Evolution of Economic Segregation Using Agent-based Model*

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Abstract

Economic segregation is an important phenomenon that is seen throughout the world in both developed and developing countries. Much theoretical and empirical analysis has sought to investigate the sources of economic segregation and to assess methods of mitigating its effects. Traditional models focus heavily on income inequity as a primary source of segregation. Our model uses a novel construct in which immigration and capital growth are evaluated as factors leading to economic segregation. We find that not only do these factors cause substantial economic segregation, but that they lead to higher levels of economic segregation when compared to a reference model based primarily on income distribution. Thus, capital growth and immigration factors merit further study for empirical investigation and eventual policy recommendation with respect to identifying and mitigating economic segregation.

Keywords: agent-based model, economic segregation, income inequality, Gini Coefficient, Index of Dissimilarity.

1 Introduction

1.1 Economic Segregation

Economic segregation is a common social phenomenon in US and some European developed countries (Massey and Mary, 2003; Dorling and Rees, 2003; Friedrichs et al., 2003; Hardman and Ioannides, 2004; Meen et al., 2005; Eitle et al., 2006). Although not as widely studied as racial segregation, economic segregation-the degree to which different economic classes live spatially apart from one another-has become an important focus of research in the past 20 years (Swanstrom et al., 2004). Economic segregation is visible at several geographic levels in the UK. Regionally, significant differences separate the North and South of England. For example, Gross Value Added is about 70 percent higher for London residents than for residents of the North East, and grew 60 percent faster per annum in London from 1989 to 2000 (Robinson, 2004). 29 per cent of households in London and the South East have incomes in the top quintile nationally, compared to just 13 to 15 percent in the northern regions (ONS, 2004). Even among demographically similar groups, regional differences are stark. The employment rate for young men with no qualifications living in council housing in the South East rose from 58 percent in 1993 to 65 percent in 2002. By contrast, employment among the same group in the northern conurbations fell from 32 percent to 25 percent over the same period (Faggio and Nickell, 2003). Yet economic segregation reaches beyond a simple North-South divide. At the local authority level, some London boroughs and northern cities and towns share high levels of deprivation associated with limited local job opportunities, low

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employability and incomes among the local population (ODPM, 2004). And the US also experienced increasing separation between the poor and the affluent in metropolitan cities, towns and neighbourhoods in the latter half of the twentieth century (Massey and Fischer, 2003; Swanstrom et al., 2004). An analysis of census income data for cities and suburbs in the nation's 50 largest metropolitan areas between 1980 and 2000 shows that:

The overall per capita income gap between central cities and suburbs remained unchanged between 1990 and 2000. However, the city and suburban income gaps in the Northeast and Midwest are still wide and growing. The gap between the richest and poorest suburbs increased rapidly during the 1980s and more slowly in the 1990s, although patterns of inequality vary widely across the country. Generally, the suburban income gaps are largest in the Sun Belt metro areas such as Phoenix, Los Angeles, and Houston (Swanstrom et al., 2004).

Some researchers suggested that the increase in economic inequality caused the increase in economic segregation (Durlauf ,1996; Wilson, 1987; Mayer, 2001). In 1999, among 14 industrialised EU nations and the United States, the United States was the worst in the overall extent of income inequality, and the UK is the second worst. These two countries have severe economic segregation (Smeeding, 2004).

Growth in income inequality may thus disadvantage the less well-off, not just temporarily, but over extended periods of time. For example, about half of British individuals in the bottom income quintile in 1991 spent the majority of the next ten years in that same bracket (ONS, 2004).

Wealthy families whose income rises seek out high-income communities, with ample public amenities and few social problems associated with poverty, but the poor households do not have the economic affordability to move. The increase in economic inequality results in an increase economic segregation because the rich move to more homogeneously affluent neighborhoods and the poor are trapped in more homogeneously poor neighborhoods (Mayer, 2001). Polarisation of incomes generally has made the places where poor individuals live relatively poorer, even as high-income areas have grown relatively richer (Berube, 2005).

Rising inequality is part of the 'macro' picture, but 'micro decisions' by households contribute even more directly to economic segregation (Berube, 2005). In the process of choosing where to live, low-income households, acting as rational consumers, tend to seek out communities that provide higher social spending and lower-cost housing (Glaeser et al., 2000). High-income families, by contrast, may seek out communities with lower social spending burdens and higher property values and price appreciation in line with other high-income households' demand for housing in the area (Glomm and Lagunoff, 1998).

This process, often described as 'residential classification', is the natural tendency in a free market. These household movements will maintain or strengthen social ties, and contribute to economic segregation (Gordon and Monastiriotis, 2003). And some housing policies stimulated these residential movements, such as public housing policy, strengthening the links between housing and deprivation. The concentration of poverty and disadvantage in public housing sectors is one of the most important issues that the central governments in the US and the UK paid more attention to in recent 10 years (Stone, 2003).

Learning from the literature about economic segregation in some western countries, we find that spatial economic segregation is usually related with several reasons, including income inequity, residential classification and housing policy. Driven by the above forces, some western developed counties have different extents of spatial economic segregation, as a result of the evolution process from disorder to order in the real estate market.

1.2 Historical Discussion of Chinese Real Estate Market.

Chinese real estate market developed later than some western countries, but much faster in recent years. In this paper, we will use agent-based model to analyze whether there will be serious economic segregation led by the market forces and housing policies in China. First, we will discuss some history of Chinese real estate market.

We separate the history into four periods as follows:

1.2.1 Traditional housing allotment system (1949-1978)

Low rent and housing allotment are the products of the planned economy. Under planned economy, a part of capital which should be used for consuming was concentrated for building the country, leading to the price of work force lower than its value in a long period. Wage is only a part of the compensation for the work force reproduction, and others are substituted by the lower level of the substantial allotment, including housing allotment. During this period, the central government and the local government are both responsible for the urban housing construction, regarding the housing investment as a non-productive investment which is arranged behind the basic construction investment. There is no special housing fund, and the housing construction funds are usually appropriated in that period emphasizing ‘first production and then living’. Urban people’s living conditions decline for the lack of housing fund and the population increase. Until 1978, the average of urban dwelling areas per capita goes down from 4.5 square meters in 1949 to 3.6 square meters.

1.2.2 Experimental Selling Houses (1979-1990)

Deng Xiaoping(1978)[1] gave an important discussion of housing problems. He proposed that we could try more ways to solve the housing problems, such as allowing individual building houses or individual building with public subsidies, and also divided payments. Deng (1980) pointed out that not only the new houses but also the old houses can be sold, and the housing rent must be adjusted according to the housing price(different rents in different places), and he also pointed out that the low-wage workers should be subsidized as the rents went up. June 1980, the Central Committee of the Communist Party of China and State Department transmitted the Compendium of National Basic Construction Meeting, which allowed individual building houses, individual buying houses and individual owning their own houses. This was the first commodity housing policy in due form in China. In 1981, more than 60 cities and part of towns in China had implemented the full-price-selling housing policy, and the price of the new public houses was generally 120-150 RMB per square meters, which was about 4-5 times of the households’ income for a 2-bedroom dwelling house. Many cities allow installment, while the prompts were different from 2 years to 15 years and interest rates were also different across the country. But until the end of 1981, only about 3000 houses had been sold, and the full-price-selling policy was too bad to be replaced by the subsidy-selling policy. In 1982, four cities including Zhengzhou, Shashi, Changzhou and Siping were chosen experimentally for new houses subsidy-selling policy, in which individuals only need to pay $\frac{1}{3}$ of the total housing price, and the other $\frac{2}{3}$ were subsidized by the local governments or the enterprises the individuals were working for. The total housing price was reduced largely for the subsidy policy that many families could afford to buy a new house with only 2 years’ income. The subsidy-selling policy of the public houses has been extended to 160 cities and 300 towns in 27 provinces until the end of 1985, selling 10,928,000 square meters of dwelling houses in total. But subsidy-selling policy was opposed strongly by many enterprises and local governments, who were responsible for $\frac{2}{3}$ of total housing price. In most cities, the subsidy which should be paid by the local governments was paid by the enterprises, and the more workers buying houses, the more subsidies an enterprise paying for. Finally, the subsidy-selling housing policy was broken off in 1985. There are several reasons for failure of the subsidy-selling policy. During this period, in which Engel Coefficients of urban households were about 60%, many Chinese families could not afford to buy the houses with low total income and little savings. And at the beginning of 1980’s, the Civilization Revolution had just finished in which many houses were occupied or confiscated without giving back, and many people could not change their views to buying houses, afraid of being called the house owners. And for the low rent welfare housing still existed, the residents paid much less rent than the installment interest every month.

[1] <成思危等. 1999. 中国城镇住房制度改革. 民主与建设出版社.>

Finally, many enterprises did not support the subsidy-selling policy, for they should pay for too much subsidy. Increasing Rent with Subsidy (1986-1990) Increasing Rent with Subsidy policy was that public housing rent should be modified according to five factors(including depreciation, maintaining expenses, overhead expenses, investment interests and housing taxes), and part of the increasing rent should be subsidized at a certain percentage of the worker wage. In 1986, Yantai, Changzhou, Bengfu and Tangshan were chosen as the first experimental cities for housing reform. In Feb. 1988, the State Department held the first National Housing Reform Meeting, publishing National Housing Reform Scheme in Different Stages and Batches (No.11, National Publishing [1988][2]). The key to the reform was improving the housing rent for maintaining the house, accelerating the house buying, and realizing the perfect cycle of the housing funds. Some cities (such as Shenzhen, Tangshan, chengdu and so on) have had some progress in housing reform during this period, during which they could guarantee the depreciation and maintaining expenses for the current public houses, reducing the unreasonable housing demands. But in 1988, there happened serious inflation in China with the CPI increasing ratio of 20.7%, leading to the economic panic. Under the cost pulling effect, the national economy would be much more deteriorated for the accelerated inflation, if the increasing rent with subsidy scheme continued. So the increasing rent with subsidy scheme, which was planned to be finished within 3-5 years, was stopped. In 1988, some relative departments suggested to disposing of the houses, for which rent was less than maintaining expenses, with depreciation to reduce the burden. Although without any formal documents, according to the incomplete statistics, 6,450,000 square meters of public houses had been sold with the average price at 65.7RMB/square meters in 1988. From 1988 to 1990, central government tried best to regulate the national economy and didn't allow selling public houses with much lower prices.

1.2.3 Increasing Housing Sales and Housing Rent without Allowance (1991-Jun. 1998)

As the national economy was much stronger and the standard of living was much improved in the 1990's, housing system reform was paid more attention, and was regarded as an important aspect of economy system reform. In Jun. 1991, the Notice about Accelerating the Urban Housing Reform (No.30, National Publishing [1991][3]) was published by State Department, giving emphasis to solving the people's dwelling problems through the housing reform, improving living conditions, directing the rational housing consumption, commercializing the housing gradually and developing real estate industry in China. Many cities (such as Beijing, Shanghai and so on) published the detailed housing reform scheme, whose main ideas were about selling houses at a discount and increasing the housing rent without subsidy. Unlike big cities, some middle and small cities didn't implement the housing reform normally, and there happened the third selling houses at much lower prices. In Jun. 1992, State Department held Housing Reform meeting to stop selling houses at lower prices. In Jul. 1994, the Decision about Deepening the Urban Housing System Reform (No.43, National Publishing [1994][4]) pointed out that we must set up the new urban housing supply system, including commodity houses and affordable houses, and implement the housing accumulation fund system comprehensively. In Aug. 1996, the Opinion about Supervising the Sales of Public Housing pointed out that total income from the public houses belongs to the enterprises selling the houses, and should be used as housing construction and housing reform. The housing reform has achieved some success during this period. As an important way to realize the housing allotment with currency, the amount of national housing accumulation fund has reached 98bn RMB by the end of Jun. 1998. Among 35 middle and big cities in china, the average public housing rent had reached 1.29RMB per square metre, much more than before, and the housing rent had been increased to cost level

[2] <国务院．关于印发在全国城镇分期分批推行住房制度改革实施方案的通知. Feb. 25, 1988.>

[3] <国务院．关于继续积极稳妥地进行城镇住房制度改革的通知. Jun.18, 1991.>

[4] <国务院.关于深化城镇住房制度改革的决定. Jul. 18, 1994.>

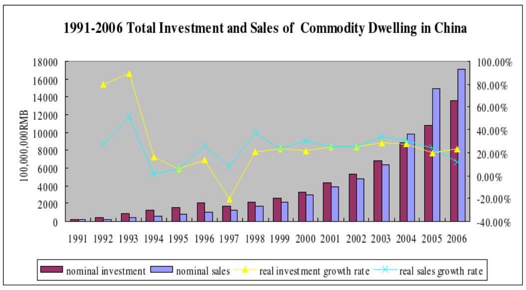

Figure 1: 1991-2006 Total investement and sales of commodity dwelling in China

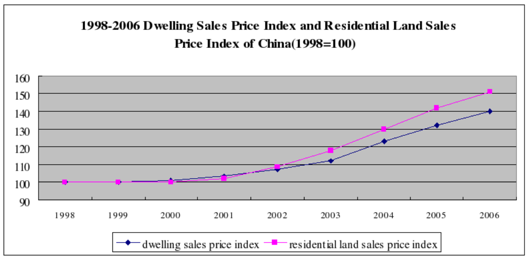

Figure 2: 1998-2006 dwelling sales price index and residential land sales price index of China(1998=100)

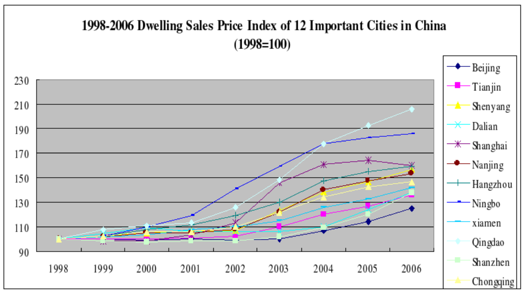

Figure 3: 1998-2006 Dwelling sales price index of 12 important cities in China (1998=100)

in some big cities, such as Shenzhen. And national urban housing ownership rate had been more than 50% with part of cities more than 60% in the Jun. 1998[5]

1.2.4 Housing Allotment with Currency (Jul.1998 - Now)

In Jul.3 1998, State Department published the Notice about Accelerating the Urban Housing Reform More, in which the substantial housing allotment was stopped and housing allotment with currency was encouraged. The Notice also points out that multiple degrees of urban housing supply system should be set up and given priority to the affordable housing. Real estate industry developed fast in China since 1991, for the housing allotment with currency is better for the development of commodity housing market. And as the Chinese economy is stronger, many families, whose incomes have increased more, want to improve their living conditions. Shown as Figure 1, there is an initially irrational increase in 1992-93 and a big decline relative to the Asian Crisis in 1997. After 1998, total investment and sales of commodity housing[6] both kept increasing at high speeds of more than 20% every year. Total Commodity dwelling investment increased more than 5 times from 1998 to 2006 (212bn RMB& 1361bn RMB), and commodity dwelling sales in 2006 was nearly 10 times that in 1998 (172bn RMB& 1704bn RMB).

More and more houses can be bought and sold freely in the market, and the commodity housing price was no longer decided by the government, but by the market. The dwelling price and residential land price rise up very fast in recent 5 years in China, especially in some big cities, although the inflation rates were much lower than 3.5%. (See Figure 2 and Figure 3).

It is proposed to set up harmonious society in China, but some middle-low and low income families cannot afford the higher and higher housing prices. Central government implemented a new public housing policy, providing affordable houses to middle-low income families and low rental houses for lowest income families. The income limits are different in different cities for different types of public houses. For example in 2006, the families in Beijing, whose monthly income per capita is below 580RMB (35% of average urban residents' income per capita in Bei-

[5]<建设部住宅与房地产司、建设部住房制度改革办公室..当前住房制度改革政策问答..北京，中国物价出版社，1998.>

[6]According to the classification standard made by National Bureau of Statistics of China, commodity housing mainly includes commodity dwelling, office building and commercial business building. In this paper, our focus is on commodity dwelling, the investment of which is about 70% of total commodity housing investment in recent 5 years.

jing), can apply for low rental houses. But in Kunming (in Yunnan province), the income limit applying for low rental houses in 2006 is 210RBM per capita per month (24% of average urban residents' income per capita in Kunming). The new public housing policy is different from before, for the capital gap is collected by the governments, not the enterprises. The advantage of the new policy is that the residents working in different enterprises are equal when applying for public houses, but the disadvantage is that most of the residents in the public housing neighborhoods have very low income. And also the income inequity increases in recent years, the income growth rate of the high-income families is much higher than the low-income families in China, especially in some big cities. The wealthy continue getting richer and richer and the poor get poorer and poorer.

2 Model

The philosophy of our model has been to create a toy model which is as simple as possible while capturing some of the complexity of the housing market. We began with a model published by Bernard and Willer (2007). This model is set on a topologically toroidal, $N \times N$ lattice in which the lattice sites represent areas of land on which a household may live. The boundary conditions ensure that the space is homogenous and so there is no central lattice site. In reality the world is also isotropic, that is to say that all directions are spatially equivalent. The model world is not isotropic because the lattice is aligned to a particular orientation. These are points to be aware of but their effects are minimised by the simplicity of the model. The only effect that space has is on the total value of a plot of land. The households themselves are always able to see everywhere in the world equivilantly.

2.1 The landscape

The value of a plot of land, v_i, is determined at any given time as a linear combination of its natural value and the average richness, R_j, of the surrounding four nearest neighbors,

$$v_i = b_i(1-e) + \frac{e}{4}\sum_j^{nn} R_j \tag{1}$$

where e is a parameter which is the endogeneity which falls in the range $[0, 1]$. We have elected to ignore the four diagonal next-nearest neighbours for simplicity and do not expect this to change our results significantly. The natural value of a lattice site b_i is an exogenous housing price which is meant to encapsulate the aesthetic beauty and undeveloped worth of the area of land. This value ought to be spatially correlated somehow, since we expect the beauty of our surroundings to change continuously during a walk through the countryside. In other words, rivers and lakes as well as fertile soil are on a larger scale than the household lattice sites we are modelling. In order to simulated a smooth but random landscape, we seed the values of b_i with uniform random numbers in the range $[0, 100]$ and then perform a simulated diffusion process. On a square lattice this means iterating the following formula a number of times,

$$b_i(t+1) = \frac{1}{5}\left(b_i(t) + \sum_j^{nn} b_j(t)\right)$$

Our intension is to create a landscape such that the spatial size of an average fluctuation lies somewhere between the size of one lattice site and the size of the entire lattice. We found that we could achieve this with forty iterations of the above scheme. This process inevitibly reduces the overall variance on natural value so that any one lattice site has a natural value of 50 ± 5.

The second term in equation 1 represents the dependence on human factors. These might begin as developments which enhance the natural qualities of the land such as irrigation and road building but eventually, via schools and hospitals, approach luxurious retail outlets and exclusive bars and restaurants. These amenities are supported by local financial contributions and are expected to be proportional to the surrounding wealth. As a simplification, the land vale determination process happens on a short enough time scale to be considered instantaneous by the model. The richness R_i of a plot of land is a measure of the financial wealth of the occupying household. If a plot is vacant then this value is zero. In Bernard and Willer (2007) model,, the richness is fixed from the beginning of the run and is conceived as the income of the household. The model we developed has a dynamic richness which is better described as a capital.

2.2 Capital Growth

If income is used as the measure of wealth then the simplest models are rental in nature. So a household may only live somewhere if they can afford the regular payments. Otherwise, as in the Benard-Willer model, they are forced to move elsewhere. We wanted to capture the concept of ownership because in this way the value of the house is added to a houshold's buying power. This is in fact a more realistic case becasue in 2006, 72% of households were owned by the occupiers. We use capital, C, as the measure of richness. In order to keep the model as simple as possible, we actually removed income altogether. Rather than have income contibuting to a growing capital, we instead envisage the capital as being invested and growing exponentially with a rate constant, ρ. In other words, the rate of change of capital, $\frac{\mathrm{d}C}{\mathrm{d}t} = \rho C$. Hence we are modelling a different kind of household. These households are at the higher end of the economic scale that do not work for a steady income but instead are the owners of companies or stock investors. Since the effective income is proportional to the capital, it affects the value of the surrounding plots in the same way as income and equation 1 need not be modified. We do not explicitly take account of a cost of living, however if the cost of living per year obeys the mathematical form $L = f + lC$, where f and l are global constants, then our rate of change of capital becomes,

$$\frac{\mathrm{d}C}{\mathrm{d}t} = (\rho - l)C - f$$

which, after a change of variable, to $C' = C - \frac{f}{\rho - l}$ is just $\frac{\mathrm{d}C'}{\mathrm{d}t} = (\rho - l)C'$. This result means that any cost of living which is proportional to capital, like lC, can be absorbed in our parameter ρ. Furthermore, any constant cost of living, such as f, amounts to changing the meaning of having zero capital. If your effective capital, C' is less than zero then you are on a downward spiral into debt. It is this C'that we are modelling. The dynamics described in the next section forbid any household from making a move which would lead them into effective debt. Hence by making the approximating assumption that the cost of living obeys this simple linear form, we can avoid explicitly including it in our model. The same argument holds true for any other income which follows this form.

2.3 Dynamics

In a single iteration of the model, one plot of land is chosen uniformly at random as the active component, A. If A is a vacant then with probability p_I a new household moves in. Regardless of the current value of the plot, the new owner is assumed to have a small amount c_0 left over to begin investing. If A is occupied then the occupier emigrates with a probability p_E. Otherwise, a second passive plot, P, is chosen at random. If P is a vacant site then the household occupying A is given the option of moving to P. The household will want to move if the value is higher $v_P > v_A$ and will be able to move if the the cost is not too great i.e. $v_P \leq v_A + c_A$. Hence the condition for a move is then,

$$0 < \Delta v \leq c_A$$

where $\Delta v = v_P - v_A$. If a move takes place then the moving household loses capital as $c_P = c_A - \Delta v$. Afterwards c_A is set to zero and finally, the values of the nearest neighbours of both A and P are recalculated. We consider the time after which we expect every household to have searched for a vacant plot to be a *year*. For an $N \times N$ lattice, that is every N^2 iterations. It is after this amount of time that households receive their returns on their capital investments. Every year,

$$c_i \rightarrow c_i' = c_i(1 + \rho)$$

for all lattice sites, i.

3 Results

All of the runs we will discuss here were carried out on a 65×65 lattice. This means that a year was 4225 iterations. In recent two years, some relative researches (i.e., Bruch 2006; Bernard and Willer 2007) have proposed and tested the importance of endogeneity in similar models and so we set the value constant here. We the endogeneity constant, $e = 0.7$ which along with the starting capital $c_0 = 10$ means that human influences on value dominate from an early stage. Although this is the case, we find that these parameters are enough to allow the landscape of b_i values to affect the distribution of households. The varied parameters were the rate of return, ρ and the probability of immigration, p_I, and emigration, p_E. The population of the lattice is controlled by varying the ratio of these probabilities. The rate of population change will be the rate of immigration minus the rate of emigration. If we look at the rate of change of the mean population we find

$$\frac{\mathrm{d}\bar{n}(t)}{\mathrm{d}t} \propto (N^2 - \bar{n})p_I - \bar{n}p_E$$

Eventually the lattice will fill to capacity and the rate of change of population will fall to zero. Hence, the mean population, $\bar{n}$, will always approach,

$$\bar{n}(t) \to N^2 \frac{p_I}{p_I + p_E}$$

as $t \to \infty$. We ran the model with three initial conditions in the first (*empty*) scenario, we begin with an empty lattice and set $p_E = \frac{2}{3}p_I$. This gives us a rapid growth which heads towards a population of $\frac{3}{5}$ capacity. In the second (*immigrated*) scenario, we take a run initiated as *empty* which has reached a population of $\frac{1}{2}$ capacity. At this point we reset the clock to zero and also set $p_E = p_I$. Finally (*radial*), we run the simulation beginning from a population of $\frac{1}{2}$ capacity where the households are initially given capital as a function of their distance from and arbitrarily chosen centre. The function takes its form from a fit to data taken from the Beijing Land Price Distribution which was found to be approximately power law with a exponent of $\frac{3}{4}$.

There are ten land price degrees in Beijing, with the central land (first land degree) is the most expensive, and then cheaper as the location is farer from the center[7]. And the housing price distribution is nearly the same as the land price, both of which can be seen as radial price distribution.

[7] <北京市国土资源和房屋管理局出让处, 北京房协房地产估价专业委员会. 2002. 北京市基准地价.>

3.1 Wealth-based Segregation

There is current debate regarding which types of segregation measures are best, as well as the merits of each measure (Bernard and Willer 2007; Reardon and O'Sullivan 2004). Yet these arguments have little bearing on our model, since we have chosen to remain in the virtual world and compare our simulation findings with regard to our control simulation. Our research is merely a substantive approach to evaluating effects of behavioral changes rather than creating a normative methodology which is applicable in the real world. Therefore, we chose measurements that were abundant in the literature and easy to understand. Following with traditional segregation measures, we analyzed the evenness of each agent-based model using the Index of Dissimilarity, D, which describes the proportion of the minority group that would need to relocate in order to achieve perfect integration. Namely,

$$D = \frac{1}{2} \sum_i \left| \frac{p_i}{P} - \frac{q_i}{Q} \right|$$

where p_i is the proportion of residents with wealth above the global median within the i^{th} neighborhood, P is the total proportion of residents with wealth above the global median, q_i is the proportion of residents with wealth below the global median within the i^{th} neighborhood and Q is the total proportion of residents with wealth below the global median. The second segregation measure calculated is the Spatial Dissimilarity Index, D^*, which describes the average weighted difference between neighborhood and city composition. This measurement was proposed by Reardon and O'Sullivan (2004) as a response to the possible lack of spatial information and aspatial nature of the traditional Dissimilarity Index. As they point out, "Unlike its aspatial analog, the spatial dissimilarity index cannot be interpreted as the proportion of the population who would have to move to achieve complete integration. However, it can be interpreted as a measure of how different the composition of individuals' local environments are, on average, from the composition of the population as a whole" (Rearson and O'Sullivan 2004). The other reason for choosing this metric is because it is the same metric used by Bernard and Willer (2007), whose agent-based model we used as a comparison to our own. Mathematically, the Spatial Dissimilarity Index can be expressed as

$$D^* = \frac{1}{2Q(1-Q)} \sum_i \frac{t_i}{T} |q_i - Q|$$

where t_i is the number of households in the i^{th} neighborhood, T is the total population, q_i is the proportion of poor households in the i^{th} neighborhood and Q is the proportion of poor households in the total population. By calculating and comparing D and D^*, our analysis describes the complimentary segregation metrics of both evenness and exposure. The below graphs show the results for both D and D^* for our comparison reference model as well as our model with the two different initial conditions of random initial distribution of land values and radial initial distribution of land values.

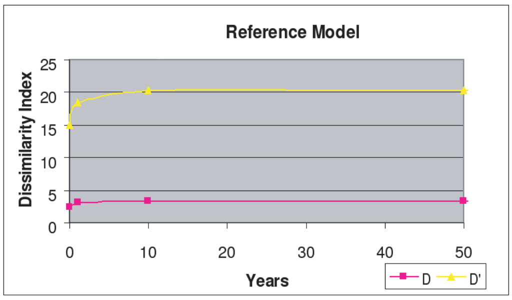

Figure 4: Dissimilarity Index over time in the Benard-Willer reference model

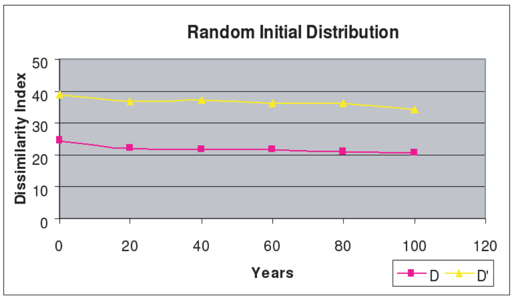

Figure 5: Dissimilarity Index over time with random initial conditions

Since the D and D^* indices in each trial are constantly relative by only a scalar magnitude, we will regard the spatial and aspatial dissimilarities of the graphs as one in the same trend. Also, the particular values of segregation are not regarded as important as the trends and dynamics of the simulations over time. This is because the exact metric values depend on lattice size, neighborhood size, time scale, as well as the measures of wealth used. For out initial simulations, these values all differed. In the future, we hope to make consistent these and other factors so a more quantitative analysis can be done. For the present, however, our models must be analyzed strictly by qualitative comparison. Our first observation is that the reference model quickly converges to a steady state where segregation remains relatively constant (see Figure 4). Although the time scale is different, the same observation can be made by our random initial distribution scenario. The difference is that while the reference model increases to a limit, the random distribution model is decreasing (see Figure 5). More simulations and analysis must be done to see the exact reason for this discrepancy. Speculation suggests that whereas the reference model began even and emerged to a more segregated state, our model began in random states that were actually more segregated than what is caused by our behavioral rules. Therefore, we must test simulations in the future with varying degrees of random initial conditions and varying strength of behavioral preference that may lead to segregation. Our second observation is that the simulation with radial initial distribution shows at first a decreasing segregation metric that gradually increases over time (see Figure 6). We now see that the trial should be run for a longer period of time to see whether the D indices will continue to rise, will reach a limit, or will oscillate. We presume that the segregation will continue to rise until it reaches a steady state. Our speculation is that the ordered initial condition creating correlation between the initial land values and the distance from the center of the lattice will immediately exhibit segregation based on this separation of land values. As time increases and households pursue random properties based on behavioral rules, the segregation becomes less rigid and more mixed. As time continues, however, the behavioral preferences will begin to create large, mostly static populations with high degrees of segregation even larger than initially created. Obviously, our initial research provides only cursory looks at superficial examples that cannot be translated yet into any firm analysis. Parameters must be tweaked,

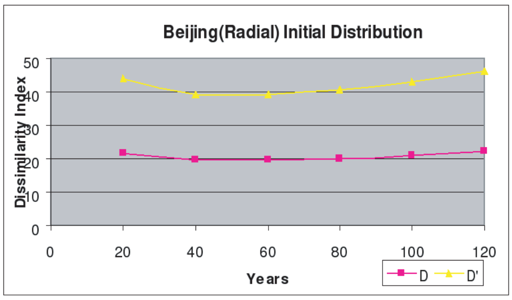

Figure 6: Dissimilarity over time with *radial* initial conditions

standardized, and extended so we can more concretely examine the effects of preferential household behavior on segregation. Our models have provided a great start, however, at how we need to look at the problem of housing markets using agent-based models and given us valuable insight on both the prospects and limitations of modeling such a complex systems using computer simulation.

3.2 Income Inequality

Having created the model, some measures are necessary to determine what effect, if any, the parameters of the model have on economic segregation. For each initial condition, the one of the two parameters, immigration/emigration probability and yearly returns to capital, is varied while the other is kept constant. Immigration / emigration probabilities are varied from 0.006 to 0.01 by a 0.001 step while the yearly returns to capital are varied from 0.01 to 0.05 by a 0.01 step. Thus, with 3 initial conditions, this meant 9 separate cases or 27 different simulation set-ups total. Each simulation ran for a period of 100 years and data is collected every 20 years or 6 data-sets per simulation set-up. This process was repeated 20 times per set-up in order to generate a significant sample size for analysis. The next step involved analysis of the data to generate some measures that allow the emergent behavior of the agents in the model in each type of set-up to be compared. Though the goal of the model was to look at factors that may affect economic segregation, income inequality is another important measure that can be used to compare the effects of the different model parameters. The most common measure of income inequality is the Gini-Coefficient (myles,2005), G. This measure is found by calculating two-times the area between the Lorenz curve and a 45 degree line so that,

$$G = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{i}{n} - I_i\right)$$

where n is the number of households in the population and I_i is the cumulative proportional income due to the i^{th} household ordered such that poorer households are counted first (myles,2005). Thus, if income were distributed equally, I_i would equal $\frac{i}{n}$ for all i and the Gini coefficient would vanish. As more income inequality exists, the Gini coefficient grows and eventually reaches a value close to one. For our simulations, we calculated G based on the net-wealth of each household (capital plus asset value) since a person buying a house would see a drop in their capital that does not reflect there overall net-worth and relative economic position with respect to the rest of the population. The below graphs show the results of Gini Coefficient calculations for the different initial conditions for varied immigration probability and yearly capital returns.

The first case above is for the first initial condition where the landscape is initially empty and is slowly populated by immigration. As noted before, the immigration rate is higher than the emigration rate in this case as the community goes through a growth phase. In this case, the initial Gini Coefficient is 0 for all cases since no population exists. As soon as the simulation begins, however, the Gini Coefficient begins to grow for all cases. Varying the immigration probability from 0.006 to 0.01 seems to have little effect on the Gini Coefficient while varying the capital returns from 0.01 to 0.05 has a substantial effect on the Gini Coefficient. For capital returns, the Gini Coefficient ranges from 0.12 to 0.61 which indicates that the larger the annual returns to capital, the larger the likely effects on economic inequality. In the second case, the initial condition began essentially where the last case left-off. Once the landscape was populated, immigration probability was set equal to emigration probability such that the overall population in the landscape roughly remained constant. The below graphs show the Gini Coefficient results

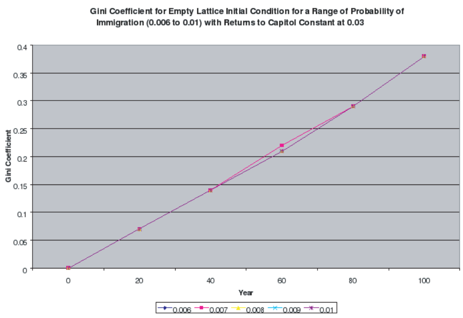

Figure 7: Gini coefficient for the *empty* initial conditions over immigration probability at $\rho = 0.03$

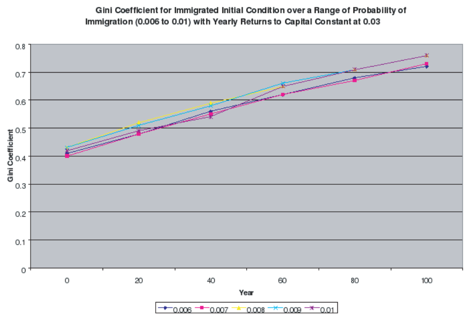

Figure 9: Gini coefficient for the *immigrated* initial conditions over immigration probability at $\rho = 0.03$

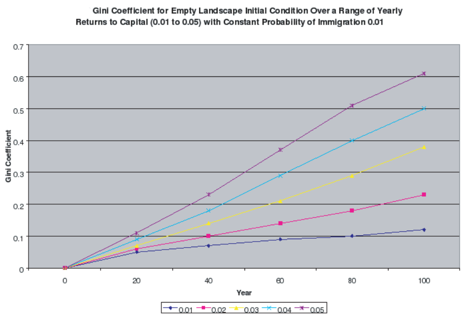

Figure 8: Gini coefficient for *empty* initial conditions over return rate ρ with $p_I = 0.01$

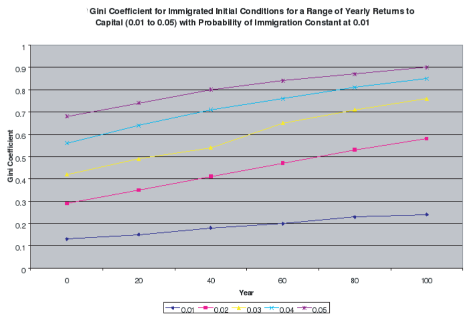

Figure 10: Gini coefficient for *immigrated* initial conditions over return rate ρ with $p_I = 0.01$

for this second scenario for the range of immigration/emigration probability and yearly capital returns paramaters. (See Figure 7 and Figure 8)

Just as in the previous case, we see that the parameter of capital growth has a substantial impact on overall economic inequality. In this case, for yearly capital returns from 0.01 to 0.05, the resulting Gini Coefficient after 100 years ranged from 0.24 to 0.90 respectively. A capital growth factor of 0.05 coupled with an immigrating/emigrating population resulted in an extremely inequitable distribution of wealth. The effects of immigration/emigration probability are more ambiguous but again in this case do not seem to have a major impact on the resulting Gini Coefficient over the tested range of 0.006 to 0.01. Perhaps a larger variance in the immigration/emigration probability used might lead to different results and this could be addressed in future simulations. Finally, the last case included a population randomly distributed on a Beijing landscape lattice. The Gini Coefficients for the different simulations for this initial condition are shown below. (See Figure 9 and Figure 10)

The results for the radial simulations reveal that capital growth again is the major factor impacting economic inequality. While immigration may play a small role, the effects are not nearly as strong those caused by varying the yearly returns to capital. In fact, over the small range tested from 0.006 to 0.01, there seems to be an unexpected result that immigration in some cases actually decreased the Gini Coefficient. To explore this further, future studies should include a wider range of immigration parameters for study. The Gini Coefficients for yearly returns to capital after 100 years range from 0.00 to 0.05 is 0.10 to 0.65 respectively. In fact, for this initial condition, a test case where there were no yearly returns to capital was tested and as can

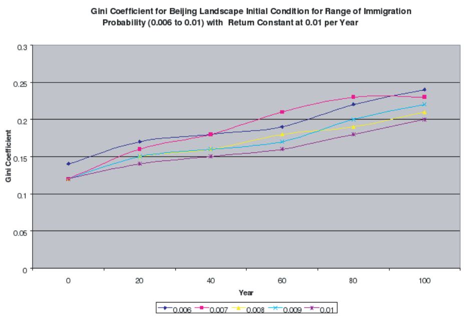

Figure 11: Gini coefficient for the *radial* initial conditions over immigration probability at $\rho = 0.03$

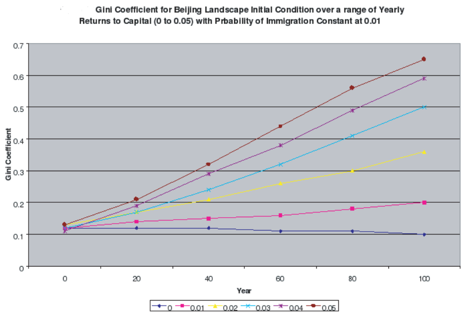

Figure 12: Gini coefficient for *radial* initial conditions over return rate ρ with $p_I = 0.01$

be seen in the above graph immediately above, the Gini Coefficient actually decreased over time in that case. Thus, the three cases all indicate that capital growth may be a substantial source of economic inequality. Further study of the immigration/emigration probability may be necessary before reaching any conclusions with respect to the effects of that parameter. (See Figure 11 and Figure 12)

4 Discussion

4.1 Policy Context of Agent-Based Segregation Models

While our model is context-free in terms of exogenous environmental, political, and policy influences, we find it imperative to examine the future implications of how economic and social policies may be incorporated into models such as the one outlined in this paper. We believe that our exploration into housing dynamics using agent-based modeling is a necessary first step, but that more detailed and context-sensitive models are possible future extensions of this research. Agent-based models help develop neighborhood theories that emerge from varying initial conditions and behavioral rules (Bernard and Willer 2007) by providing large numbers of virtual experiments with no real-world consequence. Likewise, theories on policy can also be tested and refined using agent-based models.

As mentioned in the historical section of this paper, the Chinese housing market is at a critical point in its development. While the actual volatility or robustness of the housing market has yet to be truly tested, it is impossible to imagine the market's current growth rate sustaining indefinitely. Therefore, we feel that increased virtual trials of computer simulations may offer the estimated effectiveness of certain policy implications without disrupting the market's current status.

More specifically, the ultimate goal of our long-term research is to find suitable policy suggestions for the China housing market that would avoid the blunders of the public housing policies that permeated Western countries following World War II. Though well-intentioned, the concentration of state-sponsored, low-income in countries like the United States often led to poverty stricken slums with high crime and disintegrated infrastructure.

The causes of slums are admittedly complex and not fully understood, so we focused on one phenomenon commonly associated with slums: residential segregation. With a variety of causes and effects, residential segregation has been found to be a significant factor in continuing socioeconomic inequality (Bernard and Willer 2007; Massey, Gross, and Eggers 1991). In addition, segregation is a common metric used in urban studies to describe social and economic dynamics, and has been used historically in agent-based models (Schelling 1971, 1978; Fossett 2003; O'Sullivan 2005; Bruch and Mare 2004; and others).

Our model supports this by demonstrating emergent segregation based on the simple behavior of random residences moving to more valued land whenever possible. We found that this preference to move to higher-value land accompanied by the influence of neighbor's wealth on land values creates significant economic segregation regardless of initial conditions. Intuitively, this makes sense since any preference given as a mass social behavior for each individual agent will eventually accumulate over time. Given the nature of these agent-based models as complex systems, common sense tells us that even these random moves involving slight preference will ultimately find a "tipping point" or phase transition that will attract agents to increasing segregation.

So if segregation is an expected phenomenon stemming from aggregated individual preference, our ultimate research question becomes: What policies will reduce the natural tendency of residential segregation at an urban level? Three policies we have considered introducing into our model at a later time are rent control, housing vouchers, and various methods of taxation. Each method has obvious benefits and drawbacks that will be described in short. However, the full impact of these policies cannot be predicted, and this is why we feel that implementing such policies on our agent-based model is the best way to investigate the long-term behavior of such policies.

The reason why we chose to speculate on these three policies is largely a reflection on our model's parameters as well as the ambiguity of other measures of social good. As mentioned before, our team of researchers has no disillusion that the cause and effect of slums is quantifiable, let alone curable. Also, any housing market is well beyond the scope of prediction even with the aid of simulation. Therefore, we have simplified our focus to looking purely at segregation because it has been shown to correlate with socioeconomic inequity (Massey, Gross, and Eggers 1991) and have reduced our parameters to purely quantifiable monetary values of land and capital wealth. Measures or policies based on social capital, on the other hand, were not considered due to the ambiguity of a precise definition (Portes 1998, Fisher 2005, Manski 2000, Kadushin 2004) as well as the uncertainty of its impact on a neighborhood's socioeconomic well-being (Reingold, Ryzin, and Ronda 2001). We will now discuss how rent control, housing vouchers, and certain taxation principles may be incorporated into our model in the future.

4.1.1 Rent Control

One simple form of housing policy involves controlling rent by either fixing housing prices or controlling the rate that a property values can increase, sometimes by tying the rental price increase to inflation or the location's cost of living index. Another type of rent control that has been gaining popularity in the United States is called 'affordable housing'. Landlords under this policy are forced to rent to households that are a certain percent below the poverty line and providing rent that is only a fixed percent of the household's annual income. (There are now many papers regarding affordable housing: Sazama 2000; Quigley and Raphael 2004; Genovese 1991 to name a few). Some research has already been done incorporating rent control into agent-based model housing markets. Using agent-based models much like ours, Bradburd et. al. (2006) found that rent ceilings affect market outcomes and distribution, and Bernard (1999) found that markets with rent control often had lower-income residents as well as lower vacancy rates. The concept of rent control can be easily adapted into our model. Currently, the value of each property in our model is based on its initial, basic value plus the value of the adjacent properties. The influence of adjacent properties can be marginalized and mitigated to varying degrees to test whether less segregation occurs when the property values are not entirely based on free market phenomenon. In China, however, there is sure to be resistance to this approach because the already large presence of government control in most aspects of Chinese economy. Referring again to the historical section of this paper, the housing market has only been recently liberated from tight government regulation, and this deregulation has contributed greatly to its substantial growth in recent years. For obvious reasons, investors and the government alike may be unwilling to slow their newfound economic housing boom with rent control.

4.1.2 Housing Vouchers

Another form of housing policy depends on the relocation of low-income households into more affluent areas that they would not normally be able to afford under normal market conditions. Arguments for this type of program claim that low-income households who have access to better amenities and have more exposure to other income levels are more likely to increase their own wealth status (Varady and Walker 2003). This relocation can either be forced, or by distributing housing vouchers to low-income residents so that they can afford housing in more affluent areas. Programs like the Gautreaux Program, Moving to Opportunity, and others in the United States have experimented with housing vouchers with varying degrees of success. Varady and Walker (2003) give a good summary of these programs as well as findings on their neighborhood impacts. Within our model, a household's capital increases over time and is also dependent on the property value, which is partially calculated based on location. This is the driving mechanism that allows households on affluent properties to gain even more capital, which they then use to move to higher-valued locations. To implement a housing voucher system, we would simply need to artificially increase the capital of a portion of low-income households so that they could afford higher-valued property. Another aspect that could be included would be to 'tax' the wealthier households and give that capital to the poor in the form of housing vouchers. This would create a zero-loss policy for the government so that it would not accumulate a deficit. One drawback of our current model for the use of this approach is that there is no separation between income and capital. Therefore, we would need to devise a way to distinguish between artificially inflated capital (low-income residents with housing vouchers) and traditionally earned capital (higher-income residents).

4.1.3 Taxation

Lastly, taxation is a way for governments to try to influence free market decisions without directly disturbing the market. Of course, there are many tax options that a system can use, and we will not talk about all of them. Using only the model's parameters of land value and household capital, various taxes can be introduced into the model. Property tax based on land values, wealth tax based on household capital, and income tax based on increased capital are just some of the tax structures that can be used to experiment with market impact. China already has these taxes in place, so it is no stretch to add them to our model in addition to other policy ideas. One tax that has been present in China for years but only recently begun to be enforced is the property improvement tax that charges developers based on the increased value of their acquired property after development. Our group sees this tax as having a potentially large impact on the housing market, and incorporating it into our agent-based model may provide intuition on whether this tax will actually slow development in China or whether it will merely increase land values.

5 Conclusion

This paper represents an effort to extend agent-based modeling of residential segregation dynamics and patterns. Especially, we are the first to forecast whether there will be urban economic segregation in China, although Chinese commodity housing market developed only less than 20 years but very fast since 1998.

We introduce the capital, the immigration probability and emigration probably into our model, and ran the model with three initial conditions. The advantage of our methodology is that we capture the concept of ownership and in this way the value of the house can be added to a household's buying power. But in most of previous relative literatures, including the latest one (Bernard and Willer 2007), they only consider the income as the household's wealth or richness, neglecting the housing value which is very important for a family when deciding to buy a new house. Also, we calculate the Index of Dissimilarity and Gini Coefficient to measure and compare the simulation results of our model and the reference model.

At last, our research group finds it important to look at the potential for agent-based models like ours to influence policy decisions even though we understand the limitations of such attempts. However, by simplifying both the causes and effects of real-world phenomena, little direct correlation can yet be made between the simulations and the real world. So we will improve our model and try to test ‘policy-simulation’ in our agent-based model in the future.

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