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Neighborhood Dynamics and the Distribution of Opportunity

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Wilson (1987) argued that policies ending racial discrimination would not equalize opportunity without addressing residential sorting and neighborhood externalities. This paper studies related counterfactual policies using an overlapping-generations dynamic general equilibrium model of residential sorting and intergenerational human capital accumulation. In the model, households choose where to live and how much to invest toward the production of their child's human capital. The return on parents' investment is determined in part by the child's ability and in part by an externality determined by the human capital in their neighborhood. We calibrate the model with two neighborhoods and neighborhood-specific production technologies to data from Chicago when mobility was restricted by race. We then conduct three numerical experiments by eliminating the restriction on neighborhood choice, equalizing production technologies, or both. We find that allowing residential mobility generates persistent income inequality, even when technologies are equalized across neighborhoods. Equalizing technologies only equalizes opportunity for residents in the originally segregated neighborhood when high-income households reside there. Our findings suggest that policies aimed at improving outcomes in impoverished areas should feature incentives for high-income households to stay or migrate into the neighborhood.

JEL codes: D31, D58, E24, J24, R23.

Keywords: Neighborhood externality, Segregation, Human Capital.

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1 Introduction

Decades have passed under civil rights laws aiming to foster racial equality, yet race is still highly correlated with educational attainment and income in the United States. How can we reconcile persistent racial disparities with racial equality under the law? Strong spatial correlations in outcomes suggest that effects from localized differences in resources and social interactions, or neighborhood effects, could be sustaining the observed differences in human capital by race.

Understanding the formation and influence of social settings has broad implications because, as stressed by Lucas (1988), "Human capital accumulation is a *social* activity, involving *groups* of people in a way that has no counterpart in the accumulation of physical capital." Wilson (1987) was highly influential in drawing attention to these issues, especially as they pertain to the geographic distribution of individuals and resources, through his seminal analysis of the concentration of poverty in Chicago between 1970 and 1980. Wilson documented that even after the victories of the Civil Rights Movement, African Americans continued to live in lower-quality neighborhoods than their white counterparts, and important outcomes like poverty rates actually *worsened* in many black neighborhoods.

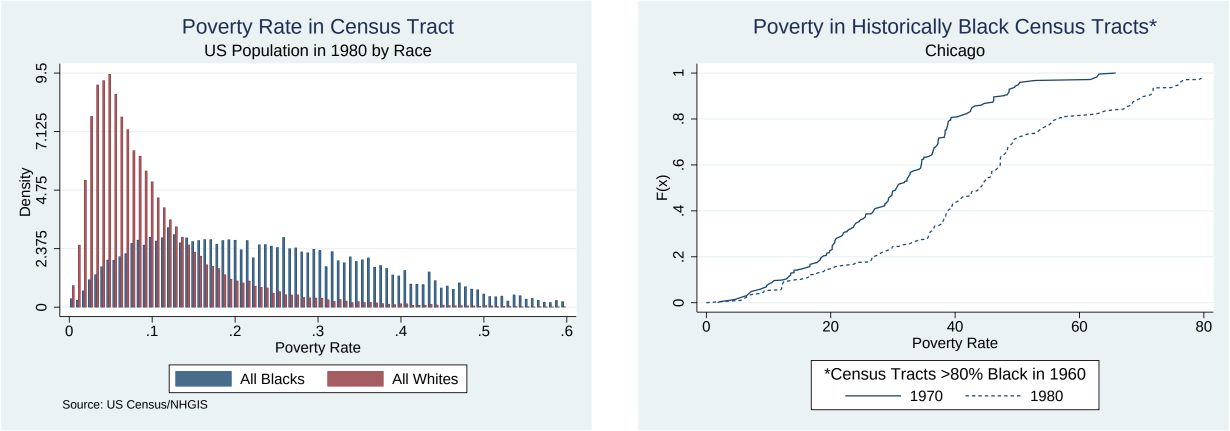
Poverty Rate in Census Tract
US Population in 1980 by Race
Source: US Census/NHGIS
Poverty in Historically Black Census Tracts*
Chicago
*Census Tracts >80% Black in 1960

Figure 1: Poverty in the US and Chicago

Wilson (1987) interpreted these data as evidence of mechanisms that could perpetuate racial inequality even in the absence of racial discrimination. Wilson's theory explaining these observations is that under segregation high-income African Americans supported an externality in their neighborhoods which increased the return to investment in human capital. The end of legal segregation allowed for the outmigration of high-income households, which reduced this externality and therefore produced persistent poverty by discouraging investment in human capital. Despite the widespread influence of Wilson's work (Sampson (2012)), it remains difficult to jointly model the key features of this hypothesis in a way that can be taken to the data.

This paper quantifies neighborhood effects in Chicago in the mid-twentieth century using a heterogeneous agents dynamic stochastic general equilibrium model in the spirit of Bewley (1986), Aiyagari (1994), Huggett (1996), and Krusell and Smith (1998) with three additional features: residential sorting, neighborhood externalities, and intergenerational human capital accumulation.

In the model, households choose where to live and how much to invest toward the production of their child's human capital. The return on parents' investment is determined in part by the child's ability, and in part by an externality from the average human capital in their neighborhood, so that the technology for the intergenerational accumulation of human capital lies somewhere between Becker and Tomes (1979) and Calvó-Armengol and Jackson (2009).

Adults get utility from both their own consumption and the discounted expected utility of their descendants. This forward-looking behavior of households is particularly important for studying neighborhood transitions. Previous literature has assumed that parent's utility is defined over current period variables only, connecting generations through a desire to leave bequests or through child's future income (Badel (2010) is a noteworthy exception.). This myopic behavior implies that parents ignore any information about the future states of neighborhoods. This is especially important for location decisions. When agents anticipate a decline in the quality of their neighborhood and internalize the costs of the deterioration (through their descendants' utility), they are more willing to move away and, by moving, induce their neighbors to exit as well.

We use the history of racial discrimination in Chicago as a source of variation in both the mobility rules and technologies that households face.[1] We provide evidence that during the mid-20th century, Chicago could be broadly viewed as two neighborhoods, with households allocated to these neighborhoods by race. To parameterize the model we first divide Chicago in 1960 into a "black" and "white" neighborhood (N1 and N2, respectively).[2] While allowing for neighborhood-specific technologies for the accumulation of human capital, we then calibrate the model without mobility to match the empirically observed 1960 income distributions in each neighborhood.

We first conduct a numerical experiment by allowing for mobility, which might be interpreted as the counterfactual resulting from eliminating legal racial discrimination alone. This is one of the central thought experiments suggested by Wilson (1987)'s ex-post analysis of Chicago between 1970 and 1980, and we find that the calibrated model predicts an immediate and complete depopulation of N1. Only very poor households would choose to live in N1 in this world; so poor, in fact, that such levels are never visited by agents in the model.

To better understand the roles of unequal technologies and mobility, we conduct two additional counterfactual policies. In the first, we allow for mobility while also equalizing technologies across neighborhoods. This counterfactual might be associated with Martin Luther King, Jr.'s ex-ante vision for the integration of Chicago.[3] While households in both N1 and N2 prefer the transition path to this new steady state over the initial steady state, the associated steady state is still characterized by permanent income inequality. It is important to note here that our model generates

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[1] See Johnson (2014) and Fuchs-Schuendeln and Hassan (2015) for related identification strategies.

[2] We focus on Chicago because of its prominent role in the neighborhood effects literature initiated by Wilson (1987), as well as its central role in the civil rights movement for open housing (King (1998), Polikoff (2006)). We focus on the period between around 1960 because one could interpret legislative victories of the Civil Rights Movement like the Fair Housing Act of 1968 as a discrete change to residential sorting rules.

[3] While King is often remembered in terms of his work for open housing, integrating schools was also a primary focus of his work in Chicago, and improving the general conditions in N1 was another major goal. See Chapter 28 of King (1998) for a description of King's work in and vision for Chicago.

permanent income inequality across neighborhoods even with no frictions to moving and no racial preferences.

Finally, we examine what would happen if the restriction on mobility between N1 and N2 were maintained while equalizing their technologies. This counterfactual might be associated with Malcolm X's ex-ante vision of separation.[4] Households in N1 prefer this policy to allowing for mobility alone. The reason is that over time N1 makes a smooth transition to a human capital distribution like N2's. Since high income households stay in N1, all residents benefit from the resulting buildup in the neighborhood's externality.

These results highlight the importance of mobility. In the presence of neighborhood externalities, place-based income inequality will persist if mobility is allowed from unequal initial conditions like those present in Chicago in 1960. Similar results will obtain even if technologies are equalized across neighborhoods, in the sense that there will still be strong stratification by income and ability across neighborhoods under such policies. Equalizing technologies is only effective in equalizing the distribution of opportunity across neighborhoods when high-income households reside in N1.

Our analysis exchanges a relatively small increase in theoretical abstraction for the ability to empirically implement a model that includes not only residential sorting and neighborhood externalities, but also dynamics. While there are well-developed theoretical and empirical literatures related to Wilson (1987), researchers have typically been forced to abstract entirely from important features of Wilson's hypothesis in order to take their models to data.[5] In the literature studying the Moving to Opportunity (MTO) housing mobility experiment, for example, analyses are either entirely focused on sorting (Galiani et al. (2012)), or else must adopt stylized, static models of sorting in order to identify neighborhood effects on outcomes (Kling et al. (2007), Aliprantis and Richter (2014), Aliprantis (2014a), Pinto (2014)).[6]

Badel (2010) is the most similar paper in the literature to ours, which to our knowledge is the first to use a Bewley-Aiyagari model to study neighborhood externalities. His analysis divides the United States into two representative communities, one mostly black and the other mostly white, and accounts for 70 percent of the difference between earnings of black and white households. While our model shares some of the features of that paper (forward-looking agents, idiosyncratic child ability shocks, neighborhood externalities and housing prices), Badel (2010) is a steady state analysis, whereas we also compute transitions after policy changes. In addition, our technology for human capital production differs in that child ability enters in our model as a substitute to other inputs rather than as a complement. Finally, in Badel (2010), race has a central focus, being both an explicit household type and affecting household utility via preferences over the racial composition of neighbors.

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[4] For example, see X's definition of black nationalism in X (1990) or the related discussion in O'Flaherty (2015).

[5] Most closely related from this theoretical literature are Lundberg and Startz (1998) and Durlauf (1996), which also includes Loury (1977), Loury (1981), Bénabou (1996), Bénabou (1993), Glomm and Ravikumar (1992), Bowles et al. (2009), and Epple and Romano (1998).

[6] The empirical micro literature generally only includes two features of Wilson's hypothesis at most: Rich microeconometric models of residential sorting are rarely specified and estimated jointly with outcomes (Ioannides (2010), Bayer et al. (2007)), even in the rare case that they do include both sorting and dynamics (Bayer et al. (2011)).

We use race to initially constrain households' mobility and technology for accumulating human capital. Beyond determining initial conditions, however, race is not the source of any other heterogeneity in our model, such as ability or preferences. Thus, households could have been allocated based on any arbitrary rule, like eye color or initial location, as in the cases of North versus South Korea or East versus West Germany. In this sense, our analysis is more fundamentally about how residential sorting and neighborhood externalities drive the distribution of human capital over time.

The remainder of the paper is structured as follows: Section 2 presents four stylized facts that are used to motivate the model. Section 3 presents a dynamic general equilibrium model of neighborhood dynamics and human capital accumulation. Section 4 presents the calibration of the model to data from Chicago in 1960, and Section 5 presents the results of the numerical experiments we implement with this model. Section 6 concludes.

2 Stylized Facts

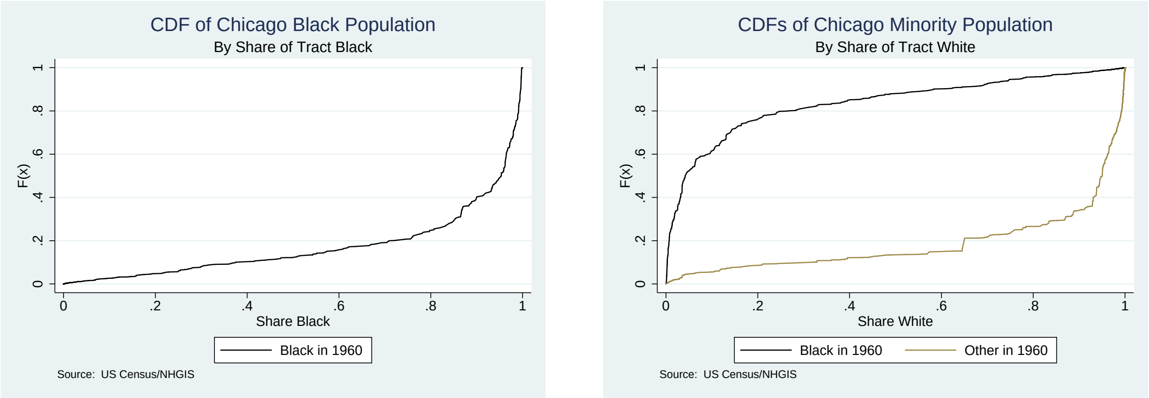
The central issue in the neighborhood effects literature is understanding what generates spatial correlations in outcomes. Is the local environment a primary cause of individuals' outcomes, or do people with similar outcomes simply choose to live near each other? In nearly all contexts, the endogeneity of neighborhood selection has represented a fundamental obstacle to identifying neighborhood effects and distinguishing between these explanations.

This analysis offers insight into the broad question of how neighborhood externalities impact income inequality, using Chicago in the 20th century as a circumstance restricting the endogeneity of neighborhood selection. Here we establish four stylized facts about the decades before 1960 to justify the key features of our model as we apply it to Chicago: There were two neighborhoods in the city; they were defined by race; they were unequal; and there was no mobility between the two for decades.

2.1 Stylized Fact 1: Black Residents of Chicago Lived in Black Areas

The black ghetto in the US was born between 1890 and 1940 and grew between 1940 and 1970 (Cutler et al. (1999)). Massey and Denton (1993) note that blacks and whites were not particularly segregated before 1900. This changed in the first decades of the 20th century in response to the Great Migration, in which large numbers of African Americans moved to Northern cities from the South. By 1930, in most urban areas in the US the boundaries within which blacks were allowed to live had been established through violence, collective anti-black action, racially restrictive covenants, and discriminatory real estate practices (Massey and Denton (1993)).

Focusing on Chicago, in 1930 two-thirds of all black residents lived in census tracts that were 90 percent black or more, and by 1940 this had grown to over three-quarters (Hirsch (1998), p 4). In 1960 the median black person in Chicago lived in a neighborhood that was 95 percent black (Figure 2a), which actually *increased* to 98 percent by 1990. In our empirical analysis we define neighborhood N1 as all census tracts in which 80 percent or more of the residents were black in 1960, and under this definition a full 75 percent of African Americans in Chicago lived in N1 in 1960.[7] Figure 2b shows that the level of segregation experienced in African American neighborhoods was unlike that of the immigrant enclaves experienced by other minority groups (See also Massey and Denton (1993) on this point, especially Chapter 2.).



(a) Blacks in Chicago

(b) Minorities in Chicago

Figure 2: Segregation of Minorities in Chicago in 1960 and 1990

2.2 Stylized Fact 2: Limited Black Mobility

Violence was a key factor restricting mobility from black neighborhoods to the rest of Chicago. Between 1945 and 1950 alone Chicago experienced 357 “incidents” related to housing (Hirsch (1998)). Meyer (2000) discusses several of these incidents, such as the complete razing of a house purchased by an African American woman located just two blocks outside of the ghetto, or the firebombing of a house that killed two children (p 89). Rubinowitz and Perry (2002) conclude that racial crimes “around housing conflicts... became the norm in Chicago the way other forms of racial violence, such as lynchings and church bombings, became commonplace in the South” (p 347). This environment had not changed much by the time Martin Luther King, Jr. led a march in Chicago for open housing in 1966: His group was met by such violent resistance that he was led to conclude “The people of Mississippi ought to come to Chicago to learn how to hate” (Polikoff (2006), p 41).

Legal roadblocks also restricted blacks from moving into white neighborhoods. For example, in 1924 the National Association of Real Estate Brokers’ code of ethics adopted the statement that “a Realtor should never be instrumental in introducing into a neighborhood. . . members of any race or nationality. . . whose presence will clearly be detrimental to property values in that neighborhood” (Massey and Denton (1993), p 37). This provision remained in effect until 1950.

Recognized as a spokesperson for [the Civil Rights Movement and] the African American experience of the mid-twentieth century (Polsgrove (2001)), the writer James Baldwin was challenged in a debate over his use of the word ghetto to describe black neighborhoods: “There is no law in America or indeed no practice in America that makes rich Negroes live in the . . . as-you-call-it

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[7] These data are all consistent with the national data presented in Cutler et al. (1999); see especially Table 4.

'ghetto.' " Famously careful with his words, Baldwin reacted strongly that, "I stick to the word ghetto… [because] There is no way for any black man to move out of it… I say ghetto, and I say ghetto because you can't move out…" (Baldwin (1989), pp 115-116).

2.3 Stylized Fact 3: Separate and Unequal Neighborhood Externalities

Separation would not necessarily be a problem for economic outcomes if blacks and whites lived in separate but equal neighborhoods (Cutler and Glaeser (1997), Borjas (1995), X (1963)). But racial discrimination precluded this possibility in the decades before the Civil Rights Movement: N1 and N2 were not equal in important ways related to the intergenerational transmission of human capital.

Schools in Chicago were segregated in the decades prior to 1960. In 1945 the president of the NAACP branch serving Chicago stated: "We have segregated schools outright… They are as much segregated as the schools in Savannah, Georgia, or Vicksburg, Mississippi" (Homel (1984), p 27). Chicago's school boards adjusted attendance-area boundaries to segregate students in schools along the same lines they were segregated geographically (Homel (1984)). In 1964, the first time the Chicago Board of Education published racial statistics, 67 percent of black students attended high schools that were (more than 90 percent) black, and 89 percent of black elementary school students attended black schools (Neckerman (2007), p 95).

School segregation impacted individual-level experiences because black schools did not have the same resources as white schools. Black schools faced overcrowding, resulting in limited instruction time with odd schedules, difficulty staffing teachers, and fewer resources for things like facilities relative to white schools (See Chapter 4 of Neckerman (2007), especially pages 88-97.). While it is hard to find historical data on measures of school quality by race for Northern schools since they were not explicitly segregated (Collins and Margo (2006)), these data from Chicago are consistent with evidence from the South that teachers' pay was lower in black schools relative to white schools (Collins and Margo (2006)), class sizes were generally larger and the length of the school year was shorter (Collins and Margo (2006), Orazem (1987)), and other inputs were lower (Margo (1986)).

African Americans residing in N1 faced discrimination in other important processes such as redlining practices that decreased the family and community resources that could have been devoted towards the transmission of human capital to children (Squires (1997), President's National Advisory Panel on Insurance in Riot-Affected Areas (1968)), as well as discrimination in the justice (Blackmon (2008)) and health care systems (Washington (2006))

2.4 Stylized Fact 4: There Were *Two* Neighborhoods

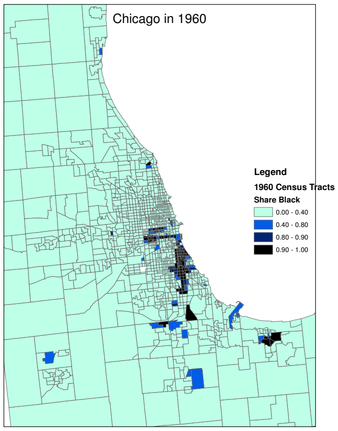
Defining the word "neighborhood" is crucial to determining whether a two-neighborhood model is a useful lens through which to look at Chicago in 1960. The literature does not give much guidance on this topic: Durlauf (2004) notes that nearly all empirical studies in the neighborhood effects literature take a particular neighborhood structure as known *ex ante*, despite the centrality of this definition. The appropriate definition of neighborhood is likely to depend on the specific analysis under consideration (See Sampson (2012), especially Chapter 3, or page 37 of Lucas (1988).).

The salience of race in Chicago justifies defining neighborhoods in terms of racial composition. Social interactions and resources were distributed in Chicago according to geographically determined racial lines, whether they pertained to schooling (Neckerman (2007)), housing (Polikoff (2006)), or broader political processes (Sampson (2012), pages 40-42). Even in 1980 and 1990, Conley and Topa (2002) find that racial/ethnic composition was by far the most important predictor of spatial correlation in unemployment across census tracts in Chicago.

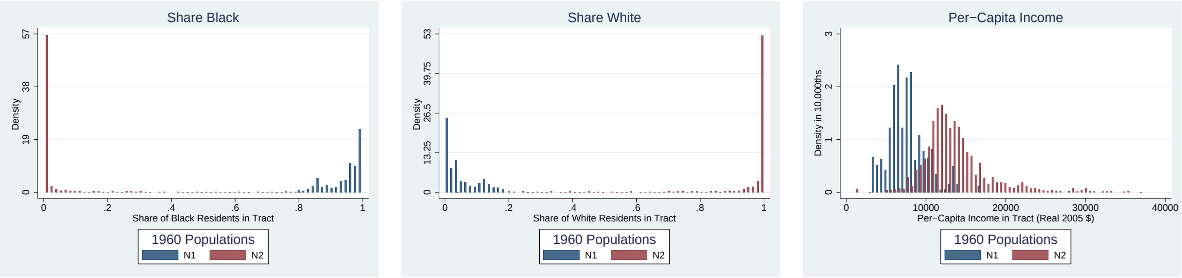
Furthermore, the definition of race in the US justifies a model with precisely *two* neighborhoods. The one-drop rule categorizing individuals with *any* African heritage as being African American has generated a binary definition of race that is quite different from the broader spectrum experienced in other locations (Hickman (1997), Arthur (1999)). For a striking example, consider that President Barack Obama classified himself as black, and black alone, on the 2010 US Census (Roberts and Baker (2010)).

The data also provide justification for viewing Chicago in 1960 as two neighborhoods defined in terms of racial composition. Almost all of N1 is spatially connected (Figure 3), and spatial proximity is considered to be a key determinant of neighborhood externalities (Sampson (2012), Bayer et al. (2008)).

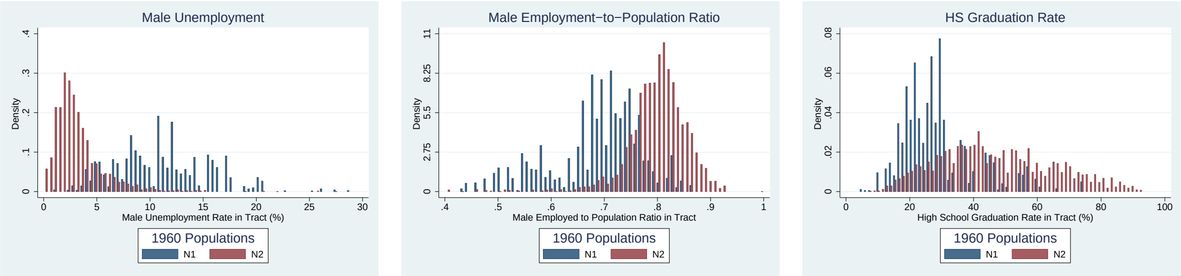
Figure 3: Racial Composition of Neighborhoods in Chicago, 1960



Additionally, Figure 4 shows that N1 and N2 were fundamentally different in 1960 according to several measures of human capital. Thus while one could imagine there being important variation in the externalities experienced by residents within each neighborhood (Pattillo (2003)), our two-neighborhood division is a useful abstraction. In terms of racial composition, Figures 4a and 4b illustrate that N1 and N2 were racially homogenous in a way suggesting two distinct externalities. The neighborhood externality in our model operates through income, which could involve mechanisms operating through other outcomes like employment or educational attainment. One could easily interpret the census tracts in N1 and N2 as coming from two distributions for these mediators.



(a) Share Black (b) Share White (c) Income



(d) Male UR (e) Male EPR (f) High School Graduation Rate

Figure 4: Distributions of Census Tract Characteristics by Neighborhood in 1960

We emphasize that because N1 is the focus of our analysis, we are most concerned that its residents experienced a "uniform" neighborhood externality. Future research can relax our abstraction from the variation in the externality experienced by residents in the much larger area of N2.

3 A Model of Neighborhood Dynamics and Human Capital Accumulation

We now present a dynamic general equilibrium model of the intergenerational accumulation of human capital. The model is a generalization of Becker and Tomes (1979), with three additional features: Residential sorting, location-specific inputs to production (ie, a neighborhood externality), and forward-looking agents. We expand on the roles of these mechanisms where they appear in the model description below.

3.1 Households

A unit continuum of overlapping generations households lives in a city that is divided into two neighborhoods. Each household consists of two individuals, a parent and a child, and all individuals live for two periods: At the end of each period adults die, children become adults, and new children are born. Adults receive utility from consuming housing services whose units are ordered according to a single housing quality index ($s \in \mathbb{R}_+$), a non-housing good ($c \in \mathbb{R}_+$), and the discounted expected utility of their offspring. Children receive no utility until they become adults, however parents are altruistic; therefore, a household is functionally identical to an infinitely-lived dynasty.[8] Preferences for a dynasty take the form

$$U\left(c,s\right)=E_0\sum_{t=0}^{\infty}\beta^t u\left(c_t,s_t\right)$$

where β is the discount factor between a parent and its offspring.

Each household is characterized by its state vector (h_t, a_t, n_t), where $h_t \in \mathbb{H} = [\underline{h}, \overline{h}] \subset \mathbb{R}_+$ is the human capital level of its adult, $a_t \in \mathbb{A} \equiv \{\underline{a} = a_1, a_2, \ldots, a_n = \overline{a}\} \subset \mathbb{R}_+$ is the ability of its child to produce human capital, and $n_t \in \{N1, N2\}$ is the neighborhood in which the household ends the period. We assume that (h_t, a_t, n_t) is a random vector whose joint distribution μ_t has density function $f_t : \mathbb{H} \times \mathbb{A} \times \{N1, N2\} \to \mathbb{R}$ defined by $f_t(h, a, n)$, and we sometimes refer to the conditional density $f_{N1,t} = \frac{f_t(h,a,N1)}{\sum_{a\in\mathbb{A}}\int_{\mathbb{H}} f_t(h,a,N1)dh}$, with $f_{N2,t}$ defined analogously. A neighborhood is a joint density of human capital and ability $f_{n,t}$, a per-unit price of housing services $p_{n,t}$, an externality level $\chi_{n,t}$, and a share of the citywide population.

We define human capital as the skills and knowledge that generate labor income. We think of human capital not only in terms of the skills acquired through formal education, like those measured by the AFQT, but also in terms of any of the other factors that help to determine labor income, like personality traits and social skills (Borghans et al. (2008)). The child's human capital is determined by a function $G : \mathbb{R} \times \mathbb{A} \times \mathbb{H} \times \mathbb{H} \to \mathbb{H}$ defined by

$$h_{t+1} = G\left(Z_n, a_t, i_t, \chi_{n,t}\right). \tag{1}$$

Under this specification, human capital is produced by the combination of four sources: three factors of production (innate ability a_t, private investment i_t, and a public good $\chi_{n,t}$), and a neighborhood-specific technology for combining these inputs summarized by a Total Factor Productivity (TFP) parameter (Z_n). We think of ability as immutable characteristics, including cognitive and non-cognitive abilities. Private investment is consumption foregone for the sake of endowing one's child with human capital. This might be time spent with the child (ie, on homework after school, providing healthy meals, safe transportation to and from school), or money spent on the child (ie, tutors, extracurricular activities, and summer camps).

The public good is meant to capture a wide range of spatially-determined mechanisms, like schools and safety. We think of the externality level χ_n in terms of resources devoted to things like teachers and police, and the TFP parameter Z_n as capturing institutional differences across neighborhoods in the productivity of these resources. This production allows for identical levels of ability and private and public investment to produce different levels of human capital. As an example, similar tax revenues devoted to hiring more teachers or police (captured in χ_n) could be inputs to institutions with different levels of productivity (Z_n). One can additionally interpret the externality level χ_n as summarizing the social interactions one typically has, as determined by

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[8] Because this paper focuses on the effects of forces external to the household (i.e., the neighborhood), we abstract away from the distributions of consumption and housing services across household members.

peers and role-models in the neighborhoods, under the assumption that peer quality is positively correlated with parents' human capital. G is assumed to be strictly concave in each argument.

The timing of decisions and updating is shown below in Figure 5. There are two subperiods. In the first, neighborhood distributions change because households sort across neighborhoods. In the second, neighborhood distributions change because of the evolution of human capital across generations.

More specifically, at the beginning of period t, an adult with human capital h_t resides in one of the two neighborhoods, the location n_{t-1} chosen by their parent. In the first subperiod, the adult has a child, observes its ability a_t, and chooses whether or not to move. The initial distribution of households $\widehat{\mu}_t$ is updated according to the law of motion $\mu_t = \widetilde{\Psi}(\widehat{\mu}_t)$, and the first subperiod ends. Taking as given the price and externality in the chosen neighborhood, in the second subperiod the household chooses consumption c_t, housing services s_t, and investment in its child's human capital i_t. Each household's human capital is updated according to $h_{t+1} = G(Z_n, a_t, i_t, \chi_t)$, adults die, children become adults, a new child is born with ability a_{t+1}, and the second subperiod ends.

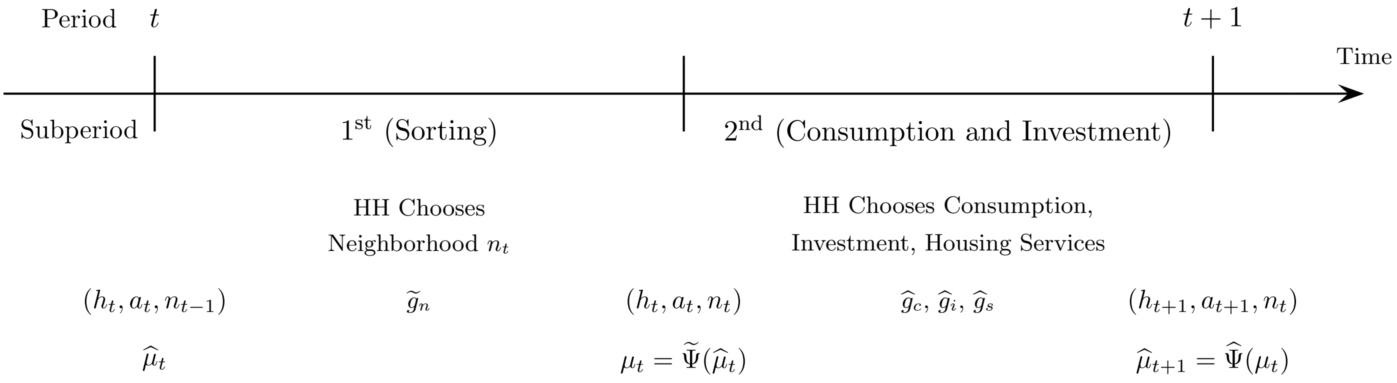

Figure 5: Updating of Households and Neighborhoods over Time

We assume rational expectations, meaning that households know the sequence of neighborhood externalities and housing prices, so that households are able to solve a well-posed problem. This requires that households' expectations about the neighborhoods are consistent with the neighborhoods realized by the moving and investment decisions of all households. This implies that households know both the law of motion determined by moving decisions $\left(\mu_t = \widetilde{\Psi}(\widehat{\mu}_t)\right)$ and the law of motion determined by investment decisions/the production technology and the ability process $\left(\widehat{\mu}_{t+1} = \widehat{\Psi}(\mu_t)\right)$ so that households have perfect foresight over the full sequence of relevant human capital externalities and housing prices. Under segregation, this is simply the sequence in the neighborhood in which the household resides, either $\{\chi_{N1,t}, p_{N1,t}\}_{t=0}^{\infty}$ or $\{\chi_{N2,t}, p_{N2,t}\}_{t=0}^{\infty}$. When moving is allowed, perfect foresight means knowledge of the full sequence of intra-temporal human capital externalities and housing prices for both neighborhoods, $\{\chi_{N1,t}, \chi_{N2,t}, p_{N1,t}, p_{N2,t}\}_{t=0}^{\infty}$.

Under rational expectations, conditional on choosing a location, each household has a well-defined budget constraint

$$c_t + i_t + p_{n,t}\, s_t \leq \omega_t h_t.$$

A key feature of our model is the distinction between the intra-temporal updating rule $\widetilde{\Psi}$ and the inter-temporal updating rule $\widehat{\Psi}$, since the wealth distribution typically only changes *intertemporally.* In similar incomplete markets models of physical capital accumulation with transitional dynamics (e.g., Ríos-Rull (1999)), the rule Ψ would typically only capture end of period changes to the household state vector from the idiosyncratic shock process and optimal investment decisions. Here, though, the wealth distribution in neighborhood n can change both intertemporally, as human capital changes across generations due to investment decisions, and *intratemporally* due to migration decisions.

This distinction matters because the composite rule for updating distributions between time periods $\Psi = \widehat{\Psi}\left(\widetilde{\Psi}(\cdot)\right)$ changes depending upon the sorting rules $\widetilde{\Psi}$ permitted. If no sorting is permitted, so that $\widetilde{\Psi}\left(\widehat{\mu}_t\right) = \left(\widehat{\mu}_t\right)$, then the central assumption that production is a function of neighborhood-specific human capital implies that any differences in neighborhood steady states can only exist if neighborhoods differ in either household preferences, the ability process, or the human capital production function.[9] Our model assumes the final explanation. These differences could arise from many sources like racial discrimination, political economy for public services like schooling (Ichino et al. (2010), Glomm et al. (2011)), crime and personal security (Anderson (1999), Aliprantis (2014b)), or social efficacy (Sampson et al. (1999)).

3.2 The Firm

We assume that non-housing goods are produced in a national market. For simplicity, we assume that this market wage rate is 1, and we assume that labor is perfectly mobile so that the city-wide wage ω is also equal to 1.

Housing services Q are produced by a price-taking firm using labor according to a constant returns to scale function of effective labor, H, and land, L:

$$Q = H^{\alpha} L^{1-\alpha}, \qquad 0 < \alpha < 1.$$

Taking the wage rate as given, the firm supplies units at the neighborhood-specific price p_n. Solving the firm's maximization problem and imposing that supply equals demand in each neighborhood, i.e. $Q_n = S_n = \sum_{a \in \mathbb{A}} \int_{\mathbb{H}} g_s(h,a,n) f(h,a,n) dh$ for housing services in both locations returns the

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[9] See Kremer (1997) for a related model in which sorting has negligible implications for steady state inequality when it is assumed there is a constant technology across neighborhoods.

pricing equations[10]

$$
\begin{aligned}
p_n &= \frac{\omega}{\alpha}\left(\frac{S_n}{L_n}\right)^{\frac{1-\alpha}{\alpha}}, \qquad n = 1, 2 \\
&= \frac{\omega}{\alpha}\left(\frac{pop_n}{L_n}\bar{S}_n\right)^{\frac{1-\alpha}{\alpha}}.
\end{aligned}
$$

The last expression decomposes the market clearing price into the product of average housing demanded in the neighborhood $\bar{S}_n$ and the ratio of population residing in n to the land available, which we refer to as the congestion ratio. $\frac{\alpha}{1-\alpha}$ is the price elasticity of supply. As α approaches unity, the price becomes extremely sensitive to changes in either input. Note that because of our assumption of a national labor market, in our model Chicago is a small open economy for labor. This implies that labor will be paid the same to produce both the non-housing good and housing services.[11]

Notice that the price of housing acts like a congestion cost. The more that households sort into the same neighborhood, the higher the cost is to everyone. At the same time the price in the other neighborhood decreases, encouraging migration back. Without congestion costs, corner solutions where one neighborhood is empty are likely to arise.

3.3 Sorting Rules

The recursive formulation and equilibrium concepts of the model depend crucially on the types of neighborhood mobility permitted. To show these distinctions explicitly, especially as they pertain to our empirical analysis, we will state the recursive problems solved by households and define a competitive equilibrium under each sorting policy separately. The broad point helpful for interpreting the remainder of the model description is that because we are studying Chicago in the mid- to late-twentieth century, we allow different sorting rules depending on the time period under consideration. We assume that up to 1960 households are prohibited from moving across neighborhoods (i.e., $n_{t+1} = n_t$). In this case, the model is of two economies that do not interact with each other.

We then interpret the legal victories of the Civil Rights Movement as a change to a new model in which households are allowed to move across neighborhoods. We assume that the prohibition on sorting is removed between 1960 and 1970, and that the new two-neighborhood model allowing for sorting characterizes Chicago until 1990. Neighborhoods N1 and N2 become interconnected in

---

[10] In equilibrium, there are rents to land equal to

$$
\frac{1-\alpha}{\alpha}\left[\left(\frac{pop_1}{L_1}\right)^{\frac{1}{\alpha}}\bar{S}_1^{\frac{1}{\alpha}}L_1 + \left(\frac{pop_2}{L_2}\right)^{\frac{1}{\alpha}}\bar{S}_2^{\frac{1}{\alpha}}L_2\right].
$$

We assume that these rents go to the absentee landlord.

[11] Because we do not model race, we are unable to account for racial discrimination in the labor market. The focus of this analysis is to quantify the impact of neighborhood externalites and sorting on outcomes with a general model that abstracts from legal racial discrimination.

this second model, as intra-period migration flows change the price of housing and the return to investment in each neighborhood.

3.4 Recursive Formulation and Equilibrium

The household's problem can be described recursively by a nested value function:

$$V\left(h, a, n_{-}\right)=\max _{n}\left\{\max _{c, i, s}\ u(c, s)+\beta E V\left(h^{\prime}, a^{\prime}, n\right)\right\} \tag{2}$$

subject to:

$$c+i+p_{n}\, s \leq \omega h, \tag{3}$$

$$h^{\prime}=G\left(Z_{n}, a, i, \chi_{n}\right). \tag{4}$$

Solving 2 subject to 3 and 4 returns the value function V and decision rules $\widetilde{g}_n$, $\widehat{g}_c$, $\widehat{g}_i$, and $\widehat{g}_s$ for location, consumption, investment, and housing services, respectively.

One of the distinguishing features of our model is the forward-looking behavior of households. The continuation value $\beta EV\left(h', a', n\right)$ makes the parent's utility a function of the entire sequence of their descendants' utilities. Related models in the literature on intergenerational mobility typically assume that the parent's utility is a function only of current period variables. This might include the size of bequests to their children (Glomm and Ravikumar (1992)) or the education/income level of their children (Fernandez and Rogerson (1998)).

Forward-looking behavior could lead to very different choices for households in our model. Because parents care about their children's *utility* in our model, their decisions will take into account the future trajectories of neighborhoods. For instance, if a transition between steady-states implies that a neighborhood will decline over time, forward-looking households will move sooner than households that only care about current-period neighborhood characteristics. This has major implications for the rise and fall of neighborhoods, and by implication, intergenerational mobility (Becker and Tomes (1986)).

We now state our equilibrium concept:

Definition 1. *A* ***steady-state recursive competitive equilibrium with moving (MRCE)*** *is a set of neighborhoods, a value function* $V(h, a, n_{-})$*, policy functions* $\widetilde{g}_n(h, a, n_{-})$*,* $\widehat{g}_c(h, a, \widetilde{g}_n(h, a, n_{-}))$*,* $\widehat{g}_i(h, a, \widetilde{g}_n(h, a, n_{-}))$*,* $\widehat{g}_s(h, a, \widetilde{g}_n(h, a, n_{-}))$*, and laws of motion* $\widehat{\Psi}$ *and* $\widetilde{\Psi}$ *such that*

1. Given prices and the laws of motion, V, $\widetilde{g}_n$, $\widehat{g}_c$, $\widehat{g}_i$, and $\widehat{g}_s$ solve the household's problem.

2. The housing market clears in each neighborhood:

$$S_n=\sum_{a \in \mathbb{A}} \int_{\mathbb{H}} g_s(h, a, n) f(h, a, n) dh \quad \text{for} \quad n=N1, N2$$

3. Nbd externality depends on its residents, $\chi_n = X(\mu)$.

4. $\widetilde{\Psi}$ is consistent with the moving decisions $\widetilde{g}_n$ of households in neighborhoods N1 and N2.

5. The law of motion $\widehat{\Psi}$ is consistent with human capital decisions $g_{h'}(h, a, n_-) = G(Z_n, a, g_i(h, a, n_-), \chi_n)$ and the ability process.

6. The joint distribution of human capital and ability is stationary $\widehat{\mu}' = \widehat{\Psi}\left(\widetilde{\Psi}\left(\widehat{\mu}\right)\right) = \widehat{\Psi}\left(\mu\right) = \widehat{\mu}$.

3.4.1 Equilibrium in the Model with Segregation (SRCE)

Definition 2. *A* ***steady-state recursive competitive equilibrium under segregation (SRCE)*** *is an MRCE under the following restriction:*

SRCE-a $n = \widetilde{g}_n(h, a, n_-) = n_-$

Note that an implication of the SRCE-a restriction is that the law of motion for sorting is trivial: $\widetilde{\Psi}\left(\widehat{\mu}\right) = \widehat{\mu}$. In other words, since there is no location decision in the model under segregation; nothing happens in the 1^{st} sub-period (See Figure 5.).

3.4.2 Existence and Characterization of Equilibria in These Models

We show in Appendix A that the household's problem under segregation can be expressed recursively, and furthermore prove the existence of an SRCE. Appendix B discusses how one might prove the existence of an MRCE, as well as the condition in such a proof that is difficult to show analytically, and some intuition of how this condition could be met.

4 Model Specification and Parameterization

4.1 Sorting Equilibria and Production

It is worth considering the types of sorting patterns that can give rise to stable asymmetric equilibria in this model, since they influence the specification of several functional forms and the calibration of some of the important parameters. In the absence of binding moving constraints (e.g., fixed cost of moving, moving opportunity shock), a little reflection makes clear that an MRCE must be one of two types. Either the neighborhoods are identical (same prices, same externality levels, and same wealth distribution) or they are asymmetric where one neighborhood has a higher externality value and higher housing price than the other. It would be inconsistent with optimizing behavior for one neighborhood to have a low externality and high house prices since households would choose to move away from that location, which in turn would induce the firm to lower its housing price.

In order for an asymmetric equilibrium to be sustained, the moving decisions $g_n\left(h, a\right)$ must have a particular ordering over h. Without loss of generality, label the low externality/low price location $N1$ and the other $N2$. The required ordering in the moving decision rule is summarized in the following condition:

Sorting Condition (sorting by h) : *Given neighborhood prices* $p_{N1} < p_{N2}$ *and externalities* $\chi_{N1} < \chi_{N2}$, *for any* $a_i \in \mathbb{A}$, *if* $g_n(h_1, a_i) = N2$, *then* $g_n(h_2, a_i) = N2$ *for all* $h_2 > h_1$.

The Sorting Condition says that given ability, high human capital households are willing to pay more for a high externality than are low human capital households.[12] The intuition for this condition is illustrated by considering how sorting changes N2 in response to a price increase. The Sorting Condition ensures that all else constant, a price increase in N2 will induce an outflow of *below average* (in N2) human capital households, increasing the externality in N2. This rise in the externality compensates households who remain and pay the higher housing price, allowing for a higher-income, higher-price neighborhood to exist in a stable equilibrium under the Sorting Condition.

Suppose that in contradiction to the Sorting Condition, high human capital households were the first to move in response to a price increase. Then the implied sorting would reduce the externality in N2, penalizing the remaining households. This would push more above average human capital households to move, decreasing the externality in N2 still further, illustrating how a higher-income, higher-price neighborhood cannot exist in a stable equilibrium without sorting rules satisfying the Sorting Condition.

Theoretically, inputs of production must be complements in order to satisfy the Sorting Condition. If private investment and the externality are substitutes, then high-income households are capable of offsetting a low externality by spending more privately. Since in this case the neighborhood externality is not as important to these high-income households, they are attracted to the low price neighborhood where they can afford more housing. Thus if inputs are substitutes, high-income households will not sort into the high-price, high-externality neighborhood (N2). A similar equilibrium failure results from the “chasing problem” discussed in Durlauf (1996).

In contrast, if private investment and the neighborhood externality are complements, then high-income households cannot easily offset a low externality by spending more privately. Thus, high-income households could be willing to pay a higher price for housing in exchange for a higher externality. Since households have a desire to smooth consumption over time, a high human wealth household in particular has a strong motivation to endow its child with a high level of human capital. The increasing marginal cost of producing human capital gives these households an incentive to locate in a high externality location.

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[12] Bénabou (1993) makes an analogous assumption in terms of the cost of skill acquisition (A2).

4.2 Production Function Specification

Recalling Equation 1, we specify that h' units of human capital are produced next period according to the Constant Elasticity of Substitution (CES) production function

$$\begin{aligned} h' &= G\left(Z_n, a, i, \chi_n\right) & (5)\\ &= Z_n\Big(\lambda_a\, a^{\gamma} + \lambda_i\, i^{\gamma} + (1-\lambda_a-\lambda_i)\, H_n^{\gamma}\Big)^{\frac{1}{\gamma}}. & (6) \end{aligned}$$

where the externality level χ_n is determined as:

$$\chi_n = H_n = \sum_{a \in \mathbb{A}} \int_{\mathbb{H}} h f_n(h,a) dh,$$

or the intra-period average human capital in neighborhood n. This production function renders our model as a generalization of the Becker-Tomes model of the intergenerational transmission of human capital (Becker and Tomes (1979), Becker and Tomes (1986)), with the novel feature being the neighborhood-specific externality inspired by Wilson (1987).

Although the properties of our model depend crucially on Equation 5 (Goldberger (1989)), the literature is far from settled on its correct specification. In the related Education Production Function (EPF) literature, for example, "there is a remarkable lack of consensus over which inputs increase children's achievement and to what extent" (Todd and Wolpin (2007), p F4).[13] The neighborhood effects literature is similarly divided on the existence of neighborhood externalities, let alone whether and how specific neighborhood characteristics behave as factors of production.[14]

Our specification including neighborhood human capital as a factor of production is consistent with the evidence that the human capital level of one's ethnic group has important effects on the intergenerational transmission of human capital (Borjas (1992)), with residential segregation being an important mechanism in this process (Borjas (1995)). Our specification is also consistent with the literature on Becker-Tomes. Mulligan (1999) suggests neighborhood externalities as a potential generalization to improve the predictions of the Becker-Tomes model. For example, data from multiple generations in Sweden indicate that the standard Becker-Tomes model under-predicts the persistence of labor income across generations (Lindahl et al. (2014)), while

---

[13] This is probably related to the data limitations requiring researchers to adopt specifications imposing strong and arbitrary restrictions on the production technology. The EPF literature also models the technology of skill production in terms of a single child. Thus even the most general specifications in this literature rule out social interactions (Cunha et al. (2010), p 904), an important component of the neighborhood externalities at the heart of our analysis.

[14] While there is quasi-experimental evidence of the existence of neighborhood externalities on educational attainment, employment, and wages (Rosenbaum (1995), Rubinowitz and Rosenbaum (2000), Mendenhall et al. (2006), Bayer et al. (2008)), as well as on adults' contemporaneous employment and wages (Rosenbaum (1995), Rubinowitz and Rosenbaum (2000), Aliprantis and Richter (2014), Bayer et al. (2008)), there is also quasi-experimental evidence that changing the neighborhood alone (ie, perhaps not changing schools) is not sufficient to affect children's outcomes (Oreopoulos (2003)). There is disagreement about how to interpret the experimental results from the Moving to Opportunity (MTO) housing mobility program (Ludwig et al. (2008), Clampet-Lundquist and Massey (2008), Sampson (2008), Aliprantis (2014a)). For example, different groups of researchers have drawn opposing conclusions from MTO about the existence of neighborhood externalities on employment and wages (Ludwig et al. (2013), Aliprantis and Richter (2014), Pinto (2014)).

Calvó-Armengol and Jackson (2009) show that a neighborhood externality can generate greater persistence in human capital across generations than the standard Becker-Tomes model.

The CES functional form adopted in (5) allows for flexibility in parameterizing the factors of production either as substitutes or complements (Uzawa (1962)). We restrict the technology so that inputs are complements in production (ie, $\gamma < 0$) for both theoretical and empirical reasons. We discussed the theoretical reasons why inputs must be complements for prices to support a general equilibrium when mobility is allowed in Section 4.1. Empirically, the best available evidence indicates that parental investments (i) and investments in public schools (part of χ_n in our model) are likely to be complements (Grawe (2010)).

An important feature of our production function is that because a has a finite upper bound, complementarity between inputs ensures that the marginal cost to producing h' becomes infinite at some point. As a result, h will be bounded above by a maximal sustainable human capital level (and hence we are assured that an equilibrium will exist - see the Appendix for further discussion). Complementarity guarantees that there exists some x_h such that for any χ_n in $\mathcal{H}$, all households with human capital above x_h will choose a lower level for their child. Without this restriction or a similar one, it would be possible for a sufficient mass of households to have human capital above some high level that would generate a large enough externality for h to grow for all households. In such a case the mass of households above x_h will be even larger the next period, and so too will be the externality, generating explosive dynamics.

4.3 Utility, the Stochastic Ability Process, and Fixed Parameters

Period utility is assumed to be separable in housing services and non-housing goods as follows:

$$u\left(c_t, s_t\right) = \frac{c^{1-\nu_c}}{1-\nu_c} + \theta \frac{s^{1-\nu_s}}{1-\nu_s},$$

where $\frac{1}{\nu_c}$ is the intertemporal elasticity of substitution in non-housing consumption and ν_s is the curvature of utility with respect to housing.[15] The ratio $\frac{\nu_s}{\nu_c}$ is the elasticity of substitution between housing and non-housing goods. We restrict $\nu_s > \nu_c$ so that households' demand for housing services relative to non-housing services declines in income. Intuitively, this restriction is placed to help satisfy the Sorting Condition, so as to rule out wealthy households being the first to move away in response to housing service price increases.

Children are born with innate ability for producing human capital, a. Ability has a finite support $\mathbb{A} \equiv \{\underline{a} = a_1, a_2, \ldots, a_n = \overline{a}\} \subset \mathbb{R}_+$, where the stochastic ability process is a stationary Markov chain with transition probabilities denoted by $\pi(a_i|a_j)$. The transition probabilities are calibrated to approximate the continuous AR(1) process

$$\log(a_{t+1}) = \rho_a \log(a_t) + \varepsilon_a, \quad \varepsilon_a \sim N\left(0, \sigma_a^2\right),$$

---

[15] See Chambers et al. (2009) for a discussion of important features of the data best matched using a separable utility function.

using the Rouwenhorst method (Kopecky and Suen (2010)).

4.4 Calibrating a SRCE to 1960 Data from Chicago

4.4.1 Data and Variables

Most of the data used in the calibration exercise are tract-level decennial census data for 1960 from the National Historical Geographic Information System (NHGIS, Minnesota Population Center (2004)). The first variable is the share of African-American residents in each census tract, which we use to define neighborhoods N1 and N2. This variable is the number of African Americans in each tract divided by the total number of residents.

N1 is defined as all Census tracts with a share black greater than or equal to 0.80 in 1960, and N2 is defined as all remaining census tracts in the city. Census tracts are part of N1 in subsequent years if they are contained within 1960's N1. Figure 3 show the share black in Chicago census tracts in 1960. We can see that N1 contains Chicago's "Black Belt," the segregated area in which most of the city's African Americans lived.

Parameters are also calibrated to match moments from data on per-capita earnings, which we use to measure human capital. This variable is created as the aggregate income in each census tract divided by the total number of residents, where aggregate income is created from variables on the income of families and unrelated individuals, and then converted to 2005 dollars using the appropriate BEA GDP price deflator.

4.4.2 Calibration Results

Six model parameters are calibrated jointly to match six inter-neighborhood and intra-neighborhood moments. In addition to moments from the US Census data from Chicago in 1960, we also calibrate the model to match moments from the literature and the National Income and Product Accounts (NIPA). With respect to the intergenerational elasticity (IGE) of earnings, Solon (1999)'s survey concludes that the correlation among American brothers in the permanent component of their log earnings is somewhere around 0.4, and that most of the estimates of the IGE in the literature fall in a range between 0.3 and 0.5. While there is evidence that the IGE is higher (Mazumder (2005)) or lower (Behrman and Taubman (1985)), we target 0.4 in part because of Aaronson and Mazumder (2008)'s estimate of a 0.43 time-invariant IGE between 1950 and 2000. The moments targeted in the model calibration are displayed below in Table 1.

Table 1: Moments Used to Calibrate the Model

Moment	Source	Data 1960	Model Steady State
H_{N1}/H_{N2}	1960 US Census	0.56	0.55
$H_{N2}/Q^h_{N2}(0.50)$	1960 US Census	0.95	0.97
$CORR\,(ln(h), ln(h'))$ in N2	Aaronson and Mazumder (2008), Solon (1999)	0.40	0.40
$VAR\,(log(h))$ in N2	1960 US Census	0.20	0.16
pS/C in N2	1960 NIPA	0.22	0.26
$Q^h(0.50)/Q^h(0.10)$ in N2	1960 US Census	1.33	1.60

We must set several additional model parameters in order to calibrate the model. Some parameters are set to values within the plausible ranges found in the literature, like $\nu_c = 1.5$ and $\nu_s = 2.0$.[16] We set $\beta = 0.67$ so that the complete-market annualized interest rate equivalent in our model is three percent for 15-year periods. The total factor productivity (TFP) parameter Z_{N2} is an arbitrary scaling factor, which we set to 4.

While there is strong justification for the complementarity between inputs in production function, there is not strong evidence on precise loadings beyond this broad characterization. We cannot separately identify the λ_a and λ_i parameters. Therefore we adopt the following specification with one factor loading parameter λ and the residual $(1-\lambda)$ divided between the other factors:

$$h' = Z_n\bigg(\phi_a(1-\lambda)a^\gamma + (1-\phi_a)(1-\lambda)i^\gamma + \lambda H_n^\gamma\bigg)^{\frac{1}{\gamma}}.$$

Under this specification, if ϕ_a is set near zero, then the wealth distributions become degenerate. Alternatively, for ϕ_a near one, investment becomes irrelevant, so income becomes a stochastic process independent of individual investment decisions. We thus set ϕ_a to 0.3. The housing production technology parameter α is set to generate a price elasticity of supply of 1.77.

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[16] While our utility function is similar in form to the ones used in Fernandez and Rogerson (1998) and Badel (2010), our parameterization implies that housing and non-housing are substitutes with an elasticity of substitution of 1.33. The elasiticy in Fernandez and Rogerson (1998) is –0.6 (complements), and in Badel (2010) it is 1.0.

Table 2: Model Parameters

	Parameter	Value	Identification
Preferences: $u(c,s) = \frac{c^{1-\eta_c}}{1-\eta_c} + \theta \frac{s^{1-\eta_s}}{1-\eta_s}$			
Utility Function (Consumption)	η_c	1.5	Set by the Authors
Utility Function (Housing Services)	η_s	2.0	Set by the Authors
Utility Function (C v S)	θ	0.11	Calibrated
Time Preference	β	0.67	Set by the Authors
Production Function: $h' = Z_n \left(\phi_a (1-\lambda) a^{\gamma} + (1-\phi_a)(1-\lambda) i^{\gamma} + \lambda H_n^{\gamma} \right)^{\frac{1}{\gamma}}$			
TFP	Z_{N1}	2.93	Calibrated
TFP	Z_{N2}	4.0	Set by the Authors
Production Share	ϕ_a	0.30	Set by the Authors
Production Share	λ	0.39	Calibrated
Elasticity of Substitution Parameter	γ	–0.92	Calibrated
Ability Process: $\ln(a') = \rho_a \ln(a) + \epsilon_a$			
Standard Deviation of Shocks	σ_a	0.60	Calibrated
Persistence	ρ_a	0.01	Calibrated
Firm's Production Function: $Y = Y(N, L) = N^{\alpha} L^{1-\alpha}$			
Technology Parameter	α	0.64	Set by the Authors

Table 2 lists the values of the parameters of the calibrated model. The values are in line with those of the most similar paper in the literature (Badel (2010)). The low persistence of the ability process is in line with recent evidence that even in Sweden, environment has a much larger influence on intergenerational mobility than genetics (Black et al. (2015)).

In addition to the targeted moments from both the data and the calibrated model displayed Table 1, the model fit is also displayed in Figure 6, which plots the distribution of per-capita income for each neighborhood in the 1960 data against its model counterpart from the calibrated steady state. Given the relatively small number of adjustable parameters, we feel that the model does a good job of capturing inequality in both neighborhoods. In particular, the model well-approximates the distribution for $N1$, the focus of this paper.

5 Numerical Experiments

We conduct three numerical experiments with the calibrated model, interpreting the years after 1960 as part of a transition path from the steady state SRCE in 1960 to either a new MRCE or SRCE steady state. We first consider a new MRCE in which not only is mobility allowed, but the technology in N1 is also equalized with that in N2 ($Z_{N1} = Z_{N2}$ MRCE). To understand how mobility and technology individually contribute to these results, we also consider the transition paths to a new equilibrium in which mobility remains restricted but technologies are equalized ($Z_{N1} = Z_{N2}$ SRCE) and in which mobility is allowed but the technologies remain the same ($Z_{N1} \neq Z_{N2}$ MRCE).

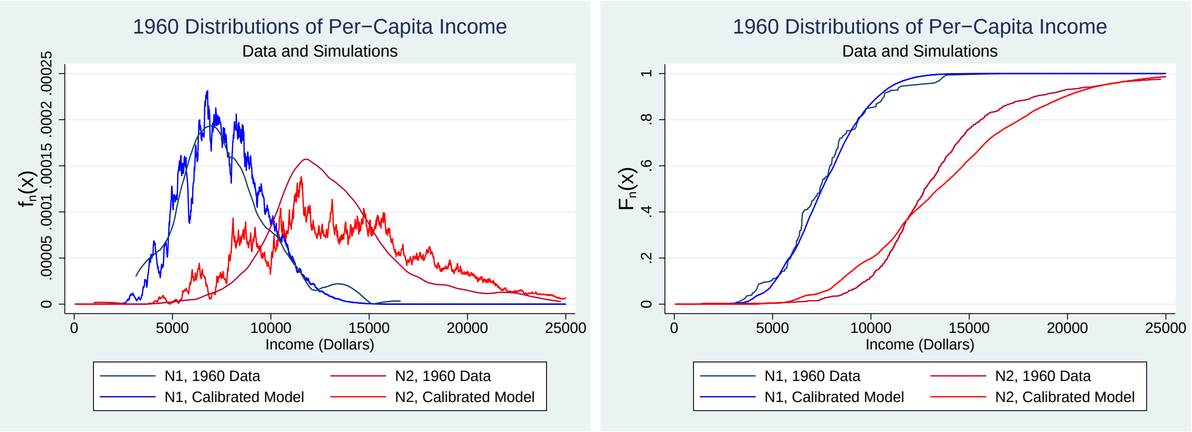
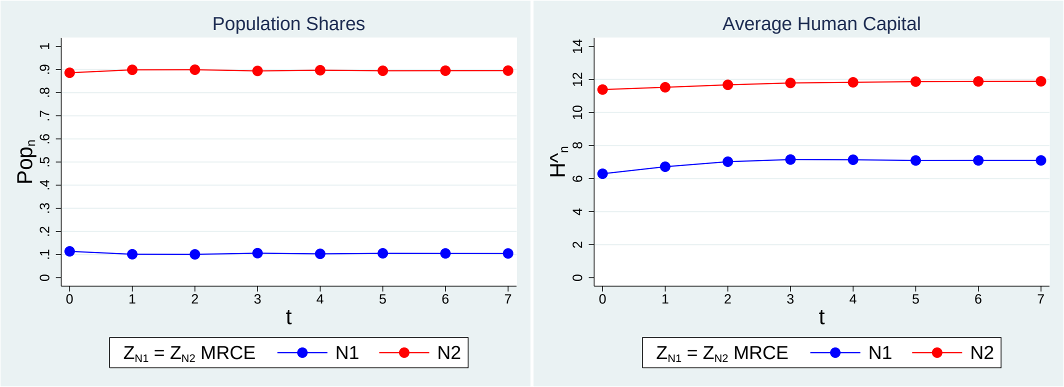


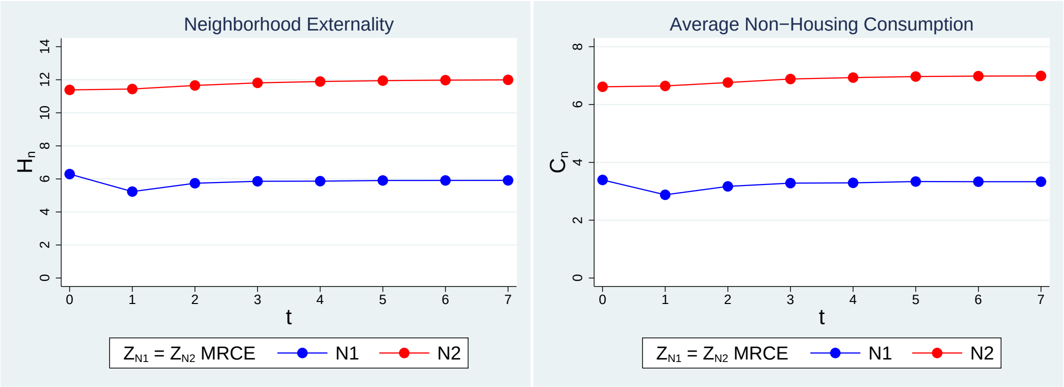
Figure 6: Distributions in 1960, Data and Simulations

Allowing for mobility and equalizing technologies might be associated with Martin Luther King, Jr.'s ex-ante vision for the integration of Chicago (King (1998)). Maintaining the restriction on mobility between N1 and N2 while equalizing their technologies might be associated with Malcolm X's ex-ante vision of separation (X (1990)). And finally, allowing for mobility with unequal technologies across N1 and N2 might be interpreted as the counterfactual resulting from eliminating legal racial discrimination alone. This is one of the central thought experiments suggested by Wilson (1987)'s ex-post analysis of how residential sorting and neighborhood externalities contributed to outcomes in Chicago between 1970 and 1980.

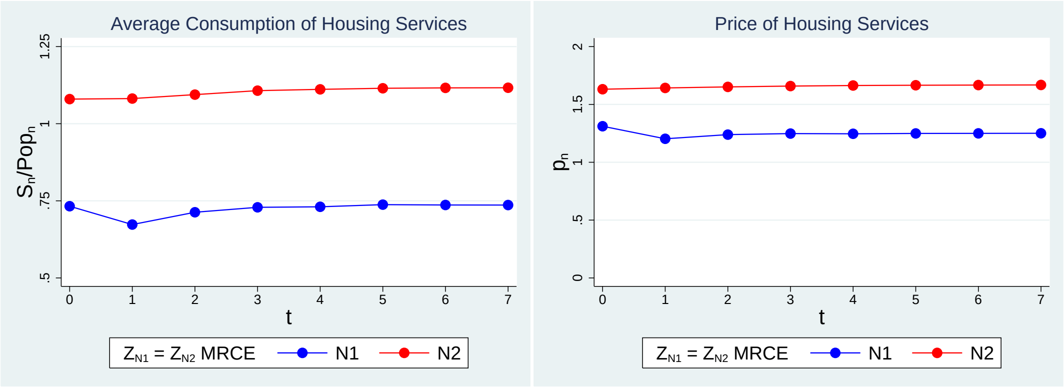
5.1 The Transition Paths



(a) $Pop_n = \sum_{a\in\mathbb{A}} \int_{\mathbb{H}} \widehat{f}(h,a,n)dh$ (b) $\widehat{H}_n = \sum_{a\in\mathbb{A}} \int_{\mathbb{H}} h\widehat{f}_n(h,a)dh$



(c) $H_n = \sum_{a\in\mathbb{A}} \int_{\mathbb{H}} hf_n(h,a)dh$ (d) $C_n = \sum_{a\in\mathbb{A}} \int_{\mathbb{H}} g_c(h,a,n)f_n(h,a)dh$



(e) $\overline{S}_n = \sum_{a\in\mathbb{A}} \int_{\mathbb{H}} g_s(h,a,n)f_n(h,a)dh$ (f) $p_n = \frac{\omega}{\alpha} S_n^{\frac{1-\alpha}{\alpha}}$

Figure 7: The Transition Path after Moving Allowed and Technologies Equalized

Figure 7 shows the transition path after allowing mobility and equalizing technologies. Along the transition to the $Z_{N1} = Z_{N2}$ MRCE, the population share in each neighborhood is little changed with N2 gaining an additional 1.4 percent of the city population (Figure 7a). This muted change in population shares, however, masks a considerable amount of sorting across neighborhoods.[17] Migrants into N1 have low- to moderate- human capital. Figure 7c shows that the externality in N1 decreases slightly, as the right tail of N1 exits. Over time, the outflow of human capital is partially offset as households in N1 increase their investment in response to the change in TFP. As a result, N1 average human capital rises (Figure 7b). The increase in investment early in the transition causes consumption of both housing and non-housing goods to dip in the early periods of the transition. These both rise back to their initial values later, as income rises. Although average housing demand is unchanged in N1, the price still falls after allowing sorting because the congestion ratio decreases (Figure 7f).

Compared to N1, N2 experiences a positive composition change after sorting. Immigrants from N1 bring high human capital while households exiting N2 are below the neighborhood average. The result of this income stratification is an increase in the production externality and higher long-run average human capital. The housing services price in N2 has a very muted response, increasing by only 1.7 percent of its initial value from a combination of slightly higher average housing demand and a bit more congestion.

Figure 8 compares the $Z_{N1} = Z_{N2}$ MRCE transition with those that result from changing only one feature of the model at a time, either equalizing technologies alone or allowing mobility alone. Equalizing the technologies but maintaining a restriction on moving leads to a gradual increase in human capital as residents respond to the improved technology (Figure 8d). Eventually, the transition reaches a new steady state where neighborhoods are completely equal (with the exception of population share). This steady state is equivalent to a single neighborhood with land mass $L_1 + L_2$. Naturally, N2 is unaffected because TFP is the same in either case.

Figure 8d shows how sorting positively impacts N2 at the expense of N1. Notice that although N1 average income rises in the world where technologies are equalized when households have a choice over location, it rises much more when they do not. This is due to the the positive contribution to the production externality from high-income N1 residents. If moving is allowed, those households go to N2 early in the transition, stunting the income prospects for N1, and boosting average income in N2 instead.

N1's fate is worst when moving is allowed but the technology in N1 is unchanged. If TFP is left unequal across locations and mobility allowed, N1 is rapidly abandoned. The population share in N1 declines from 11.4 to 0.0 percent in one period (Figure 8a). With the migration of all N1 households, N2 average human capital declines by 5.1 percent initially (Figure 8c), and then returns slowly to its steady state level. Average housing services is reduced by 3.7 percent permanently as congestion pushes up the equilibrium price. In the end, this experiment also effectively results in a single neighborhood but one in which the distribution of households across neighborhoods is less efficient.

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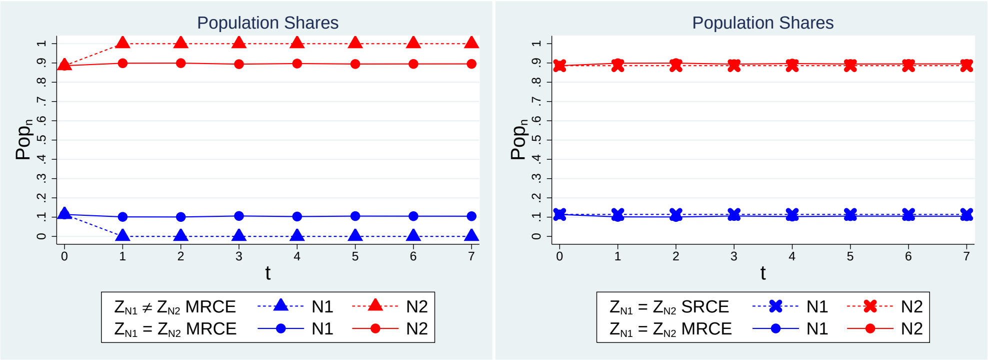
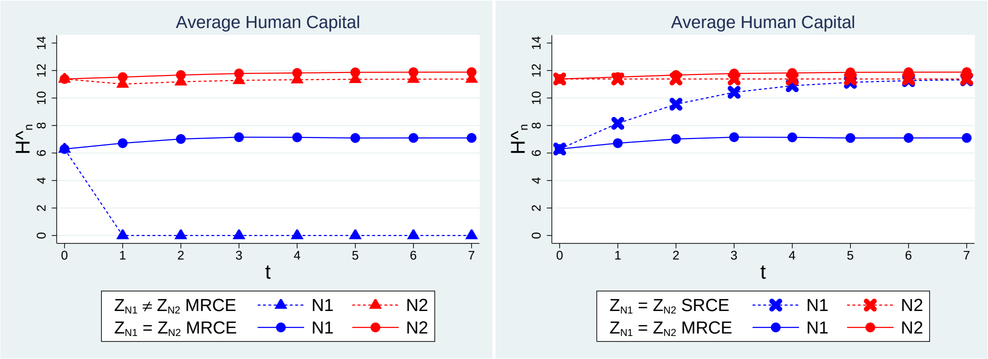
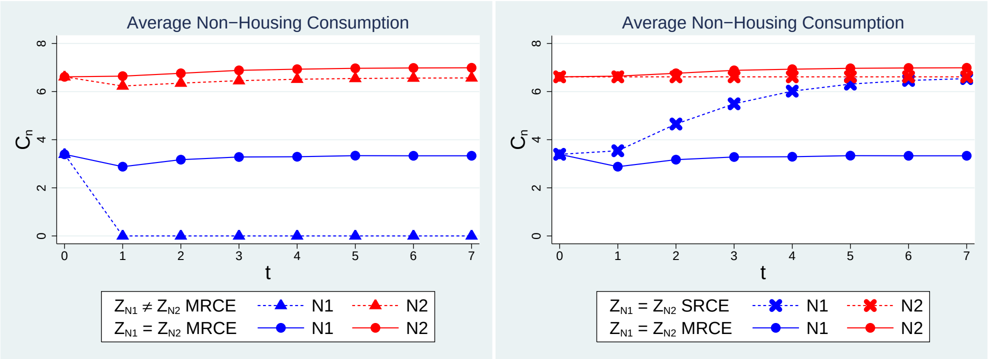
[17] Moving decisions in the transition are close to the steady state decisions, which are shown in Section 5.2.



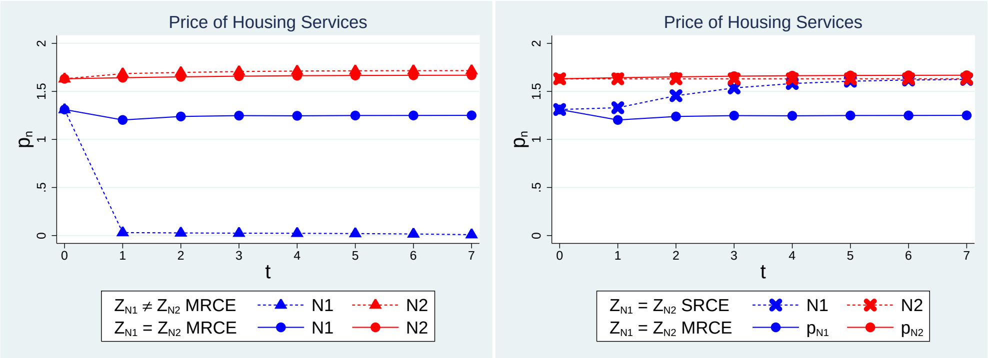
(a) Moving Allowed (b) Tech Equalized



(c) Moving Allowed (d) Tech Equalized



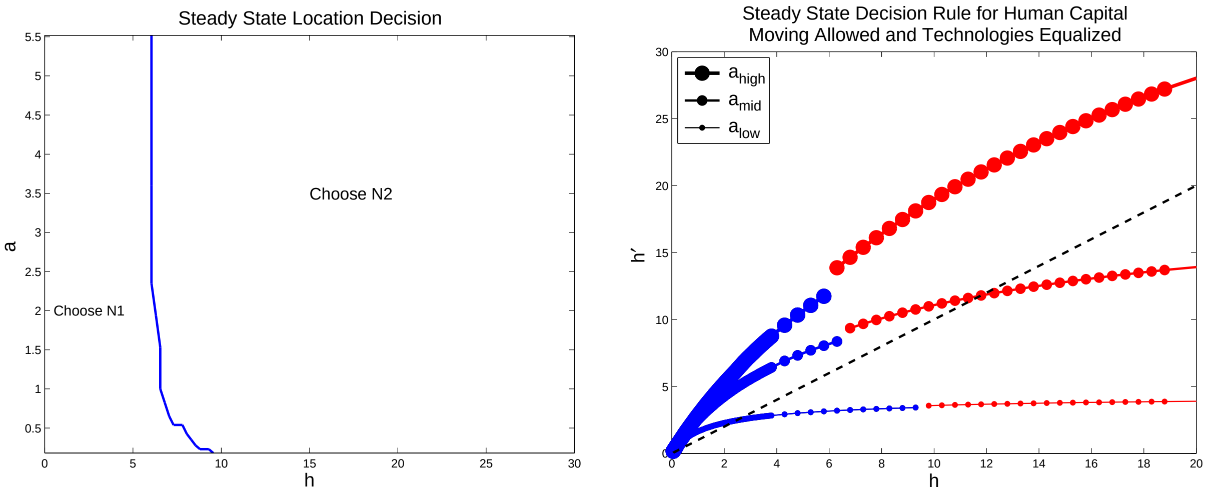
(e) Moving Allowed (f) Tech Equalized



(g) Moving Allowed (h) Tech Equalized

Figure 8: The Transition Path after Moving Allowed or Technologies Equalized

5.2 The New Steady States after Allowing for Moving



(a) $\widetilde{g}_n$

(b) $\widehat{g}_{h'}$

Figure 9: Moving Allowed and Technologies Equalized

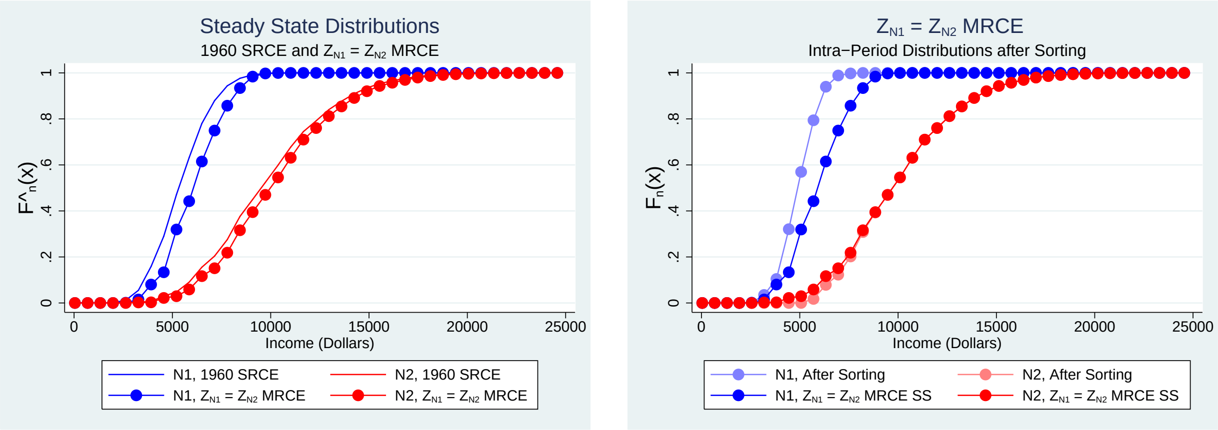
Figures 9a and 9b show the residential location and human capital decision rules in the $Z_{N1} = Z_{N2}$ MRCE steady state. Figure 9a illustrates that conditional on ability, there is some human capital level h_a for which households below h_a choose to live in N1, while households with $h > h_a$ live in N2. This figure also shows that high-ability households move to N2 at a lower income level, while low-ability households must have a higher income to move to N2.

The human capital decision rules in Figure 9b help to understand how households cycle through the distribution of h, a, and n in the $Z_{N1} = Z_{N2}$ MRCE. Low-h households choose to reside in N1. The only way to leave N1 is to receive a string of sufficiently high ability shocks, so as to increase the household's h. Once the household has built up its h, it may receive a high enough ability shock so as to move to N2. Households in N2 remain there, cycling around the human capital distribution in response to ability shocks, until they receive a string of sufficiently low ability shocks.

The role of ability is especially stark when looking at the decision rule of the lowest ability households. Receiving the lowest ability draw drastically limits the amount of h' passed on to the next generation, making N1 the optimal location for most low-ability households. Regardless of income, a household in N2 that receives a child with the lowest ability level will exit N2 with certainty within two periods. If h is low enough, it will move immediately. If not, it will wait one period when h' will necessarily be below the moving threshhold for any a'.

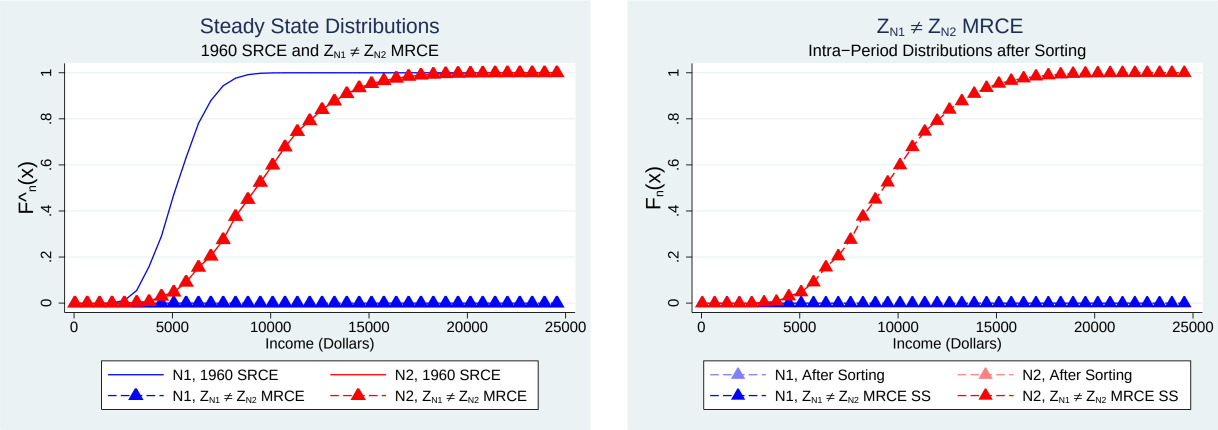
When neighborhood TFP is unequal, the income threshhold at which households move to N2 is so low that N1 is empty. Furthermore, for h below this threshhold, the human capital decision rule is above the 45 degree line for all ability types, meaning N1 is not poverty trap. Even if a zero-measure group of households were exogenously relocated from N2 to N1, they would eventually accumulate enough income to escape, after which they would never revisit N1.

The result of these decision rules is that in the MRCE with equalized technologies, households in the right tail of N1 move to N2, households in the left tail of N2 are moving to N1, and so the intra-period distribution μ exhibits greater inequality across neighborhoods than does the steady state distribution $\widehat{\mu}$ (Figure 10b). In the MRCE with unequal technologies, everyone moves to N2 (Figure 11).



(a) $\widehat{\mu}$ (b) μ

Figure 10: Moving Allowed and Technologies Equalized



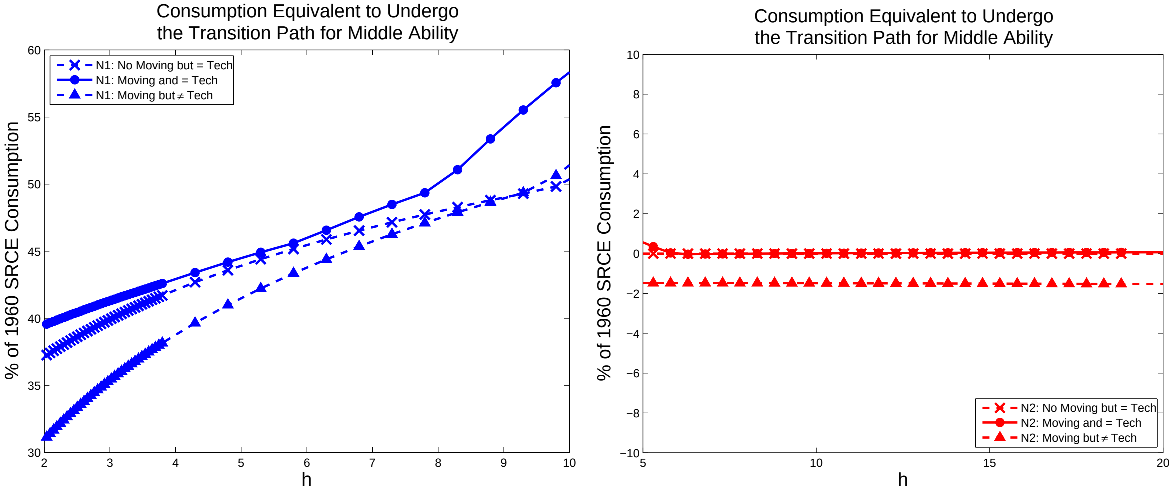
(a) $\widehat{\mu}$ (b) μ

Figure 11: Moving Allowed but $\neq$ Technologies

5.3 Welfare

Figure 12 shows consumption equivalents for the counterfactual policies. This is the percent change of a household's consumption in the 1960 SRCE steady state that would be required for them to be indifferent between remaining in the 1960 SRCE steady state and undergoing the given transition path. A first detail to notice is that every household in N1 prefers any of the three transitions to remaining in the initial segregated equilibrium.

Among the three transitions, moving with equalized technology is preferred to the other two polices by every N1 household. The intuition for why it is preferred to moving with unequal



(a) Middle Ability in N1

(b) Middle Ability in N2

Figure 12: Welfare

technologies is straightforward. Both N1 and N2 are more attractive locations when technology is equal relative to when technology is unequal. The reason households prefer moving with equal technology to a policy with equal technologies and no moving is more subtle. While it is true that the N2 externality and N2 price are higher with moving than without moving, the differences are small. It is the outcome of N1 that makes moving with equal technologies more attractive. N1 becomes the optimal location for a household with below average income and a low ability child. Such a household cannot take full advantage of a high externality and so moves to N1 and consumes more housing. Under the policy of unequal technologies, N1 is completely abandoned, effectively forcing these households to remain in a more expensive location. It is this choice of suitable locations depending upon income and ability that make moving with equal technologies attractive to all N1 households.

Nearly all households who initially live in N2 have the same preference ordering as their N1 counterparts.[18] Initial N2 residents also almost universally prefer moving with equal technologies to the initial segregated, unequal policy. This is because under moving with equal technologies, the externality in N2 goes up for a very small increase in price, and the N2 residents get the option to move to N1 when they have a low ability draw.

The welfare consequences are very large for households starting in N1. On average, initial steady state consumption would need to be increased by 47.7 percent to make these agents indifferent between living in the SRCE with unequal technology and transitioning to the MRCE steady state with equal TFP. The same calculation returns 44.6 percent and 46.1 percent for the MRCE with unequal TFP and the SRCE with equal technology, respectively. For households in N2, the welfare effects are much smaller. The average consumption equivalence is 0.08 percent for the MRCE with equal TFP and −1.5 percent for the MRCE with unequal technology.

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[18] There is a very narrow range of income in the middle where households prefer a lower externality and price than arises in N2 with moving and equal technology. The restricted moving policy with equal technologies provides this.

There are changes to the land rents accruing to the absentee landlord. If the absentee landlord discounts the future at the same rate as households do, the present discounted value of rents increases by 4.7 percent under both policies with equal TFP. The unequal TFP MRCE generates the largest change in profits at 6.9 percent, which is due to the congestion resulting from the entire population living in one location.

6 Conclusion

In this paper, we solve a dynamic heterogeneous agent incomplete market model with location choice and local production externalities. We use a two-neighborhood model without moving to represent Chicago when it was legally segregated, and calibrate the model allowing for unequal technologies. We then consider three policy experiments. First, we remove location restrictions but leave technology unequal across neighborhoods. This results in a rapid and complete abandonment of N1 and high housing costs in N2 due to more congestion. Second, we maintain the restrictions to location choice but equalize technology. In stark contrast to the first experiment, average income in N1 slowly rises until in the long run N1 is a less populated replica of N2. Finally, we allow households to sort across locations and equalize technology. This increases average income in both locations, but also leads to a stratified equilibrium where households with high ability draws and sufficiently high income locate in N2, while N1 becomes a haven where low-to-moderate income households move to consume cheap housing after receiving a low ability draw. Contrasting the last two experiments highlights the powerful role location choice plays in determining the effectiveness of policies designed to increase income in impoverished neighborhoods.

This work is meant to be an initial step in quantifying neighborhood transitions with sorting and externalities. Some extensions could be promising. Location choice is extreme in this paper: either households can costlessly change locations or they cannot move at all. The addition of frictions, either through moving costs or random moving opportunities, could alter the results here in a meaningful way. On the one hand, frictions would make it harder to exit a declining neighborhood, and a fixed cost of moving would be especially onerous on the poor. This could lead to poverty traps. On the other hand, features which keep high human capital households from moving work against the emergence of poverty traps. Also, this paper focuses in detail on a two neighborhood model, but extending the framework to more than two neighborhoods would be productive in general and likely necessary for some questions. To study the "white flight" experienced in some cities, for instance, it seems natural to have at least three neighborhoods. Finally, throughout our experiments, we abstract from persistent racial bias. Work aimed at understanding the effect of persistent racial bias as in Badel (2010) seems fruitful. For example, an adaptation of our model could be used to study persistent wealth inequality between populations which have experienced segregation and adverse lending policies. We leave these ideas to future work.

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