least as implemented here, can produce the full complexity of segregation patterns seen in real cities. In these simulations discrimination dynamics can combine with other factors and produce key elements of hyper-segregation, namely, uneven distribution of minority ethnic groups from majority ethnic groups, high majority group isolation, and large majority-minority differences in centrality. But other aspects of hyper-segregation seen in many urban areas emerge only when broader ethnic preferences are active. These include high levels of uneven distribution between ethnic minority groups and high levels of isolation and clustering for minority groups in multiethnic cities. It is premature to view the results here as definitive. However, they are intriguing and warrant further attention.

Finally, the results here suggest that it can be useful to pursue agent models that incorporate multiple generating mechanisms in an effort to produce complex patterns of segregation. One benefit of this approach is that different dynamics may interact to generate telltale patterns "signatures" for the operation of particular factors. Another benefit is that the possible role of any one generating mechanism is not considered in isolation and instead is evaluated in the context of a more holistic model capable of generating familiar segregation patterns seen in urban areas.



## 9. THE STANDING AND FUTURE PROSPECTS OF AGENT MODELS OF SEGREGATION

Agent models have generated valuable insights about the dynamics of residential segregation in urban areas. While these insights are celebrated by many, their influence in the broader literature on residential segregation is modest. Some scholars view Schelling's (1971) contributions as having important implications for understanding ethnic residential segregation (e.g., Clark, 1991, 1992; Thernstrom and Thernstrom, 1997; Glazer, 1999). But this view is not yet the norm outside of economics and the agent modeling literature and insights from agent modeling efforts are often viewed with skepticism or ignored completely in many surveys of the field (e.g., Charles, 2001, 2003; Galster, 1988, 1989; Massey and Denton, 1993; Yinger, 1996; Farley, Danziger, and Holzer, 2000).

What accounts for this situation? It is not weakness in Schelling's (1971) formal analyses of preference effects; they have held up well and have been extended in subsequent theoretical work (e.g., Young, 1998). Critics of Schelling's insights regarding segregation dynamics (e.g., Goering, 2006; Krysan and Farley, 2002; Massey and Denton, 1993; Yinger, 1996) have offered useful observations on the importance of understanding the historical origins and current context of preference distributions. They have not offered compelling formal critiques of the potential proximate effects of ethnic preferences. Proponents of agent models do bear some responsibility for skeptics' concerns. Simulation studies have sometimes been oriented to a narrow audience and failed to engage the broader theoretical and empirical literatures on residential segregation. In addition, they have sometimes not given sufficient attention to clarifying how abstract models can be relevant for thinking about real world residential segregation dynamics. Happily, to the extent that such shortcomings have occasional occurred, they are not intrinsic to the methodology and they are steadily becoming less common. Thus, I believe the future will bring increasingly productive dialog between traditional segregation researchers and researchers who draw on agent modeling frameworks.

Agent modeling is of course only one tool among many that are available for studying residential segregation, but its potential is only just beginning to be tapped and it is likely to take on greater importance in the future. I believe its expanded use will stimulate clarification and refinement of segregation theories. Useful computational models embody social science theory and knowledge of the conditions and dynamics contributing to residential segregation and the task of model building requires that theory and knowledge be articulated clearly enough to permit satisfactory representation in modeling frameworks. Efforts to craft agent models can help highlight gaps and ambiguities in existing theory and knowledge and also can stimulate debate about which aspects of real world social structures and social dynamics warrant closest attention. My optimistic view is that continuing progress in refining and strategically exercising agent models will help advance our understanding of how macro-level patterns of residential segregation in urban areas emerge from micro-level dynamics.



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