The Process of Ghetto Formation: Evidence from Chicago

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1 Introduction

Residential segregation along ethnic and racial lines is a fact of life in the US and in many other countries. A substantial body of literature documents the economic and social costs of segregation. Ethnic sorting retards inter-generational improvements for relatively disadvantaged groups[1], reduces empathetic connections between ethnic groups and therefore diminishes political support for redistribution (as in Cutler, Elmendorf and Zeckhauser (1993)) and increases statistical discrimination because whites, for example, end up relying more on stereotypes of blacks instead of actual experience (Wilson 1987).

While we know a great deal about the outcomes of residential segregation on society the mechanism which gives rise to ghettos[2] in the first place is less clear. What features make a residential area in the city particularly susceptible to ethnic

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[1]Borjas (1995) found that ethnicity has an external effect even after controlling for parental background and the socio-economic characteristics of a neighborhood. Neighborhood peers appear to affect the skills and norms of the young in particular, such as the probability of being involved in crime and the propensity of youths to be out of school or work (see, for example, Case and Katz (1991), and Glaeser, Sacerdote, and Scheinkman (1996)). Cutler and Glaeser (1997) compared the outcomes of blacks between cities and found that blacks in racially more segregated cities earn less income and are more likely to become single mothers or drop out of high school.

[2]The term "ghetto" is used nonpejoratively throughout the paper in order to denote a racially or ethnically segregated community.

transition? Can we explain why transition occurred so rapidly in North American cities and gave rise to the core of the modern black ghettos between the years 1900 and 1920? Finally, why are ghettos such as the one on the south side of Chicago so persistent over time?[3]

To better understand these questions this paper proposes and tests a simple model in which segregation can arise through the decentralized decisions of many residents who continuously move out of and into the city. A central parameter of the model is the extent to which residents interact with their neighbors. The model gives the most realistic predictions if residents interact locally, i.e. they weigh interaction with geographically close neighbors much more heavily than interaction with distant neighbors.

The empirical test of the model is conducted using a new dataset for the city of Chicago which tracks the ethnic composition of the city during the years of the 'Great Migration' between 1940 and 1960 on a block level. This allows me to estimate the critical 'radius of interaction' which turns out to be very low, about 150 meters (500 feet). This evidence suggests that residents indeed interact locally. Using the census data for 1910 and 1920, we also estimate the rate at which residents move into and out of locations to be approximately between two and three years, which provides a benchmark for the length of the time period in the theoretical model.

The paper is organized as follows. we introduce a simple general equilibrium model of the housing market in the next section. Section 4 discusses the evolution of different types of residential areas inside the city and emphasizes the distinction between local and global interaction. In section 5 we discuss the new dataset, and the estimation of the weighting function is reported in section 6.

2 The Housing Market

The city consists of an infinite number of locations $z_i \in R$ $(i = 1, 2, ..)$ which are distributed on a two-dimensional plane. Each location is populated by one of two types of agents: blacks and whites. Time is continuous and at each point in time the pattern of settlement is defined by a configuration $\eta : R \to \{0, 1\}$, where the values 0 and 1 denote a white and black resident respectively. The population of the city is continuously churned as residents move out and new agents move in. Agents move out at fixed rate 1 and the vacant apartments are immediately

[3] Cutler, Glaeser and Vigdor (1997) documented that the correlation across cities between segregation in 1890 and segregation in 1990 is as high as 50 percent. Residential segregation affected all ethnic minorities in the US to varying degrees. For African Americans, however, it is unique in its severity and persistence over several generations. Second- and third-generation non-black immigrants generally lived in much less segregated neighborhoods than their parents. For a good reference see chapter three in K. Taeuber and A. Taeuber (1965).

reallocated by a competitive housing market. There is obviously the need to match 'model time' to calendar time which will be done later using census data. Roughly speaking, one time period in the model corresponds to between two and three calendar years.

2.1 Housing Characteristics

At time t a location z_i is characterized by the set of parameters

$$Q_{i,t} = \left(X_{i,t}, q_{i,t}, \zeta_{b,i,t}, \zeta_{w,i,t}\right). \tag{1}$$

The rental price of the apartment at location z_i is $p_{i,t}$. The function $X_{i,t}(d) = X_{z_i,\eta_t}(d)$ captures the number of black residents who live a distance d away from location d at time t. The quality of the location is described by $q_{i,t}$, and $\zeta_{b,i,t}$ and $\zeta_{w,i,t}$ are location and time-specific shocks which affect the utility of black and white agents respectively.[4]

2.2 Preferences

Each newcomer into the housing market is described by her ethnicity (b or w), her preference for quality θ and her tolerance schedule $\alpha_b(x)$ and $\alpha_w(x)$ where

$$x_{i,t} = \int_0^\infty f(y)\, X_{i,t}(y)\, dy. \tag{2}$$

The black (white) tolerance schedule is increasing (decreasing) in x which is itself a summary measure for the distribution of black residents around location z_i and is increasing in X.

This particular functional form deserves some discussion. The statistic $x_{i,t}$ is a weighted sum of the number of black residents who live at various distances from location z_i and summarizes to what extent a resident at location z_i comes into contact with her black neighbors. We expect that residents pay more attention to neighbors close to them such that the function $f(d)$ is decreasing in d. We impose the following regularity condition such that expression 2 is well defined (for some $\epsilon > 0$):

$$\lim_{d\to\infty} d^{1+\epsilon} f(d) = 0 \tag{3}$$

Since the function $X_{i,t}$ can increase at most at rate d this regularity condition ensures that $x_{i,t}$ is finite. In this paper we will frequently focus on a particularly

[4] An important example for such an effect would be a near-by factory which employs a large number of African Americans who prefer to live close to the factory in order to minimize commuting time.

convenient weighting function which fully weighs all neighbors up to a distance r and attaches zero weight to everyone else. We will refer to the parameter r as the 'radius of interaction'.

It is analytically very convenient to make the tolerance schedule a function of $x_{i,t}$ rather than $X_{i,t}$. However, this simplifying assumption does not appear to be too strong since it only requires that the extent to which an agent at location z_i interacts with her neighbors is independent of her type.[5] The tolerance schedule then captures the degree to which agents like or dislike such contact.

The utility $U_{i,t}^w$ derived by a white resident at location z_i at time t can then be written as follows:

$$U_{\theta,\alpha_w,t}^w (Q_{i,t}) = \overline{U} - p_{i,t} - \theta q - \alpha_w (x_{i,t}) + \zeta_{w,i,t} \tag{4}$$

Similarly, the utility $U_{i,t}^w$ of a black resident is:

$$U_{\theta,\alpha_b,t}^b (Q_{i,t}) = \overline{U} - p_{i,t} - \theta q - \alpha_b (x_{i,t}) + \zeta_{b,i,t} \tag{5}$$

2.3 Market Equilibrium

At any point in time apartments are vacated because agents move out of the city. We assume that at time t vacant apartments with characteristics Q are distributed according to the density function $F(Q)$ such that $\int_Q dF = 1$. There is also an inflow of new agents which exactly matches the outflow of agents.[6] A share μ_t of these agents is white. Whites preferences for quality and neighbors of the opposite color are distributed according to $G^w(\theta, \alpha^w)$ while the preferences of blacks are distributed according to $G^b(\theta, \alpha^b)$. Each agent has the outside option of not moving into the city which gives her zero utility.

We can define equilibrium in the real estate market as follows:

Definition 1 *A market equilibrium consists of a pricing schedule $p^*(Q)$ and allocation rules $Q^w(\theta, \alpha^w)$ and $Q^b(\theta, \alpha^b)$ such that the following conditions are ful-*

[5] Interactions between residents are to a considerable extent random. For example, residents have little control over whom to meet when they wait at a bus stop or go shopping.

[6] This assumption is not essential but technically convenient because it fixes the distribution of agents with different tolerance schedules.

filled:

$$
\begin{aligned}
U^w_{\theta,\alpha_w,t}\left(Q^w\left(\theta,\alpha^w\right)\right) &\geq 0 && (6)\\
U^b_{\theta,\alpha_b,t}\left(Q^b\left(\theta,\alpha^b\right)\right) &\geq 0 && (7)\\
U^w_{\theta,\alpha_w,t}\left(Q^w\left(\theta,\alpha^w\right)\right) &\geq U^w_{\theta,\alpha_w,t}\left(Q'\right) \quad \textit{for all } Q' && (8)\\
U^b_{\theta,\alpha_b,t}\left(Q^b\left(\theta,\alpha^b\right)\right) &\geq U^b_{\theta,\alpha_b,t}\left(Q'\right) \quad \textit{for all } Q' && (9)\\
\mu\int_{\theta,\alpha^w} I\left(Q'=Q^w\left(\theta,\alpha^w\right)\right)dG^w\left(\theta,\alpha^w\right) &+ \\
(1-\mu)\int_{\theta,\alpha^b} I\left(Q'=Q^b\left(\theta,\alpha^b\right)\right)dG^b\left(\theta,\alpha^b\right) &= F\left(Q'\right) && (10)
\end{aligned}
$$

The first two conditions ensure that no incoming agent prefers her outside option of not moving to the city. Conditions 8 and 9 require agents to choose an optimal apartment given the price schedule. Finally, the last condition is an adding up constraint which ensures that the market for each type of location clears.

The next theorem guarantees that the housing market can always achieve at least one equilibrium.

Theorem 1 *For each F, μ, G^b and G^w there is an equilibrium satisfying the conditions in definition 1.*

Proof: see appendix

The next proposition captures an important monotonicity property of the market equilibrium:

Proposition 1 *For a given quality of housing q and fixed location shocks ζ_w and ζ_b the share of blacks at all locations with characteristics (x,q,ζ_b,ζ_w) is (weakly) increasing in x.*

Proof: Assume not. In this case there are black residents who strictly prefer some location z_i over z_j even though $x_j > x_i$. This can only be the case if $p^*_j > p^*_i$. But then the white residents who have chosen location z_j should strictly prefer z_i which is a contradiction. QED

Proposition 1 is important because it allows us to express the probability that some apartment with characteristics $Q_{i,t}$ is occupied by a new black agent in reduced form as

$$\text{Prob}\left(z_i\text{becomes black}\right) = H\left(F,G^b,G^w,q_{i,t},\zeta_{w,i,t},\zeta_{b,i,t},x_{i,t}\right) \tag{11}$$

such that $\frac{\partial H}{\partial x_{i,t}} > 0$. This equation will allow us to estimate the weighting function f from black data and decide to what extent interaction between neighbors is local rather than global.

3 Residential Areas

3.1 Geometry of Interaction

Up to now the geometry of the neighborhoods was left unspecified in the model. However, the dynamics of neighborhood transition depends very much on the way residents interact with one another. To analyze this question the city is subdivided into many large but finite 'residential areas' with n locations $R^A = \{z_1, .., z_n\}$. These locations form the vertices of a connected graph G defined through a symmetric neighborhood relation $G \subset R^A \times R^A$. Each resident z has a natural neighborhood $N(z) = \{z' \,|(z, z') \in G\}$. We restrict attention to three possible residential geometries. *Bounded neighborhoods* have a complete graph $G_B(n)$ such that individual neighborhoods coincide with the entire residential area. There are also two local geometries with easy intuitive representations: one-dimensional *streets* $G_S(n)$ and two-dimensional *inner-city areas* $G_C(n)$. On a street, residents are located on a circle with each agent having two neighbors on both sides. An inner-city area consists of a torus of size $\sqrt{n} \times \sqrt{n}$ such that each resident has four neighbors.[7] Streets have the lowest possible connectivity of a regular connected graph, while bounded neighborhoods have the highest. Inner-cities take an intermediate position.[8] Both streets and inner-cities have intuitively related graphs of higher order if we allow for individual neighborhoods of radius $r > 1$ in the standard Euclidean norm. These geometries are denoted with $G_S^r(n)$ and $G_C^r(n)$ respectively. Figure 1 shows both a street and an inner-city with respective neighborhoods of radius 2.

Agents attach unit weight to their neighbors and zero weight to non-neighbors. The weighting function f is then summarized by the 'radius of interaction' r. The parameter $x_{i,t}$ simply becomes the share of residents who are black and live at most a distance r away from location z_i. It will be convenient to define the share of white residents in the neighborhood of a location as $y_{i,t} = 1 - x_{i,t}$.

Note that for a large radius r the individual neighborhood of a resident comprises the entire residential area, and one again obtains the bounded neighborhood geometry.

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[7] Looking at a circle and a torus respectively avoids the need to specify boundary conditions.

[8] The *connectivity* $C(G)$ of a finite graph G is defined as the lowest upper bound for the minimum length path connecting any two residents on the graph, i.e. $C(G) = \max_{z_i, z_j \in R} d(z_i, z_j)$ where $d(z_i, z_j)$ denotes the length of the minimum length path connecting z_i and z_j. The smaller $C(G)$ the better connected the graph. Bounded neighborhoods have $C(G_B) = 1$, a street $G_S(n)$ has connectivity $\left[\frac{n+1}{2}\right]$ and the inner city $G_C(n)$ has an intermediate connectivity of $2\left[\frac{\sqrt{n}}{2}\right]$.

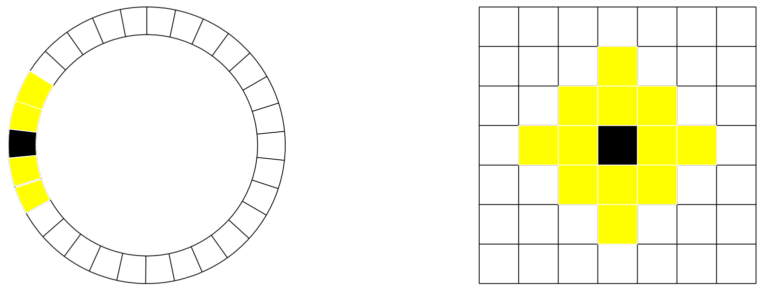

Figure 1: Street and inner-city geometries with individual neighborhoods of radius 2

3.2 Switching Functions

Incoming black and white residents do not like to be isolated at their new locations. All whites and all blacks have identical, group-specific tolerance levels α_w and α_b respectively. The tolerance level marks the maximum share of neighbors of a different ethnicity a prospective tenant is prepared to accept. We assume that $\frac{1}{2} \leq \alpha_i < 1$, i.e. agents are generally happy to live in integrated areas where both ethnic groups share the neighborhood equally. The tolerance schedules of black and white residents can then be written as follows:

$$\alpha^b(x) = \begin{cases} D & \text{if } y > \alpha^b \\ 0 & \text{otherwise} \end{cases} \tag{12}$$

$$\alpha^w(y) = \begin{cases} D & \text{if } x > \alpha^w \\ 0 & \text{otherwise} \end{cases} \tag{13}$$

$D > \overline{U}$ ensures that an incoming agent would rather not move into the city than pick a location where she would feel isolated.

There are therefore three types of vacancies in the city: at a share $F_{1,t}$ of all vacant location white residents feel isolated, at a share $F_{3,t}$ of vacant locations black residents feel isolated and a share $F_{2,t}$ of locations are acceptable to both. We can therefore calculate the probability λ_t that such a vacant location is occupied by a white resident as follows:

$$\lambda_t = \frac{\mu_t - F_{1,t}}{F_{2,t}} \tag{14}$$

All locations within the same residential area are assumed to have uniform quality q. The location specific shocks $\zeta_{b,i,t}$ and $\zeta_{w,i,t}$ are distributed such that they are both zero with probability $1-\epsilon$ and with equal probability $\frac{\epsilon}{2}$ either favor blacks or whites.

The evolution of a residential area can now be described by the probability that a vacant apartment 'switches' the color of its resident. The switching function

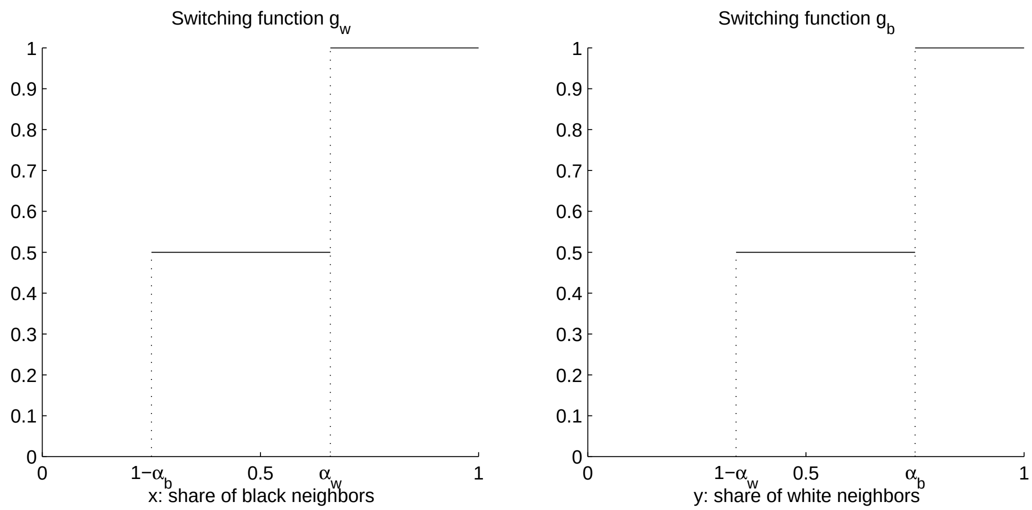

Figure 2: Switching functions for white/ black transition (g_w) and black/ white transition (g_b) for tolerance levels $\alpha_w = \frac{2}{3}$, $\alpha_b = \frac{3}{4}$, no location specific shocks ($\epsilon = 0$) and $\lambda_t = 0.5$

$g_w(x)$ $(g_b(x))$ denotes the probability that a vacant apartment switches from white to black (black to white):

$$g_w^\epsilon(x) = \begin{cases} \frac{\epsilon}{2} & \text{for } x < 1 - \alpha_b \\ 1 - \lambda_t & \text{for } 1 - \alpha_b \leq x \leq \alpha_w \\ 1 - \frac{\epsilon}{2} & \text{for } x > \alpha_w \end{cases} \tag{15}$$

$$g_b^\epsilon(y) = \begin{cases} \frac{\epsilon}{2} & \text{for } y < 1 - \alpha_w \\ \lambda_t & \text{for } 1 - \alpha_w \leq y \leq \alpha_b \\ 1 - \frac{\epsilon}{2} & \text{for } y > \alpha_b \end{cases} \tag{16}$$

Figure 2 illustrates the typical shape of the resulting switching functions in terms of the share of neighbors of the opposite color. Note, that the switching functions are increasing in the share of neighbors of the opposite color as required by proposition 1.

3.3 Characterizing the Dynamics

The evolution of a residential area can now be described by a continuous time Markov chain η_t on the space of configurations Z where η_0 is the initial configuration. It is easy to see that the model has a unique ergodic distribution μ_∞^ϵ over the set of configurations Z which describes the long-run behavior of the system.[9]

[9]Appendix **??** shows how to associate a Markov chain with the continuous time Markov process. The transition matrix P^ϵ of that chain is regular as $(P^\epsilon)^n$ has no non-zero entries - each

The long-run behavior of the system is therefore independent of the initial conditions which is in itself of little interest unless the ergodic distribution can be classified. Will the process spend most of its time around segregation configurations or around mixed configurations? How does the equilibrium depend on parameters of the model, i.e. the geometry, the tolerance levels of both groups and the balance in the housing market?

It is the easiest to characterize the ergodic distribution of the share of black residents in a residential area when its size n becomes large. The long-run share of black residents can be formally described as a scalar random variable $\tilde{X}_n^\epsilon$. The concept of 'clustering' helps us to understand its behavior.

Definition 2 *A sequence of random variables* $\left\{\tilde{X}_n\right\}$ *on the interval* $[0,1]$ *is said to cluster over the set* $I \subset [0,1]$ *if* $P\left(\tilde{X}_n \in I\right) \to 1$ *as* $n \to \infty$.

For example, we can interpret clustering of the residential neighborhood process on a street $G_S(n)$ around a black share close to 1 in the sense that large streets will become black ghettos in the long run.

Although clustering captures the long-run behavior of the process well, it does not tell us how fast a neighborhood I is reached over which the process clusters. Waiting times are a very useful measure for the speed of convergence to equilibrium, as was first emphasized by Ellison (1993). With respect to clustering, the relevant measure is the maximum waiting time $W(n,I)$ in which the process reaches I for the first time starting from any initial configuration:

$$W(n,I) = \max_{\zeta \in Z} \left[E\left(\min t \,|X(\eta_t) \in I \quad \text{and} \quad \eta_0 = \zeta\,\right)\right] \tag{17}$$

$X(\eta)$ here denotes the share of black residents in configuration η. Unless that waiting time remains bounded as n increases, the evolution of the process will be determined by the initial conditions rather than the long-run equilibrium.

4 The Dynamics of Neighborhood Transition

To analyze how a city responds to changes in the share of black newcomers to the city (i.e. changes in μ_t) it is necessary to examine how different types of residential subareas of the city are affected. Note that changes in μ_t translate into monotonic changes in the parameter λ_t because the variables F_i are stock variables which change only slowly.

configuration of the geometry can be reached after n steps with positive probability (Kemeny and Snell 1960, Theorem 4.1.2). Therefore the process is ergodic (Kemeny and Snell 1960, Theorem 4.1.4).

This section looks at two questions which are of particular interest. First of all, how susceptible is an initially all-white residential area to the 'invasion' by blacks as the balance in the housing market changes (λ_t decreases below $\frac{1}{2}$). Second, how stable is such an area after transition has occurred? To make this question interesting it is assumed from now on that blacks have a higher tolerance level than whites such that 'white ghettos' are less stable than 'black ghettos'.[10] The first question sheds light on what types of residential areas are most likely to turn into a ghetto in response to an influx of blacks into the housing market. The second question addresses the stability of black ghettos.

4.1 Bounded Neighborhoods

All-white neighborhoods turn out to be very stable even if the influx of blacks into the housing market leads to a substantial decrease in λ_t. The intuition is very simple: since blacks feel isolated in such an area only a small number of blacks will move into the neighborhood in response to random location-specific shocks. Unless these shocks (captured by ϵ) are very frequent and large, the share of blacks is unlikely to reach the threshold share $1 - \alpha_b$ necessary for the majority of black newcomers to feel comfortable at this location.

The next theorem shows that eventually such an area will transit and become permanently black in the long-run due to a series of random shocks. However, the waiting time for this transition increases exponentially with the size of the residential area.

Theorem 2 *Consider a residential neighborhood process on $G_B(n)$ with initially no black residents. Blacks are assumed to dominate the housing market, i.e. $\lambda_t < \frac{1}{2}$.*

1. *(Long-run behavior) The process clusters around any neighborhood of a black share of $x^* = 1 - \frac{\epsilon}{2}$.*

2. *(Medium-run behavior) The process reaches a neighborhood of the long-run black share $x^* = 1 - \frac{\epsilon}{2}$ after a waiting time of the order A^n with $A > 1$.*

3. *(Stability) After having become a black ghetto the ghetto will break up in response to an influx of whites into the market ($\lambda_t > \frac{1}{2}$) only after a waiting time of order B^n with $B > 1$.*

Proof: see appendix

[10] Empirical studies such as the General Society Survey reveal that whites discriminate more strongly than blacks (see Cutler, Glaeser and Vigdor (1997)).

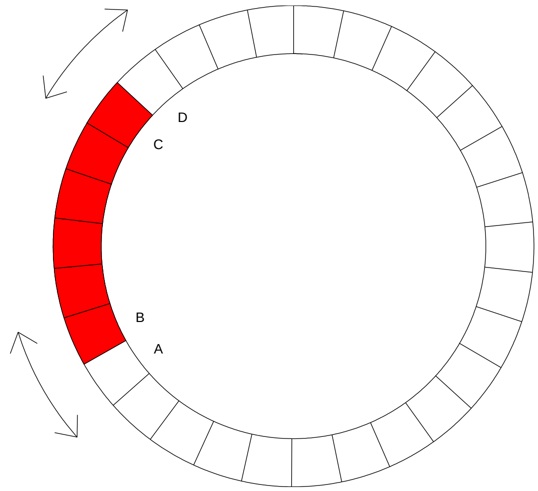

Figure 3: All-white street $G_S^{r=1}(n)$ with a single black cluster: if residents A to D move, members of both ethnic groups are equally interested in vacant apartments.

4.2 Rapid Segregation on Streets

While bounded neighborhoods respond very slowly to changes in the housing market streets behave radically different. This can be easily seen by looking at the evolution of a predominantly white street. The intuition is most clear for a simple street $G_S^{r=1}(n)$ with radius of interaction $r = 1$ although the argument is readily generalized to higher-order streets.

Such a street will occasionally face invasion by small black clusters due to location-specific shocks as illustrated in figure 3. Under the assumption that such shocks are rare (i.e. ϵ is small) vacant apartments *inside* of black and white clusters are almost always taken only by black and white residents respectively because other agents would feel isolated. However, if apartments at the boundary of the cluster become vacant (such as A or D) apartment seekers from both ethnic groups will be interested in them. The boundaries of the black cluster therefore move according to a random walk with absorption (the process ends if one of the clusters vanishes). The drift of this random walk is solely determined by the composition of the housing market, i.e. λ_t. As blacks dominate the housing market the black cluster is likely to grow rather than shrink. Standard probability theory tells us that the probability of the black cluster taking over the entire street is bounded away from zero even for very large streets. Moreover, the waiting time for this transition is of the order of n.[11] As the expected number of black seed

[11] These are standard results from random walk theory (Stirzaker 1994, section 5.6).

clusters also increases linearly with the size of the street the waiting time for a transition to a black ghetto can even be shown to be finite and independent of the size of the street.

Using the reverse argument the resulting black ghetto is stable *as long as* blacks dominate the housing market (i.e. $\lambda_t < \frac{1}{2}$). Although occasional white clusters will invade the ghetto they are more likely to shrink rather than expand and will therefore die out with a probability approaching 1 for large streets. However, the stability of streets hinges exclusively on the black dominance of the housing market. As soon as whites dominate the housing market again the ghetto will dissolve rapidly.

The next theorem makes this intuitive argument precise and generalizes it for streets with radius of interaction $r > 1$.

Theorem 3 *Consider a residential neighborhood process on a street $G_S^r(n)$ with initially no black residents.*

1. *(Long-run behavior) There exists a critical value $0 < \hat{\lambda}(r, \alpha_w, \alpha_b) \leq< 1$ such that the street becomes a black ghetto in the long run if blacks sufficiently dominate the housing market ($\lambda < \hat{\lambda}$), i.e. the process clusters on the interval $[x_b^*(\epsilon), 1]$ with $\lim_{\epsilon \to 0} x_b^*(\epsilon) = 1$.*

2. *(Medium-run behavior) The process reaches any neighborhood of its long-run equilibrium in finite time, i.e. the waiting time is of the order $O(1)$.*

3. *(Stability) There exists a critical value $0 < \hat{\lambda}(r, \alpha_w, \alpha_b) \leq< 1$ such that if whites sufficiently dominate the housing market and $\lambda_t > \tilde{\hat{\lambda}}$ the black ghetto will dissolve after a finite waiting time of order $O(1)$.*

Proof: see appendix

4.3 Rapid Segregation and Ghetto Persistence in Inner-City Areas

Inner-city areas are an interesting 'hybrid' geometries because in some way they behave both like streets *and* bounded neighborhoods. If blacks are sufficiently tolerant a predominantly white residential area can rapidly turn into a ghetto by the same contagious mechanism as observed on streets. However, if blacks are sufficiently intolerant the process tends to become uni-directional. The black ghetto will break up less easily than a street ghetto when blacks cease to dominate the housing market.

The following condition on group tolerance levels is sufficient to generate this asymmetry and is assumed to hold from now on for inner-cities.

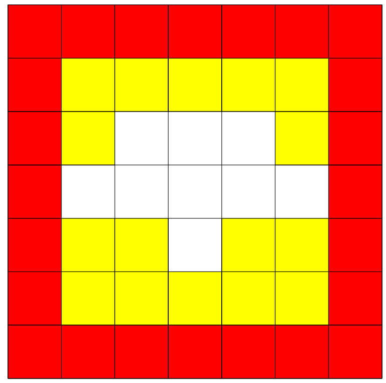

Figure 4: Isolated white cluster in an inner-city area $G_C^{r=1}(49)$. The cluster can be covered by a 5×5 rectangle (lightly shaded).

Assumption 1 *Blacks can tolerate whites constituting 75 percent or more of their neighbors ($\alpha_b \geq \frac{3}{4}$), while whites can only tolerate blacks making up slightly more than 50 percent of their neighbors ($\alpha_w < \frac{1}{2} + \frac{r}{m}$).*[12]

This assumption ensures that a black cluster inside a predominantly white neighborhood can expand rapidly if blacks dominate the housing market sufficiently and turn it into a stable ghetto. The first two parts of theorem 3 concerning the medium- and long-run evolution of the residential area in response to an influx of blacks into the housing market therefore carries directly over from streets to inner-cities.

Theorem 4 *Consider a residential neighborhood process on an inner-city $G_C^r(n)$ with initially no black residents.*

1. *(Long-run behavior) There exists a critical value $0 < \hat{\lambda}(r, \alpha_w, \alpha_b) \leq< 1$ such that the street becomes a black ghetto in the long run if blacks sufficiently dominate the housing market ($\lambda < \hat{\lambda}$), i.e. the process clusters on the interval $[x_b^*(\epsilon), 1]$ with $\lim_{\epsilon \to 0} x_b^*(\epsilon) = 1$.*

2. *(Medium-run behavior) The process reaches any neighborhood of its long-run equilibrium in finite time, i.e. the waiting time is of the order $O(1)$.*

Proof: see appendix

[12]The size of an individual neighborhood on the inner-city area $G_C^r(n)$ is m, i.e. $|N(z)| = m$. If the radius of interaction is $r = 1$ ($r = 2$) we have $m = 4$ ($m = 12$) and whites can tolerate at most two (seven) black neighbors.

However, ghettoization tends to be uni-directional and significantly more stable than on streets even when blacks cease to dominate the housing market. The reason is that small random clusters of white residents can no longer expand as easily as clusters of black residents inside a predominantly white inner-city area. Figure 4 shows such a white cluster referred to as 'small' if it is "encircled" by black residents, i.e. it does not span the residential area.[13] Such a cluster can be covered by a rectangle which is convex in the two-dimensional geometry. For this reason, each apartment vacated by a black resident along the boundary of this rectangle has more black than white neighbors. More precisely, a vacant apartment outside the rectangle has a black neighborhood share of at least $\frac{1}{2}+\frac{r}{m}$ which exceeds the tolerance level of whites. Close to the corners of the rectangle the black share even approaches 75 percent. Therefore, the white cluster can never expand beyond the rectangle unless tolerant house-seekers move in along the boundaries. Incoming black agents, on the other hand, can easily invade the white cluster. Obviously, the cluster has to die out in this environment and can never take over the inner-city regardless of the balance in the housing market as the following lemma shows.

Lemma 1 *Under assumption 1 and in the absence of location specific shocks ($\epsilon = 0$) an "encircled" white cluster in an inner-city area $G_C^r(n)$ will die out almost surely for any balance in the housing market $0 < \lambda_t < 1$.*

Proof: see appendix

A white cluster can therefore only survive if it is 'large' and no longer encircled. The stable 'large' cluster shown in figure 5 serves as an example.

The minimum number of completely tolerant house-seekers who have to move into the black ghetto in order to form a non-encircled white cluster grows with $\sqrt{n}$. On streets, on the other hand, the minimally stable white cluster has only size $[2r(1-\alpha_w)]^+$, which does not depend on the size of the street. Intuitively, it should therefore take longer to leave a black inner-city ghetto than leave a black street ghetto if the share ϵ of tolerant agents is small. The next theorem confirms this intuition by comparing the waiting times until the share of white residents exceeds some share $\delta < 1$ in an inner-city and on a street *of the same size n.*

Theorem 5 *Given an inner-city area $G_C^r(n)$ and a street $G_S^r(n)$ are of equal size n, Assumption 1 on the black and white tolerance levels holds, and the share ϵ of tolerant agents is small, the waiting time until the share of whites exceeds δ satisfies $W_C(n,[0,1-\delta]) \geq \epsilon^{-\left[\frac{\sqrt{n}}{r+1}\right]}$ in the inner-city area and $W_S(n,[0,1-\delta]) \sim \epsilon^{-[2r(1-\alpha_w)]^+}$ on the street.*

[13] Formally, a cluster of residents is said to be "encircled" in an inner-city with radius of interaction r if the cluster can be covered by a rectangle with width and length not exceeding $\sqrt{n}-1-r$. This ensures that the dynamics of the process along the boundary is not influenced by the finiteness of the inner-city.

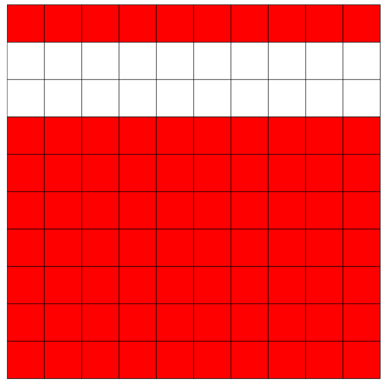

Figure 5: 'Large' non-encircled white cluster in an inner-city with radius of interaction $r = 1$

Proof: see appendix

The ratio $\frac{W_C(n,[0,1-\delta])}{W_S(n,[0,1-\delta])}$ of the waiting times to leave an inner-city and street ghetto respectively, can become arbitrarily large if there are few tolerant house-seekers and the size of the residential area is large. The "encircling phenomenon" therefore lends persistence to black inner-city ghettos, and makes the ghetto formation process uni-directional.

5 The Data

5.1 Problems with Existing Datasets

Testing any micro model of ghetto formation is difficult with existing data sets. A suitable data set has to satisfy at least three properties. First of all, it should either cover the years 1900-1920 during which the core of the American ghetto formed in most US cities, or the period of the 'Great Migration' from 1940-1960 when the ghettoes consolidated and expanded rapidly. Second, the data should be disaggregated below the tract level in order to estimate the radius of interaction between residents which is a crucial primitive of the model. As shown in the previous section the evolution of a residential area depends on its geometry of interaction. Finally, the data has to be geocoded in order to calculate the precise geographic distance of each location from one another.

None of the existing datasets meet all of these three criteria. The Bureau of the Census did not publish data below the ward level before 1940. Therefore, data for the years 1900-1920 has to be extracted from the original census enumerations which are available on microfilm. Starting from the 1940 census the population census did publish tract level data which has been computerized and collected in the Elizabeth Mullen Bogue Files (Bogue 2000). Also starting in 1940 the new census of housing started to publish disaggregated data on the block level for most metropolitan areas. Block data is far more useful for testing the model than tract data: in 1940 Chicago, for example, the median city block covered an area of only 20,500 square meters ($\approx 143 \times 143$ meters) while each tract consists of 18 blocks on average. To the best of our knowledge none of this data has been computerized so far. The IPUMS microdata series (Ruggles and et. al. 1997) is not suitable for testing models of segregation because the sampling procedure samples only two to three families for each enumeration district in the years 1900-1920 (similar sampling rates apply for the years 1940-1960). Since each 1910 ED consists of two to three 1940 blocks the IPUMS series do not allow us to calculate the composition of the neighborhood of each agent in the series.

The most serious limitation for testing micro-models of segregation has been the lack of geocoded data even for the tract level before 1980. In that year the Bureau of the Census began to report the GPS coordinates of the boundary of each census block and tract. Starting with the 1990 census this information was made available to the public through the TIGER files.

5.2 Collection of Chicago Block Data from 1940-1960

For testing the model a new data set has been constructed based on the published block statistics of the Census of Population and Housing for the city of Chicago for the years 1940-1960. The Bureau of the Census published both the raw tabulated data for each of the roughly 17,000 blocks of the city and the maps which were used by the enumerators.

The data was scanned and computerized using Optical Character Recognition (OCR). The accuracy of this technology for the present dataset is at least 99 percent, i.e. less than 1 percent of the numerical characters have been omitted or misinterpreted by the program.[14]

The geo-coding of the blocks and tracts of the city was accomplished with the help of the 1990 TIGER files. These files contain the coordinates of the boundaries of all blocks and tracts of the city of Chicago. Since the basic street grid of Chicago did not change much throughout the 20th century about 90 percent of all 1940-1960 blocks can be matched directly to 1990 blocks. Unfortunately, this mapping cannot be accomplished without using the original maps. Tracts are typically chosen in order to minimize changes over time. Nevertheless, tracts were subdivided and

[14]The scanning and OCR was performed by the company PrimeOCR using their own software. The main advantage of OCR rather than punching in the data manually are scale economies: the OCR software has to be customized to the particular formatting of each census year at some fixed cost. The marginal cost of scanning the data of a particular area is extremely low.

recombined in such a way that the number of tracts decreased from 919 in 1940 to 855 in 1960. Moreover, the census used a different block numbering for each census year even when the boundary of the corresponding tract (and its number) did not change.

To facilitate mapping the 1940-60 blocks into 1990 blocks a MATLAB program was developed and used by the research assistants. About 90 percent of all 1940-60 blocks could be matched directly to 1990 blocks. In order to properly match the remaining 10 percent additional lines were manually added to the TIGER files.[15]

5.3 Description of the Block Data

Table 1 contains the list of variables derived from the Census publications for the year 1940. The 1950 and 1960 Census data was mapped into the set of variables as shown in tables 2 and 3.

The variables are subdivided into six subsets. The location variables define the precise coordinates and labelling of a block in a census year. Each block lies within one of the 75 PLACES of Chicago and has a TRACT and a BLOCK label. The center of mass of each block is defined by (CENTERX,CENTERY) using kilometers as the unit of distance. The area of a block is given in AREA in terms of square meters. The link variables NEXTTRACT and NEXTBLOCK provide a way to link each 1940 (1950) block to the corresponding 1950 (1960) block and therefore construct a time series for each geographic location.

The quality variables for housing in a block include GROUP (set to 1 if more than 10 percent of all housing units are group quarters), STRUCTURES (number of buildings in a block), UNITS (number of apartments), AGE19xx (number of apartments built between the years 19xx and 19(xx+10)), AGE1800 (apartments built before 1800), BATH (share of apartment with bath and toilet), NOBATH (share of apartments with toilet but no bath).

Price variables include RENT in Dollars and VALUE (thousands of Dollars). MORTGAGE indicates the share of OWNERS who have a mortgage on their apartment.

The most important demographic variable is NONWHITE which indicates the number of heads of households who are non-white (the definition of non-white includes American Indians but not Mexican Americans). BLACKSHARE is the share of black families in the block and imputed by dividing NONWHITES through the sum of OWNERS and TENANTS. TENANTS and OWNERS indicates the number of heads of households who own/ rent their housing unit, respectively. CROWDED indicates the number of apartment in which more than 1.51 persons

[15]Geo-coding a city of the size of Chicago on the block level using the MATLAB software takes about 60 hours. The software is freely available from the author upon request.

live in each room. Figures 7, 8 and 9 illustrate the changes in the ethnic composition of Chicago for each of the three census years.

X0 to X10 captures the composition of the neighborhood in a 1500 meter radius from the center of the block. Xd is defined as the number of black households who live exactly a distance $d \times 150$ meters away from the center of the block divided by the total number of households within the 1500 meter radius.

5.4 Collection of Micro Household Data for Chicago 1910-1920

The block data is not helpful in estimating entry and exit rates of residents into and within Chicago. For example, if a specific block has 100 white families both in 1940 and 1950 we do not know if the 1950 families are the same families as the 1940 ones. To explore this question one has to go back to the original census schedules as they were compiled by the enumerator.

For that purpose, a specific enumeration district (number 403) was chosen in the 1910 census. The enumeration district lies to the west of downtown Chicago and is a transition area as it turns from predominantly white in 1900/10 to predominantly black in 1920. The ED has 177 white and 32 black families in 1910, and 32 white and 118 black families in 1910. Only 7 of the surnames of white families in 1920 can be matched to 1910 and none of the black families can be matched.

6 Estimation

In order to apply the theory two primitives of the model have to be estimated. First of all, it is important to find out whether residents interact across large distances or locally. In the former case the bounded neighborhood model with global interaction is adequate. However, if interaction is local a street or an inner-city geometry is needed to describe the evolution of neighborhoods. In order to distinguish between local and global interaction the weighting function f has to be estimated as defined in equation 2:

$$x_{i,t} = \int_0^\infty f(y) X_{i,t}(y)\, dy. \tag{2}$$

If the weighting function decays only slowly a global interaction interpretation is adequate. If it decays fast the local interaction model applies. The second primitive of the model is an estimate for the rate at which residents exit residential areas, and new residents arrive. This parameter is necessary to scale the dynamic model and compare Monte Carlo simulations to the actual evolution of neighborhoods.

6.1 Estimating the Radius of Interaction

The weighting function f can be extracted by estimating the reduced form equation 11:

$$\text{Prob}\left(z_i \text{becomes black}\right) = H\left(F, G^b, G^w, q_{i,t}, \zeta_{w,i,t}, \zeta_{b,i,t}, x_{i,t}\right) \tag{11}$$

As was shown in proposition 1 the probability of a location being occupied by a black agent is monotonic in the level of interaction with black neighbors at that location (controlling for quality of the apartment), i.e. $\frac{\partial H}{\partial x_{i,t}} > 0$.

More precisely, we will estimate the following version of equation 11:

$$G_{i,t} = \alpha_t Q_{i,t} + \beta_t x_{i,t} + \gamma_t x_{i,t}^2 + \epsilon_{i,t} \tag{18}$$

The left-hand side variable $G_{i,t}$ denotes the growth rate of black residents in block i between time t and $t+1$ which is defined as:

$$G_{i,t} = \log\left(1 + NONWHITE_{i,t+1}\right) - \log\left(1 + NONWHITE_{i,t+1}\right) \tag{19}$$

$Q_{i,t}$ is a set of quality variables which include BATH, NOBATH, DENSITY (defined as STRUCTURES/UNITS), AGE1930, AGE1920, AGE1900 and AGE1800. Finally $x_{i,t}$ is parameterized as follows:

$$x_{i,t} = \sum_{d=0}^{10} \delta_{d,t} Xd \tag{20}$$

We normalize $\delta_{0,t} = 1$. The sequence of weights $\hat{\delta}_{i,t}$ are the only estimates we are interested in because they capture the rate at which interaction between residents decays.

Equation 18 is estimated for both the years 1940 and 1950 separately. Combining the data in a single regression does not make much sense because the estimates for α, β and γ are likely to be time-dependent since they are derived from the reduced form. Moreover, the weighting function f is likely to be time-dependent as well if the distribution of racial tolerance levels changes over time.

The results of the 1940 and 1950 regressions are shown in table 4. Although the reduced form coefficients on the quality variables are hard to interpret they look reasonable: blocks with a greater share of older buildings and apartments without toilets or bathrooms are more likely to see an increase in the share of black households. Furthermore, blocks with high DENSITY are more likely to turn black. Low-density blocks had few structures and many housing units which presumably indicates the presence of apartment buildings which were of higher quality and less affordable for black residents. The estimated coefficient on $\hat{x}_{i,t}$ is positive and strongly significant as required by proposition 1.

More interesting are the estimates $\hat{\delta}$ of the weighting function f which are shown in table 5 for the years 1940 and 1950. The weighting functions for both years are also plotted in figure 6 (including 95 percent confidence intervals). It is obvious that the weighting function is decreasing fast and is indistinguishable from zero for most distances greater than 500 meters.

Using GMM we can fit a simple exponential decay function of the form $\delta_{d,t} = \exp(-\theta d)$ to our estimates of the weights and get $\hat{\theta}_{1940} = -1.55$ (0.76) and $\hat{\theta}_{1950} = -1.65$ (0.66). Using an average decay coefficient $\theta = 1.6$ we can estimate the 'radius of interaction' r through the following back of the envelope calculation:

$$r^2\pi = \int_0^\infty 2z\pi \exp(-\theta z)\, dz \tag{21}$$

$$r^2 = \frac{2}{\theta^2} \tag{22}$$

This translates into $r \approx 0.88$ or $r \approx 133$ meters since the unit of distance is assumed to be 150 meters. Therefore, interaction between residents seems to be highly local.

6.2 Problems with Estimation

There are several problems with estimating the weighting function f through the reduced form equation 11. First of all, regressing the growth rate of the black population in a tract during the 10 year interval between two consecutive census years on the ethnic composition of the neighborhood in the base year is not strictly consistent with the theory because most of the incoming black residents will move in at random times during that 10 year period. However, during these intermediate years the neighborhood composition changes as well. Therefore, using the ethnic composition of the neighborhood in the base year introduces a bias in the estimation of the weighting function. Fortunately, this bias goes in the right direction since we should find less evidence for local interaction rather than more.

A more serious problem is that the error term $\epsilon_{i,t}$ in the estimated equation 18 is likely to be positively correlated with the right-hand regressors $X_{d,t}$. This error is supposed to soak up all location and time-specific shocks at location $z_{i,t}$. However, these shocks are likely to be both spatially correlated and serially correlated over time. Therefore, a positive shock in 1940, for example, which makes a location more attractive to black residents is likely to have made both this and surrounding locations more attractive to blacks in 1930. Therefore, the ethnic composition $X_{d,t}$ at 1940 will be positively correlated with the error term in 1940. If the spatial correlation of the error terms decreases fast enough, the resulting bias will go in the wrong direction: we would estimate a weighting function which is too local.

6.3 Estimating the Moving Rate

The moving rate can be very easily estimated from the micro household data which was collected for the years 1910-1920. Since only seven out of 199 families stay in the ED after 10 years and the survival function has the form $\exp(-gt)$ where g is the rate with which agents move in and out and t is calendar time we obtain $g \approx -3.35$. This implies that one time period in the model corresponds to about 2-3 calendar years.

References

Bogue, D. (2000): "CENSUS TRACT DATA, 1940-1960: ELIZABETH MULLEN BOGUE FILE," ICPSR version. University of Chicago. Community and Family Study Center. 1975 (producer), Inter-university Consortium for Political and Social Research (distributor).

Borjas, G. J. (1995): "Ethnicity, Neighborhoods, and Human-Capital Externalities," *American Economic Review*, 85, 365–389.

Case, A. C., and L. F. Katz (1991): "The Company You Keep: The Effects of Family and Neighborhood on Disadvantaged Youths," Working Paper 3705, National Bureau of Economic Research.

Cutler, D., D. Elmendorf, and R. Zeckhauser (1993): "Demographic Characteristics and the Public Bundle," in *On the Role of Budgetary Policy during Demogrpahic Changes*, ed. by B. Wolfe. International Institute of Public Finance, Paris, France.

Cutler, D. M., and E. L. Glaeser (1997): "Are Ghettos Good or Bad?," *Quaterly Journal of Economics*, 112, 827–872.

Cutler, D. M., E. L. Glaeser, and J. L. Vigdor (1997): "The Rise and Decline of the American Ghetto," Working Paper 5881, National Bureau of Economic Research.

Ellison, G. (1993): "Learning, Local Interaction, and Coordination," *Econometrica*, 61, 1047–1071.

Glaeser, E. L., B. Sacerdote, and J. A. Scheinkman (1996): "Crime and Social Interactions," *Quaterly Journal of Economics*, 111, 507–48.

Kemeny, J. C., and J. L. Snell (1960): *Finite Markov Chains*. D. Van Nostrand Company, Princeton.

Ruggles, S., and M. S. et. al. (1997): "Integrated Public Use Microdata Series: Version 2.0," available at http://www.ipums.umn.edu., Minneapolis: Historical Census Projects.

Stirzaker, D. (1994): *Elementary Probability*. Cambridge University Press, Cambridge.

Taeuber, K. E., and A. F. Taeuber (1965): *Negroes in Cities*. Aldine Publishing Company, Chicago.

Wilson, W. J. (1987): *The Truly Disadvantaged: The Inner City, the Underclass, and Public Policy*. University of Chicago Press, Chicago, IL.

Table 1: Variable Means and Standard Variations for 1940 Chicago data

Variable	Mean	SD	Variable	Mean	SD
Location ID			*Demographic Variables*		
PLACE	35.61	22.56	NONWHITE	4.70	27.07
TRACT	467.20	291.32	BLACKSHARE	0.054	0.210
BLOCK	15.38	14.40	TENANT	46.70	96.72
CENTERX	47.36	5.12	OWNER	14.82	15.39
CENTERY	42.53	10.46	CROWDED	0.099	0.236
AREA	24949	60365	*Neighborhood Composition*		
Quality Variables			X0	0.00010	0.00048
GROUP	0.05	0.23	X1	0.00118	0.00485
STRUCTURES	24.73	20.31	X2	0.00234	0.00906
UNITS	64.25	101.68	X3	0.00343	0.01261
AGE1930	1.72	9.57	X4	0.00438	0.01501
AGE1920	18.53	39.90	X5	0.00530	0.01697
AGE1900	25.19	60.54	X6	0.00635	0.01911
AGE1800	17.00	46.47	X7	0.00745	0.02122
NOBATH	0.18	0.30	X8	0.00857	0.02349
BATH	0.76	0.32	X9	0.00968	0.02579
Price Variables			X10	0.00531	0.01437
RENT	32.79	13.45	*Link Variables*		
VALUE	NA	NA	NEXTTRACT	464.80	290.74
MORTGAGE	0.61	0.28	NEXTBLOCK	16.25	15.64

N=16204

The Census divides Chicago into 75 1990 PLACES. In 1940 Chicago had 919 TRACTs which were further subdivided into BLOCKs. The center of each block is (CENTERX,CENTERY) using kilometers as the unit of distance. The area of a block is AREA (in square meters). The quality variables for housing in a block include GROUP (set to 1 if more than 10 percent of all housing units are group quarters), STRUCTURES (number of buildings in a block), UNITS (number of apartments), AGE19xx (number of apartments built between the years 19xx and 19(xx+10)), AGE1800 (apartments built before 1800), BATH (share of apartment with bath and toilet), NOBATH (share of apartments with toilet but no bath). Price variables include RENT in Dollars and VALUE (thousands of Dollars). MORTGAGE indicates the share of OWNERS who have a mortgage on their apartment. NONWHITE indicates the number of heads of households who are non-white which includes American Indian but not Mexican Americans. BLACKSHARE is the share of black families in the block and imputed by dividing NONWHITES through the sum of OWNERS and TENANTS. TENANTS and OWNERS indicates the number of heads of households who own/ rent their housing unit, respectively. CROWDED indicates the number of apartment in which more than 1.51 persons live in each room. X0 to X10 captures the composition of the neighborhood in a 1500 meter radius from the center of the block. Xd is defined as the number of black households who live exactly a distance $d \times 150$ meters away from the center of the block divided by the total number of households within the 1500 meter radius. NEXTTRACT and NEXTBLOCK link the 1940 block to the next census year.

Table 2: Variable Means and Standard Variations for 1950 Chicago data

Variable	Mean	SD	Variable	Mean	SD
Location ID			*Demographic Variables*		
PLACE	36.08	22.82	NONWHITE	7.72	35.39
TRACT	471.13	292.63	BLACKSHARE	0.076	0.241
BLOCK	16.72	16.42	TENANT	46.57	84.55
CENTERX	48.31	5.18	OWNER	21.56	26.21
CENTERY	42.32	10.65	CROWDED	0.078	0.201
AREA	24543	51695	*Neighborhood Composition*		
Quality Variables			X0	0.00015	0.00060
GROUP	0.04	0.19	X1	0.00179	0.00635
STRUCTURES	25.60	20.43	X2	0.00360	0.01210
UNITS	67.48	88.79	X3	0.00520	0.01608
AGE1930	1.83	9.92	X4	0.00656	0.01850
AGE1920	19.31	42.04	X5	0.00789	0.02059
AGE1900	26.05	61.53	X6	0.00945	0.02321
AGE1800	17.66	47.37	X7	0.01104	0.02564
NOBATH	0.17	0.28	X8	0.01268	0.02830
BATH	0.79	0.32	X9	0.01433	0.03134
Price Variables			X10	0.00783	0.01748
RENT	42.46	13.45	*Link Variables*		
VALUE	11.19	4.07	NEXTTRACT	443.51	267.20
MORTGAGE	0.60	0.27	NEXTBLOCK	16.21	14.88

N=16688

The variable definitions are identical to the ones used for 1940 (see table 1) with some important exceptions. There is no information on the share of mortgaged apartments, the presence of group quarters, number of structures in a block and the age distribution of apartments available for the 1950 census. These variables were constructed by mapping the 1950 blocks to 1940 blocks and use the information available for that year.

Table 3: Variable Means and Standard Variations for 1960 Chicago data

Variable	Mean	SD	Variable	Mean	SD
Location ID			*Demographic Variables*		
PLACE	36.98	23.22	NONWHITE	13.50	49.08
TRACT	452.88	269.19	BLACKSHARE	0.135	0.317
BLOCK	17.06	16.26	TENANT	44.14	73.65
CENTERX	48.16	5.24	OWNER	22.97	14.72
CENTERY	42.00	10.87	CROWDED	0.131	0.193
AREA	23719	38139	*Neighborhood Composition*		
Quality Variables			X0	0.00026	0.00078
GROUP	NA		X1	0.00316	0.00833
STRUCTURES	NA		X2	0.00640	0.01603
UNITS	70.80	82.37	X3	0.00937	0.02168
AGE1930	NA		X4	0.01189	0.02554
AGE1920	NA		X5	0.01432	0.02901
AGE1900	NA		X6	0.01723	0.03298
AGE1800	NA		X7	0.02018	0.03690
NOBATH	0.067	0.155	X8	0.02306	0.04073
BATH	0.88	0.24	X9	0.02567	0.04407
Price Variables			X10	0.01424	0.02501
RENT	77.36	21.62	*Link Variables*		
VALUE	17.66	4.98	NEXTTRACT	NA	
MORTGAGE	NA		NEXTBLOCK	NA	

N=17113

The variable definitions are identical to the ones used for 1940 (see table 1) with one exception: the variable CROWDED now indicates the number of apartment in which 1.01 or more persons live in each room. There is no information on the share of mortgaged apartments, the presence of group quarters, number of structures in a block and the age distribution of apartments available for the 1960 census. Many tract boundaries changed between 1950 and 1960 reducing the number of tracts to 855 from 919 in 1940 and 916 in 1950.

Table 4: Estimated effects of housing quality and extent of interaction with black neighbors on growth rate of black population (see reduced form equation 11).

Variable	Year 1940	Year 1950
BATH	-0.090	0.344
	(0.036**)	(0.129***)
NOBATH	0.140	0.135
	(0.043***)	(0.157)
DENSITY	-0.086	-0.058
	(0.010***)	(0.015***)
AGE1930	-0.0008	0.0028
	(0.0005)	(0.0008***)
AGE1920	-0.000	0.0018
	(0.0001)	(0.0002***)
AGE1900	0.0013	0.0021
	(0.0001***)	(0.0001***)
AGE1800	0.00141	0.0012
	(0.0001***)	(0.0002***)
$\hat{x}_{i,t}$	272.45	416.40
	(92.45***)	(155.16***)
$\hat{x}_{i,t}^2$	-282.52	-279.12
	(350.12)	(252.13)

Note: N=16204. Standard errors for the coeffiecients appear in parenthesis.
*/**/*** Significantly different from 0 at the 10%/5%/1% level.

Table 5: Estimated weighting function $f(X_{i,t}) = \sum_{d=0}^{10} \delta_{d,t} Xd.$.

Variable	Year 1940	Year 1950
X0	1.0000	1.0000
	NA	NA
X1	0.1888	0.1382
	(0.0553***)	(0.0568***)
X2	0.0730	-0.0008
	(0.0264***)	(0.0295)
X3	0.0709	0.0334
	(0.0176***)	(0.0189*)
X4	0.0801	-0.0075
	(0.0133***)	(0.0130)
X5	0.0115	0.0529
	(0.0107)	(0.0099***)
X6	0.0171	0.0054
	(0.0086**)	(0.0074)
X7	0.0091	-0.0135
	(0.0068)	(0.0060**)
X7	0.0203	-0.0026
	(0.0063***)	(0.0052***)
X9	-0.0110	0.0062
	(0.0057*)	(0.0041)
X10	0.0086	0.0054
	(0.0065)	(0.0050)

Note: N=16204. Standard errors for the coeffiecients appear in parenthesis.
*/**/*** Significantly different from 0 at the 10%/5%/1% level.

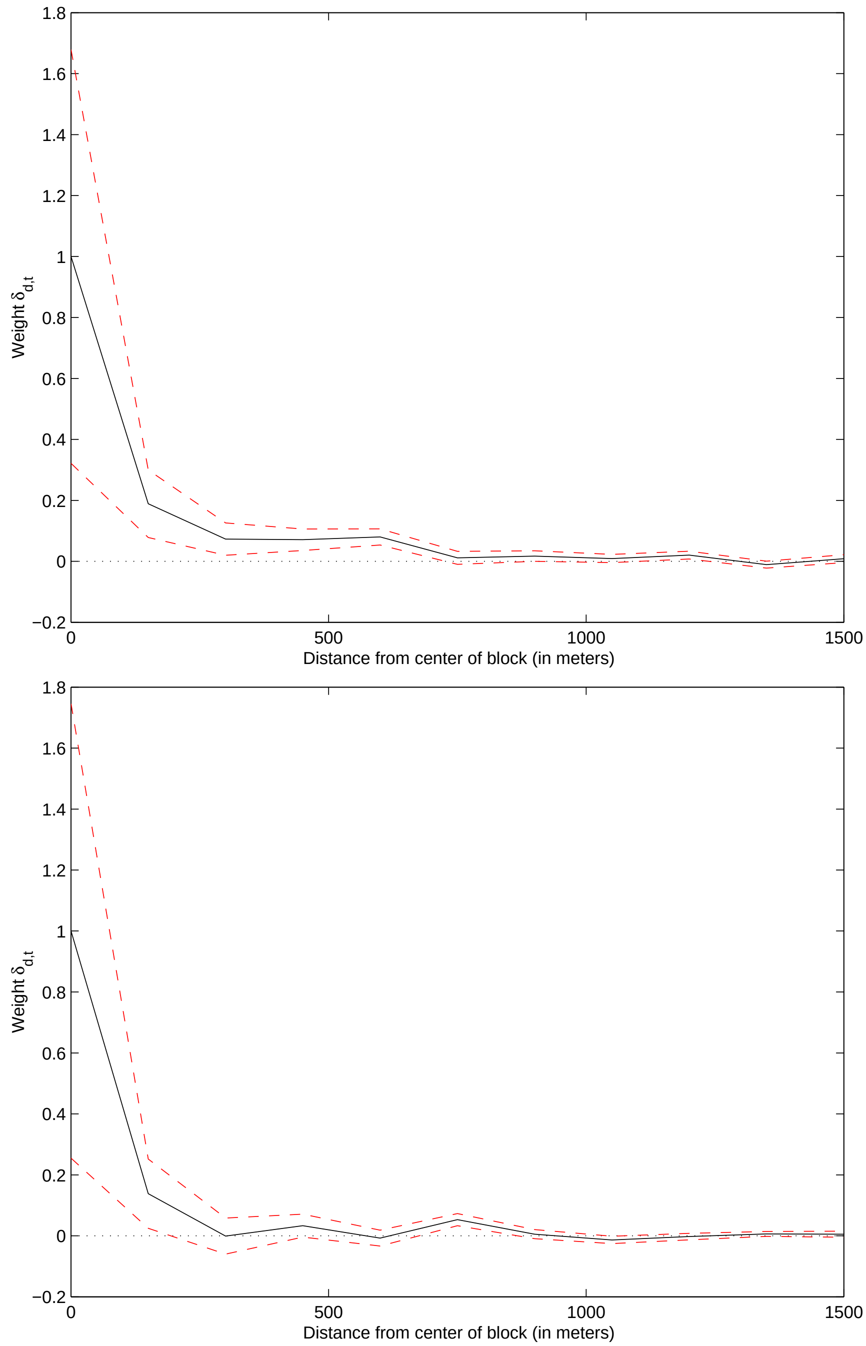

Figure 6: Comparison of weighting function $f(X_{i,1940}) = \sum_{d=0}^{10} \delta_{d,1940} Xd$ (top) and $f(X_{i,1950}) = \sum_{d=0}^{10} \delta_{d,1950} Xd$ (bottom). 95 percent confidence intervals are indicated through dashed lines

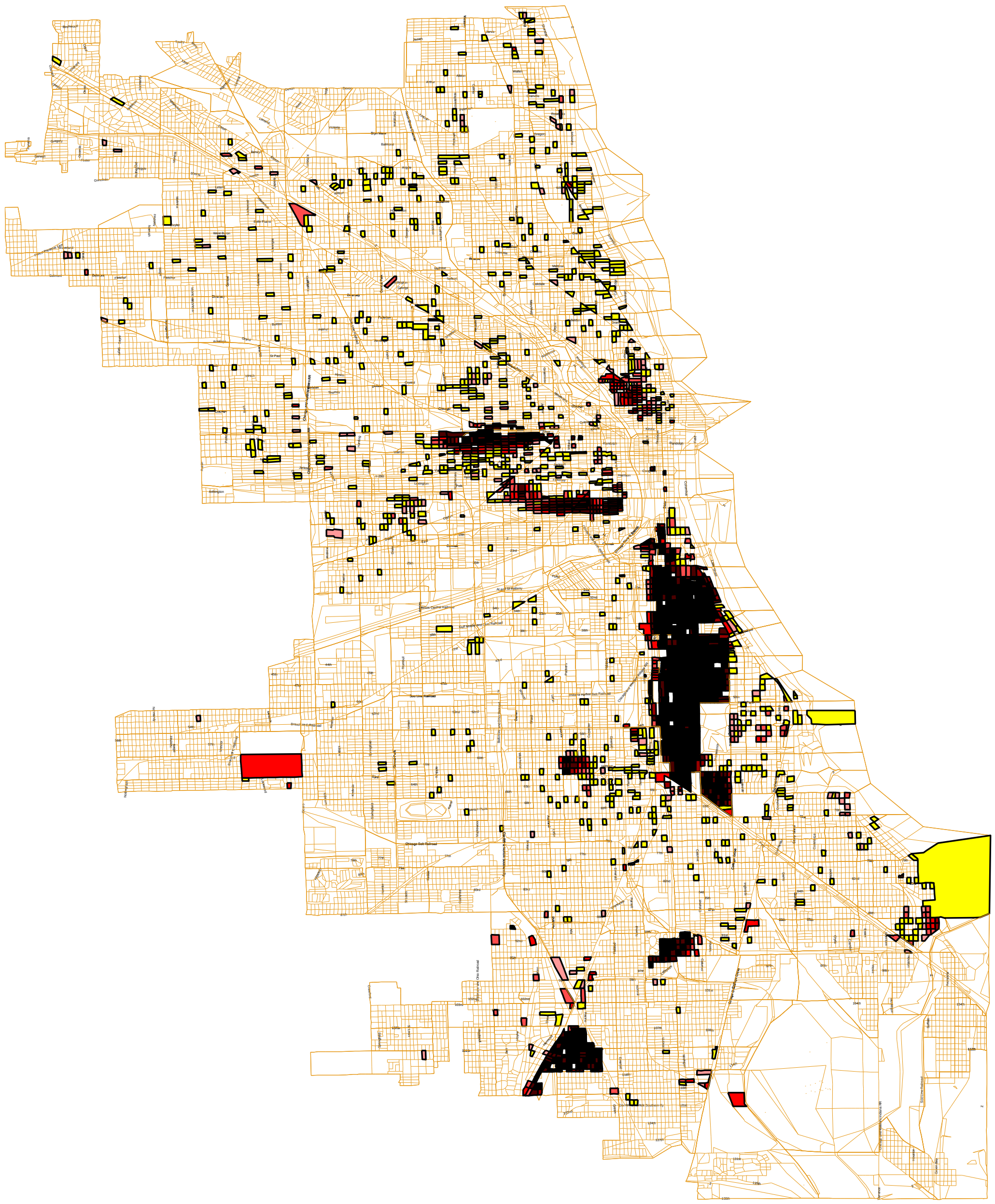

Figure 7: Ethnic map of Chicago for 1940. Blocks with 1-5 percent blacks are colored yellow, with 5-10 percent are pink, with 10-25 percent are orange, 25-50 percent are red, 50-75 percent are dark red, 75-95 percent are brown and blocks with more than 95 percent black households are black.

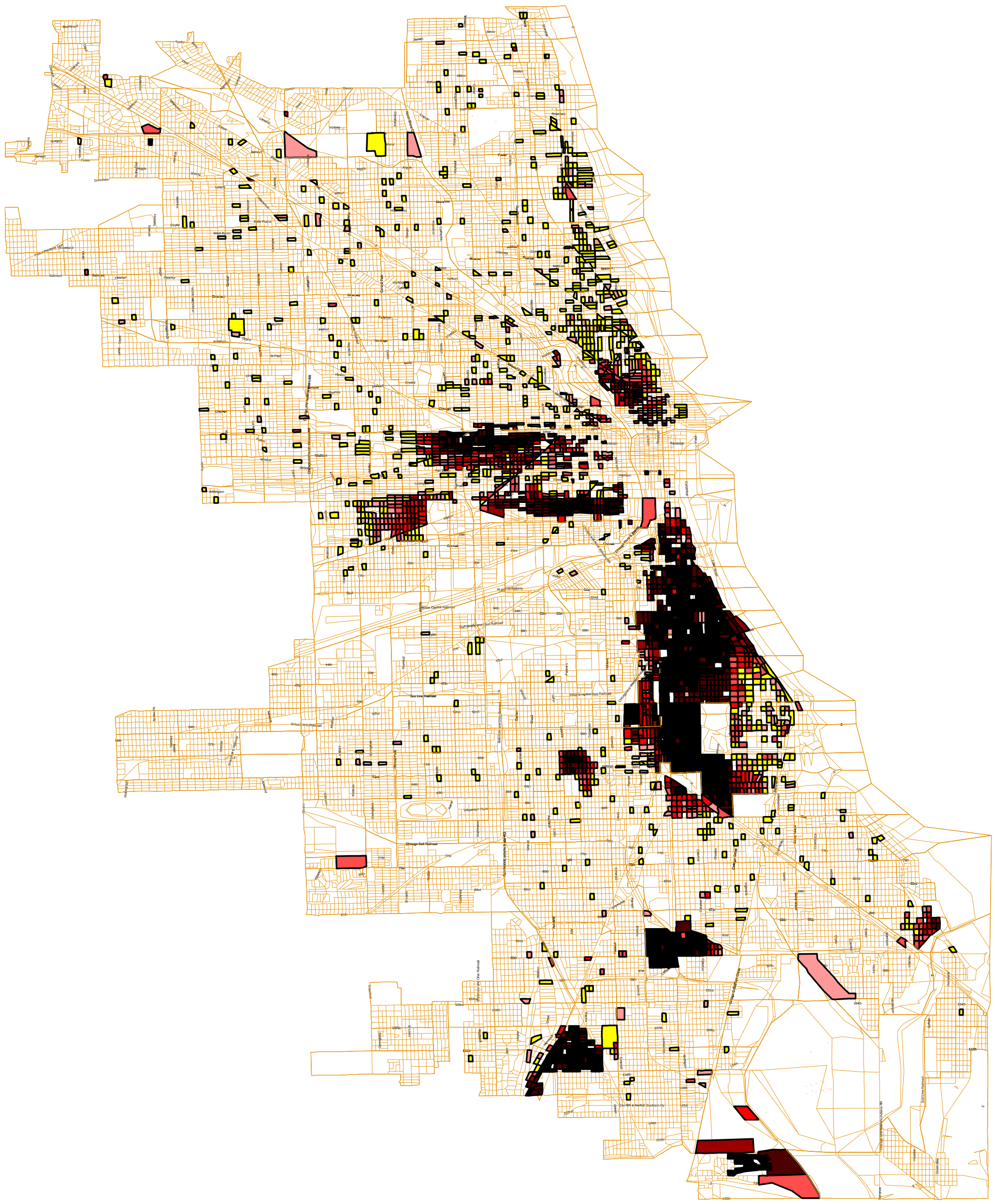

Figure 8: Ethnic map of Chicago for 1950. Blocks with 1-5 percent blacks are colored yellow, with 5-10 percent are pink, with 10-25 percent are orange, 25-50 percent are red, 50-75 percent are dark red, 75-95 percent are brown and blocks with more than 95 percent black households are black.

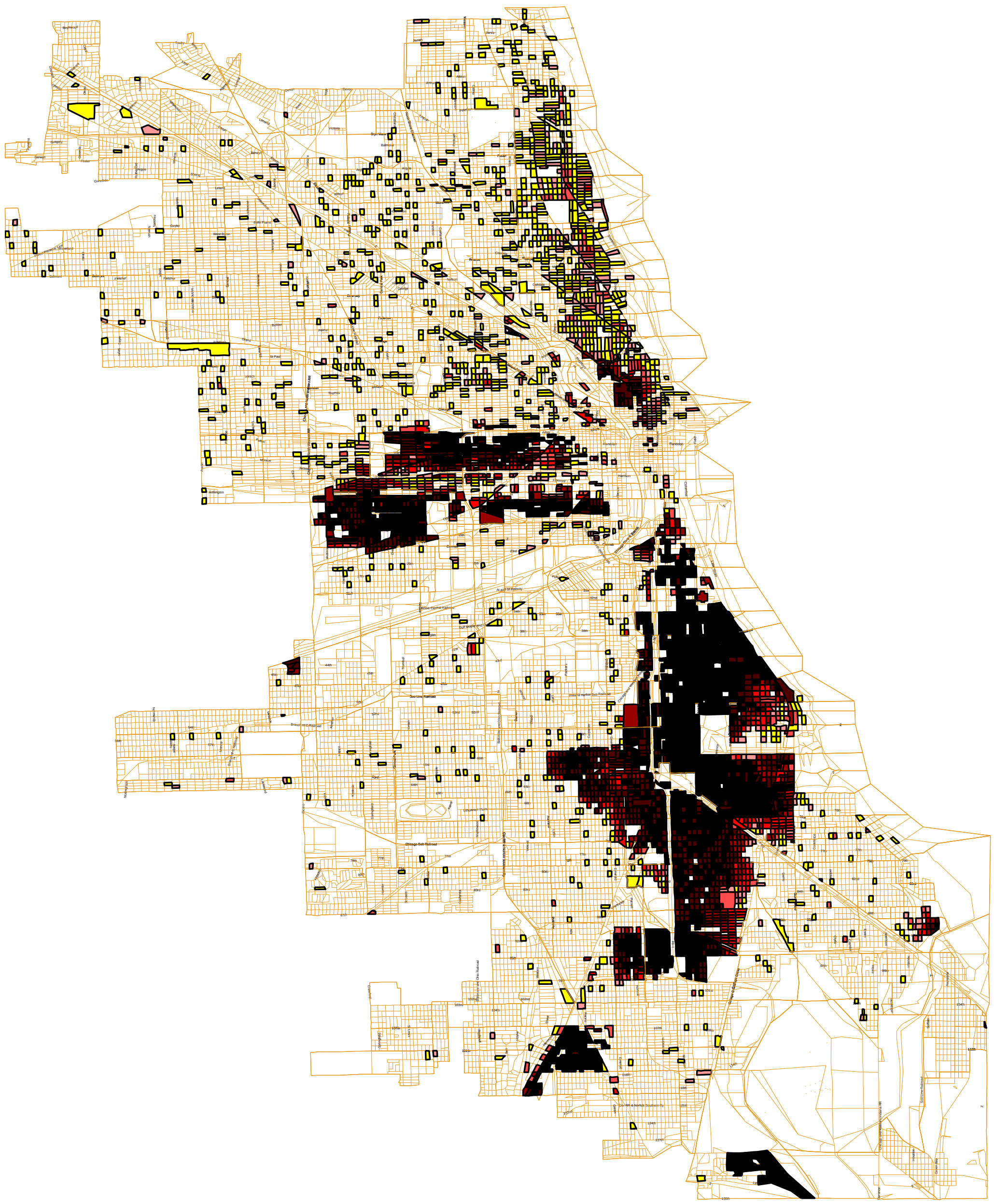

Figure 9: Ethnic map of Chicago for 1960. Blocks with 1-5 percent blacks are colored yellow, with 5-10 percent are pink, with 10-25 percent are orange, 25-50 percent are red, 50-75 percent are dark red, 75-95 percent are brown and blocks with more than 95 percent black households are black.