Using ABM to Illuminate Social Processes Leading to Environmental Injustice

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Abstract. Compared to the accumulated empirical evidence on the disproportionate collocation of environmental disamenities with racial and ethnic minorities, there is considerably less clarity with regard to why or how the inequality occurs in communities. This article uses agent-based modeling to test three competing theories that may explain why environmental disamenities are located where they are – cost factors alone, benign intentions to favor majority populations, or malign intentions to target minority populations. The simulation results demonstrate that a purely neoclassical world—one in which firms and residents care only about costs—does not lead to environmental injustice. Nor does a similar world in which disamenity-producing firms seek to locate away from majority residents. Two conditions led to environmental injustice in the simulation: when disamenity-producing firms aim to locate near minority populations, or when residents prefer to live near other residents like themselves.

Keywords: Environmental Justice, Discrimination, Agent-Based Model

1 Introduction

Research into issues of environmental risk disparities between different population groups started in the United States around 1987 [1]. At this initial phase of research, the predominant approach was a normative focus on issues of fairness, with terminology rooted in the racial and social justice activist traditions (see [2]). During the subsequent development of this area of research, several different terms (e.g., environmental racism, environmental equity, and environmental justice) for the phenomenon have been used and debated. In the scholarly literature, environmental justice (EJ) is most frequently used, probably to signal an examination of the phenomenon rather than a rush to judgment about what will be found. Within the advocacy community and the social justice tradition, the term environmental racism is also prevalent.

In general, empirical research has reported the disproportionate collocation of minorities with environmental hazards or hazardous facilities, but it is more challenging to disentangle why and how the inequality occurs. In this exploration into social processes of the collocation phenomenon, we use the term environmental justice (or EJ) to indicate this field of study generally, and the term environmental *in*justice to indicate findings of disproportionate environmental risk based on race or ethnicity while controlling for other factors such as cost and income. Our endeavor in this project is also to differentiate between environmental injustice and environmental racism. We concur with those who argue that "racism" should be used to denote intentional acts of discrimination, rather than unequal outcomes. In the current literature, there is little direct evidence of environmental racism as here defined, though there is much evidence of environmental injustice. This difference is not merely semantic; successful policy remedies are dependent upon the reason for the problem. In order to inform policy, it is imperative to understand complex social processes of this overdetermined problem.

In the EJ research, three primary factors are posited to affect disamenity location: prices, politics, and discrimination [3]. Differentiating between these three causes is difficult, and so far the EJ literature has not tackled the definition of what types of social behavior would lead to observed minority-disproportionate outcomes. The assumptions have been that they are either caused by firms targeting minorities (racism) or by minorities not caring as much about the environment and so choosing lower prices for houses that include nearby disamenities at a greater rate than majority residents. This paper uses agent-based modeling to experiment with scenarios assessing three possible social processes to see which is more consonant with observed patterns of disamenity collocation: a perfectly competitive world in which firms maximize utility by minimizing costs; a political process such that polluting firms prefer to benefit majority residents by locating hazardous facilities elsewhere; or a discriminatory process in which locating disamenities with minorities increases utility for polluting firms. Through the simplified reality of an agent-based model, we can explicitly experiment with these types of decision-making processes, while holding all other potential exogenous effects constant, and investigate which scenarios do or do not lead to outcomes that approximate empirical observations.

2 Modeling Environmental Injustice

To build a prototype agent-based model of environmental injustice in social-ecological systems, we relied on the finding of the previous research that has examined EJ outcomes [4]. In brief, the artificial system consists of residents, firms and plots of land as presented in Figure 1. Both agents seek for a plot of land that they can reside, but decision criteria are quite different. Agents' attributes and their decision rules are described below in details.

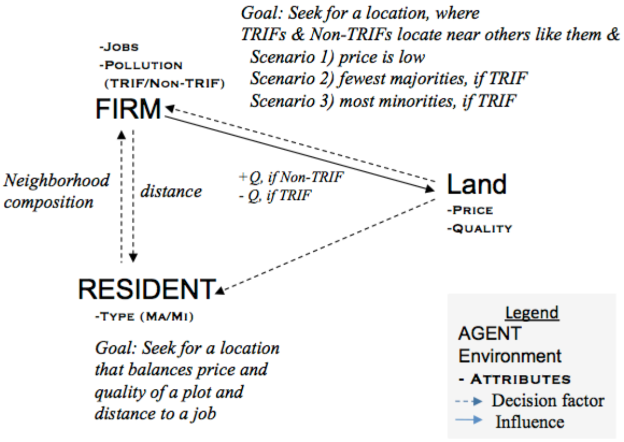
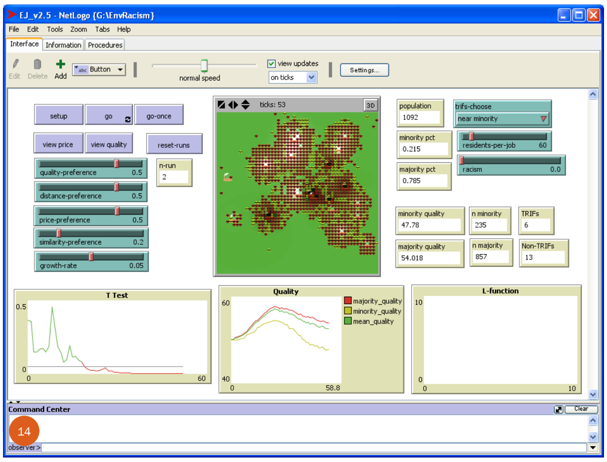


Fig. 1. A conceptual framework of the EJ ABM

2.1 Environment

Figure 2 presents the interface of the ABM in NetLogo. As displayed in the middle panel, the artificial system consists of two key decision-making agents (i.e., firms and residents) within a 50X50 landscape. Thus, there are 2,500 empty plots of land that one agent (resident or firm) may occupy at any given time.



quality-preference 0.5
distance-preference 0.5
price-preference 0.5
similarity-preference 0.2
growth-rate 0.05
n-run 2
population 1092
minority pct 0.215
majority pct 0.785
trifs-choose near minority
residents-per-job 60
racism 0.0
minority quality 47.78
majority quality 54.018
n minority 235
n majority 857
TRIFs 6
Non-TRIFs 13

Fig. 2. The interface of the EJ ABM in NetLogo

For experimentation, two indicators, price and quality of plots, are set to a value of 50. The value can vary and range from 0 to 100 with an expected value of 50 during the simulation. Other key assumptions of the landscape are as follows:

All agents are assumed to make decisions in the context of bounded rationality. When residents or firms make location decisions, their "vision" is limited to a random set of 100 possible locations [5]. The environmental quality of plots of land is assumed to be a spatial function of the proximity to amenities (nonpolluting firms) and polluting disamenities. The quality of plots within certain radii of new firms proportionally decreases or increases, at a rate that declines by distance, due to the siting decision of each firm. Quality deteriorates more when firms pollute more.

The price of a plot is also spatially based, as a function of resident demand. Prices are adjusted upward or downward depending on the relative potential utility level of the plot, as well as the local vacancy – with higher utility and lower nearby vacancy, plot prices rise. With lower utility and higher vacancy, prices fall [6].

A population growth rate is set to moderate expectations with regard to the growth characteristics of the region being modeled (a 5% annual growth rate was assumed for all trials). Depending upon the growth rate, random residents are asked to replicate themselves, keeping the split between majority and minority residents at roughly around 70% to 30% respectively. The "death" of some residents also opens previously occupied spaces upon which new residents can locate.

2.2 Agents' Attributes

The major function of *Firms* is to provide jobs for *Residents* (a benefit), and each resident is employed at one firm. Firm agents possess two attributes: the number of jobs that they can offer and the amount of pollution that they produce. In the current simulation, firms neither vary in the number of jobs they provide nor in the nature of those jobs. When the residential population exceeds the number of jobs available, a new firm is established. When a firm is established, the amount of pollution it produces is randomly assigned from a uniform distribution with a range from 0 (no pollution) to 10 (highest pollution). When the value assigned for a firm is (strictly) greater than 5, the firm is labeled as a polluting firm, or a toxic release inventory firm (TRIF), and otherwise the firm is classified as non-polluting, or a Non-TRIF.

Similarly, there are two types of *Resident* agents: majorities and minorities. In the beginning of the model, 50 residents are randomly introduced within a radius of 20 patches of the center of the region. Since a Non-TRIF is placed in the center, the 50 residents occupy one of the 399 patches surrounding the initial firm. Of the 50 residents, 70% are categorized as members of the majority and 30% as minorities. Residents are otherwise assumed to be homogenous in all other attributes including income and pollution preferences. Residents seek a desirable residential location near a firm at which they will work; for employment purposes they do not differentiate between TRIF and Non-TRIF firms.

2.3 Decision Rules

The goal of both types of agents is to find a plot that they can occupy. Agent decision rules are centered on agents scanning and selecting the plot that best suits their preferences at any given time and space. Agents choose the plot that satisfies the following criteria.

1) *Firms.* Three different decision scenarios are designed to examine how societal environmental injustice emerges as a result of firms' location decisions. In all scenarios, we assume that there are agglomeration benefits [7] such that Non-TRIFs prefer to locate near Non-TRIFs and TRIFs prefer to locate near TRIFs. Firms' decision scenarios are as follows, where "FS" indicates "Firm Scenario":

> FS(1): Both TRIFs and Non-TRIFs choose a plot with the lowest price.
> FS(2): Non-TRIFs choose a plot with the lowest price, but TRIFs choose a location where a low proportion of majorities live.
> FS(3): Non-TRIFs choose a plot with the lowest price, but TRIFs choose a location where a high proportion of minorities live.

2) *Residents.* When resident agents seek a plot, they aim to balance proximity to a firm, environmental quality, and plot price. More formally:

$$U_{ij} = \frac{1}{p_j}^{\alpha} \cdot {q_j}^{\beta} \cdot \frac{1}{d_{ik}}^{\gamma}$$

where the utility (U) of plot j for resident i is determined by the price and quality of j and distance between a resident i and a firm k. The α, β, and γ terms are balancing parameters which we constantly set at 0.5 for each parameter in the current simulation, indicating that residents evenly balance the desire for a high quality plot with low price and proximity to firm locations [8]. Residents may also have a preference for locating in proximity to similar types of residents. If residents have a similarity preference, they will exclude any plot of land that does not meet their preference criterion; for example, if the similarity preference is assumed to be 80%, minority agents will only consider locating on plots where at least 80% of the agents on neighboring plots are also minorities. Using this constraint, we also modeled three scenarios of residential preference, where "RS" indicates "Resident Scenario".

> RS(1): Residents have no similarity preference.
> RS(2): Residents prefer that at least 20% of nearby residents are the same "race".
> RS(3): Residents prefer that at least 80% of nearby residents are the same "race".

2.4 Model Outcomes

The model outcome of primary interest is the average quality of minority and majority residential plots. We ran sets of simulation trials in order to understand the decision conditions under which minorities end up in lower-quality areas than majorities on average. Therefore, through each trial the average majority and minority quality are tracked and compared. We also compare results at the end of each trial in order to assess the end result of quality variation for each of the different decision scenarios.

3 Analysis

We assessed a total of nine distinct scenarios, crossing each of the three firm decision scenarios (FS(1), FS(2), and FS(3)) with each of the three residential similarity preference scenarios (RS(1), RS(2), and RS(3)). Each of the nine scenarios was run through 200 trials, generating 1800 observations to examine aggregated environmental quality variations for residents at the termination step. Regardless of the decision-making scenario, during each simulation run approximately 15 firms were created, and about 6 of the firms were TRIFs. Overall of the decision scenarios, on average, the majority quality score was 52.8 and the minority quality score was 50.9. The mean difference between the two was 1.9.

3.1 Comparison of environmental quality between majorities and minorities

In Table 1, we summarize simulation outcomes, including mean quality scores for both types of residents, the difference between the quality scores for both types of residents, t-statistics, and p-values. Inside the table, each cell is labeled with an identifier (C1, C2, etc.) for each social interaction between firms and residents. C1, C2, and C3 present simulation outcomes under the three TRIF location decision scenarios with residents having no similarity preference (RS(1) for each of FS(1), FS(2), and FS(3)). C1 represents the economically rational choice of selecting the location with the lowest price; since it includes no residential similarity preference, C1 is most like a neoclassical, perfectly competitive world. C2 conceptualizes a political decision to avoid harming majority residents, and C3 shows the results of a discriminatory decision to locate on the plot with the most minority residents nearby. In a like manner, C4-C6 compare quality outcomes when residents have a similarity preference of 20% (RS(2)), and C7-C9 display when the similarity preference was set at 80% (RS(3)).

End-of-trial environmental quality scores were statistically significantly different for each of the scenarios except C1 and C2 at p-value < 0.001. In C2, a quality difference between majorities and minorities was significant at p-value < 0.05, a difference not considered significant after using the Bonferonni correction setting the overall significance threshold at p < .006 [9]. In C1, environmental quality was not statistically different between majorities and minorities. The table also shows that the variation in quality became larger moving down and right in the table. In other words, the largest mean difference in environmental quality was reported when the TRIF location decision criterion was to locate near minorities and when residents had an 80% similarity preference.

Table 1. Comparing environmental quality between majorities and minorities

		TRIF location decision criteria		
		Lowest price *(FS1)*	Fewest majority nearby*(FS2)*	Most minority nearby*(FS3)*
Resident similarity preference	None*(RS1)*	C1 Q_{ma} = 53.25 Q_{mi} = 53.22 Diff. = .03 t = .30 (p = .77)	C2 Q_{ma} = 52.26 Q_{mi} = 52.04 Diff. = .22 t = 2.31 (p = .02)	C3 Q_{ma} = 51.63 Q_{mi} = 51.33 Diff. = .30 **t = 3.55*** **(p < .001)**
	At least 20% of residents similar nearby*(RS2)*	C4 Q_{ma} = 53.90 Q_{mi} = 52.02 Diff. = 1.88 **t = 12.86*** **(p < .001)**	C5 Q_{ma} = 53.28 Q_{mi} = 51.14 Diff. = 2.14 **t = 14.23*** **(p < .001)**	C6 Q_{ma} = 52.02 Q_{mi} = 49.85 Diff. = 2.17 **t = 16.03*** **(p < .001)**
	At least 80% of residents similar nearby*(RS3)*	C7 Q_{ma} = 52.88 Q_{mi} = 49.97 Diff. = 2.91 **t = 16.43*** **(p < .001)**	C8 Q_{ma} = 53.02 Q_{mi} = 49.44 Diff. = 3.58 **t = 18.82*** **(p < .001)**	C9 Q_{ma} = 52.93 Q_{mi} = 49.16 Diff. = 3.77 **t = 20.98*** **(p < .001)**

Note: * p-value < .006, using Bonferonni correction setting overall confidence at 0.95, two tailed; n = 200 for all tests.

3.2 Quality gap under different decision scenarios

Figure 3 presents the dynamics of the quality gap between majorities and minorities under the nine scenarios. To calculate a quality gap between the two, the average environmental quality score for minorities was subtracted from the average score for majorities at each simulation tick. Larger positive values indicate scenarios where the average majority quality was higher than the average minority quality. It is worth noting that a negative value would indicate a scenario where average minority quality exceeded average majority quality, an outcome only seen within the first five ticks under only a few of the scenarios; otherwise, at virtually every tick in virtually every case, majority quality exceeded minority quality even if only by a very small amount. We use the same cell identifier labels in Figure 3 as we used in Table 1. For example, C1 in Figure 3 corresponds to the result of the FS(1)-RS(1) scenario.

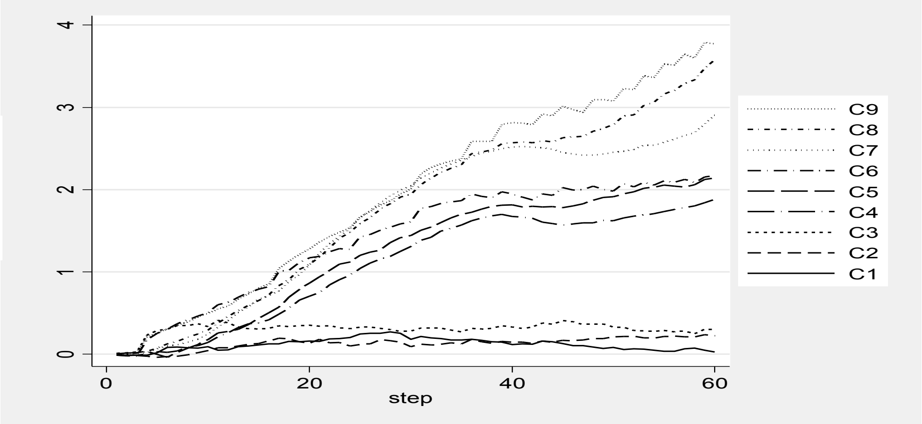


Fig. 3. Quality difference between majorities and minorities

A clear set of three clusters of scenarios is readily apparent. The bottom three lines (C1, C2, and C3) in Figure 3 represent the quality gaps between majorities and minorities under no similarity preference. The middle three lines (C3, C4, and C5) show the gaps under the 20% similarity preference, and the top three lines (C7, C8, and C9) are the quality gaps under the 80% similarity preference scenarios. We observed the most consistent difference in quality over time when residents' similarity preference was assumed to be 20%. From nearly the beginning to the termination of the simulation, there was noticeable difference in quality between the three TRIF decision scenarios (C4, C5, and C6). These gaps seem to stabilize to a certain point around tick 50. The quality gap grew rapidly until about tick 40 and thereafter grew at a much slower rate. Among the three sets of similarity preferences, there was a larger difference in the level of the quality gap between the scenarios with 0% and with 20%, compared to the scenarios with 20% and with 80%.

4 Discussion

From this virtual experiment, we observe that environmental injustice outcomes within a system result from the social interactions between firms and residents rather than being solely based on the independent decisions of firms. A purely neoclassical world—one in which firms and residents care only about costs—does not lead to environmental injustice. Nor does a similar world in which disamenity-producing firms seek to locate away from majority residents. In the world modeled here, only two conditions can lead to environmental injustice: a goal by disamenity-producing firms to locate near minorities, or a preference by residents to live near other residents like themselves. A race-blind world cannot lead to environmental injustice.

We expected that, when TRIFs specifically chose to locate in minority areas, then the quality differential between majority and minority residents would be higher than if TRIFs chose the lowest-price plot or a plot that was removed from large majority populations. Indeed, in the simulation, there were substantial quality differences for residents if TRIFs chose to avoid locating near majorities versus locating near minorities, but only if the resident similarity preference was not zero. In these cases, the gap between majority quality and minority quality was larger when TRIFs located near minority residents than when they located away from majority residents. Along similar lines, the gap was larger when TRIFs located away from majority residents versus simply choosing the lowest-priced plots. As soon as TRIFs began to make location choices that were not strictly economically rational, differences in quality began to emerge. These differences are important, and while these trials test extremes of TRIF siting choices, it seems clear that there is a potential for real differences in environmental quality for different minority populations.

However, this difference is only part of, and perhaps only a small part of, the larger story. As soon as we introduced even a relatively modest assumption regarding resident similarity preferences (as seen in [10]), differences in environmental quality became substantially more pronounced even under the scenarios in which TRIFs made strictly economically rational decisions. An assumption of no similarity preference is probably unrealistic, yet our results point to a conclusion whereby TRIF siting choices do not appear to have nearly as much impact on the quality differential as residential siting choices. These experiments suggest that even relatively slight preferences by residents to live near others like them have a substantially larger effect on environmental injustice outcomes than even overt, nefarious behavior by polluting firms.

The main insight this model provides is a suggestion that an important facet of environmental injustice may be due to aggregate residential choices more than to the choices of firms to specifically target or avoid certain populations. This has very important policy implications since it suggests the solution to environmental injustice may not be where it has been looked for. It also turns attention from the possibility that racial and ethnic minorities care less about the environment than majorities—an assumption that has itself been viewed as racist—to the possibility that the preference to live near those "like" oneself may have even more consequences than previously realized. Environmental injustice may result without environmental racism – or if racism is indeed the explanation, the important actors may not be polluting firms. To the extent our ABM is relevant to the real world, it suggests that EJ policies should focus more on reducing preferences for racial similarity in residential location than on changing firm location decisions. Of course, the former task is more difficult than the latter.

In summation, this research contributes to the discussion of environmental injustice by offering an explicit operationalization of environmental racism, examining three competing explanations of the disproportionate collocation of hazardous facilities, and providing potential insights for policy makers in setting rules about the siting of environmentally hazardous facilities.

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