# A MODIFIED AGENT-BASED MODEL OF SLUM FORMATION

## THE IMPACT OF VOTE-BANK POLITICS AND UNRESTRICTED UPSCALE PRIVATE DEVELOPMENT

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## AUTHOR BIO

Alexander McGrath is a non-profit professional currently working as an analyst on national grant programs in the Washington, DC metro area. Prior to this he earned his degree in city and regional planning from Cornell University, where his academic work focused on quantitative methods of planning and how they can be employed to better understand larger issues that impact individuals in urban and rural environments. Alexander's research has focused on employing these methods to better understand the current rapid changes in Vietnam and the impact of new housing developments on the city's outskirts.

## ABSTRACT

This paper investigates how the inclusion of political lifecycles and unrestricted housing development by private developers will impact the spatial arrangement and density of slums in a virtual urban environment. To do this, I build on the agent based model (ABM) entitled "Slumulation" developed by Crooks, Koizumi and Patel (2012). The intention of this is to generate conversation around the ways individual action impact the urban environment, and also how other stakeholders in the city create conditions that motivate the emergence of certain spatial arrangements over time. Through the addition of code into the original model, I am able to augment the actions of two actors in particular: politicians and developers. Borrowing from literature, I include local political cycles that minimize the interaction between urban dwellers and politicians throughout most of the simulation, except for in the case of election times where special consideration is made that allows for lower rents and lax rule enforcement in exchange for political support. In the center of this city, housing developers are programmed to build housing for high- and middle-income households because the real estate sector and government policies are encouraging the construction of a new and modern urban image that slowly prices out lower-income residents of the inner city. These additions show that local politics and development without efforts to mitigate the impact on individual households may contribute to slums, high density urban neighborhoods, and the peripheralization of the city's most vulnerable.





## INTRODUCTION

Urban slums represent a potentially tenuous living condition for many individuals in expanding global cities. In the case of unauthorized urban slums, inhabitants face threats of demolition, lack of access to basic services provided by the municipality, and high density. Dr. Amitabh Kundu (2005) explains that, in the case of India, evicted individuals from urban slums may join growing numbers of settlers on the urban peripheries which can make it difficult for them to access jobs that are concentrated in more central locations. I argue that this presents an opportunity for urban planners to consider the ways in which spatial inequalities arise in cities, and how to address them. Looking to literature, I chose to test the impact of local politics and urban redevelopment on the development of informal settlements and slum conditions in the city. By using an Agent-Based Model (ABM), I allow for consideration of how the decision making of city inhabitants can either counter or exacerbate these conditions.

Slum formation is of growing concern considering that, according to UN Habitat, over 860 million people lived in slums as of 2013 (Housing & Slum Upgrading). The basis for this paper is an Agent-Based Model (ABM) developed by Andrew Crooks, Naoru Koizumi, and Amit Patel (2012) titled "Slumulation," which models slum formation and allows for thought experiments in a modifiable virtual city environment. This paper investigates how the inclusion of political lifecycles and unrestricted housing development by private developers will impact the spatial arrangement and density of slums using a modified version of Crooks, Koizumi, and Patel's original "Slumulation" model. Housing and slum conditions are central considerations to international development planners. Related to this are considerations of the state of infrastructure in rural areas or the city's periphery as settlements expand outward. The quality of life in slums is of greatest concern given that these domiciles by definition lack access to basic amenities such as sanitation, water, and adequate living space (UN Habitat). The full impact of policies intended to reverse the negative effects of slums may not be realized until a number of years after their implementation.

This leads to additional questions about public health and social justice. More alarming than exposure to potentially harmful living conditions in slums is the potential for individuals to benefit from exploiting their existence. In his article discussing occupancy urbanism, Solomon Benjamin (2008) describes the short-term actions that politicians take to benefit slum dwellers in exchange for vote capital, a process known as vote-bank politics. I argue that local politics can be exploited by political actors through election cycles, and that it could potentially occur in any location where voters stand to gain something in exchange for political support. In the case of this simulation, political support is exchanged for relaxed enforcement in slums, allowing higher density. I further test the claim that this process does not follow a linear or constant pattern, but rather a cyclical one. This can be understood as more active participation and engagement between political actors and slum dwellers in sync with voting cycles. Therefore, the first modification I include is a recurring binary switch that makes political actors active only every four years, an arbitrary number selected for the simulation. Otherwise, it is assumed that protecting or engaging with slum dwellers to gain support is a relatively low priority for politicians.

A second function included in the modified "Slumulation" is the presence of developers that build housing exclusively for high-income or middle-income households. This concept comes out of David Harvey's (2003) discussion of displacement of long-standing household groups in favor of higher-value land uses. Shenjing He and Fulong Wu (2007) discuss property-led development that spurs gradually raising housing prices which in effect excludes low-income groups from settling newly developed zones of the city. The case of China provides an example of private real estate interests benefitting from government policies intended to redevelop urban centers and generate economic growth. These policies may take the form of relaxed zoning or special permissions granted to businesses and investors (He and Wu 2007). Developers are included in the original model; however, I have created a stipulation that upon entering the market the developer agents are assigned at random high- or





middle-income categories for which they will build. This is implemented into the original program as a binary switch, similar to the political cycle inclusion.

## *THREAT TO INFORMAL SETTLEMENTS*

As the model progresses, city-center land values and rents increase, due in part to the actions of private developers. Low-income individuals or those assigned to the informal economic sector have access to few opportunities to pay the escalating rents. This leads them to share living space or move to more affordable locations in the city. When the number of individuals sharing a parcel of land exceeds a pre-set maximum, the parcel is designated as a slum in practice. There is an additional vulnerability in cases where these slums are not legally sanctioned informal settlements.

This process is expedited when developers are programmed in the model to develop parcels of land only for high- or middle-income individuals. This is meant to mimic the trends identified by He and Wu (2007) in Shanghai, where property-led redevelopment has resulted in the displacement of older residents. This occurs because the redevelopment entails increased commercialization and improvements to the built environment intended to create a modern image that drives up rents.

If dislocated residents cluster in new parts of the city, this can contribute to an increasing spatial fault line between social and economic classes. In order to address what Joana Barros (2005) refers to as the "peripheralization" of poor residents, planners need to better understand the long-range impact of urban policies meant to develop the city.

The primary concern here is the impact on slum dwellers in either case, and I attempt to quantify and develop an understanding of what potential impacts, both positive and negative, either phenomenon might have on individuals. The augmented model presented here is intended to answer two questions: what impact lax enforcement for informal settlements and slums has  on individual living conditions (in this case, resident density), and what the spatial impact of unrestricted development geared towards higher-income groups looks like for the city as a whole.

My hypothesis is that the inclusion of political cycles and private development will hasten the rate at which peripheralization occurs. Political cycles will incentivize slum formation on peripheral zones by making housing more affordable at the expense of quality-of-life conditions. Private development will gradually increase the cost of housing in the center of the city, and accommodate higher-income households. A commentary can be made on the distribution and sharing of public goods, and, even more so, on access to vital amenities and resources, by looking at the spatial arrangement that emerges from these interactions. This is especially relevant for countries that have not yet developed rural infrastructure, where peripheralization may equate to a very real difference in quality of life.

### *AGENT-BASED MODELING (ABM)*

This paper simulates slum formation and peripheralization through Agent-Based Modeling (ABM). ABM offers a unique advantage in that it allows for emergent macroscopic patterns resulting from the aggregate behaviors of diverse actors in a shared spatial-temporal environment (Gulyás and Mansury 2007). ABM also permits the manipulation of predetermined parameters to easily control which variables are active in a simulation , compare between trials, and test the sensitivity of the model results.

The original "Slumulation" model includes three classes of actors in the environment: individual house seekers, developers, and politicians. Actions of agents occur independently of one another and create conditions in the spatial organization of the city, and in this way indirectly impact other agents. Individual preference for affordable housing, limited by their economic means, motivates house seekers to stay or occupy in a particular location. Individuals are also assigned to a formal or informal economy at random when they enter into the system. One advantage of ABM is that it allows a simultaneous view of the city at the household and city-level perspective. This method is most comparable to Cellular Automata (CA) models, which utilize cell categories and the interaction between neighboring cells to track emergent patterns (Augustijn-Beckers, Flacke and Retsios 2011).





In general, the defining features of ABM are (1) the inclusion of heterogeneous actors interacting with one another (2) in a simulated environment and (3) with a bounded rationality. Agents can also learn at the individual level, which culminates in the emergence of larger patterns at the population level as a result of individual interactions between agents and with the environment (Gilbert 2008).

It is important to clarify the assumptions and limitations of ABM and what it can inform. In both the original and modified versions of "Slumulation," there is no distinction between land types and suitability for different land uses. Space is occupied by residential and not by commercial activities. This model also lacks motivation for behavior beyond the primary functions of housing developers and politicians or more direct interaction between these two agents. It is possible to code this into further modifications of the model; however, my model only looks at the direct impact of vote-bank politics and unrestricted upscale development, all else equal.

## PREVIOUS STUDIES

### *COMPUTER MODELING OF SLUMS*

As mentioned above, the primary model used to complete this exercise is the "Slumulation" model developed by Crooks, Koizumi, and Patel (2012). Like the augmented model used for this paper, Crooks, Koizumi, and Patel utilized NetLogo to complete their study.[1] The primary questions addressed by the authors were how slums develop, how they expand, and what helps cities mitigate slum formation. In order to account for individual household choice, Crooks, Koizumi, and Patel focus on the UN Habitat's fifth criteria for defining a slum: insufficient living area, measured in terms of population density. In practice, this criteria is met when three or more people occupy a single room (Crooks, Koizumi, and Patel 2012; UN Habitat). In the model, a parcel is classified as a slum when there are more households than housing units in a given site. Other criteria of slum definition are not explicitly considered as they do not operate solely

[1] All changes made to code were marked with a stamp (asm337) in order to provide proper credit to the model developers and help distinguish original coding from my own modifications.

through individual household choice (i.e., water and sanitation infrastructure).

The modeling of slums and informal settlements is of interest to a wide variety of disciplines. This, coupled with the relative newness of Agent-Based Modeling, means that the literature is both expansive and nascent. As such, the included literature below is not exhaustive, but has been selected for relevance to the study at hand. Michael Harold Lees, Bharath Palavalli, Karin Pfeffer, Debraj Roy, and Peter Sloot (2014) describe the current trends in study and modeling approaches to slum formation, which include Cellular Automata and Agent-Based Modeling. Both forms of modeling are dynamic and accommodate complex and adaptive systems in a simulated environment that gives rise to emergent behavior.

Cellular Automata (CA) as a modeling approach has been used to study a variety of urban phenomena. In particular, it has been used to predict land use and land cover changes due to urban growth in specific locations (Aniya and Mundia 2007). CA is also used in predicting long-term urban growth (Clarke, Gaydos, and Hoppen 1997). These models can be enhanced by the use of Geographic Information Systems (GIS) to better capture and calibrate for local circumstances. An example of this is Keith Clarke, and Leonard Gaydos' (1998) application of GIS to previously developed CA models. Xia Li and Anthony Gar-On Yeh (2000), in another example, apply GIS to CA models to predict scenarios and outcomes for sustainable urban development. Remy Sietchiping (2004) also makes use of GIS and CA to model the formation and growth of informal settlements.

The application of ABM to slum formation and informal settlement modeling is a new and proliferating practice (Lees, Palavalli, Pfeffer, Roy and Sloot 2014). There is growing literature on the actual application and design of such models for urban phenomenon (Batty 2005; Gilbert 2008; Barros 2012; Benenson and Torrens 2004). Likewise, there is a growing application of this method to better understand social processes (O'Sullivan 2009). Of course, this includes Crooks, Koizumi, and Patel (2012) in the development of "Slumulation", which is an attempt to incorporate the various features of previous models into one environment. One of the most famous examples of ABM applied to urban phenomenon is Thomas Schelling's





(1971) model of emergent spatial segregation based on individual and group characteristics. ABM's use in modeling specific informal settlements can be found at the household level for settlements in Tanzania (Augustijn-Beckers, Flacke and Retsios 2010). Joanna Barros (2012) uses ABM to create a model of peripheralization in Latin American cities, and explores how urban development projects spatially reinforce divisions between societal categories where low-income groups are pushed to the city's fringe.

## ORIGIN OF THE MODIFICATIONS

The model presented here is intended to make these measures more dynamic than in the original model presented by Crooks, Koizumi, and Patel. The addition of a political cycle is rooted in Solomon Benjamin's work on occupancy urbanism and vote-bank politics. Benjamin (2008) describes a process by which ground-up lobbying can result in access to land and lax restrictions in exchange for guaranteed voter-list access in municipal elections. This presents some short-term benefits, but in such a system the perpetuation of slums may be more beneficial to political agents in the long run. Benjamin's paper focuses primarily on India, while the application is not location-specific in the augmented model presented here. Michael Chege (1981) also details the potential for political agents to leverage poverty to their advantage for political support in Nairobi slums. The inclusion of this function is intended to spatially represent the impact that this process has over time on slum density, location, and population size. Special attention is paid to how this impacts the potential well-being of slum dwellers across the simulation, testing the hypothesis that short-term gains may not equate to better living conditions for these individuals in the long run.

The second modification is a consideration of the impact that urban renovation programs may have on low-income households and slum dwellers. Building on historical processes, Neil Smith (1979) argues that, at a certain point, central city districts become prime for profitable capital investment. This modification to the original model is intended mostly to mimic a growing real-estate industry in the virtual city. Harvey (2003) discusses the external pressure that might push low-income residents from areas with high land-value. Benjamin (2008) also discusses this phenomenon in rapidly urbanizing cities of India that hope to rival established global cities such as London in image. Additionally, this process can be seen in a number of case studies including neighborhoods in Shanghai, Shenzhen, and Seoul (He and Wu 2007; Wang, Wang, and Wu 2009; Lee, Lee and Yim 2003). The inclusion of this function, I hope, may shed some light on what the ramifications are of not including sufficient political mechanisms to guarantee housing for low-income households within city centers.

## MODEL DETAILS

### *PURPOSE*

In the original "Slumulation" model[2] the authors create an environment in which thought experiments can be conducted in a virtual environment. Their model includes interactive parameters that users can modify to suit their particular questions. These include, but are not limited to, city growth rates, rent diffusion rate, and prime land percentage. There are also agent-specific choice parameters that include staying power and price sensitivity at the household level (Crooks, Koizumi, and Patel 2012). A complete list of the parameters included in the original "Slumulation" and their assigned values can be found in Table 1 below. The purpose of including political cycles and exclusive development patterns is two-fold. First, I hope to test the weight that intermittent but consistent political action has on the spatial patterns of the city, attempting to mimic the intermittent nature of political campaign cycles. Second, I hope to raise questions about how to best mediate the potentially negative ramifications of developers on select populations if there are no economic or political control mechanisms.

### *VARIABLES AND SCALE*

The size of the city environment is specified in the original "Slumulation" model as 51' x 51' parcels fixed on a grid, yielding 2,601 sites where housing may be built or upgraded. Similar to the original model, the modified version includes nine alike political wards of equal size. Variation in the total slum population in these wards triggers change in the politician-slum dweller relationship within the ward boundaries, as seen in Equation 2. Simulations were run for a total of forty iterations and ten complete political cycles in simulation, allowing for patterns to emerge.

[2] The original "Slumulation" model is constructed in NetLogo and available online for access at: http://css.gmu.edu/SlumFormation/SlumFormation/Home.html





The parameters and decision-making variables are left intact from the original "Slumulation" model. In order to test my own additions, the parameters are held at fixed values for every trial. These values are intended to mimic the state of cities in developing countries as described by the 2013 UN Human Settlements Program report on global urbanization trends. For example, the population growth in urban centers in the developing world has nearly doubled since the 1970s. This growth is characterized by high rates of rural-to-urban migration and a strong informal economic sector that accounts for up to thirty percent of economic activity in some places (UN Human Settlements Program 2013). This is especially important considering that individuals in the informal economy experience vulnerability to outside forces (Sassen 2007). Land endowments, price sensitivity, and staying power were assumed to be at levels that only moderately impact the cityscape for the sake of not distorting the simulations. More in-depth discussion on each parameter can be found in the original "Slumulation" literature by Crooks, Koizumi, and Patel (2012). The primary measure used to monitor changes in this paper will be density.

### *TYPES OF AGENTS*

The model environment contains three agent classes: house seekers, political actors, and developers.

**House seekers** are physically present in the environment and occupy space within the cityscape. They are randomly assigned an income level in either the formal or informal economy. The general motivators of house seekers are housing affordability (considered to be less than one third of income) and proximity to the center of the city. More agents are added to the system annually, which are also randomly assigned a household income group and to the formal or informal economy. They are assigned household categories based on income levels, which then determine if they will be eligible to occupy the new housing developments.

**Developers** are not physically present in the environment. They buy and invest in empty patches in the city by building new units for profit. In the modified scenarios, the developers will randomly build housing that is limited to either middle-income or high-income households. This is in relation to the trends discussed above.

**Politicians** are not physically present in the environment either. They can accept payable rent, or effective rent that is defined by the percentage of the population living in slums in a given political ward (Crooks, Koizumi, and Patel 2012). The modified version includes a cycle of political activity, where the impact of politicians is only active once every four iterations in the simulation. This differs from the original model's political function that included continuous impact of local politicians on effective rent in their political wards.

## PROCESS OVERVIEW

### *DECISION MAKING*

At the beginning of each cycle, developers seek empty land parcels and make decisions on what type of housing to develop. This process is dictated by the developer code, depicted in Figure 1 below. Figure 1 shows the augmented developer-agent decision process, which triggers development on empty parcels and categorizes them random as "(DEV) = 2", indicating a middle-income housing category, or "(DEV) = 3", indicating a high-income housing category, with a fifty-fifty probability.

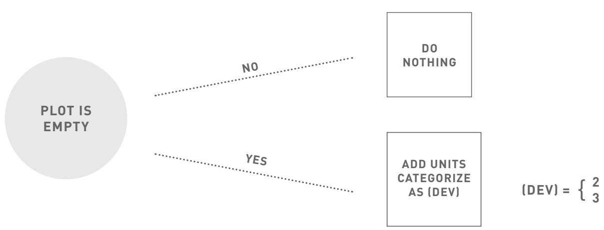


FIGURE 1: DECISION TREE FOR DEVELOPER AGENTS



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At the beginning of every iteration households weigh the payable rent against their willingness to share, willingness to stay, and their neighbors' rent to assess whether or not to stay in a location or relocate in every iteration of the simulation. When a parcel is unoccupied, the developer agent is created temporarily to construct new housing on a site. Political agents determine the rent payable (ERit) based on the slum population at a given iteration.

House seekers are primarily impacted by the actual and effective rents, where Rit represents rent of particular plot i at time t, ß is the fraction of economic growth from the housing market, G is the economic growth rate, d is the selected diffusion rate, and Rj represents the rent at the neighboring plots j of a particular plot. Interaction between slum dwellers and political agents creates what Crooks, Koizumi, and Patel refer to as effective rent (ERit), which may be cheaper than actual rent, where Nit is the number of units, αjt is the proportion of the slum population in the given ward, and Sit is a binary variable that signifies whether a site is a slum ("1" if it is, "0" if it is not). Shifts in rent will influence individual decisions between moving or staying in a location.

In order to generate the results presented below, simulations with code modifications were initialized and averaged across three trials, using the "Slumulation" model without political or developer activity as the baseline in order to understand the path by which these measurements reach their final values. Two time-dependent graphs that track density across income groups and slum-population distribution, functions found in the original model, are shown in Appendices A and B.

## DESIGN CONCEPTS

### *EMERGENCE*

The inclusion of political cycles and upscale development is intended to test the larger spatial patterns that result when political influence on slum formation is not equally prevalent at all times, and when developers are incentivized to build exclusively for middle- or high-income households. These patterns emerge as a result of individual household choices to rent or move after considering circumstances, local incentives, and the effective rent prices in their neighborhoods.

### INTERACTION

Politicians' decisions impact the local effective rent that slum dwellers pay. Similarly, developers' decisions about which type of housing to build can exclude particular household groups in the simulation. Lastly, individuals' choices to move or remain and share domiciles impacts the overall landscape at the local level.

### ITERATION

The key factor that leads to emergence is the iteration across many cycles that allows for residents not only to make decisions based on their local conditions, but for this to contribute to the emergence of unique clustering patterns as a result of political cycles and development over time.

Once the baseline was established, the three subsequent scenarios included: the political cycle function, the development function, and both modifications implemented simultaneously. Implementing each modification separately and then together allows for a better understanding of how each function impacts the city, and how they interact together to impact the city.

### INITIALIZATION

| PARAMETER | CONSTANT VALUE |
|---|---|
| Population Growth Rate | 2.5% |
| Diffusion Rate | 0.02 |
| Economic Growth Rate | 3.5% |
| Prime Land Percentage | 10% |
| Inappropriate Land Percentage | 10% |
| Informality Index | 0.7 |
| Price Sensitivity | 0.4 |
| Staying Power | 0.4 |
| City Limits | |
| Size | 51' x 51' |
| Initial Inequality | 10 |

**TABLE 1: CONSTANT PARAMETER VALUES FOR ALL SIMULATIONS**



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### ADDITIONAL PARAMETERS

In the augmented model, both political cycles and development activities are executed programmatically in the form of a binary switch. I include a new binary variable POL(Cycle), which is active only every fourth cycle in a simulation. Otherwise, political influence remains inactive. When it is active, the effective rent for a given political ward will differ based on the slum population, resulting in lower rents for slum dwellers residing in that ward. This effect is seen in the modified Equation 2.1. The modified parameter (DEV) dictates the behavior of developers when active, where the development variable is restricted to two categories representing high- and middle-income categories.

### SUBMODELS

The cycle of four years for political activities was chosen to allow for a majority of years where local political function was not impacting the cityscape. Subsequently, forty years was chosen to allow for any emergent spatial patterns to have ample time to develop, after a set of ten political cycles. The parameters above were chosen somewhat arbitrarily, but mostly through a trial-and-error process that ensured that no single parameter would have a proportionally unequal impact on the system.

It might be interesting, in the future, to observe the impact of variation in political cycles for different wards—as, in these scenarios, the political cycle is exactly the same in each locality. At this juncture, however, the model presented helps to map the potential interactions between developers' activities, accounting for political environments and the individual selection of affordable housing. In other words, the model includes spatial variation with constant temporal impacts across the wards.

## TRIALS AND RESULTS

The impact on density is the primary focus of this study. Table 2 includes the most relevant numbers yielded from the four scenarios. Appendix A includes selected graphs from individual trials representative of these results. These graphs are best used to view the path by which the density begins, transforms, and finally arrives at the numbers below.

| GROUP | SCENARIO: "SLUMULATION" (CONTROL) | WITH POLITICAL CYCLE | WITH POLITICAL CYCLE/ UPSCALE DEVELOPMENT | WITH UPSCALE DEVELOPMENT |
|---|---|---|---|---|
| Low-Income | 2.03 | 2.02 | 1.82 | 2.18 |
| Middle-Income | 1.43 | 1.47 | 1.44 | 1.45 |
| High-Income | 1.27 | 1.21 | 1.23 | 1.21 |
| Inner-City Slum | 2.28 | 2.27 | 2.13 | 2.70 |
| Peripheral Slum | 2.15 | 2.22 | 2.04 | 2.19 |

**TABLE 2: DENSITY ACROSS VARIOUS HOUSEHOLD GROUPS (AVERAGE OF OCCUPANT DIVIDED BY NUMBER OF UNITS ACROSS THREE TRIALS)**

**"Slumulation" (Control)**: In the control scenario it seems that low-income houses experience the highest density. This is to be expected as these households are most likely to split rent to make it affordable to occupy a particular location. This particular model shows a higher density within inner-city slums, although both peripheral and city slums have higher densities on average than all income groups alone.

**Political Cycles**: When political cycles are introduced there is negligible shift in the density amongst household groups. This is the same for the inner-city slums, which show a slight decrease in density. However, peripheral slums experience a slight increase (0.07 occupants per unit). This supports the theory that political activities may incentivize slum formation on city outskirts, by making these





areas more affordable and by lax rule enforcement. Local political behavior then, and not just rent increases in the city center may explain part of the peripheralization of poor residents.

**Political Cycles and Upscale Development**: The simultaneous inclusion of upscale development and political cycles seems to actually decrease the density of low-income households and slums by significant amounts. It remains more or less the same for both middle-income and high-income households. This scenario also shows the lowest density of any of the scenarios for slums, both in the inner city and periphery.

**Upscale Development**: When the upscale development activity is implemented in the model and not matched vis-à-vis political activities that would benefit slum dwellers, there is a drastic increase in density of low-income households and slums. This is as expected, though there appears to be a substantial growth in slum density in the inner city. This is likely due to the staying power of agents in desirable city locations. Rapid rent increases force poor residents to split housing both inside and outside of the city, and the political activity that might mitigate costs in slums is not able to taper this effect.

### *IMPACT ON SLUM LOCATION*

The location of slums is the secondary question of this exercise. This number is helpful in clarifying results, since this simulation is not associated with a real spatial environment. The more pressing result is the shift in populations in relation to the city center across trials. Table 3 summarizes the populations on average in slums throughout the city as a whole, as well as in slums on the periphery of the city versus within the city center. Appendix B includes select graphs from trials to show the time aspect of the population distribution within slums relative to the entire slum population in the interface.

| NUMBER OF SLUMS | CITY | CENTER | PERIPHERY |
|---|---|---|---|
| "Slumulation" (Control) | 217 | 96 | 121 |
| With Political Cycle | 210 | 93 | 117 |
| With Political Cycle/Upscale Development | 149 | 69 | 81 |
| With Upscale Development | 115 | 44 | 71 |

**TABLE 3: SLUM LOCATION**

**"Slumulation" (Control)**: In the control simulations, slum dwellers were slightly more likely to be found in the periphery of the city. Peripheral informal settlements comprised roughly fifty-five percent of overall informal dwellings in the entire city.[3]

**Political Cycles**: When political activity is implemented on a cyclical pattern in the model, there is a decrease in the number of slums, but this is coupled with increase in population density of peripheral slums. So, while the inclusion of political activities such as vote-bank politics may not contribute to the formation of slums in this case, it does appear that they do at least increase the likelihood and density of slums in the model.

**Political Cycles and Upscale Development**: This scenario produces fewer slums, and it appears that, while inclusion of political activity perpetuates slums, upscale development decreases slums. There is, however, a greater total number of peripheral slums than in the other simulations. If we accept that the city may attract more development, as Neil Smith (1979) discusses, this would push out more residents, as we see in the cases of China and South Korea above (He and Wu 2007; Lee, Lee and Yim 2003).

**Upscale Development**: When upscale development is active in the model and political cycles are disabled, the slum population is at its lowest. This, again, supports the hypothesis that vote-bank politics and local political activities perpetuate the existence of slums. This case, however, has the largest proportion of peripheral slum locations, expressed as the percentage of peripheral slums divided by the total number of slums city-wide. This gives evidence that the growth of the central-city district may contribute to the peripheralization seen in cities.

[3] City-wide measurements account for both the center of the city as well as surrounding areas into which the population expands.





## *CLUSTERING PATTERNS*

The figures below show the representative distribution of households, as seen in the NetLogo interface. Figure 2 shows the arrangement seen in the control trial. Every triangular marker represents the dominant household type of that particular parcel. In every case, it is apparent that the low-income household group is most prevalent outside of the city, and, when inside of the city, it is typically as part of a slum.

Figure 2 shows the densest arrangement of low-income households and inner-city slums, as well as less sprawl. This might be associated with a case of inner-city decay, though it is also very obvious that there is some spatial segregation between the different income levels of household groups.

Once upscale development is introduced into the system, the clustering of low-income households that remain within the city becomes even more visible. Figure 4 shows the case in which political cycles are not active, and the sprawl seems to be the least visually noticeable in this case. The parcels are also the densest, which may explain why the outward growth is less significant, but the conditions are not necessarily any more ideal for low-income households if we consider density and crowding conditions.

Over the span of forty years, the density of low-income groups eventually begins to stabilize in each trial except in the case of upscale development alone, which visually converges with the average density of slums near the end of the simulation. Middle-income and high-income households seem to remain at a relatively stable level of density throughout the entire trial in each scenario.

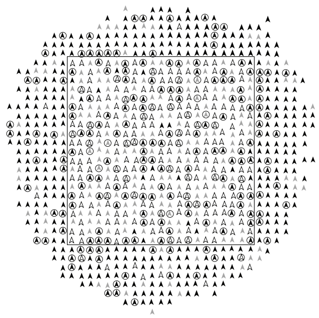

FIGURE 2: "SLUMULATION" (CONTROL)

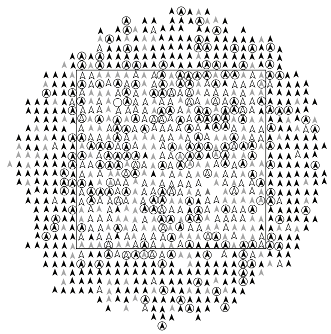

FIGURE 3: POLITICAL CYCLES

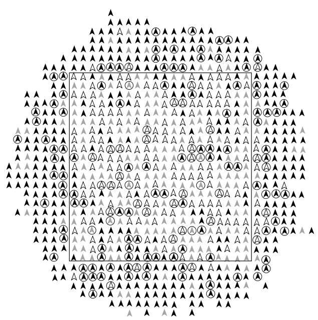

FIGURE 4: UPSCALE DEVELOPMENT

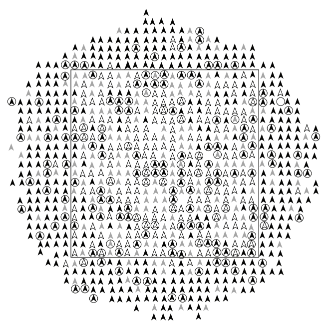

FIGURE 5: POLITICAL CYCLE/ UPSCALE DEVELOPMENT

**KEY**

| HOUSEHOLD CATEGORIES | SYMBOLS |
|---|---|
| LOW INCOME HOUSEHOLD | SLUM |
| MIDDLE INCOME HOUSEHOLD | CITY BOUNDARY |
| HIGH INCOME HOUSEHOLD | |





## DISCUSSIONS AND CONCLUSIONS

The initial focus of this exercise was to modify an existing code for slum modeling developed by Crooks, Koizumi, and Patel (2012). The initial model includes three agents: house seekers, developers, and politicians. The modifications specifically attempt to enhance the behavioral patterns of the two latter agents. It is assumed that developers seek to build high- or middle-income housing in order to maximize their profits. This precludes low-income households from settling into new or recent redevelopments in the model. In addition, political behavior is limited to a cyclical pattern that mimics increased interest in vote-bank politics that depend on the relevance of election platforms (Benjamin 2008).

In general, it was found that the inclusion of political cycles contributed to the existence of slums, and to the sprawling effect of the city, which is in line with the literature put forth by Benjamin. The inclusion of upscale development actually drove the total number of slums down, but it drove up density of low-income households and slums and led to a very visible peripheralization of these same groups.

In all of the modifications to the original model, density rates and location for middle- and high-income households are the least volatile. I attribute this to the fact that these households have higher incomes and are able to withstand rent increases in the model without having to consider alternative locations or needing to share living quarters. Considering these results alongside the fact that these households are more likely to enjoy upward mobility, as part of the formal economy, points to the possibility that those households that experience more volatility in their living conditions may also be less likely to gain access to the means to escape that volatility.

The question that arises from this study is not whether vote-bank politics can be considered detrimental to poor households, but in which ways vote-bank politics can harm or benefit poor households. If this practice helps to decrease density in the slums because of relaxed rent conditions imposed on parcels of land, this can in fact have positive health implications and make resource management and sanitation an easier task in some settlements. Further modeling might take into consideration access to amenities, and locational dependent capital earnings to engage the question of whether these settlements result in less capital cost but larger time costs to the poor or in decreased economic opportunity. Policies should then consider intervention that addresses the specific ways in which these households are made vulnerable.

While the high density achieved in inner-city slums in the final model of unrestricted upscale private development without political actions are high and potentially dangerous for slum dwellers, there may be some benefits to higher density found alongside the upscale developments. These include lower opportunity cost in traveling to place of work and easier access to public goods generally associated with upscale neighborhoods such as safety, sanitation, and infrastructure.

Crooks, Koizumi, and Patel discuss future iterations of "Slumulation" to include further articulated agents and environment to match real-world circumstances. These include more advanced decision-making power of individual agents, such as developers responding to the demand for housing and politicians weighing the potential financial incentives from developers in competition with vote-bank politics, and an expansion of criteria for slums to include all of the UN Habitat's criteria, as opposed to density alone. Lastly, they mention the possibility of eviction as a potential addition in future models (2012). I propose that additional considerations might include how the informal economy interacts with surrounding land parcels, especially when considering small-scale informal food vendors to whom density represents increased business potential. Other expansions might include commercial parcels and stronger preference for amenities and infrastructure, including natural amenities such as air and water quality.

This paper expands on the work of Crooks, Koizumi, and Patel, and, specifically, provides further consideration of the temporal factors that contribute to slum formation. I question how local political cycles can spatially impact slums, thus including a cyclical time element on top of the already included linear progression of the model. Furthermore, I incorporate examples from the literature in which



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governments and developers collude to develop city centers around "new" and "modern" images of urban identities, thus precluding lower-income residents from these spaces due to high costs (He and Wu 2007).

These findings are applicable to actual urban policy in that they point to the way in which interactions between developers and citizens can have real and lasting effects at the individual household level, especially in the absence of clear political controls to mitigate potentially dangerous effects of increased density and spatial peripheralization of citizens. The actions of developers, all else equal, severely impacted the location of slums and poor households in this simulation, where developers were allowed to act freely without market or political restrictions. Another outcome is the suggestion that the interactions between various stakeholders has spatial and temporal impacts on the city scape, and that the city is not shaped simply by top-down or bottom-up process but rather is the result of a delicate network of actors and circumstances.

The model also points to the risk of irreversible impacts on the city due to the interactions between these three different types of actors. As density rises and slums form in certain parts of the city, these conditions are either exacerbated in the model or would be difficult to improve without aggressive and potentially harmful remediation at the household level.

Given the relative simplicity of this hypothetical environment, this simulation should not be used in the design of actual policies for cities, but rather to inform the thinking behind what factors might influence individual household decision-making processes. The conditions do not match any specific city, and stay static throughout the model. Furthermore, the calculations of growth, as detailed by Crooks, Koizumi, and Patel, needs further articulation to more closely resemble reality (2012). The narrative that arises from the model that can inform the thought process for urban policy might go as follows: urban developers have invested heavily in the city center; the resulting increase in rents and living expenses have contributed to the increasing tendency for poor households to occupy the city's peripheries, where local politics provide incentives in the form of relaxed enforcement of housing regulations. This process, overall, has contributed to the growth of slums, and policies should consider intervention within this chain of interactions if planners hope to improve the quality of life for citizens residing in potentially harmful living environments. In short, this exercise highlights the importance of considering time and relationships between stakeholders when approaching issues of spatialized challenges in the city. The various overlapping incentive structures interplay with individual decision-making to generate spatial patterns in the city. The responsible use of this simulation may be less in the service of policy design and more of framing approaches to policy, and highlighting the need for guided and more structured qualitative work to draw further conclusions in light of these findings.

There may be some short term benefits for slum dwellers in cases of relaxed political enforcement, but they may be filling a void in a local system that in the long run may disadvantageslum dwellers. The fact that these individuals live in densely populated households signifies a failure of other city services, and does not indicate an inherent loss of agency among these individuals. This provides an opportunity to advocate for community-based planning in order to help capitalize on the need for such locally driven services for individuals, as it appears that local conditions are very powerful in shaping the city at the ward level.



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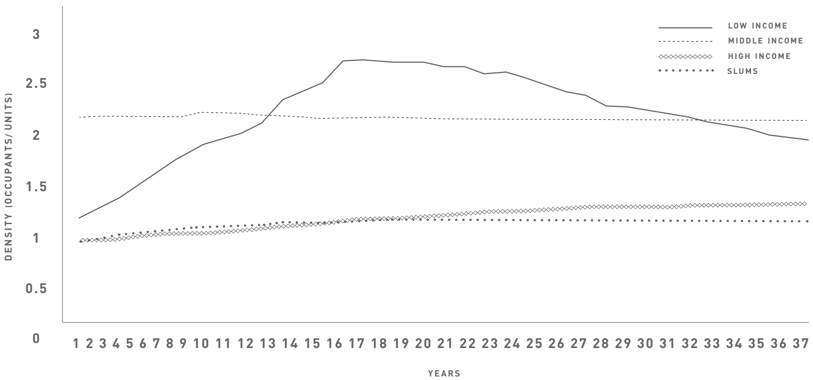
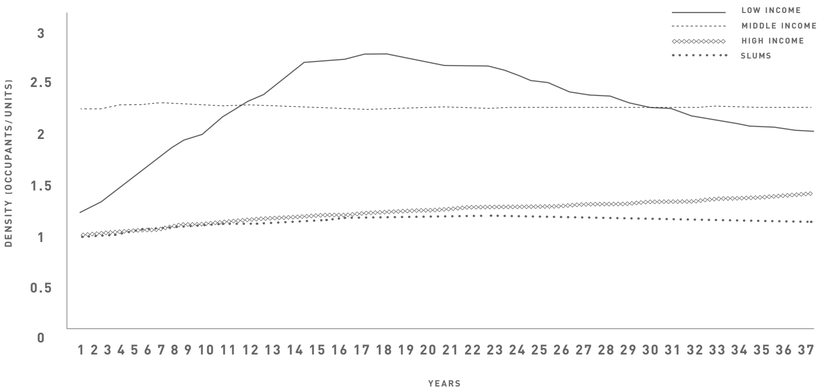
## APPENDIX A: DENSITY PATTERNS

### DENSITY BY GROUP: SLUMULATION (CONTROL)



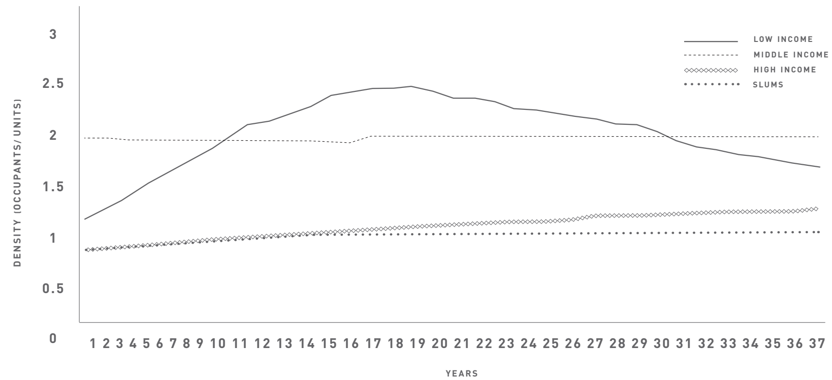

### DENSITY BY GROUP: POLITICAL CYCLE



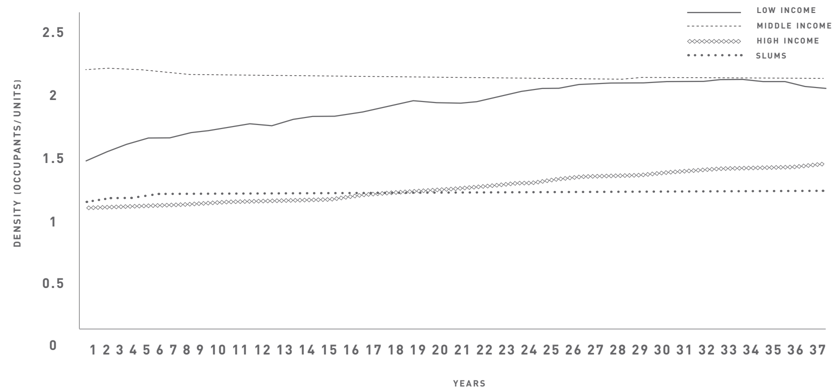





### DENSITY BY GROUP: POLITICAL CYCLE/UPSCALE DEVELOPMENT




### DENSITY BY GROUP: UPSCALE DEVELOPMENT



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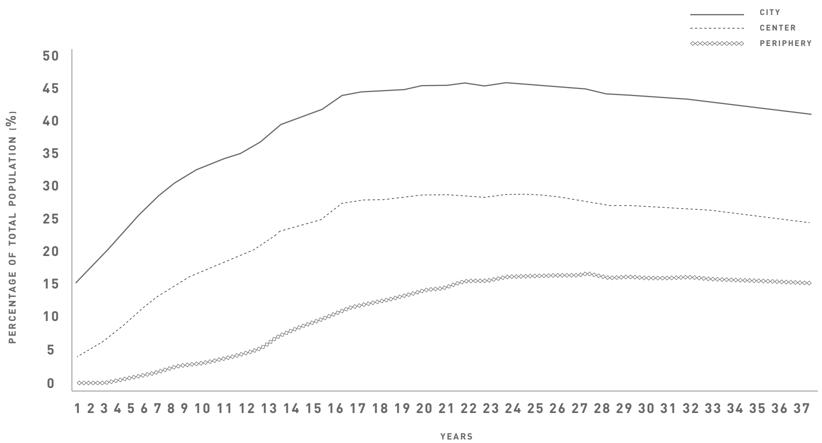
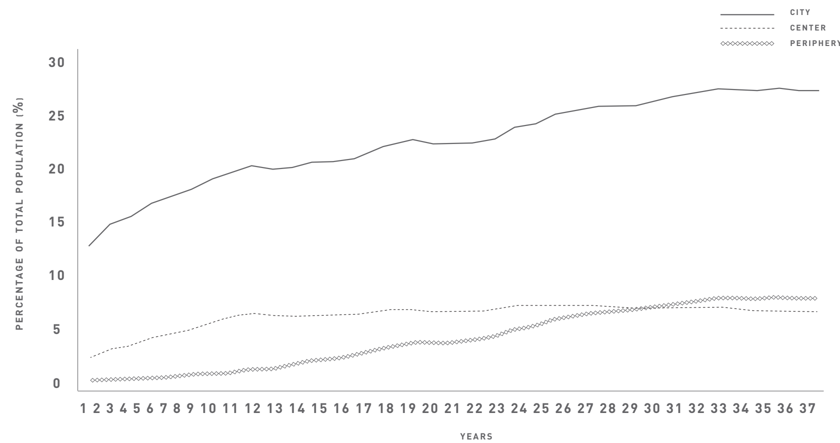
## APPENDIX B: SLUM LOCATION POPULATION PATTERNS

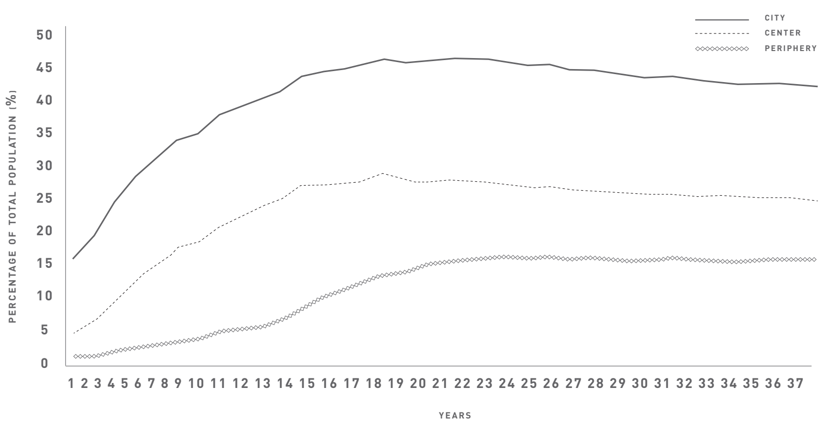
**SLUM POPULATION AS PERCENTAGE OF TOTAL POPULATION: SLUMULATION (CONTROL)**



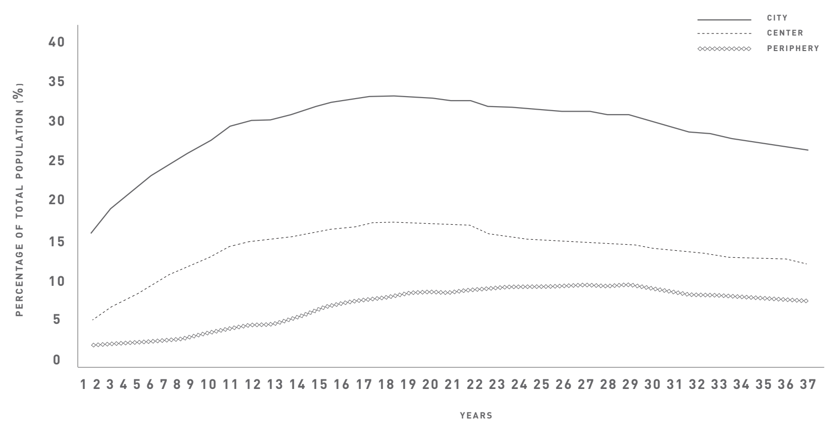

**SLUM POPULATION AS PERCENTAGE OF TOTAL POPULATION: UPSCALE DEVELOPMENT**




**SLUM POPULATION AS PERCENTAGE OF TOTAL POPULATION: POLITICAL CYCLE**




**SLUM POPULATION AS PERCENTAGE OF TOTAL POPULATION: UPSCALE DEVELOPMENT/POLITICAL CYCLES**



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