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The Emergence of Racial Segregation in an Agent-Based Model of Residential Location: The Role of Competing Preferences*

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Abstract

Models of segregation dynamics have examined how individual preferences over neighborhood racial composition determine macroscopic patterns of segregation. Many fewer models have considered the role of household preferences over other location attributes, which may compete with preferences over racial composition. We hypothesize that household preferences over location characteristics other than racial composition affect segregation dynamics in nonlinear ways and that, for a critical range of parameter values, these competing preferences can qualitatively affect segregation outcomes. To test this hypothesis, we develop a dynamic agent-based model that examines macro-level patterns of segregation as the result of interdependent household location choices. The model incorporates household preferences over multiple neighborhood features, some of which are endogenous to residential location patterns, and allows for income heterogeneity across races and among households of the same race. Preliminary findings indicate that patterns of segregation can emerge even when individuals are wholly indifferent to neighborhood racial composition, due to competing preferences over neighborhood density. Further, the model shows a strong tendency to concentrate affluent families in a small number of suburbs, potentially mimicking recent empirical findings on favored quarters in metropolitan areas.

Keywords: segregation dynamics, race, class, urban spatial form, household location

Racial segregation has long been an American dilemma (Massey and Denton, 1993; Myrdal, 1944). In particular, African Americans have long been more segregated from European Americans than any other ethnic group in the United States (Massey and Denton, 1993). While the segregation of African Americans has declined in the last decade, the decline has been small and African Americans remain more segregated than Latino Americans or Asian Americans (Charles, 2003; Iceland et al., 2002). It is therefore unsurprising to find a tradition

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of dynamical modeling of segregation, descended from the seminal work of Schelling (1978) that examines how individual preferences over neighborhood racial composition determine regional-level patterns. Many of these models have tested the robustness of Schelling's central finding that actual levels of segregation tend to be much higher than the level that any individual wants. Laurie and Jaggi (2003) find that expansion of the radius over which neighbors influence each other leads to a mix of stable and unstable regimes, while O'Sullivan et al. (2003) find that a hierarchical model that includes interactions within bounded neighborhoods leads to more rapid segregation than the standard Schelling model for small bounded neighborhoods.

These models have typically assumed that individuals have preferences only over racial composition; they ignore other factors that can influence household location decisions.[1] Further, the models have typically failed to include a structure in which agents bid for houses. In reality, households make decisions about location in response to a number of different factors, including structural features of houses, characteristics of the household, and a variety of neighborhood characteristics that may include, but are certainly not limited to, racial composition of the neighborhood. A household then must purchase a house in a particular location, and high demand in one neighborhood will increase the price of houses in that neighborhood. Empirical evidence of household location decisions has demonstrated the importance of schools (Bogart and Cromwell, 2000), public safety (Farley, 1987), density patterns (Gordon and Richardson, 1997), and changes in household income (Margo, 1992) in addition to the racial and economic composition of neighborhoods. Like racial composition, many of these neighborhood characteristics are endogenous to household location decisions; rather than being exogenously determined, they co-evolve with the spatial distribution of households. Many factors, both exogenous and endogenous, can reinforce segregation patterns. For instance, the value of elite public schools is capitalized into housing prices. This creates economic barriers to neighborhood entry, which leads to economic segregation that is often highly correlated with racial segregation. Other factors may offset segregation forces, e.g., sufficient heterogeneity in preferences among whites for amenities associated with higher density neighborhoods can lead to more integrated neighborhoods. Distinguishing among these competing factors and analyzing their interactions is important in understanding the dynamic evolution of segregation patterns and for informing policies that seek to address social and economic inequality.

Finally, models of residential segregation have typically assumed symmetry of preferences. Members of different groups equally prefer to congregate with members of their own groups. In the case of segregation of African Americans in the United States, there is empirical evidence that preferences are not symmetrical. Rather, European Americans have traditionally been more averse to African American neighbors than vice-versa (Massey and Denton, 1992; Charles, 2003).

We hypothesize that household preferences over location characteristics other than racial composition affect segregation dynamics in nonlinear ways and that, for a critical range of parameter values, these competing preferences can qualitatively affect segregation outcomes. To test this hypothesis, we develop a dynamic and spatially explicit agent-based model that examines macro-level patterns of segregation as the result of interdependent household location choices. The model incorporates household preferences over multiple neighborhood characteristics, some of which are endogenous to residential location patterns, and allows for income differences across races as well as income heterogeneity among households of the same race. The basic version of the model posits two household types, black and white, in which black households are assumed to have a lower range of income levels and thus are more restricted in their moving opportunities. Eighty percent of the households are white and twenty percent are black. Household behavior is modeled within a utility theoretic framework in which the household evaluates the net benefits from moving to a given residential location and, subject to an income constraint, moves if the net benefits from moving exceed the opportunity cost. Households have preferences over key endogenous attributes of the neighborhood that change over time with the cumulative spatial distribution of households. For both groups, three neighborhood attributes matter. The first shared component of utility is the quality of public services, such as schools and police protection. This quality is determined by the aggregate taxable income of all households living within the same jurisdiction. The second shared component is neighborhood density, which is a combined measure of the density of a household's own lot and the development density within the surrounding 25–49 cells. The third shared component is the quality of private services or amenities, which is determined by the individual household's disposable income and the (aggregate) population density within a neighborhood of 25–49 cells. For whites, the proportion of black households within a neighborhood, which is considered to be composed of nine cells, is a further component of utility. Blacks, on the other hand, are indifferent to neighborhood racial composition. Housing price is endogenously determined as the result of aggregate demand factors that capture the relative demand for housing at each location. Transportation costs and household income, which along with housing prices determine the households' spending on all other goods, are exogenously determined.

Space is defined on a two-dimensional grid of 100×100 cells in which each cell corresponds to a block. The city is defined by the central 40×40 block of cells that is associated with a higher maximum density level (30–40 households per cell). This block of cells is surrounded by a suburban ring of cells that are subject to a lower maximum allowable density (20–30 households per cell). The suburban area is further delineated into four, equal-area jurisdictions, which, along with the city boundary, are used to determine the aggregate revenues from taxes that determine the quality of schools and public services. All employment is assumed to be located in the central city; thus, transportation costs are a linear function of distance to the city.

Segregation can be measured along a number of different dimensions (Massey and Denton, 1988). In this model, segregation is measured as the ratio of whites to blacks in the central city, a very simple way of conceptualizing the dimension of segregation known as centralization (Massey and Denton, 1988).

At the beginning of the simulation, whites are randomly distributed across the inner city and the suburbs, while blacks are randomly distributed across the inner city and a belt of suburban cells surrounding the inner city. The model evolves in discrete time steps conceptualized as a quarter of a year. At the beginning of each time step, a subset of households is randomly chosen. Eligible households calculate the utility generated from a move to each block with available housing and a move is accepted if it is financially feasible and increases its utility. At the end of the time step, after all selected households have evaluated their moving options and have either engaged in a move or not, the endogenous features of the model (housing prices and neighborhood features) are updated. The model is specified with national-level data on metropolitan population and income distributions. Functional forms for household utility are specified using data from empirical studies published in the literature. The model is executed in Fortran and run on a VMS cluster. Simulation of the model is performed for a ten year time period (40 time steps) or until the spatial pattern reaches a static equilibrium point.

Work using this model is still in a preliminary stage. However, preliminary findings demonstrate the range of parameter values for which alternative specifications of preferences generate segregation. For example, we find that relatively small changes in whites' preferences for low density neighborhoods generate a sharp increase in segregation as shown in figure 1. This occurs even though their preferences for ethnically homogeneous neighborhoods are either non-existent or so weak that by themselves they are insufficient to generate segregation. In this case, as whites purchase housing in lower-density neighborhoods they drive prices in those neighborhoods beyond the reach of the poorer blacks. Economic segregation mimics racial segregation.

Moreover, in the absence of spatial preferences but the presence of racial preferences on the part of whites, segregation also occurs quite rapidly (figure 2). Symmetry in racial preferences is not necessary for segregation to occur.

A third preliminary finding is that the positive feedback loop in which clustering of affluent—in this model, white—households leads to improved public amenities which, in turn, attract more affluent households tends to concentrate all of the white households in one or two suburbs, while pricing the poorer black households out of the same suburbs. This dynamic of suburban concentration is strongly path dependent: the more homogeneous the suburb, the more it attracts similar individuals and asymmetrical clusters arise as a result. This result is clearly preliminary and requires more analysis; for instance, there are negative feedback loops such as congestion effects and possible increases in crime with increasing

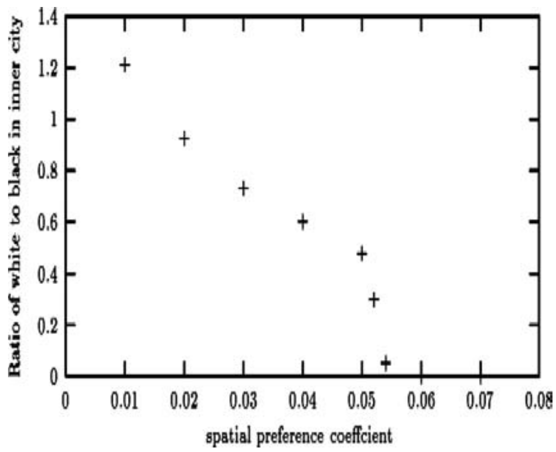

Figure 1. Segregation as a function of whites' preference for low density neighborhood.

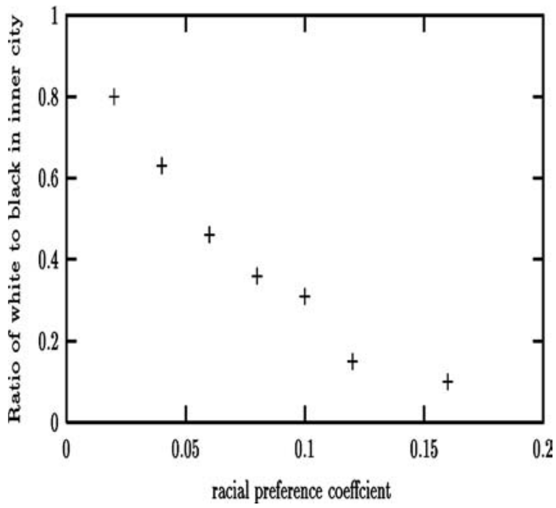

Figure 2. Segregation as a function of whites' preference for white neighbors.

population for which this model does not account. However, the feedback loop is strongly reminiscent of Orfield's (2002) argument that metropolitan areas tend to produce favored quarters in which concentrations of wealth lead to improved amenities which draw further wealth.

These results will not come as an overwhelming surprise to sociologists; there is a long-standing debate over the sources of residential segregation, and it has long been argued that economic segregation can mimic racial segregation (Massey and Denton, 1993). However, an agent-based approach can sharpen our analytic understanding of the linkages between individual motivation and macro-level outcomes in segregation and metropolitan structure, and can focus our attention far more powerfully on the feedback loops that affect those outcomes. This approach is important for advancing our collective understanding of segregation dynamics since macroscopic patterns of segregation are readily observable, but the underlying mechanisms that generate these patterns, including the structure of household preferences, are not. Future work with this model will focus on the relationship of different household preference structures to the dynamics of emergent spatial structure, with the hope that different preferences will lead to different and distinguishable dynamical paths to residential segregation.

Note

1. An exception is Benenson, Omar and Hatna (2002), who develop an agent-based model in which agents choose residences based on a dissonance score based on multiple individual differences between themselves and their neighbors as well as between their own ethnicity and the ethnic architectural style of a prospective dwelling.

References

Benenson, I., I. Omer, and E. Hatna, (2002), “Entity-Based Modeling of Urban Residential Dynamics: The Case of Yaffo, Tel Aviv,” *Environment and Planning B: Planning and Design,* 29(4), 491–512.

Bogart, W.T. and B.A. Cromwell (2000), “How Much is a Neighborhood School Worth?” *Journal of Urban Economics*, **47**(2), 280-305.

Charles, C.Z. (2003), “The Dynamics of Racial Segregation,” *Annual Review of Sociology*, **29**, 167–207.

Farley, J.E. (1987), “Suburbanization and Central-City Crime Rates: New Evidence and a Reinterpretation,” *American Journal of Sociology*, **93**(3), 688–700.

Gordon, P. and H. Richardson (1997), “Are Compact Cities a Desirable Planning Goal?” *Journal of the American Planning Assoc*., **63**(1), 95–106.

Iceland, J., D.H. Weinberg, and E. Steinmentz (2002), United States Census Bureau, series CENSR-3, *Racial and ethnic segregation in the United States: 1980–2000*. Washington, DC: U.S. Government Printing Office.

Laurie, A J. and N.K. Jaggi (2003), “Role of ‘Vision’ in Neighborhood Racial Segregation: A Variant of the Schelling Segregation Model,” *Urban Studies*, **40**(14), 2687–2704.

Margo, R. (1992), “Explaining the Postwar Suburbanization in the United States: The Role of Income,” *Journal of Urban Economics*, **31**, 300–310.

Massey, D.S. and N.A. Denton (1993), *American Apartheid: Segregation and the Making of the Underclass*. Harvard University Press, Cambridge, MA.

Massey, D. S. and N.A. Denton (1988), “The Dimensions of Racial Segregation,” *Social Forces*, **67**(2), 281–315.

Myrdal, G. (1944), *An American Dilemma: The Negro Problem and Modern Democracy*. Harper, New York.

Orfield, M. (2002), *American Metropolitics: The New Suburban Reality*. Washington, D.C.: The Brookings Institution Press.

O’Sullivan, D., J. Macgill, and C. Yu (2003), “Agent-Based Residential Segregation: A Hierarchically Structured Spatial Model,” presented at Agent 2003, University of Chicago, Argonne National Laboratory, October 2–4.

Schelling, T. (1978), *Micromotives and Macrobehavior*. Norton, New York.

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