SimPolSeg: An Agent-Based Simulation of Political Migration Dynamics and Geographic Polarization*

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Abstract

In this paper I simulate neighborhood level political migration dynamics following a change in neighborhood racial composition using *SimPolSeg*, an original agent-based modeling software program. *SimPolSeg* simulates agent behavior according to the Migration-Polarization (MP) theory of partisan sorting (Anastasopoulos 2014a). Dynamic simulations using *SimPolSeg* demonstrate how non-white migration and conservative flight lead to racially and ideologically segregated urban neighborhoods.

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1 Introduction

This paper builds upon the Migration-Polarization (MP) theory of partisan sorting described in Anastasopoulos (2014a). Using *SimPolSeg*, an original agent-based modeling algorithm, I explore patterns of racial segregation and geographic polarization according to MP Theory processes triggered by non-white migration to urban neighborhoods. Below I describe the MP Theory in more detail and present simulation results produced by *SimPolSeg*.

1.1 Theory

Since the 1950s, scholarship in several disciplines has found that the introduction of ethnically and racially diverse migrants into urban communities typically results in displacement of whites and segregation along racial and ethnic lines (Boustan 2010; Card, Mas and Rothstein 2008; Cutler, Glaeser and Vigdor 1999; Duncan and Duncan 1957; Fligstein 1981; Jackson 1985; Tolnay 2003). Schelling (1971) provided the first formal explanation for this phenomenon by showing that even if individuals have a weak preference for neighbors that are similar to them along some dimension, segregation can emerge when dynamic choices about where to live are based upon these preferences.

According to the Schelling model, tolerance for neighborhood racial and ethnic diversity determines whether an individual will relocate when changes in demographic composition occur. At higher levels of geography, tolerance determines the rate and extent to which segregation will occur. While tolerance in the Schelling model is pre-

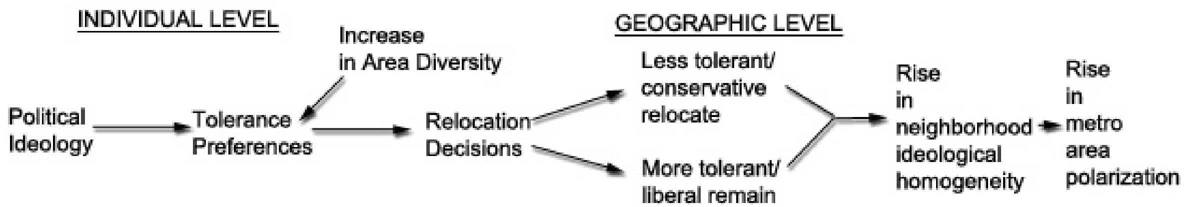


Figure 1: Outline of the Migration-Polarization Theory

sented as a preference independent of other individual attributes, in reality, factors such as age, marital status, family size, income and political ideology are correlated with it.

If this is true, then sorting induced by increases in diversity should lead to both racial AND ideological segregation (polarization) under certain conditions. This connection between political ideology and Schelling tolerance is the basis of the MP theory which is described in greater detail in Anastasopoulos (2014a) .

Figure 1 provides an outline of the MP theory. Since individual political ideology is correlated with Schelling tolerance preferences, when a demographic shift causes an increase in neighborhood diversity, a partisan sorting process is triggered. Less tolerant, ideologically conservative individuals relocate in response to increases in neighborhood diversity, while more tolerant, ideologically liberal individuals remain.

This sorting process is an engine which drives geographic polarization as ideologically conservative “movers” and liberal “stayers” cluster together. Generational replacement and other changes that follow this initial increase in diversity ensure that this pattern of polarization persists in a path-dependent manner even in the absence of subsequent migration events.

2 Agent Based Model Setup and Simulations

2.1 Preferences for Diversity

The model below establishes agent behavioral rules which determine responses to changes in neighborhood diversity in subsequent simulations. In the simulation, neighborhoods a_n, are geographically bounded spaces within a larger urban space A. Agents that reside in these neighborhoods have the following preferences: (1) *they are tolerant of diversity, but prefer neighbors that are racially or ethnically similar* and; (2) *their degree of tolerance is determined primarily by their political ideology.*

$$\eta_i = \sqrt{I_i - D_i} \tag{1}$$

$$D_i = \sqrt{\sum_{k=1}^{K} \sum_{j=1}^{J} \rho_{ji} (E[\alpha_{jk}] - \alpha_{ji})^2} \tag{2}$$

$$0 < D_i < I_i < 1 \tag{3}$$

Decisions to relocate based upon these premises are operationalized using a simple model shown in the equations above where η_i represents the tolerance of an individual i for the proportion of minorities in their surrounding area. According to premise (2), tolerance η_i is a function of political ideology, I_i. However, because tolerance also depends upon characteristics of the migrants, I include a "social distance" term, D_i, which reflects differences on a number of attributes between the agent and the minority group(s) surrounding her (Shayo 2008). Higher values of ideology I_i

correspond to greater ideological liberalism while higher values of D_i correspond to greater "social distance" between the individual and an out-group. Since political ideology plays a central role in the determination of tolerance, $D_i < I_i$.

Social distance is a measure of characteristics which differ between an individual and an out-group that takes into account the importance an individual gives to each. Mathematically, it is the normalized difference between $E[\alpha_{jk}]$, the average j^{th} attribute of group k, and α_{ji} , the j^{th} attribute of the individual. The distance on each attribute α_j is weighed by $\rho_{ji} \in (0,1)$ where $\sum_j^J \rho_{ji} = 1$, which measures the importance that an individual gives to each attribute (Shayo 2008). For the purposes of this model, these attributes and weights are fixed for each individual[1].

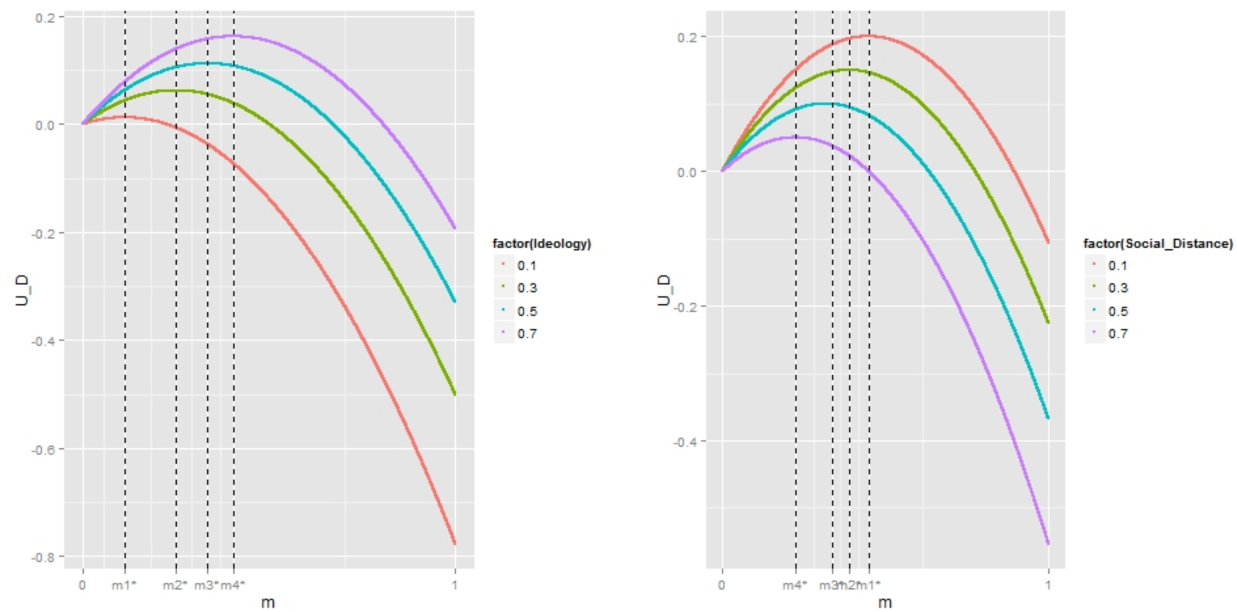
The utility that an agent receives for the residing in neighborhood n is a function of tolerance, neighborhood minority population, housing prices, schools and other neighborhood amenities such as commuting distance etc. captured by $f(p_n, \epsilon_n)$:

$$U_i^R(m, \eta_i) \quad = \eta_i m - m^2 = (\sqrt{I_i - D_i})m - m^2 + f(p_n, \epsilon_n)$$

$$0 \leq m \leq 1$$
$$0 < \eta_i < 1$$
$$0 < D_i < I_i < 1$$

Plots of U_i^R v. m with different values of political ideology and social distance in Figure 2 show that the utility an agent derives from neighborhood diversity varies

[1]While it is certainly possible that the weight ρ_{ji} an individual gives to these attributes may realistically change along with demographic changes, these considerations are to be addressed in future research. An example of this type of phenomenon could be an increase in the importance of language differences as individuals have more contact with immigrants that do not speak English.



(a) $I_i = 0.1, 0.3, 0.5, 0.7$,$D_i = 0.05$ (b) $I = 0.9$,$D_i = 0.1, 0.3, 0.5, 0.7$

Figure 2: Utility for neighborhood diversity, U_i^D v. area minority population varying Ideology I_i and Social Distance D_i

with agent political ideology and out-group social distance. The shape of U_i^R reflects the idea that agents are tolerant and have ideal levels of diversity represented by m_i^* as shown in Figure 2. The ideal neighborhood minority proportion m_i^* is obtained by simply taking $\partial U_i^R/\partial m$:

$$m_i^* = \frac{\eta_i}{2}$$

Since $0 < \eta_i < 1$, the ideal proportion minority is always less than 50%, suggesting that agents are tolerant and enjoy diversity, but generally prefer neighbors similar to themselves.

2.2 Moving Decisions

At time t, agents make decisions about whether to move from a neighborhood based upon their preferences for diversity. Since this paper is concerned with how individuals respond to *changes* in diversity, I introduce agent beliefs about whether their neighborhood will "tip" (T) and become entirely majority-minority in the future ($m_{nt+1} = 1$) based upon the current area minority population m_{nt} and the agent's diversity ideal point m_i^*. Racial tipping is a phenomenon that has been extensively documented (Card, Mas and Rothstein 2008; Easterly 2005; Patrick, Fang, and McMillan 2005; Boston, Rigsby, and Zald 1972). Using census tract data from a number of major metropolitan areas, Card, Mas and Rothstein (2008) find that racial tipping points vary between 5-20% of the minority population and tend to be higher where whites are more liberal. Thus, a model which takes fears about tipping into account provides a realistic depiction of how agents might process changes in neighborhood racial composition.

$$P[T|m_{nt}, m_i^*] = P[m_{nt+1} = 1|m_{nt}, m_i^*] = \begin{cases} \sqrt{m_{nt} - m_i^*} & \text{if } m_{nt} > m_i^* \\ 0 & \text{if } m_{nt} \leq m_i^* \end{cases} \quad 0 < m_{nt}, m_i^* < 1$$

Beliefs captured by $P[T|m_{nt}, m_i^*]$ reflect agent fears that others similar to themselves will exit the area if diversity exceeds their ideal point, m_i^*. When the minority population exceeds the agent's diversity ideal point, her subjective belief about the likelihood that her neighborhood tips depends upon the actual neighborhood population, m_{nt} ,and her minority ideal point m_i^*. The square-root term reflects the

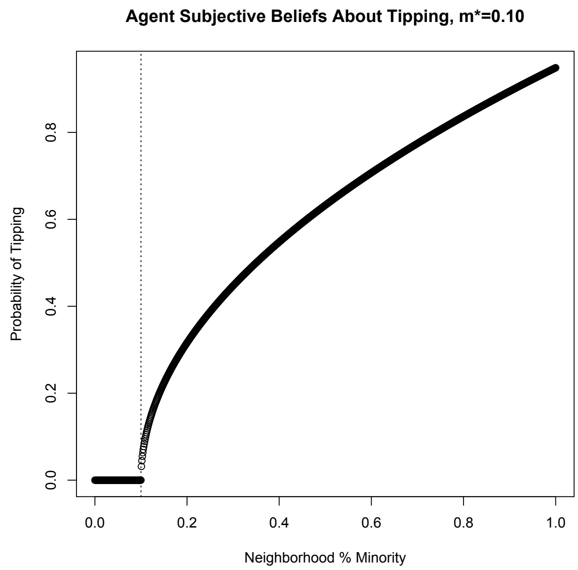


Figure 3: Subjective Probability of Tipping Across Neighborhood Minority Proportion, $m_i^* = 0.10$

behavioral assumption that increases in the minority population near the agent's minority ideal point results in steeper marginal increases in her subjective probability of tipping.

Figure 3 is a plot of subjective tipping points at different levels of neighborhood minority population when $m_i^* = 0.10$.

Incorporating these beliefs into a dynamic model, expected utility for residing in a neighborhood at any given time t is:

$$EU_{nt}^D = P[T|m_{nt}, m_i^*]U^R(T) + (1 - P[T|m_{nt}, m_i^*])U^R(T^{'}) \tag{4}$$

We can now establish a decision rule for moving in response to changes in neighborhood diversity using Equation **??**. Given preferences for diversity and beliefs about neighborhood tipping, an agent will choose to move from her neighborhood if her utility for residing there EU^R_{at} can be better satisfied elsewhere.

Thus, assuming that area fixed characteristics are the same, a rational agent will improve her utility by deciding to move in response to changes in diversity when (1) the minority population in her neighborhood exceeds her ideal point $m_{nt} > m^*$ and; (2) there is at least one other area for which $m_{n'} \leq m^*$.

Agents also take into account a cost of moving which is represented by $\delta_{a,a'}$, the Euclidean distance between two neighborhoods as measured by their coordinates on a two dimensional plane:

$$\delta_{n,n'} = \sqrt{(x_n - x_{n'})^2 + (y_n - y_{n'})^2} \tag{5}$$

$$\text{If } m_{nt} > m_i^* \text{ and } \exists n' \in A \text{ s.t. } m_{n't} \leq m_i^*: \begin{cases} \text{If } EU^R_{nt} < EU^R_{n't} - \delta_{n,n'} & \textbf{Move from } \boldsymbol{n} \\ \text{Else} & \textbf{Remain in } \boldsymbol{n} \end{cases} \tag{6}$$

Finally, Equation 5 presents the conditions under which an agent will relocate. If these conditions are met, the agent may still be left with several neighborhoods to choose from. Since the agent desires to have the highest utility for remaining in an area, of the given areas that satisfy Equation 5, she will choose the neighborhood $n' \in A$ which maximizes $EU^R_{n'} - \delta_{n,n'}$. This implies that she will to move to a neighborhood both nearest her, in terms of spatial distance and closest to her neighborhood diversity ideal point.

3 Simulation

To explore how distributions of urban political ideology would develop if agents behaved according to the model discussed in the previous section, I designed a dynamic agent-based simulation algorithm in `R` called `SimPolSeg`. The algorithm generates a set of neighborhoods with two-dimensional spatial coordinates, populates them with minority and non-minority agents that have ideologies and preferences for diversity according to the model in the previous section and then simulates moving behavior over time. Simulation details can be found in the Appendix.

3.1 Initial Values and Demographics

Variable	Symbol	Initial Value
Neighborhoods	A	$N = 20$
Mean Between Neighborhood Ideology	I_{t_0}	$\mu^I_{t_0} = 0.5$ $\sigma^I_{t_0} = 0.1$ $\mathbf{I_{t_0}}$ =`rtnorm(n=20,mu =0.5,sd=0.1)`
Minoritypop	B_{t_0}	$\mu^B_{t_0} = 5$ $\sigma^B_{t_0} = 5$ $\mathbf{B_{t_0}}$ = `rtnorm(n=20,mu =5,sd=5)`
Majoritypop	W_{t_0}	$\mu^W_{t_0} = 100$ $\sigma^W_{t_0} = 10$ $\mathbf{W_{t_0}}$ = `rtnorm(n=20,mu =100,sd=10)`

Table 1: Starting Values For Simulation

In the simulation conducted, 20 neighborhoods containing an average of 100 majority agents and 5 minority agents were generated. The mean majority "ideology" in each neighborhood was set at 0.5 with a standard deviation of 0.1 and the mean minority ideology in each neighborhood was set at 0.8 with a standard deviation of 0.1. Moving behavior depends upon these initial parameters.

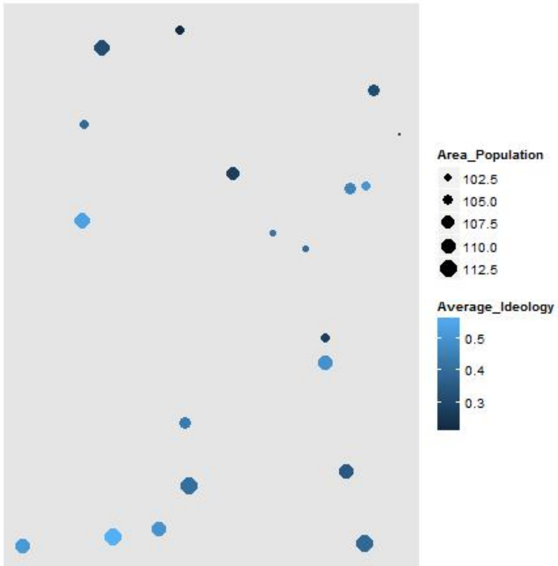
Figure 4 contains plots of the 20 areas in two-dimensional space initially and after 151 moving cycles, at which point the proportion of majority agent movers dropped below 1%. Area total population is reflected by point size.

3.2 Simulation Results

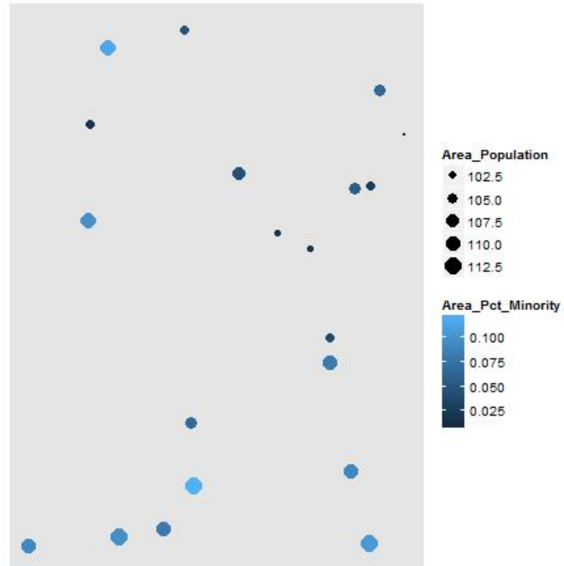
Figure 5 plots the percent of the population that moves after each time period. Moving increases dramatically during the first few time periods and then begins a steady decline toward zero after approximately 30 moving cycles.

Figure 6 is a plot of average area ideology over time for each of 20 areas. It is clear from this plot that urban area ideology diverges substantially over time as very liberal and moderate areas cluster together. This phenomenon becomes even more striking when comparing the two-dimensional maps of initial ideological and population distributions in Figure 4 (a) and (d). At the beginning of the simulation, nearly all areas are diverse and ideologically moderate. By the end of the simulation, only a few large population neighborhoods remain diverse and ideologically moderate while surrounding areas are comprised almost entirely of minorities and are ideologically extreme.

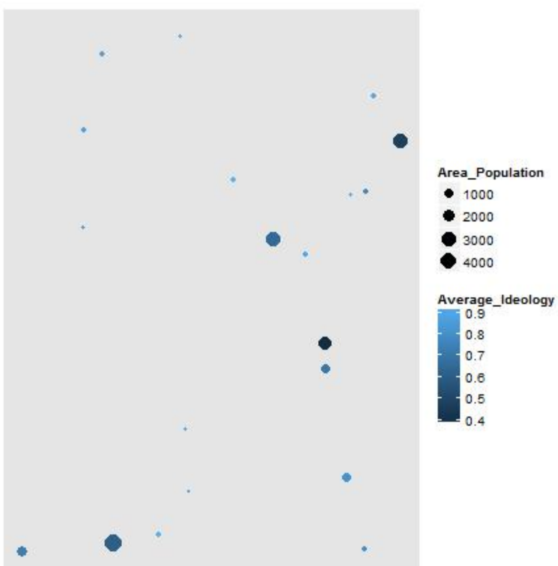
Urban ideological polarization as the result of partisan sorting becomes clear when neighborhood segregation and ideological polarization are plotted over time using the interquartile range (75th - 25th%ile) of average neighborhood ideology and percent minority in Figure 7.



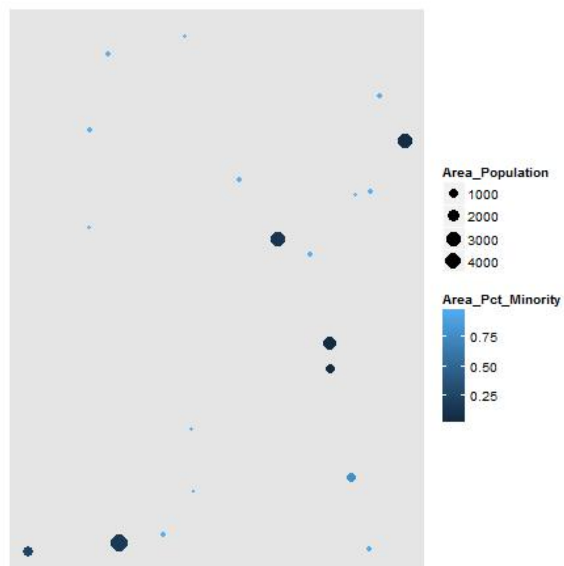
(a) Avg. Neighborhood Ideology, $t = 0$



(b) Neighborhood Pct. Minority, $t = 0$



(c) Avg. Neighborhood Ideology, $t = 151$



(d) Neighborhood Pct. Minority, $t = 151$

Figure 4: Neighborhoods in 2D Space: Avg. Ideology and Pct. Minority: $t = 0$ and $t = 151$

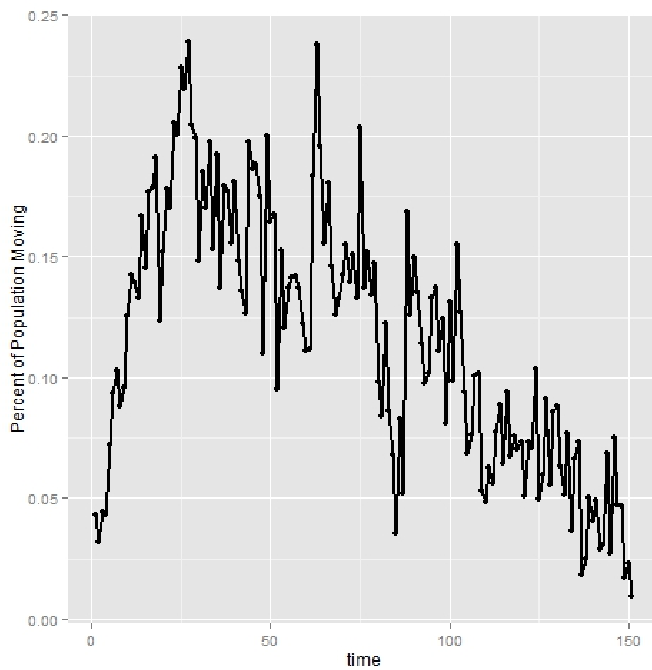


Figure 5: Movers as Percent of Total Population,$t = 0$ to $t = 151$

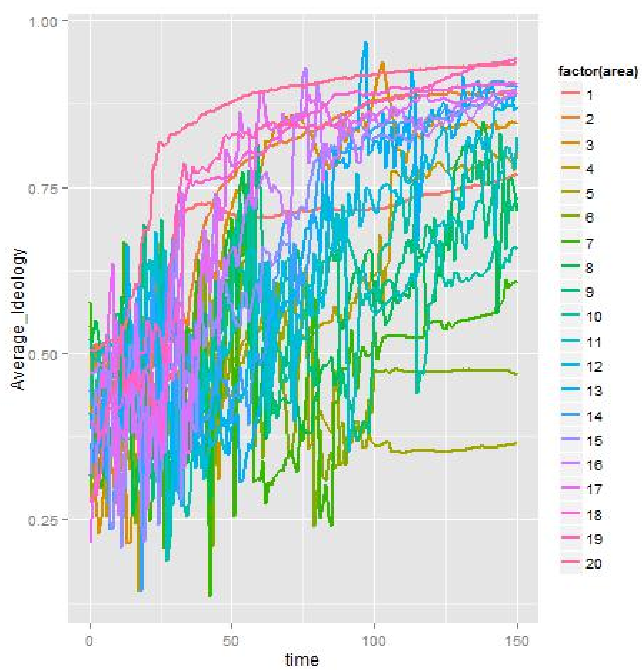


Figure 6: Average neighborhood ideology, $t = 0$ to $t = 151$

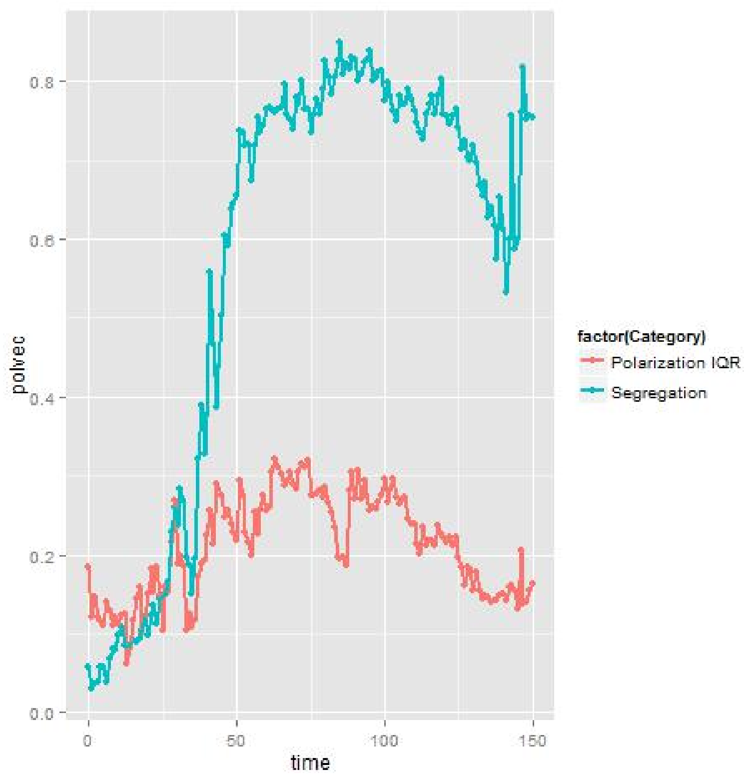


Figure 7: Polarization and Segregation Between Neighborhood,$t = 0$ to $t = 151$

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5 Appendix

Variable	Symbol	Description	Properties
Areas	A	set of simulated neighborhoods.	A = $(a_1, ..., a_N)$
Agent Ideology	I_{ai,t_0}	Ideology of an agent.	$I_{ai,t_0} \in (0,1)$
Area Ideology	I_{a,t_0}	Mean neighborhood ideology.	$I_{a,t_0} \in (0,1)$ $I_{a,t_0} \sim N(\mu^I_{at_0}, \sigma^I_{at_0})$ $\hat{\mu}^I_{at_0} = \sum_{i=1}^{N_a} \frac{I_{ia,t_0}}{N_a}$
Minoritypop	B_{a,t_0}	Neighborhood minority population	$B_{a,t_0} \geq 0$
SdMinoritypop	$\sigma^B_{t_0}$	Between-neighborhood sd of the minority group population.	$\sigma^B_{t_0} > 0$
Majoritypop	W_{a,t_0}	Neighorhood majority population	$W_{a,t_0} > B_{a,t_0} \forall a \in A$
SdMajoritypop	$\sigma^W_{t_0}$	Between-neighborhood sd of the majority group population	$\sigma^W_{t_0} > 0$

Table 2: Initial Parameter Values of `PolSegSim` Algorithm

Since the simulation is designed to reflect changes in real populations over time, two population dynamics are added to the model discussed above: (1) **population growth** - after each time period, there is a 1% increase in the majority group agent population and a $1/t^2$ "migration shock" increase in area minority population; (2) **generational replacement** - ideological preferences among new agents reflect those of the area after one round of moving.

The `PolSegSim` algorithm allows users to input five variables which determine initial characteristics of the `PolSegSim` universe. Table 2 describes these inputs which include: 1) the number of areas populated by agents; 2) average majority population of the areas; 3) majority population standard deviation between areas; 4) average minority population of the areas and finally; 5) minority standard deviation between areas. In the simulation, minority and majority populations are homogeneous within groups. The majority group, for example, could be thought of as being all white and the minority group all black.

Neighborhoods are first assigned two-dimensional spatial coordinates from a random uniform distribution and are then populated with a number of majority and minority group agents generated from a random normal distribution with means and standard deviations according to inputs 2,3,4 and 5 above. Initial ideology of each neighborhood I_{a,t_0} is a draw from a truncated random normal distribution with $N(\mu^I_{t_0} = 0.5, \sigma^I_{t_0} = 0.1)$. Minority and majority agent ideology *within* each area I_{ai,t_0} are, in turn, draws from another truncated random normal distribution[2] $N(\mu^I_{a,t_0} = I_{a,t_0}, \sigma^I_{a,t_0} = 0.1)$ with a mean equal to the randomly assigned area ideology. Average minority agent ideology within each area is assumed to be three standard deviations higher (+0.3) than average majority agent ideology. "Social distance" between groups are fixed for each agent at $D_i = 0.1$.

During each moving cycle, agents simultaneously relocate to areas when the expected utility of residing in their current area is less than their expected utility of moving: $EU^R_a < EU^R_{a'} - \delta_{a,a'}$. This generally occurs when the area minority population at any given time exceeds their diversity ideal point $m_{at} > m^*_i$ [3]. Once they have decided to move, they choose to move to an area which maximizes $EU^R_{a'} - \delta_{a,a'}$. This will be a candidate area which is both spatially closest to them as calculated by Euclidean coordinate distance and has a minority proportion closest to their diversity ideal point.

As mentioned above, to simulate real population dynamics, after each moving cycle a number of agents are added equivalent to 1% of the majority population and $1/t^2$ of the minority population. The $1/t^2$ increase in the minority population reflects migration shocks in which areas that originally had higher minority populations receive the greatest initial share of minority migration that decreases over time. New minority and majority agent ideologies are draws from a truncated random normal distribution whose mean and standard deviation are the mean and standard deviation of area ideology *after* a cycle of moving but *before* before the new agents are added.

Thus, for example, at time t agents decide to move. After they move, new average area ideology

[2]the distribution is truncated because $0 < I < 1$

[3]The only situation in which agents would not move when $m_{at} > m^*_i$ is if they happen to reside in a very isolated area where the Euclidean distance from their current location is greater than the utility gain they expect to gain in any new area, $\delta_{a,a'} > EU^R_{a'} - EU^R_a$

is computed $I_{a,t+\frac{1}{2}}$. New majority and minority agents are added to an area whose ideologies are a draw from a random normal distribution with a mean equivalent to $I_{a,t+\frac{1}{2}} = \sum_{i=1}^{N_{a,t+\frac{1}{2}}} \frac{I_{ai,t+\frac{1}{2}}}{N_{a,t+\frac{1}{2}}}$ and standard deviation equivalent to $\sigma^{I}_{a,t+\frac{1}{2}}$. Thus, new agents entering the area have ideologies in line with current area ideology after moving.

After each moving cycle, the simulation continues to run until the percent of the population that moves is below 1%. In the simulation conducted below, this occured after 151 moving cycles.