Residential Sorting, Local Environments, and Human Capital*

NICOLAI V. KUMINOFF
Arizona State University and NBER

and

SOPHIE M. MATHES
FGV EPGE

Abstract

We consider the implications of unifying the distinct literatures on residential sorting and human capital dynamics. We argue that integrating insights from recent work in both areas has important implications for future research at the intersection of environmental and urban economics. To focus attention on these implications, we summarize stylized facts from recent empirical work on residential sorting and on the effects of exposures to environmental factors on human capital. Then we outline a simple overlapping generations model that reproduces these stylized facts and use it to guide our discussion on directions for future research.

Dec 12, 2023

* Kuminoff: Arizona State University, Dept. of Economics and NBER, Tempe, AZ 85287 (kuminoff@asu.edu). Mathes: EPGE FGV, Rio de Janeiro, RJ 22250-900 (sophie.mathes@fgv.br). We benefitted from helpful conversations with Kelly Bishop, Jonathan Ketcham, Alvin Murphy, and Remy Levin. We are also grateful for helpful comments and suggestions from two anonymous referees and the Editor, Matthew Freedman. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

1. Introduction

The quantity and quality of life vary across the United States. For example, life expectancy at birth differs by as much as 20 years between US counties (Dwyer-Lindgren et al. 2017). Spatial variation in life expectancy is correlated with spatial variation in housing prices, environmental quality, and measures of human capital such as income, education, and health (Bishop et al. 2023a). These spatial correlations are thought to reflect a combination of residential sorting and cumulative exposures to local amenities such as air pollution and school quality. In this essay, we consider the life-cycle dynamics of residential sorting, amenity exposures and human capital. We propose a new framework to unify the distinct empirical literatures on residential sorting and human capital dynamics.

The residential sorting literature following Tiebout (1956) considers how heterogenous households sort themselves among differentiated neighborhoods that offer distinct combinations of housing prices and amenities. Empirical studies typically treat human capital as fixed and estimate structural parameters representing household preferences (Kuminoff et al. 2013). While neighborhood amenities are often treated as endogenous public goods that are produced, in part, by the residential sorting process, the literature is mostly silent on how contemporaneous amenity exposures affect the human capital stock.

A distinct empirical literature builds on Grossman (1972) to investigate how residential exposures to pollution and other neighborhood amenities modify human capital. Empirical studies typically treat household location as fixed and estimate causal parameters that describe how particular amenities affect physical health and cognition (Graff-Zivin and Neidell, 2013; Aguilar-Gomez et al., 2022). While the literature recognizes that heterogenous individuals can modify their amenity exposures by moving, residential sorting is usually depicted as a threat to econometric identification, rather than as a focal outcome.

Recent evidence from longitudinal analyses of administrative data suggests that the residential sorting process and the human capital production function influence each other throughout life. During childhood, exposure to neighborhood amenities affects the production of human capital, as measured by educational attainment and earnings when young adults enter the labor force (Chetty and Hendren, 2018). During adulthood, workers with higher human capital are more likely to choose to pay a premium to live in high-amenity neighborhoods that are better for their health and productivity. After retirement, residential amenity exposures continue to affect older adults' morbidity and mortality (Finkelstein et al. 2021). Understanding the life-cycle dynamics of these feedback effects may be important for evaluating the efficiency and equity of public policies targeting amenities.

The purpose of this essay is to consider the implications of connecting the economics of residential sorting and human capital production, and to suggest areas where further research is needed. We argue that integrating these core ideas has several potentially important implications for research at the intersection of environmental and urban economics. First, it implies that amenity exposures are endogenous throughout life because residential sorting may cause them to be correlated with latent features of human capital, and this endogeneity is not necessarily eliminated by focusing on exposures that occur earlier in life. Second, it implies that the structural parameters used to describe how households make tradeoffs between neighborhood amenities are endogenous to the residential sorting process, because amenity exposures affect features of human capital that, in turn, determine preferences. Combining the first two implications suggests a third: dynamic interactions between residential sorting and human capital production can generate virtuous or destructive spirals in which amenity exposures and human capital reinforce each other throughout life and across generations. Fourth, understanding the dynamic interactions between sorting and human capital production can be helpful in developing welfare measures to evaluate policies designed to meet environmental justice

goals.

The remainder of the essay is organized as follows. Section 2 summarizes some of the main stylized facts from the empirical literatures inspired by Tiebout and Grossman. Section 3 outlines a simple overlapping generations model that reproduces these facts. We refer to it as a "Tiebout-Grossman Model" because of the way that it integrates key mechanisms from the literatures that build on their seminal papers. In Section 4 we discuss model implications, before concluding in Section 5 with a discussion of opportunities for future research.

2. Stylized Facts from Recent Empirical Literature

We focus on five stylized facts about the economics of local amenities, human capital, and residential sorting. We draw on representative examples from recent literature to illustrate these facts, rather than attempt to provide a comprehensive review.[1] For expositional convenience, we define "human capital" very broadly to include physical health, cognition, and education. Likewise, we define "amenities" broadly to include all local public goods and environmental services that differentiate neighborhoods and are not formally traded in private markets. Examples include school quality, air quality, open space, and climate. We use air pollution as a focal example because it is studied extensively and is targeted by policy.

2.1. Amenities Affect the Production of Human Capital

The neighborhoods where children are raised affect their production of human capital. This stylized fact is supported by comprehensive evidence from Chetty and Hendren (2018) that children who move into a neighborhood tend to become more like their permanent-resident peers over time in terms of educational attainment and

[1] Kuminoff et al. (2013) review literature on residential sorting, Graff-Zivin and Neidell (2013) and Aguilar-Gomez et al. (2022) review literature on how environmental externalities affect human capital, Deryugina and Molitor (2021) review literature on how exposure to the bundle of amenities that differentiate residential locations affects health and longevity among older adults, Banzhaf et al. (2019) review literature on distributional implications of pollution exposure, and Hausman and Stolper (2022) review literature on information frictions in the housing market.

incomes earned in their late 20s.[2] The precise combination of amenities and peer effects that drives this convergence is not well understood, but school quality and air quality are among the amenities that are believed to contribute. For example, Chetty et al. (2014) find that when elementary and middle-school students are assigned to teachers who add value in terms of helping their students score higher on standardized exams, the students are more likely to attend college and to earn higher salaries as adults. Similarly, Ebenstein et al. (2016) and Isen et al. (2017) provide causal evidence that individuals who are exposed to higher air pollution as children tend to earn lower wages as young adults.

The link from air pollution to future earnings may manifest through both physical and cognitive channels. When air pollution increases, infant birth weight declines, children are more likely to visit the hospital, more likely to miss school and, conditional on attending school, they tend to score lower on standardized exams (Graff-Zivin and Neidell, 2013; Aguilar-Gomez et al. 2022).[3]

2.2. Amenities Affect the Productivity of Human Capital

After young adults enter the labor force, the productivity of their human capital is affected by their exposures to neighborhood amenities. For example, Bayer et al. (2008) find that neighborhood-level social interactions create informal job referral networks that affect hours worked and earnings. Air pollution exposure at home and at work is also thought to modify the productivity of human capital. Evidence is based on quasi-random variation in short-term air pollution exposures that arise from changes in wind direction and other atmospheric factors. Studies utilizing this variation have found that short-term pollution spikes reduce labor productivity among high-wage and low-wage workers who perform tasks that require different

[2] They also find that residential exposures affect the probability of teenage birth and marriage by age 26. This is notable because, like income and education, marital status and presence of children in a household are among the demographic variables that are often used to capture observable sources of preference heterogeneity in studies of residential sorting.
[3] School absences may mediate air pollution's effect on human capital. Aucejo and Romano (2016) and Liu et al. (2021) find that school absences cause lower scores on standardized exams.

combinations of physical labor and cognitive effort (Chang et al. 2016, 2019; Archsmith et al. 2018).

2.3. Amenities Affect the Destruction of Human Capital

After workers retire, the neighborhoods in which they choose to live affect the rate at which their human capital declines. For example, Deryugina and Molitor (2020) and Finkelstein et al. (2021) provide causal evidence from the over-65 Medicare population that migrants' residential location choices modify their remaining life expectancies. Mathes (2022) provides analogous evidence that residential locations affect the prevalence of chronic medical conditions. As with earlier stages of the life cycle, the precise combination of mechanisms that produce these effects remains unknown, but there is evidence that air pollution is a contributing factor. Daily spikes in particulate matter have been found to cause emergency room visits (Schlenker and Walker, 2016) and death (Deryugina et al., 2019), and elevated exposures over a decade have been found to increase the risk of being diagnosed with dementia (Bishop et al. 2023b).

2.4. Amenities are Capitalized into Housing Prices

Since people are free to move to neighborhoods with cleaner air, better schools, and better amenities in general, spatial variation in amenities within a metropolitan area will be capitalized into housing prices. This stylized fact is supported by numerous studies that have applied causal research designs to housing sales data to estimate the implicit prices of individual amenities (Kuminoff et al., 2013; Bishop et al., 2020). Likewise, since workers are free to move between metropolitan areas, some of the regional variation in amenities is also capitalized into wages.[4] These capitalization effects mean that choosing a residential location requires trading

[4] For example, Albouy et al. (2016) and Sinha et al. (2018) find that regional variation in climate is capitalized into wages as well as housing prices.

consumption of nonmarket amenities for consumption of private goods. The resulting expenditures appear to be substantial. Bieri et al. (2023) estimate that Americans implicitly spend the equivalent of 8% of their personal consumption expenditures on local amenities by choosing to live in areas where they must pay higher real housing prices and/or where they receive lower real wages.

2.5. Human Capital Affects Residential Sorting over Amenities

Households with higher human capital are more likely to pay a premium to live in higher amenity neighborhoods.[5] This stylized fact follows from combining the idea that income can provide a measure of human capital (Abraham and Mallatt, 2022) with the observation that higher-income households tend to locate in more expensive neighborhoods with better amenities (Banzaf and Farooque, 2013). Numerous studies provide cross-sectional evidence of household stratification by income (Epple and Sieg, 1999; Smith et al., 2004; Sieg et al., 2004). Moreover, Banzhaf and Walsh (2008) provide direct evidence that higher income households are more likely to react to the opening of new air polluting facilities in their neighborhoods by emigrating to cleaner areas. Other measures of human capital also affect sorting behavior. For example, Bayer et al. (2007) find that, conditional on income, higher educated parents with school-age children are more likely to pay a premium to live in neighborhoods where students enrolled in public schools tend to perform better on standardized exams.

3. A Tiebout-Grossman Model

In summary, stylized facts from the empirical literatures inspired by Tiebout (1956) and Grossman (1972) collectively suggest that exposure to neighborhood amenities affects human capital throughout life, that people can increase the production and

[5] Human capital may also affect the likelihood that individuals move. For example, highly educated workers migrate at higher rates (Bayer et al. 2011) and, among older adults, health shocks are among the most common reasons for moving (Mathes 2022).

productivity of their human capital by paying to live in neighborhoods with better amenities, and that the likelihood that people choose to do so is increasing in their human capital. In this section, we sketch a simple overlapping-generations model that embeds these features. For heuristic purposes we divide the life cycle into three stages: (1) childhood, (2) adulthood / employment, and (3) retirement.

3.1. Human Capital and Decision-Making

To focus attention on the implications of sorting behavior, we first characterize human capital dynamics and decision-making on a featureless landscape. We divide this landscape into two equally sized neighborhoods $k = \{1,2\}$. Each neighborhood has a fixed supply of N identical houses that are owned by absentee landlords and rented to a population of N adult workers and N retirees. Each neighborhood provides an identical amenity, q_k, such that $q_1 = q_2$.

Suppose that among the initial generation of adult workers, the distribution of human capital θ has support $[\theta_{low}, \theta_{high}]$ with mean $\bar{\theta}_{par}$. We initialize the model by assuming that these individuals are sorted across the two neighborhoods such that $\bar{\theta}_{1,par} = \bar{\theta}_{2,par}$. Next, we assume that N children are born to the adult workers. At the end of childhood, each young adult is endowed with human capital, θ_i, randomly drawn from a distribution with support $[\theta_{low}, \theta_{high}]$. While the support of the distribution is identical for all children, we define the mean of the distribution from which they draw in a given neighborhood, $\bar{\theta}_k$, to be a weighted sum of neighborhood amenities and mean human capital among the adult worker parents in their neighborhood.

$$\bar{\theta}_k = \lambda\, \bar{\theta}_{k,par} + (1 - \lambda)\, q_k. \tag{1}$$

Equation (1) specifies that the expected value of each child's human capital draw depends on their neighborhood environment and the composition of adults in their

neighborhood, with the relative importance of these inputs determined by λ. Since both inputs are currently assumed to be identical across both neighborhoods, the human capital production functions for children in each neighborhood are also identical.

Young adults enter the employment stage of life with their one state variable: human capital, θ_i. They choose a residential neighborhood, k, and simultaneously decide how much time to spend working for an exogenously given wage, w, and how to divide their earnings between private consumption c, the location-specific cost of occupying a house r_k, and saving for retirement s. Labor effort, l, generates disutility, which we assume is decreasing in θ. For example, labor might be more difficult for someone in worse health or with less education.

Workers receive flow utility from private consumption and neighborhood amenities, and flow disutility from labor effort.[6] They expect to survive through a subsequent retirement stage and, therefore, make decisions to maximize the sum of their flow utility and the discounted expected future utility during retirement.

$$(2) \qquad V_{adult}\,(r_k, q_k, \theta_i) = \max_{c,s,l,k} u(c, q_k) - v(l, \theta_i) + \beta E[V(\tilde{\theta}_i, s)|q_k]$$

$$s.t.\ c + r_k + s = wl$$

The flow utility from neighborhood amenities may reflect direct consumption value to the workers as well as their understanding that those amenities contribute to production of their children's human capital, for example through the quality of neighborhood schools.[7] Our assumption that the disutility of labor is mitigated by human capital, $v_{l,\theta} < 0$, implies that when workers solve the optimization problem in

[6] The labor supply decision can operate on the intensive margin, as in the case of a worker choosing how many hours to work per week during each year spent in the labor force, or on the extensive margin, as in the case of a worker choosing when to retire.

[7] Flow utility could also be modeled as depending directly on their children's expected human capital in Equation (1). However, this would require an additional assumption that parents fully understand the human capital production function.

Equation (2), those who are endowed with lower values of θ will choose to work less and, thus, have less disposable income. Thus, income is increasing in human capital.

When workers retire from the labor force and begin the final stage of their lives we assume that they experience good health, $\tilde{\theta}_i = \tilde{\theta}_{good}$, with probability p and bad health, $\tilde{\theta}_i = \tilde{\theta}_{bad}$, with probability $(1 - p)$. Further, we assume that p is increasing in the quality of amenities that retirees were exposed to during their prior employment stage. If the bad state of health is realized, retirees must pay higher out-of-pocket medical expenses m: $m(\tilde{\theta}_{bad}) > m(\tilde{\theta}_{good})$. After paying medical expenses, retirees spend the remainder of their savings on private consumption and housing. Finally, we assume that retirees receive direct utility from amenities in their neighborhoods: $u_q > 0$. Since retirement is the final stage of life, retirees simultaneously choose consumption and locations to solve the static problem shown in Equation (3).

$$\max_{c,k} u(c, q_k) \qquad (3)$$
$$s.t.\ c + r_k + m(\tilde{\theta}_i) = s$$

Thus far, we sketched a simple model of human capital and decision-making over the life cycle that embeds three stylized facts about how amenity exposures affect human capital dynamics. First, amenity exposures affect the production of human capital during childhood. Second, amenity exposures affect the productivity of labor, represented by the effect of human capital on the labor supply. Third, amenity exposures affect the destruction of human capital after retirement, represented by the effect of amenity exposures on future health.

These mechanisms collectively imply that the supply of residential amenities will affect earnings, consumption, and utility. However, thus far, the model lacks an incentive for residential sorting. Since the two neighborhoods are identical in

their provision of amenities and human capital production functions, they must have identical housing prices for the market to clear so that, in equilibrium, all adult workers and retirees are indifferent between living in the two neighborhoods.

3.2. Residential Sorting

Now imagine that unexpected events improve the amenities in neighborhood 2 and degrade the amenities in neighborhood 1: $q_2' > q_1'$. To help us characterize how this spatial variation will affect residential sorting, we invoke a version of the standard single-crossing assumption that is commonly used to establish necessary conditions for sorting equilibria (Kuminoff et al. 2013). Specifically, we assume that the marginal rate of substitution between q_k and r_k is strictly increasing in income for both working adults and retirees. This implies that indirect indifference curves only cross once and higher-income individuals have a higher marginal willingness to pay for amenities.

These features are sufficient for the model to replicate the two stylized facts from the residential sorting literature. First, the price of housing must be higher in the higher-amenity neighborhood. This follows because living in neighborhood 2 during the retirement stage increases flow utility in Equation (3) and, additionally, living in neighborhood 2 during the working stage increases flow utility through neighborhood amenities that also contribute to children's expected human capital, as well as through the discounted expected utility from the effect of amenity exposures on the probability of a bad health realization in retirement, as shown in Equation (2). This implies that the demand for housing in neighborhood 2 must be higher, so that r_2 must exceed r_1 for the housing market to clear. Thus, spatial variation in amenities is capitalized into housing prices.

Second, adult workers will sort themselves across neighborhoods by human capital. This stratification follows from combining the single-crossing condition with the labor supply decision affected by human capital embedded in Equation

(2). Workers who enter adulthood with more human capital face a lower disutility of labor. Therefore, they will optimally supply more labor and earn higher incomes. Single-crossing implies that these higher-income workers will outbid lower-income workers to live in neighborhood 2, replicating the income-based stratification pattern in Epple et al. (1993) and Fernandez and Rogerson (1996).

For example, let $\hat{\theta}$ denote the level of human capital that generates the precise level of income that makes a worker exactly indifferent between paying the higher price r_2 to live in community 2 in order to lower their risk of a negative health shock in the future while increasing their access to neighborhood amenities, and paying the lower price r_1 in exchange for higher risk and fewer amenities. The single-crossing condition implies that workers with $\theta_i < \hat{\theta}$ will choose community 1, whereas workers with $\theta_i > \hat{\theta}$ will choose community 2. In the context of our simple model, this stratification result, which is adapted from the residential sorting literature following Tiebout (1956), also captures the idea from Grossman (1972) that individuals face tradeoffs between private consumption today and better expected health and human capital in the future. In other words, working-age adults may choose to invest in their own health and in their children's human capital by paying more to live in higher-amenity neighborhoods.

When households transition to retirement and experience health shocks, some may choose to move between the high amenity and low amenity neighborhoods. Some households may optimally choose to move from the low to the high amenity neighborhood to increase their direct utility from amenities. Other households might move from the high to the low amenity neighborhood after realizing a negative health shock and increased medical expenses. Thus, our framework can accommodate migration patterns similar to those reported by Finkelstein et al. (2021), for example, that seniors move between areas with higher and lower life

expectancies at similar rates, and that healthier seniors are more likely to move to areas where average life expectancy among non-movers is higher.

3.3. Discussion

Our Tiebout-Grossman model embeds the five stylized facts that we emphasized in Section 2. To keep the model simple, we abstracted from potentially important features of residential sorting and human capital dynamics such as the contemporaneous effects of amenity exposures on workers' labor productivity and market frictions. Under the single-crossing assumption, these features can be added without changing our model's basic predictions.

For example, it is straightforward to extend Equation (2) to allow contemporaneous exposures to better amenities to increase workers' labor productivity. This would reinforce workers' existing incentive to move to the higher-amenity neighborhood to reduce their risk of experiencing a negative health shock during retirement. We could also add a utility cost of migration to reflect a combination of fiscal costs, information costs, and psychic costs of living away from family and friends. The empirical literature suggests that such costs are empirically important, but not sufficiently large to eliminate sorting behavior and amenity capitalization (Pope, 2008; Bayer et al., 2009; Hamilton and Phaneuf, 2015; Ma, 2019; Bishop et al. 2023a).[8]

Our simple model also abstracts from heterogeneity in the spatial scales at which amenities have been shown to affect the production and destruction of human capital. For example, public school quality varies between school attendance

[8] Information frictions may also vary with human capital. For example, Bakkensen and Barrage (2022) perform a door-to-door survey of Rhode Island residents and find evidence of sorting on heterogeneous beliefs over flood risk. Specifically, people living in high-risk flood zones are (mistakenly) less likely to worry about flood risk than those living further inland. Hausman and Stolper (2022) survey the literature on information frictions in the housing market and argue that it may amplify residential sorting over amenities by socioeconomic status. In our context, if reducing a worker's human capital were to attenuate their beliefs about the productivity of amenity exposures for their future health or their children's human capital, the resulting heterogeneity in beliefs would reinforce the existing stratification across higher and lower amenity neighborhoods by adult human capital.

zones whereas noise pollution and air pollution can vary locally within those zones. Our model follows residential sorting literature in assuming that neighborhoods are defined at a sufficiently high resolution that amenity exposures can be assumed to be homogeneous within a neighborhood (Kuminoff et al. 2013).[9] However, an empirical study would have to address the fact that amenity exposures can vary with mobility conditional on a residential location. That is, individuals' amenity exposures at home may differ from their exposures at school or at work. The difficulty in observing non-residential amenity exposures means that available measures of amenity exposure are likely to embed some measurement error, suggesting a need for instrumental variables (Bishop et al. 2023b).

Empirical studies have also shown that the production and productivity of human capital can be modified by short term amenity exposures occurring within each of the life-cycle stages of our model. For example, daily spikes in air pollution are thought to cause increased school absences (Graff-Zivin and Neidell, 2013; Aguilar-Gomez et al. 2022) which, in turn, has been shown to reduce students' scores on standardized exams (Aucejo and Romano 2016 and Liu et al. 2021). Similarly, daily spikes in air pollution are thought to reduce adults' labor productivity (Chang et al. 2016, 2019; Archsmith et al. 2018). Our model could be extended to accommodate higher-frequency exposures by allowing households to make location decisions and labor supply decisions more frequently within each stage, annually for example.

We leave development of a richer version of the Tiebout-Grossman model to future research. While our current framework is simplistic, it is sufficient to demonstrate that combining stylized facts from the empirical literatures on residential sorting and environmental inputs to human capital production points to promising directions for future research.

[9] While we defined the spatial landscape to contain only two neighborhoods for simplicity, it is straightforward to generalize our model to allow an arbitrary finite number of neighborhoods as in Epple et al. (1993) and Fernandez and Rogerson (1996).

4. Implications of Tiebout-Grossman Sorting

4.1. Human Capital - Amenity Exposure Spirals

Tiebout-Grossman Sorting has potential to produce spirals of amenity exposures and human capital realizations that extend throughout life, and across generations. These spirals may be virtuous or destructive. For example, as a baseline for comparison, consider an initial equilibrium for the model in Section 3.1 in which both neighborhoods are identical in terms of amenities and average human capital among adults. Now consider the first generation of children who are born after the event described in Section 3.2 that unexpectedly improves the amenities in neighborhood 2 and degrades the amenities in neighborhood 1. Children born in both neighborhoods receive human capital draws from a distribution with the same support, but the mean of the distribution is now higher in neighborhood 2 due to its improved amenities: $\lambda\,\bar{\theta}_{1,par} + (1-\lambda)\,q_2' > \lambda\,\bar{\theta}_{1,par} + (1-\lambda)\,q_1'$.[10] As a result, the children born in neighborhood 2 will, on average, enter the labor force with higher human capital, earn more income as adults and, therefore, be more likely to choose to pay to live in neighborhood 2 where better amenity exposures reduce their risk of negative health shocks during retirement, which, in turn, increases the probability that they will afford to retire in the high-amenity neighborhood. By contrast, those born in neighborhood 1 experience a comparatively destructive spiral defined by lower quality amenities, lower human capital, lower income, and worse health.

The spiral persists from one generation to the next, as the second generation of children born into neighborhood 2 benefit from exposure to adult residents with higher human capital, in addition to better amenities: $\lambda\,\bar{\theta}_{2,par} + (1-\lambda)\,q_2' > \lambda\,\bar{\theta}_{1,par} + (1-\lambda)\,q_1'$. This example also illustrates how Tiebout-Grossman

[10] In the equation, we substitute $\bar{\theta}_{2,par} = \bar{\theta}_{1,par}$ since both neighborhoods are initially assumed to have the same mean human capital among working adults, as discussed in section 3.1.

sorting may contribute to positive correlation between parental human capital and child human capital. Even in the absence of a genetic link or peer effects, i.e. $\lambda = 0$, adults with higher human capital are better able to afford to live in neighborhoods with amenities that are productive for their children's human capital. Colmer and Voorheis (2022) present evidence consistent with this hypothesis, finding that air pollution exposures affect human capital outcomes across generations.

The concept of a human capital – amenity exposure spiral raises at least three questions for empirical research. First, do these spirals contribute to the intergenerational transmission of wealth and the persistence of poverty traps (Becker and Tomes, 1979; Loury, 1981; Durlauf, 1996)? Second, if a policymaker wanted to manipulate a spiral to help achieve a policy target, what would be the most efficient way to do so? Would it be more efficient to modify the spatial distribution of amenities or to subsidize migration? Third, how important are human capital – amenity exposure spirals for evaluating the equity and efficiency of polices targeting amenities?[11]

4.2. Welfare Implications of Environmental Justice

The potential for Tiebout-Grossman sorting to amplify initial disparities in amenity exposure also relates to economic literature on environmental justice. The environmental justice literature generally focuses on the distributional effects of policies, rather than their economic efficiency or their welfare implications. This approach follows from a concern that accounting for heterogeneity in the willingness to pay

[11] It could be interesting to extend our framework to investigate how human capital – amenity exposure spirals would be exacerbated or dampened by occupational sorting and wage compensation for higher on-the-job risks to health and survival (Evans and Taylor 2020, Cropper et al. 2011). On one hand, higher wage compensation for hazardous on-the-job exposures could increase the quality of residential amenity exposures through higher incomes, dampening negative spirals. On the other hand, hazardous exposures could increase the risk of negative shocks to human capital that would lower wages, exacerbating negative spirals. It would be interesting to characterize how the net effect of these mechanisms varies with model primitives and to evaluate their empirical importance.

when evaluating a policy will tend to favor higher-income groups (Banzhaf et al. 2019). Part of the concern is that conventional approaches to environmental policy evaluation do not offer a consistent basis for addressing the extent to which the current distribution of income reflects historical dipartites in economic opportunity and pollution exposure.

Returning to the discussion of amenity spirals from Section 4.1, the environmental justice concern arises when evaluating policies that affect the workers and their children who experienced the shocks that improved amenities in neighborhood 2 and degraded amenities in neighborhood 1. During the retirement stage, expected health is higher among those who worked in neighborhood 2, which implies that their expected medical expenses will be lower, and their expected disposable incomes will be higher. Similarly, expected human capital will be higher among the workers who spent their childhoods in neighborhood 2, which implies that their mean incomes will be higher as well, as explained in Section 3.2. It follows from the single-crossing condition that the mean willingness to pay for a marginal improvement in amenities will also be higher among the groups that previously benefitted from the positive shock to amenities in neighborhood 2. However, using this cross-sectional heterogeneity to evaluate welfare effects of contemporaneous policies ignores the fact that mean willingness to pay is only higher in neighborhood 2 because its residents benefitted from a prior positive amenity shock, as opposed to those in neighborhood 1 who were harmed by a negative shock.

The environmental justice literature provides evidence that such "shocks" to amenity exposures are often correlated with race and income. That is, lower income groups and racial minority groups are more likely to be exposed to pollution for reasons other than deliberate residential sorting. Examples include disproportionate siting of pollution sources (Banzhaf et al. 2019), discriminatory behaviors by real estate agents and landlords that effectively steer racial minority groups to more polluted neighborhoods (Christensen et al. 2022, Christensen and Timmins, 2022), and

racial gaps in information about pollution (Hausman and Stolper 2022).

Empirical versions of the Tiebout-Grossman model could help to inform the environmental justice literature by measuring the impact of pre-existing disparities in amenity exposure by race and income, and enabling calculation of counterfactual welfare measures that endogenize lifetime effects of amenity exposures. For example, an empirical version of the model in Section 3 could be used to calculate how much higher (or lower) an individual's willingness to pay for improved amenities would have been had they started life in a higher-amenity (or lower-amenity) neighborhood. Similarly, one could predict the welfare implications of improving amenity exposures, taking account of the present discounted value of how improved exposures would be expected to affect individual health and income in the future.

4.3. Amenity Exposures are Endogenous

For studies that estimate causal parameters describing how pollution exposures affect measures of human capital, an implication of Tiebout-Grossman sorting is that amenity exposures are endogenous throughout life. They are endogenous in the sense that residential sorting will tend to cause amenity exposures to be correlated with human capital, which is generally difficult to fully observe and control for in empirical studies. Further, this threat to identification is not necessarily diminished by focusing on exposures that occur earlier in life, due to residential sorting by prior generations.

Of course, the suggestion that individuals' amenity exposures will be correlated with their latent human capital is unsurprising. It is a standard concern that modern research designs are expected to address (Graff-Zivin and Neidell, 2013; Aguilar-Gomez et al. 2022). However, Tiebout-Grossman sorting may also present more subtle endogeneity challenges for empirical research and policy evaluation. For example, studies estimating effects of air pollution on older adults' health necessarily focus on cohorts that survive to an advanced age. Likewise, studies of air pollution

on test scores and labor productivity use samples that are selected on attendance and employment. If the probabilities of attendance, employment, and survival are themselves affected by prior pollution exposures, then instruments may be needed to avoid sample selection biases (Bishop et al., 2023b).

Another challenge is to understand the extent to which sorting mediates long-term effects of amenity exposures. In the case of air pollution, short-term exposures have been found to have long-term consequences (e.g. Ebenstein et al., 2016; Isen et al., 2017; Colmer and Voorheis, 2022). For example, Ebenstein et al. (2016) find that elevated daily exposures during high-stakes exams not only cause the test-takers exam scores to decline, but also reduce the probability that the test-takers subsequently attend college and cause their future wages to decline. If these long-term consequences are mediated by intermediate feedback effects between human capital and amenity exposures, then knowledge of these feedback effects will be required to predict the benefits of prospective policies targeting air pollution. While it would be ideal to estimate all the feedback dynamics directly, the potential difficulty in doing so reinforces a suggestion made by Aguilar-Gomez et al. (2022) to explore the potential for using surrogate indices to combine multiple short-term treatment effects to predict long term outcomes (Athey et al. 2019).

4.4. Amenity Preferences are Endogenous

For studies that model residential sorting behavior, an implication of Tiebout-Grossman sorting is that individuals' current sorting decisions may affect their preferences for amenities in the future. It is common for static models of residential sorting to depict preference heterogeneity as a function of income and education, which are treated as exogenous endowments (e.g. Epple and Sieg, 1999; Bayer et al., 2007). However, Tiebout-Grossman sorting implies that policies that modify amenities in the short run may also modify the measures of human capital that influence how people sort themselves over those amenities in the long run.

Understanding these dynamics may be important for policy evaluation.

Prior studies have provided some initial evidence that environmental conditions can substantially influence preference formation. For example, Krupka (2009) concludes that adults' migration decisions are influenced by the amenities they were exposed to in their childhood neighborhoods.[12] More recently, Howden and Levin (2022) and Levin and Vidart (2022) find that lifetime experiences with climate and macroeconomic volatility have first-order effects on the formation of individuals' risk preferences.

Advances in econometric methods for estimating dynamic sorting models offer the potential to investigate the implications of preference endogeneity arising from Tiebout-Grossman sorting (Bayer et al. 2016). Mathes (2022) takes a first step in this direction by focusing on adults over age 65 and estimating how their preferences for climate amenities depend on their health stock which, in turn, is allowed to evolve as a function of their exposure to climate amenities such as summer heat. Accounting for sorting over these health effects increases the estimated willingness to pay to avoid future climate change by approximately 30%. Extending the approach from Mathes (2022) to incorporate earlier stages of the life cycle is an important direction for further research.

5. Summary and Further Research

In summary, we believe that integrating core ideas from the recent empirical literatures on residential sorting and human capital production into a unified framework for empirical analysis and policy evaluation holds potential to advance knowledge on important issues at the intersection of environmental and urban economics. Pursuing this line of research will require developing empirical models of residential sorting over the life cycle that include transition dynamics for human capital.

[12] Drawing on examples from Krupka: two otherwise identical individuals who develop distinct appreciations for surfing and ice-fishing early in life may, as a result, have quite different geographic preferences later in life.

Mathes (2022) provides the first empirical demonstration of this approach, focusing on dynamic feedback effects between senior citizens' location choices and the evolution of their health after age 65. The next step is to extend the approach to include working age adults and their children.

The ideal data would track individuals' residential amenity exposures and the evolution of their human capital throughout their lives, from childhood to labor force participation to retirement. This is increasingly feasible for individuals in countries such as Sweden, Denmark, and Norway that allow researchers to work with linked population-level administrative data sets. The U.S. Census Bureau has also moved in this direction by allowing special sworn status associates to propose novel administrative data projects (U.S. Census Bureau 2019). Voorheis et al. (2023) illustrate how the Census Bureau's process can be used to develop long-term measures of amenity exposures, and Cole et al. (2020) provides a broader summary of the issues involved in working with administrative data and international case studies.

Despite these recent advances in data availability, it remains difficult to develop life histories of amenity exposure and human capital for the general population. One of the challenges is that data on residential exposure to amenities such as air pollution are limited by the availability of monitoring station data that are sparse in the United States prior to the Clean Air Act of 1970. In the near term, researchers could make progress in estimating life-cycle models of residential sorting and human capital production by combining shorter and more recent longitudinal data sets describing separate sets of individuals within each stage of the life cycle (e.g. childhood, employment, retirement). In particular, causal reduced-form evidence on the effects of amenity exposures on the human capital stock could be used to discipline key parameters of a structural model of residential location choice and human capital production (Nakamura and Steinsson 2018, Todd and Wolpin 2023).

Another key challenge will be to characterize individuals' beliefs about the

effects of amenity exposures. In the model we outlined, we assumed that all adults were fully informed about the effects of exposure to amenities on the evolution of their human capital. However, scientific knowledge on the effects of amenity exposures on human capital is rapidly evolving and, conditional on the state of information, beliefs appear to be heterogeneous (Hausman and Stolper, 2022). If beliefs correlate with human capital, they have the potential to reinforce virtuous and destructive spirals of amenity exposures and human capital realizations throughout life and across generations. Surveys may provide the most direct path to establishing a mapping from individual characteristics to beliefs and help advance research in this direction.

REFERENCES

Abraham, K.G., Mallatt, J. 2022. "Measuring Human Capital." *Journal of Economic Perspectives,* 36(3): 103-130.

Aguilar-Gomez, S., Dwyer, H., Graff Zivin, J., Neidell, M. 2022. "This is air: the 'non-health' effects of air pollution." *Annual Review of Resource Economics*, 14(1): 403-425.

Albouy, D., Graf, W., Kellogg, R., Wolff, H. 2016. "Climate amenities, climate changes, and American quality of life." *Journal of the Association of Environmental and Resource Economists*, 3(1): 205-246.

Archsmith, J., Heyes, A., Saberian, S.. 2018. "Air quality and error quantity: pollution and performance in a high-skilled, quality-focused occupation". *Journal of the Association of Environmental and Resource Economists*, 5(4): 827-863.

Aucejo, E.M., Romano, T.F. Romano. 2016. "Assessing the Effect of School Days and Absences on Test Score Performance." *Economics of Education Review.* 55. 70-87.

Bakkensen, L., Barrage, L. 2022. "Flood risk belief heterogeneity and coastal home price dynamics: going under water?" *Review of Financial Studies.* 35(8): 3666-3709.

Banzhaf, H.S., Farooque, O. 2013. "Interjurisdictional housing prices and spatial amenities: Which measures of housing prices reflect local public goods?" *Regional Science and Urban Economics*, 43: 635-648.

Banzhaf, H.S., Walsh, R.P. 2008. "Do people vote with their feet? An empirical test of Tiebout." *American Economic Review*, 98(3): 843-863.

Banzhaf, H.S., Ma, L., Timmins, C. 2019. "Environmental justice: the economics of race, place, and pollution." *Journal of Economic Perspectives*, 33(1): 185-208.

Bayer, P., Kahn, S., Timmins, C. 2011. "Nonparametric Identification and Estimation in a Roy Model with Common Nonpecuniary Returns." *Journal of Business and Economic Statistics*. 29(2): 201-215.

Bayer, P., Keohane, N., and Timmins, C. 2009. "Migration and hedonic valuation: The case of air quality." *Journal of Environmental Economics and Management*, 58(1):1-14.

Bayer, P., Ferreira, F., McMillan, R. 2007. "A unified framework for measuring preferences for schools and neighborhoods." *Journal of Political Economy*, 115(4): 588-638.

Bayer, P., McMillan, R., Murphy, A., Timmins, C. 2016. "A dynamic model of demand for houses and neighborhoods." *Econometrica*. 84(3): 893-942.

Bayer, P., Ross, S.L., Topa, G. 2008. "Place of work and place of residence: informal hiring networks and labor market outcomes." *Journal of Political Economy*, 116(6): 1150-1196.

Becker, G.S., Tomes, N. 1979. "An equilibrium theory of the distribution of income and intergenerational mobility." *Journal of Political Economy.* 87(6): 1153-1189.

Bieri, D., Kuminoff, N.V., Pope, J.C. 2023. "National expenditures on local amenities." *Journal of Environmental Economics and Management.* 117: 102717.

Bishop, K.C., Kuminoff, N.V., Banzhaf, H.S., Boyle, K.J., von Gravenitz, K., Pope, J.C., Smith, V.K., Timmins, C.D. 2020. "Best Practices for Using Hedonic Property Value Models to Measure Willingness to Pay for Environmental Quality." *Review of Environmental Economics and Policy.* 14(2): 260-281.

Bishop, K.C., Kuminoff, N.V., Mathes, S., Murphy, A. 2023a. "The marginal cost of mortality risk reduction: evidence from housing markets." *Forthcoming, Journal of Urban Economics.*

Bishop, K.C., Ketcham, J.D., Kuminoff, N.V. 2023b. "Hazed and confused: the effect of air pollution on dementia." *Forthcoming, Review of Economic Studies.*

Chang, T., Graff-Zivin, J. Gross, T., Neidell, M. 2016. "Particulate pollution and the productivity of pear packers." *American Economic Journal: Economic*

Policy, 8(3): 141-69.

Chang, T., Graff-Zivin, J. Gross, T., Neidell, M. 2019. "The Effect of Pollution on Worker Productivity: Evidence from Call Center Workers in China." American Economic Journal: Applied Economics 11(1):151-172.

Chetty, R., Hendren, N. 2018. "The impacts of neighborhoods on intergenerational mobility i: childhood exposure effects." *Quarterly Journal of Economics*, 133(3): 1163-1228.

Chetty, R., Friedman, J.N, Rockoff, J.E. 2014. "Measuring the Impacts of Teachers II: Teacher Value-Added and Student Outcomes in Adulthood." *American Economic Review*, 104(9): 2633-2679.

Christensen, P., Sarmiento-Barbieri, I., Timmins C. 2022. "Housing discrimination and the toxics exposure gap in the United States: Evidence from the rental market." *Review of Economics and Statistics*, 104(4): 807-818.

Christensen, P., Timmins C. 2022. "Sorting or steering: The effects of housing discrimination on neighborhood choice." *Journal of Political Economy*, 130(8): 2110-2163.

Cole, S., Dhaliwal, I., Sautmann, A., Vilhuber, L. 2020. *Handbook on Using Administrative Data for Research and Evidence-based Policy.* Cambridge, MA: Abdul Latif Jameel Poverty Action Lab.

Colmer, J., Voorheis, J. 2022. "The Grandkids Aren't Alright: The Intergenerational Effects of Prenatal Pollution Exposure." *Working Paper.*

Cropper, M., Hammitt, J.K., Robinson, L.A. 2011. "Valuing mortality risk reductions: progress and challenges." *Annual Review of Resource Economics*. 3: 313-336.

Deryugina, T., Heutel, G., Miller, N.H., Molitor, D. 2019. "The mortality and medical costs of air pollution: evidence from changes in wind direction." *American Economic Review*, 109(12): 4178-4219.

Deryugina, T., Molitor, D. 2020. "Does when you die depend on where you live? Evidence from hurricane Katrina." *American Economic Review*, 109(12): 4178-4219.

Deryugina, T., Molitor, D. 2021. "The causal effects of place on health and longevity." *Journal of Economic Perspectives*, 35(4): 147-170.

Durlauf, S.N. 1996. "A theory of persistent income inequality." *Journal of Economic Growth*. 1(1): 75-93.

Dwyer-Lindgren, L., et al. 2017. "Inequalities in life expectancy among us counties, 1980 to 2014". *JAMA Internal Medicine*, 177(7):1001–1011.

Ebenstein, A., Lavy, V., Roth, S. 2016. "The long run economic consequences of high-stakes examinations: evidence from transitory variation in pollution." *American Economic Journal: Applied Econ.*, 8(4):36-65.

Epple, D., Filimon, R, Romer, T. 1993. "Existence of voting and housing equilibrium in a system of communities with property taxes." *Regional Science and Urban Economics* 23(1): 585-610.

Epple, D., Sieg, H. 1999. "Estimating equilibrium models of local jurisdictions." *Journal of Political Economy*. 107(4): 645-681.

Evans, M.F., Taylor, L.O. 2020. "Using revealed preference methods to estimate the value of reduced mortality risks: Best practice recommendations for the hedonic wage model." *Review of Environmental Economics and Policy.* 14(2): 282-301.

Fernandez, R., Rogerson, R. 1996. "Income Distribution, Communities, and the Quality of Public Education." *Quarterly Journal of Economics*, 111(1): 135-164.

Finkelstein, A., Gentzkow, M., Williams, H.L. 2021. "Place-based drivers of mortality: evidence from migration". *American Economic Review*, 111(8): 2697-2735.

Graff-Zivin, J., Neidell, M.J. 2013. "Environment, health, and human capital." *Journal of Economic Literature* 51(3): 689–730.

Grossman, M. 1972. "On the concept of health capital and the demand for health." *Journal of Political Economy*. 80(2): 223-255.

Hamilton, T.L., Phaneuf D.J. 2015. "An Integrated Model of Regional and Local Residential Sorting." *Journal of Environmental Economics and Management.* 74: 71-93

Hausman, C., Stolper, S. 2022. "Inequality, information failures, and air pollution." *Journal of Environmental Economics and Management,* 102552.

Howden, W., Levin, R. 2022. "The global impacts of climate change on risk preferences." *Working Paper.*

Isen, A., Rossin-Slater, M., Walker, W.R. 2017. "Every breath you take – every dollar you'll make: the long-term consequences of the Clean Air Act of 1970". *Journal of Political Economy*, 125(3): 849-909.

Krupka, D.J. 2009. "Location-specific human capital, location choice, and amdnity demand." *Journal of Regional Science*. 49(5): 833-854.

Kuminoff, N.V., Smith, V.K, Timmins, C. 2013. "The new economics of equilibrium sorting and policy evaluation using housing markets." *Journal of*

Economic Literature, 51(4): 1007-1062.

Levin, R. and Vidard, D. 2022. "Risk-Taking adaptation to macroeconomic experiences." *Working Paper.*

Liu, J., Lee, M., Gershenson, S. 2021. "The short- and long-run impacts of secondary school absences." *Journal of Public Economics*, 199: 104441.

Loury, G.C. 1981. "Intergenerational transfers and the distribution of earnings." *Econometrica*. 49(4): 843-867.

Ma, L. 2019. "Learning in a hedonic framework: Valuing brownfield remediation." *International Economic Review*, 60(3):1355-1387.

Mathes, S. 2022. "The dynamics of residential sorting and health: implications of climate change in the U.S." *working paper.*

Nakamura, E., Steinsson, J. 2018. "Identification in Macroeconomics." *Journal of Economic Perspectives*, 32(3): 59-86.

Pope, J. C. (2008). "Fear of crime and housing prices: household reactions to sex offender registries." *Journal of Urban Economics*, 64:601-614.

Roback, J. 1982. "Wages, rents, and the quality of life." *Journal of Political Economy,* 90(6): 1257-1278.

Schlenker, W., W.R. 2016. "Airports, air pollution, and contemporaneous health." *Review of Economic Studies*, 83(2): 768-809.

Sieg, H., Smith, V.K., Banzhaf, H.S., Walsh, R. 2004. "Estimating the general equilibrium benefits of large changes in spatially delineated public goods." *International Economic Review.* 45(4): 1047-1077.

Sinha, P., Caulkins, M.L., Cropper, M.L. 2018. "Household location decisions and the value of climate amenities." *Journal of Environmental Economics and Manageement*. 92: 608-637.

Smith, V.K., Sieg, H., Banzhaf, H.S., Walsh R. 2004. "General equilibrium benefits for environmental improvements: projected ozone reductions under the EPA's prospective analysis for the Los Angeles air basin." *Journal of Environmental Economics and Management*, 47: 559-584.

Tiebout, C.M. 1956. "A pure theory of local expenditures." *Journal of Political Economy*. 64(5): 416-424.

Todd, P.E., Wolpin K.I. 2023. "The Best of Both Worlds: Combining Randomized Controlled Trials with Structural Modeling." *Journal of Economic Literature*, 61(1): 41-85.

U.S. Census Bureau, Policy Coordination Office. 2019. *Handbook for*

Administrative Data Projects-DS001b.

Voorheis, J., Colmer, J., Houghton, K., Lyubich, E., Scalera, C., Withrow, J. 2023. "Building the Prototype Census Environmental Impacts Frame." *Working Paper*.