

Almagor, Jonatan; Benenson, Itzhak; Czamanski, Daniel

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The evolution of the land developers' industry in a planned city: An agent based simulation model

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The evolution of land developers' industry in a planned city
An agent based simulation model

Paper submitted for the ERSA 2014 Congress, Saint Petersburg, Russia

Jonatan Almagor

Tel Aviv University

Itzhak Benenson

Tel Aviv University

Daniel Czamanski

Technion - Israel Institute of Technology

1. Introduction

Industrial organization studies the structure of firms and markets. It describes and explains observed market structures that range from competitive to monopolistic. Although industrial organization literature has a long history, studies concerned with the land development industry are scarce. Existing evidence indicates that there is a wide variance in the structure of the land development industry in different locations. Somerville (1999) finds a rich variation in the market structure of homebuilders across metropolitan areas. The mean firm size is larger in more active housing markets, where more undeveloped land is available and where the probability of carrying out land assembly is lowest. The systematic variation in firm size is consistent with treating the homebuilding as an imperfectly competitive industry. Buzzelli (2001) analyzed the evolving firm size structure of the homebuilding industry in North America based on census data. His study finds no long term trend toward rising market concentration. Rather, the industry passed through cycles in the levels of concentration, and even when concentration peaked, it never approached the degree of centralization common in other industries. On the other hand, Coiacetto (2009) points to evidence that supports the tendency of the land development industry to concentrate. Such evidence includes the rise of large organizations of builder-developers firms that dominate the industry in the UK and are increasingly common in Australia. The use of product branding by development firms that is associated with oligopolistic strategy and the local nature of development that leads to spatial monopoly. Coiacetto (2009) suggests that variation in the development industry structure depends on local factors and sectors. Instances of high oligopoly exist and a degree of monopoly can also be achieved by spatial dominance and by the dominance of submarkets.

In city development, the behavior of land developers reflects parsimoniously all the relevant information concerning urban markets. A central driving force is the profit maximizing behavior of land developers. A developer who is capable of and willing to purchase agricultural land for future development must possess savings and display some preference for risk-taking. Her behavior is similar to R&D investments that may create innovation. Like in the case of non-spatial economy, innovation and growth are associated with a particular size-distribution of firms. According to Luttmer (2006) growth is associated with idiosyncratic firm productivity improvements, selection of successful firms, and imitation by entrants.

Regulation is an important factor affecting the land development industry structure. Land-use planning restricts the land supply and therefore holders of residential land sites acquire a degree of monopoly

power through the land they own (Ball, 2003). This may lead to the emergence of larger builder-developers because of the opportunity this gives to increase supply control and reduce competition in both land and housing markets.

In this study we confront questions concerning the evolution of the land development industry. We do that using an agent based model that simulates the development of a city regulated by a land use plan that is driven by developers who make economic decisions. We start with developers who are homogeneous in terms of wealth and simulate their economic growth as they make investments in lands and accumulate profits from construction. As developers differentiate in wealth they vary in their capabilities for making investment and in willingness to take risks. The result is various size distributions of developers that emerge under different conditions of competition and regulation. We also demonstrate the emergence of different city structures as a result of the dynamics of developer-planner.

The rest of this paper includes 5 sections. In section 2 and 3 we present the basic arguments, the fundamental structure of the model and its dynamics. Section 4 presents the results of our simulations and section 5 contains the conclusions.

2. The evolution of developers' industry - an agent based model

2.1 General description of the model

The starting point for our study is a small city and a homogeneous group of land developers. Motivated, among other, by the wish to prevent outward sprawl land-use plans divided the city into zones in which building is permitted (henceforth *urban*) and zones allocated to open space and agriculture (henceforth *non-urban*). These plans are typically amended as a result of population growth and pressure of developers to accommodate demand for housing and other buildings on land not zoned for building.

The model simulates the development of urban areas of cities that are regulated by such land use plan. The spatial evolution of cities is driven by land developers who see in the process of occasional amendments to land-use plans a source of wealth due to the sudden appreciation of land values. Land not zoned for building is typically much cheaper than land zoned for building. Some developers buy such land with the hope that within a reasonable time they will receive a land-use variance or the land-use plan amendment and building will be permitted. Such changes are uncertain and therefore risk-averse developers do not purchase land without a definite and immediate possibility to build. The expectation

of very large profits motivates risk preferring developers to buy such lands and pressure planning boards to approve building activities.

Developers expect changes in land-use plans following unexpected fluctuations of demand, changes in the priorities of the local authorities and due to other local socio-economic factors. However, the uncertainty of obtaining construction permits for such lands, both with regard to "when" and to "where" is very high. We present a model that enables investigation of the dynamics of an urban system driven by the interaction among developers and a planner/regulator. The model follows the accumulation of wealth for each of the developers as they make investment decisions and gain profits. All developers start with equal assets and use the same decision making procedures. Over time, the outcomes of developers' investments differentiate their economic state. This in turn influences their investment capabilities and decision making.

The system is driven by a population growth which is, on average, 2% per year. Following a demand, the regulator periodically extends urban zone and, in addition, issues special construction permits for purchased parcels located in the non-urban zone. Developers choose potentially profitable parcels and compete for purchasing them. They construct buildings in the urban and non-urban zones and increase their wealth. Once in every T years the regulator extends the urban zone and some of the parcels in the non-urban zone are included into the urban zone. This cycle repeats itself and the city expands (Figure 1).

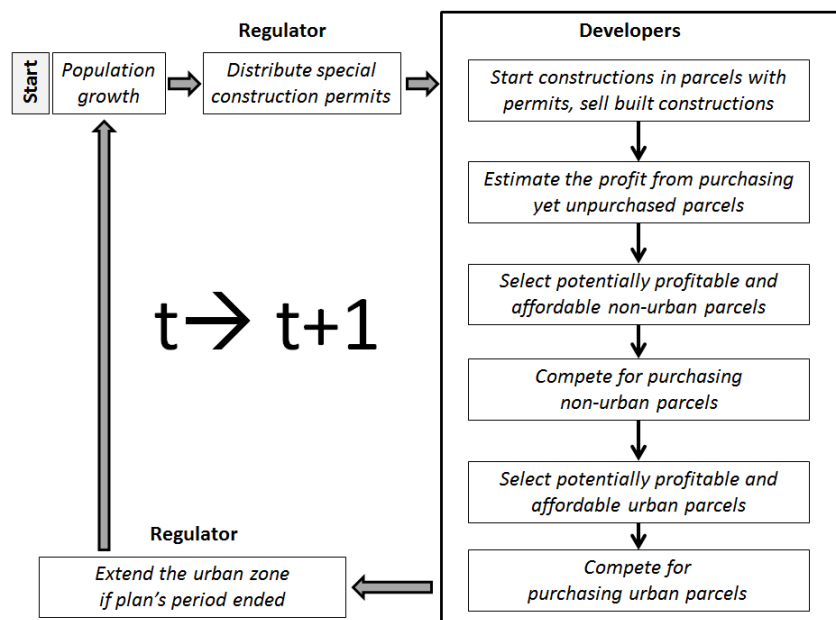


Figure 1: Model procedures

2.2 Model space and urban development plan

Model space consists of elementary spatial units - parcels. Parcel's initial state is non-developed. The land use plan specifies two zones of the model space: urban and non-urban. In urban zone construction is permitted and it is periodically extended by the regulator to guarantee the space for the expected increase in population during the time frame of the plan. In addition, the regulator can issue a number of special permits for construction in the non-urban zone.

The model space is a grid of equal square parcels, which dimensions are used below as a unit of length and of an area. Model space consists of two zones, denoted in the plan as *urban* and *non-urban*. Initially, the urban zone is a circle of a certain radius, which center is the defined as *central parcel* and all parcels are non-developed. A non-developed parcel can be purchased and constructed by a developer. In the urban zone construction is allowed everywhere; in the non-urban zone construction requires a special permit.

Once in T years the regulator extends the urban zone in order to supply lands for the population surplus that is expected during next T years. Within the extended area of the urban zone an additional *central parcel* is determined. The distance to the nearest *central parcel* determines the amount of construction permitted on a parcel.

The amount of construction permitted at a parcel P is expressed by the number of floors F(P). Within the urban zone, F(P) decays with the increase in the distance (to remind, the latter is measured in the units of parcel's size) between P and the nearest urban center as:

$$F(P) = \max\{1, \text{INT}(F(P_{\text{CBD}})/(1 + 0.2 * \text{Dist}(P, P_{\text{CBD}})))\} \quad (1)$$

Where $F(P_{\text{CBD}})$ is the number of floors in the nearest urban center and $\text{INT}(X)$ is a closest integer to X. In what follows, the value of $F(P_{\text{CBD}})$ is set equal to 30 floors and the constant 0.2 in (1) is chosen to guarantee that the minimal possible height of 1 floor will be reached far away from the center, at a distance of 70 parcels (Figure 2).

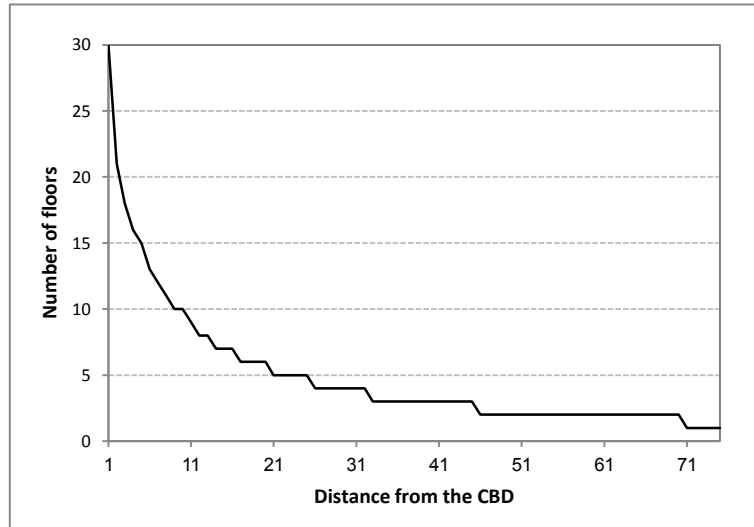


Figure 2: The height of construction as dependent on the distance between the parcel of construction and city center.

The regulator issues special permits for construction in the non-urban zone. These permissions are preferably issued for purchased parcels surrounded by a dense buildup. The regulator is also biased in favor of parcels owned by developers with large assets.

The amount of construction on the parcel P located in the non-urban zone, is assigned by the special construction permit, and does not depend on the distance between P and the nearest *central parcel*. The number $F(P)$ of constructed floors there is set according to a normal distribution which mean is equal to $F_{CBD}/3$ and STD is equal to 2.

2.3 Regulator's behavior

When the time period of the current plan is over, the regulator extends the area of the urban zone by turning some of the non-urban area into urban. Regulator extends the urban zone towards the areas where special permissions were issued and, consequently, constructions are already built. To determine these areas, the regulator, first, locates the *densest buildup neighborhood* within the non-urban zone, where the density is estimated as a fraction of buildup cells within a circle of a 6-unit radius around a cell.

The regulator then changes the status of all parcels within the densest buildup non-urban neighborhood of radius 6 from non-urban into urban. In addition, to ensure continuity to the urban zone, the parcels along the shortest path between the center of this neighborhood and the urban zone also change their state into urban and the obtained area is considered as a core area for the plan extension. The maximal

height of the construction at the *central parcel* (if not yet built) is set equal to $F(P_{CBD})$ and the new central parcel becomes an additional anchor for calculating building height as in (1).

To decide on the final size of the extension, the amount of the floor space that may be supplied in the core area of extension is estimated. If this amount is insufficient for the expected population growth, the rings of parcels around the core area (consisting of the neighborhood and the shortest path from the neighborhood to the buildup area) are added to the urban zone until the total amount of floor space that is necessary to accommodate the future population increase $\Delta Pop(t + T)$ (Figure 3) is accumulated:

$$\Delta Pop(t + T) = B(t) - A(t) + Pop(t) * (1.02^T - 1) \quad (2)$$

Where $B(t)$ is the number of city residents with no housing at t and $A(t)$ is the potential amount of construction at t that can be yet built within the urban area of the previous plan.

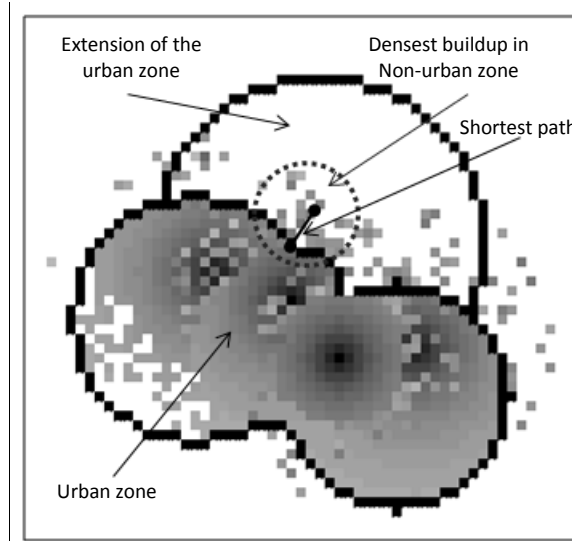


Figure 3: The process of plan extension: The center of the additional urban zone is chosen in the densest buildup neighborhood beyond the current plan and, initially, a core area of extension includes this neighborhood and the shortest path between this area and the buildup part of the urban area. Then the rings of cells around the core area of extension are added until the expected demand for floors space is reached.

Beside periodic extension of the urban zone, the regulator may issue special construction permits for construction on the non-urban parcels. The number of special construction permits issued per year is a fraction N_{sp} of the average expected yearly housing demand $M(t)$, estimated over the next 3 years:

$$M(t) = (Pop(t) * (1.02^3 - 1) + B(t) - L(T)) / 3 \quad (3)$$

Where $B(t)$ is the number of residents with no housing and $L(t)$ is the current amount of construction in progress or already finished.

See section 2.5.6 for more details on the regulator's behavior in regards to the special construction permits for non-urban parcels.

At each time step, the amount of construction that is sufficient to satisfy the current demand for housing are randomly selected among all parcels that are built at the moment and sold to the population that demands housing at this moment.

2.4 Parcel price

The price of an urban parcel P is defined in the model by the expected revenue $G(P)$ from selling the construction there. In what follows we assume that $G(P)$ is proportional to the number of floors in construction and inversely proportional to the distance between P and city center:

$$G(P) = g_{\text{CBD}} * F(P) * \text{Dist}(P, P_{\text{CBD}})^{-0.1} \quad (4)$$

where g_{CBD} is the return per one floor in the closest city center.

The market price $C(P_{\text{urban}})$ of an urban parcel P_{urban} is assumed proportional to $G(P)$:

$$C(P_{\text{urban}}) = r * G(P_{\text{urban}}) = r * g_{\text{CBD}} * F(P) * \text{Dist}(P, P_{\text{CBD}})^{-0.1} \quad (5.a)$$

where $r < 1$

The market price of non-urban parcel $P_{\text{non-urban}}$ is assumed constant.

$$C(P_{\text{non-urban}}) = c_{\text{non-urban}} \quad (5.b)$$

In what follows we assume that the price of a non-urban parcel is below the price of any parcel within the urban zone:

$$c_{\text{non-urban}} < r * g_{\text{CBD}} * (\max \{ \text{Dist}(P, P_{\text{CBD}})^{-0.1} \mid \text{by all cells } P \text{ within the urban zone of a current plan} \}) \quad (5.c)$$

2.5 Land developers and their behavior

Developers aim at enlarging their wealth by purchasing land, developing it and selling the construction. Developers compete for purchasing parcels within the urban and non-urban zones.

Developers purchase parcels and construct on them buildings in order to sell them and enlarge their assets. Developer is characterized by the *Liquid assets* $D_L(t)$ and *Total assets* $D_T(t)$ which equal to the

liquid assets $D_L(t)$ plus the value of all parcels owned by the developers at t . Initially, developer starts only with liquid assets which are equal for all developers.

At each time step all developers make several actions. First, they build on the parcels that they own which have construction permissions. Second, based on their liquid assets, they choose non-urban parcels for purchasing, compete for these parcels with the other developers, and purchase the parcels if they win. Third, using the rest of their liquid assets, they operate in the same way with regard to the urban parcels.

Developer develops a purchased parcel depending on whether it is located in the urban or non-urban zone. If a purchased parcel is in the urban zone, then a developer starts construction a year after purchasing it. The construction in the urban zone takes 1, 2 or 3 years, and the length of the period of construction is chosen randomly, with equal probabilities of each value. A purchased parcel in the non-urban zone cannot be constructed immediately. Developer has to wait until either a plan is extended to include this parcel or a special permit for constructing on the parcel is granted by the planner.

A purchase of a parcel within the urban zone is thus considered by developer as relatively expensive but certain investment because there is no delay in obtaining construction permission.

Non-urban parcels are cheap, though the period of the time until either the urban zone is extended to include some of them or special construction permit is obtained is very uncertain. Therefore developer invests in a non-urban parcel only if the potential profit from the non-urban parcel (accounting for the uncertainty) is higher than the most profitable urban parcel.

2.5.1 *Developer's estimate of the profit expected from the parcel:*

To select parcels for purchasing, developers observe all non-developed parcels and estimate expected profit from each of them. For a parcel P_{urban} in the urban zone, expected profit $E(P_{urban})$ is estimated as:

$$E(P_{urban}) = G(P_{urban}) - C(P_{urban}) - N(P_{urban}) \quad (6)$$

Where $G(P_{urban})$ is expected income from selling the construction according to (4), $C(P_{urban})$ is the price of the parcel according to (5.a) and $N(P_{urban})$ is construction cost at P_{urban} :

$$N(P_{urban}) = 0.2 * g_{CBD} * F(P_{urban}) \quad (6.a)$$

Where the construction cost of one floor is similar everywhere and is equal to 20% of the returns from selling one floor g_{CBD} located at the central parcel.

Developer's estimate of profit from a non-urban parcel $P_{\text{non-urban}}$ accounts for the uncertainty of the investment:

$$E_D(P_{\text{non-urban}}) = G(P_{\text{non-urban}}) - C(P_{\text{non-urban}}) * (1 + \alpha)^{\tau_D(t)} - N(P_{\text{non-urban}}) \quad (7)$$

Where α is the annual interest rate from an alternative investment, and $\tau_D(t)$ is developer's D estimate of the length of a period of time that is necessary to obtain special construction permission at $P_{\text{non-urban}}$. The salient feature of the model is dependence of $\tau_D(t)$ on developer's size. In what follows we assume that larger developers are more optimistic and their estimate of the length of a period of time that is necessary to obtain special construction permission in the non-urban zone is shorter than the same estimate of the smaller developer. To implement this dependence, we rank developers in descending order according their total assets $D_T(t)$ (i.e., the rank of the largest developer is 1) and assume that:

$$\tau_D(t) = \text{Integer} (2 * r_D(t)^{0.5}) \quad (8)$$

where $r_D(t)$ is a rank of developer D at t.

2.5.2 The choice of attractive non-urban parcels:

Developers split their liquid assets to purchase urban and non-urban parcels. A share $s_{\text{non-urban}}$ of developer's liquid assets can be invested into non-urban parcels that are attractive that is, potentially more profitable than the parcels in the urban zone. To recognize these parcels a developer considers all non-urban parcels that are cheaper than her liquid assets devoted for purchasing non-urban lands:

$$C(P_{\text{non-urban}}) < s_{\text{non-urban}} * D_L(t) \quad (9.a)$$

and estimates return on investment $ROI(P_{\text{non-urban}})$ for every non-urban parcel $P_{\text{non-urban}}$ satisfying (9.a)

$$ROI(P_{\text{non-urban}}) = E(P_{\text{non-urban}}) / (C(P_{\text{non-urban}}) + N(P_{\text{non-urban}})) \quad (9.b)$$

The developer estimates return on investment for all available urban parcels $ROI(P_{\text{urban}})$ and establishes maximum of the return on investment $ROI_{\text{urban_maximal}}(t)$ for the urban parcels. The non-urban parcels $P_{\text{non-urban}}$ for which

$$ROI(P_{\text{non-urban}}) > ROI_{\text{urban_maximal}}(t) \quad (9.c)$$

are candidates for purchasing by D, and she spends the share $s_{\text{non-urban}}$ of her liquid assets $D_L(t)$ to purchase one or more of them.

We consider developers to have bounded rationality; they are satisfied with one of the most profitable parcels and not necessarily the highest one (Simon, 1955, 1959). To select non-urban parcels for purchasing, a developer constructs a list of 10 non-urban parcels with the highest $\text{ROI}(P_{\text{non-urban}})$ that satisfy (9.c) and randomly selects one them, $P_{\text{non-urban},1}$. Then, the developer selects non-urban parcel that is spatially closest to $P_{\text{non-urban},1}$ and continues in this way until the total price of all selected non-urban parcels exceeds $s_{\text{non-urban}} * D_L(t)$. The aim of selecting adjacent parcels is to reduce development costs in the future, when developing these parcels. After all developers select non-urban parcels they compete for purchasing them.

2.5.3 Developers' competition for purchasing non-urban parcels

We assume that developers compete for purchasing profitable parcels and the chance to win a competition is higher for a developer with larger total assets $D_T(t)$.

At the start of the competition, the list of developers ordered by $D_T(t)$ is constructed. Developers who are higher in this list have higher chance to be the first allowed to purchase selected non-urban parcels. We account for uncertainty of the competition by random selecting the first developer to purchase the non-urban parcels among K largest developers (first K developers in the list).. The first selected developer purchases parcels of her choice, her liquid assets $D_L(t)$ decrease by the total price of the purchased parcels and she leaves the competition. Then, one of the first K largest developers in the remaining list is selected and the process is repeated until either (1) the list is exhausted, or (2) the entire stock of attractive non-urban parcels is purchased, or (3) the amount of future construction on the purchased parcels reaches $M(t)$ as defined in formula (3).

Evidently, the higher is K the higher is the uncertainty of the purchasing in regards to the total assets of the winner. For $K = 1$ the developer with largest $D_T(t)$ will be always the first to purchase then the second largest will enter the purchasing, etc.. For $K \sim N / 2$ any of the developers whose assets are higher than a median assets, can be the first.

Note, that the developer with very large liquid assets can potentially purchase an entire stock of the non-urban parcels. To avoid that, we set maximal fraction m of $M(t)$ (according to (3)) that one developer can purchase at t . The developers purchase parcels until $m * M(t)$ is reached.

2.5.4 Purchasing urban parcels

After purchasing non-urban parcels developers use their residual *liquid assets* to purchase parcels within the urban zone. As above, a process is two-stage: selection of attractive parcels and competition for purchasing them. At a first stage a developer constructs a list of parcels ordered by $ROI(P_{urban})$, randomly selects one of the first 10 of them and then selects available parcels located as close as possible to the selected parcel until the total price of selected parcels reaches the part of the $D_L(t)$ that is still available after purchasing non-urban parcels. At the second stage, developers compete for urban parcels in the same way as they competed for the non-urban ones. The same as in the non-urban purchase procedure the purchase stops once (1) the list of developers is exhausted or (2) the entire stock of attractive urban parcels is purchased, or (3) the amount of future construction on the purchased parcels reaches $M(t)$ as defined in formula (3).

2.6 Regulator's special construction permits in the non-urban zone

The regulator issues special permits for construction for purchased parcels in the non-urban zone. The number of special construction permits at t is a fraction N_{sp} of $M(t)$ the floors space demand at that moment. When deciding on whether a parcel $P_{non-urban}$ will obtain the permit or not, the regulator accounts for the density $B(P_{non-urban})$ of buildings within a 6-unit neighborhood around $P_{non-urban}$ and the relative wealth of the developer D who owns $P_{non-urban}$. The higher is the density of construction and the wealthier is a parcels owner, the higher is a relative weight $c(P_{non-urban})$ that a permission for $P_{non-urban}$ will be issued:

$$c(P_{non-urban}) = (B_{max}(t) - B(P_{non-urban}))^{-0.5} * r_D(t)^{-0.5} \quad (10)$$

where $B_{max}(t)$ is the densest buildup area at t , $B(P_{non-urban})$ is the buildup density around parcel P and $r_D(t)$ is the rank, at t , of the developer D who owns parcel $P_{non-urban}$.

The weights $c(P_{non-urban})$ are calculated for all purchased non-urban parcels and turned into probabilities by dividing on the sum of all weights. Special construction permits are issued to the purchased non-urban parcels, according to these probabilities, until $N_{sp} * M(t)$ the amount of floor space granted by the regulator with special construction permits is accumulated.

3. Implementation

The model is implemented with Netlogo, a multi-agent simulation environment (Wilensky,1999; Sklar, 2007). The user interface includes a map of parcels' state (Figure 4). Graphs present the amount of

assets for each developer as a function of time and the distribution of developers according to their wealth. Aggregate indicators such as market concentration expressed by the share of assets owned by 10 largest developers, population growth, unsatisfied demand and available floor space in the urban zone are also plotted. All model parameters can be adjusted by the user.

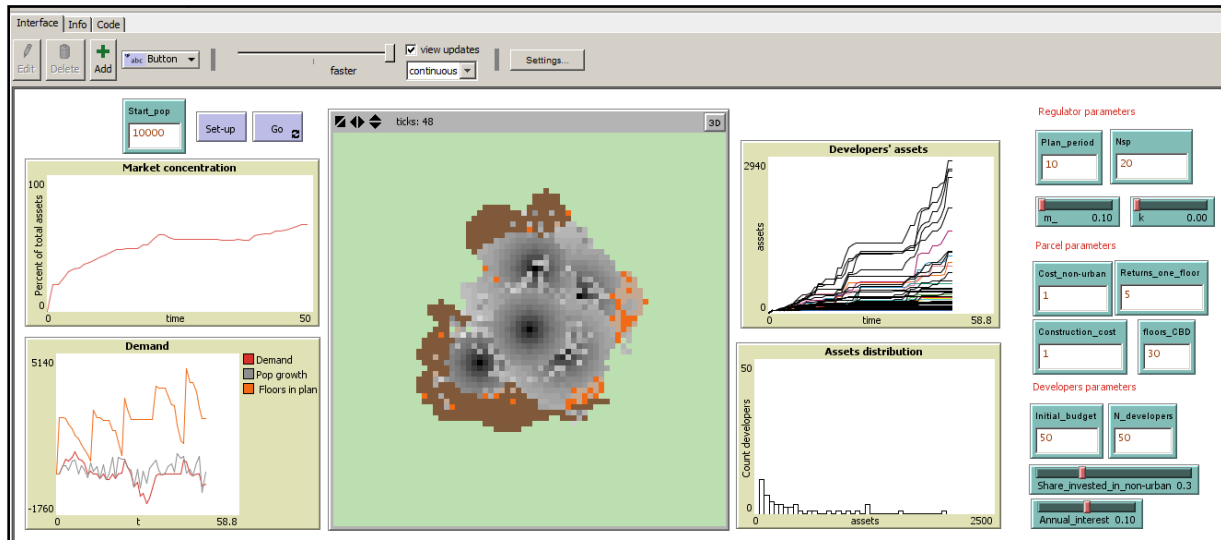


Figure 4: Model interface (Netlogo).

4. Results: Size distribution of developers

We investigate evolution of developers' size during few decades of city development. Model scenarios differ with respect to the relative advantage of the large developers in purchasing parcels and obtaining special construction permits. The parameters that are common for all scenarios are as follows (Table 1):

Parameter	Value	Description
N	50	Number of developers
s	30%	Share of developer's liquid assets that is used for purchases in the non-urban zone, every year
α	0.1	Annual interest rate for developer's alternative investment
T	10 years	The length of the planned period, in years
r	2 %	Annual population growth rate

Table 1: Parameters common for all simulation scenarios

At $t = 0$ all developers are equal, $D_L(t) = 50$ for all D , city population $P(0) = 10,000$ families and the size of the urban area is 70×70 (4900) cells.

We investigate the dynamics of developers' distribution by size after 50 years of the city's development, as dependent on three model parameters (Table 2). All runs for a certain set of parameters are repeated 10 times and the results are averaged.

Parameter	Description
N_{sp}	Percentage of current demand for housing that is issued with special construction permits, every year
m	Maximal share of current demand for floor space that one developer can purchase in the urban and in the non-urban zones, every year
K	Number of the largest developers that have identical advantage when purchasing parcels

Table 2: Parameters that vary in simulation scenarios

In what follows we present developers' distribution by size as a rank-size form that is, sorting the developers according their assets in descending order and constructing a chart that presents developer's size as a function of developer's rank in the sorted list. It is important to note, that for the uniform distribution of N developers, by size, on a $[a, b]$ interval, the density of a rank-size distribution is a linear decreasing function on an $[1, N]$ interval, which value at $x = 1$ is below a , and value at $x = N$ is above b (Figure 5).

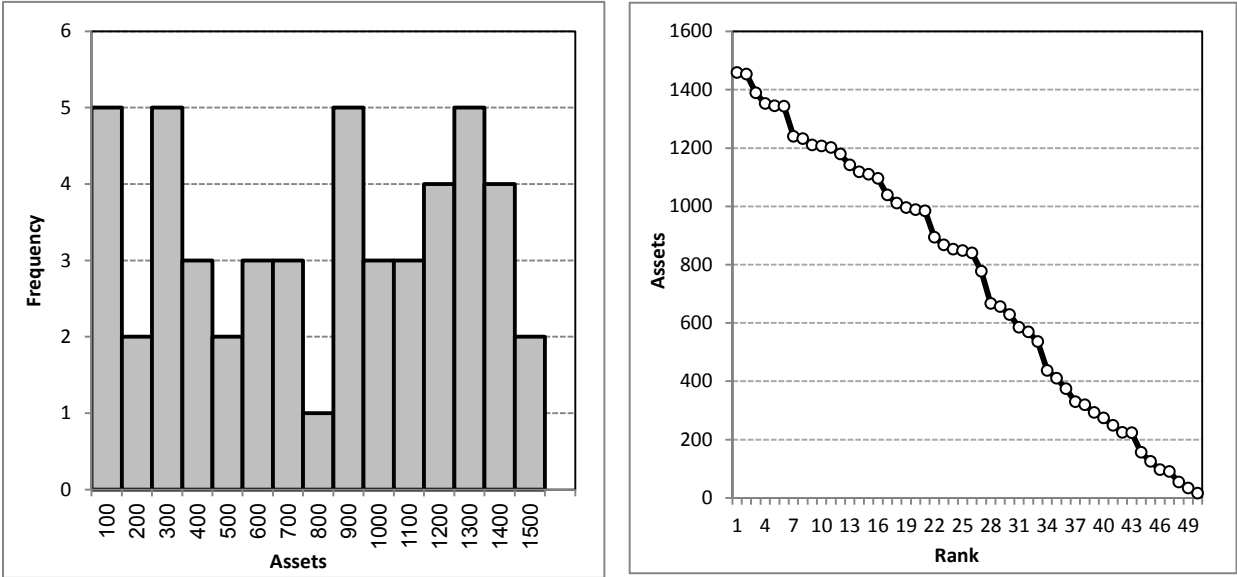


Figure 5: A sample of 50 observations from a uniform distribution on $[0, 1500]$, represented in a standard (left) and rank-size (right) forms.

4.1 The effects of advantage of size when purchasing non-developed parcels

4.1.1 Absolute advantage of size versus no size advantage

Let us start with the scenario in which the size does not influence developer's chances to purchase an attractive non-urban parcel. Formally, this scenario is characterized by $K = N$ (see section 2.5.4), $N_{sp} = 20\%$ and $m = 0.1$. Developers' assets at $t = 50$ vary between 0.3% and 4.6% of total assets and remains

uniform (Figure 6, Table 2). That is, a fully competitive market, where the right to purchasing parcels is not biased by the size of the developer, is not concentrating in time.

In the opposite case of absolute advantage to size ($K = 1$), and the same values of $N_{sp} = 20\%$ and $m = 0.1$, the distribution of assets at $t = 50$ is bimodal (Figures 6, Table 3) and the ratio of the amount of assets of the largest to that of the median developer is 23.4 that is essentially higher than the value 2.1 characteristic of the uniform distribution. According to the Figure 10, In this scenario the urban residential market is controlled by 10 largest developers who hold 77.6% of the total assets comparing to 30.3% obtained in the previous scenario (Table 3).

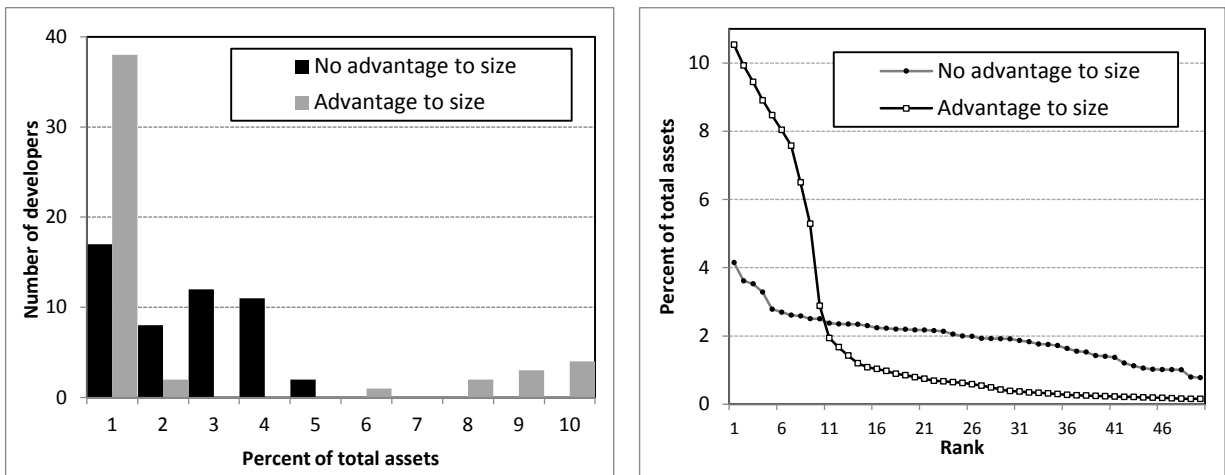


Figure 6: Developers rank-size distribution at $t = 44$ based for absolute advantage to size ($K = 1$) and for no advantage to size ($K = 50$).

Index	No advantage to size ($K = 50$)	Absolute advantage to size ($K = 1$)
Percent of assets owned by 10 largest developers	30.3	77.6
Ratio of the largest/median developers' size	2.1	23.4
Comparison to the uniform distribution, χ^2 and p	$\chi^2 = 9.1$ ($p \sim 0.17$)	$\chi^2 = 131.4$ ($p < 0.0001$)

Table 3: Characteristics of the rank-size distributions of developers by their assets at $t = 50$ for the cases of no advantage to size ($K = 1$), and of absolute advantage to size ($K = 50$).

In time, in case of random purchasing ($k = N$), developers' size distribution remains uniform all the time (Figure 7a). This is not so in scenario with the absolute advantage to size ($k = 1$). Time-evolution of developers' size in this scenario exhibits two phases (Figure 7b). During phase 1 (up to the year 10), developers remain similar in size and their size distribution remains close to uniform. Phase 2 starts when one or more developers, by chance, become larger than the others. From that time on, these developers have advantage in purchasing land and, as a result, increase their assets faster than the

smaller ones. This positive feedback results in the separation between the large and small developers towards $t \sim 20$ and in the full control of large developers over the land market towards $t = 50$.

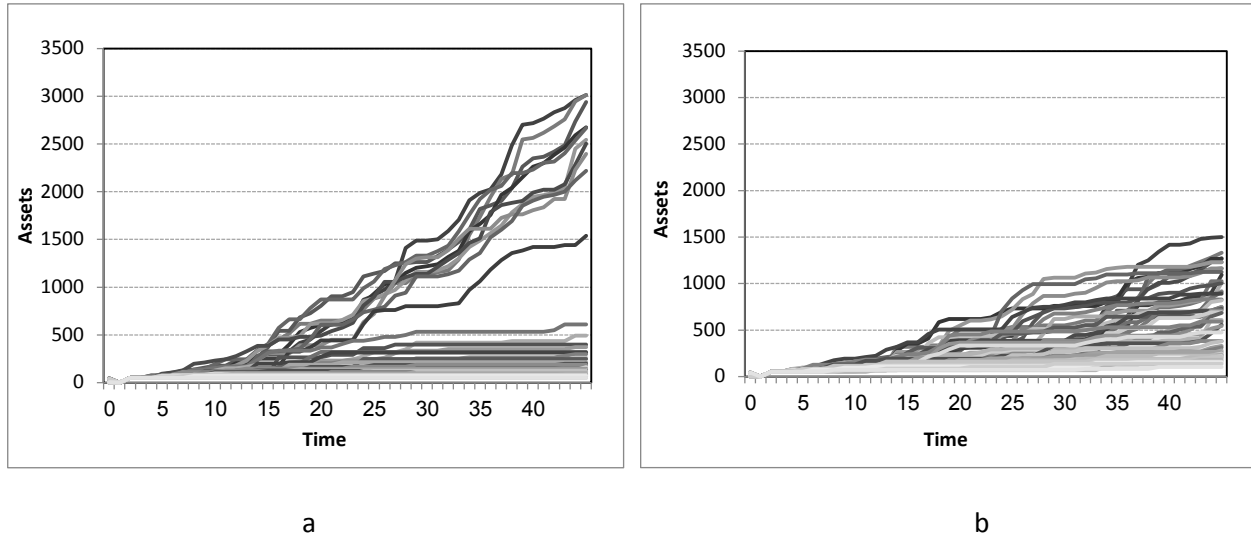


Figure 7: Dynamics of asset accumulation, by developers, (a) advantage to size; (b) no advantage to size

4.1.2 Model sensitivity to uncertainty in purchasing (K)

Figure 8 and Table 3 present developers' rank-size distributions and their aggregate characteristics as dependent on K preserving the values of $N_{sp} = 20\%$ and $m = 0.1$

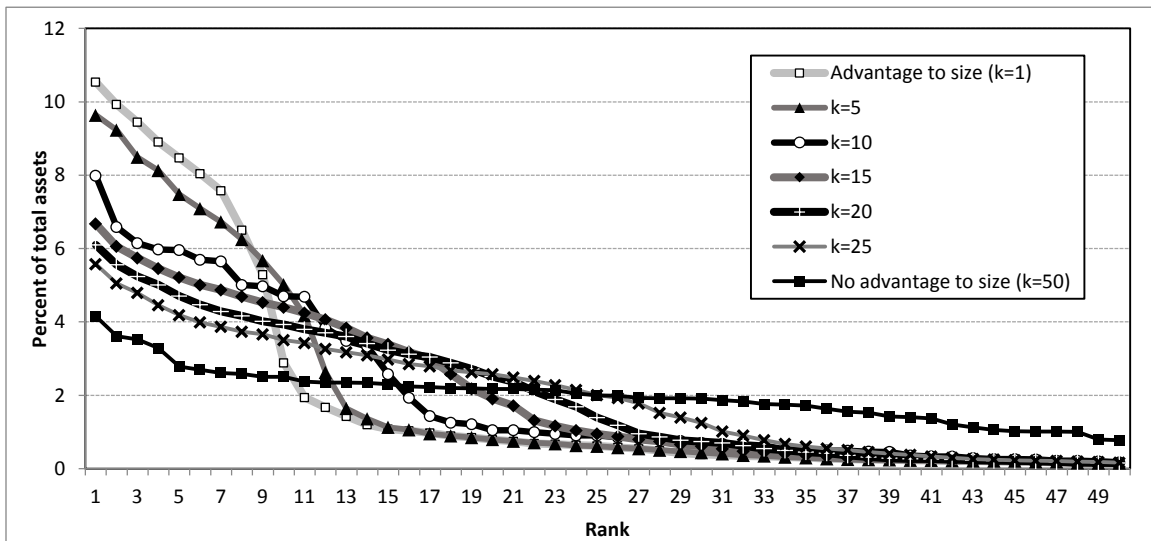


Figure 8: Developers rank-size distribution at $t = 44$ as dependent on the uncertainty in purchasing (K).

For comparison between the rank-size distribution of developers and the uniform one, we employ the following U-measure:

$$U_k = \sum_{r=1}^n (|Dr(k) - Dr(\text{uniform})|) / N \quad (10)$$

Where $D_r(k)$ is the size of developer of rank r for $k > 0$ and $Dr(\text{uniform})$ is the size of developer of rank r in the uniform distribution.

We classify as "large" the developers whose size is larger than that of the developer of the same rank in case of the uniform distribution (see Figure 8).

The influence of uncertainty is summarized in Table 4:

Index	k = 1	k = 5	k = 10	k = 15	k = 20	k = 25	K = 50
Number of large developers	10	12	15	18	21	25	-
Total share of large developers	77.6%	80.5%	76.6%	80.5%	81.9%	83.5%	-
Largest/Median developer ratio	17.5	16.3	9.1	7.3	4.7	2.8	2.1
Assets owned by 10 largest developers, %	77.6%	73.7%	58.7%	52.6%	47.5%	42.8%	30.3%
U_k measure	1.89	1.82	1.39	1.27	1.07	0.8	0.43

Table 4: Characteristics of the developers' rank-size distributions for different levels k of uncertainty in purchasing.

As it can be seen from Table 4, with the increase in the level of uncertainty the distribution of developers' size converges to the uniform distribution. However, this convergence is non-linear, the difference between the developers' distribution and the uniform remains high up to $K = 5$ and then drops and decreases with K linearly. Note that the total share of large developers only rises by 6% between $k = 1$ to $k=25$ while the number of large developers is more than doubled.

4.1.3. Assets distribution and the maximal market share m

Maximal share m of total demand for floors space that a developer can purchase every year evidently affects the potential of a developer to grow. To explore its influence on the developers' rank-size distribution we compared 4 scenarios of absolute advantage of size ($K = 1$) in which m is equal to 0.1, 0.2, 0.5 and 1. N_{sp} is kept 20%. The resulting rank-size distributions of the developers' assets are presented in Figure 9.

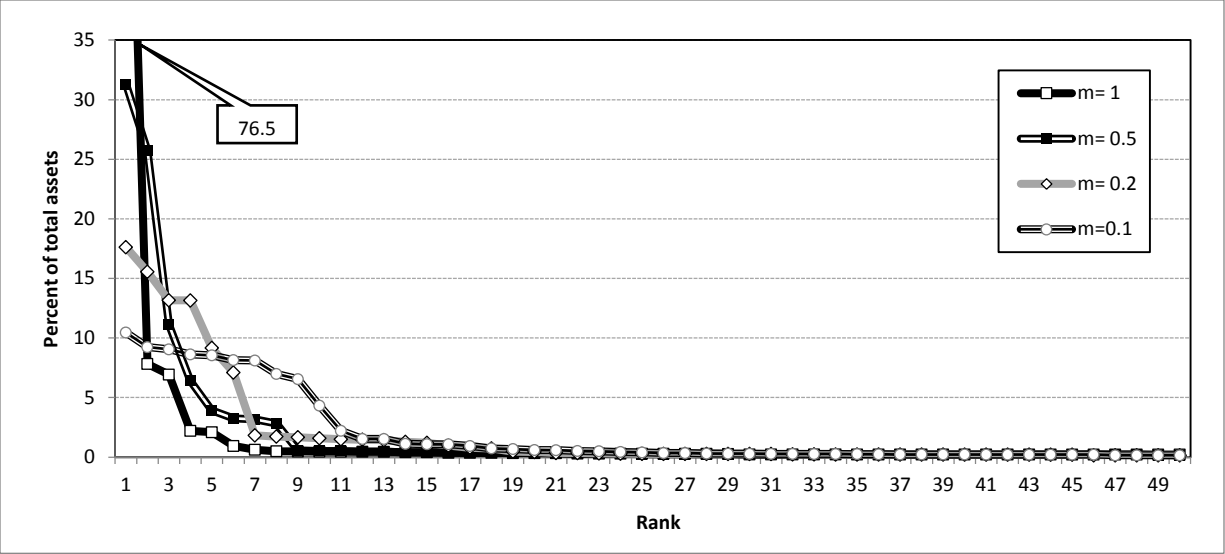


Figure 9: Assets distribution at $t = 50$ as dependent on maximal market share m .

According to the Figure 9, the higher is m , the lower is the number of large developers and "wealthier" is the largest developer. This phenomenon can be expected - given m , the entire unsatisfied demand is divided, every year, between $1/m$ largest developers. Other model phenomena, say the lack of the liquid assets for purchasing maximal share, influence model output, but, as it is seen in Table 5, the total assets of the $1/m$ large developers at $t = 50$ is indeed, loosely dependent on m and close to the 75% of the total assets in the city.

	$m = 1$	$m = 0.5$	$m = 0.2$	$m = 0.1$
Percent assets owned by $1/m$ developers	76.5%	73%	73.4%	77.6%

Table 5: Percent of total assets owned by the $1/m$ largest developers, for different values of m

In what follows we will thus use the value of $m = 0.1$ and consider the assets of the 10 largest developers, as it was done in the scenarios of the previous sections.

4.2 System dynamics as dependent on the number of special construction permits issued

The more special construction permits N_{sp} are issued by the planner, the more certain becomes the investment in *non-developed* non-urban parcels. To investigate this dependency we compared 4 scenarios with the levels of N_{sp} equal to 0%, 20%, 40% and 60%. They are investigated for the case of absolute advantage of size ($K = 1$) and $m = 0.1$

As can be seen from figure 10, the higher is the number of special construction permits the sharper is the distinction between the groups of large and small developers, and the higher is the share of the total assets held by the 10 largest developers. The latter dependence is non-linear and the overall share of total assets stabilizes at a level of 85% as far as the amount of special permissions reaches 60% (Figure 10b).

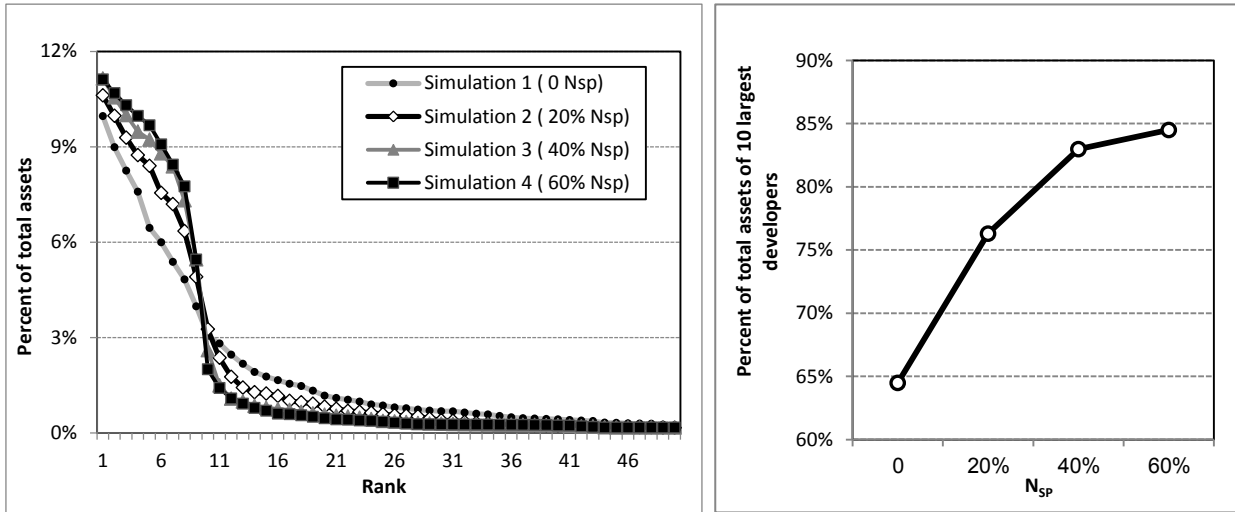


Figure 10: $t = 50$, rank-size distribution (a) and the percent of total assets at $t = 50$ held by 10 largest developers (b) as dependent on number of special construction permits N_{sp} .

4.4. The dynamics of the city pattern

We study the urban dynamics of the model for two different planning policies, when the plan is modified every 10 years and when it is established for the next 50-year period and does not modified. In the former case the urban area is extended every 10 years in respect to the population forecast for the next decade, while in the latter the urban area is established based on the population forecast for the next 50 years. We repeated each of the scenarios of the 10-year and 50-year plans three times for the case of absolute advantage of size ($K = 1$), $m = 0.1$ and $N_{sp} = 20\%$.

As can be seen in figure 11a, plan modification every 10 years essentially influences urban pattern dynamics. New urban centers reflect the history of purchasing in the non-urban zone and every run produces different urban pattern during the 50 years of the simulation.

In contrast, in all three runs the long-term, 50 years, plan produces the same mono-centric city (Figure 11b). Development takes place from the center outward to the fringes, with scattered development outside the urban zone.

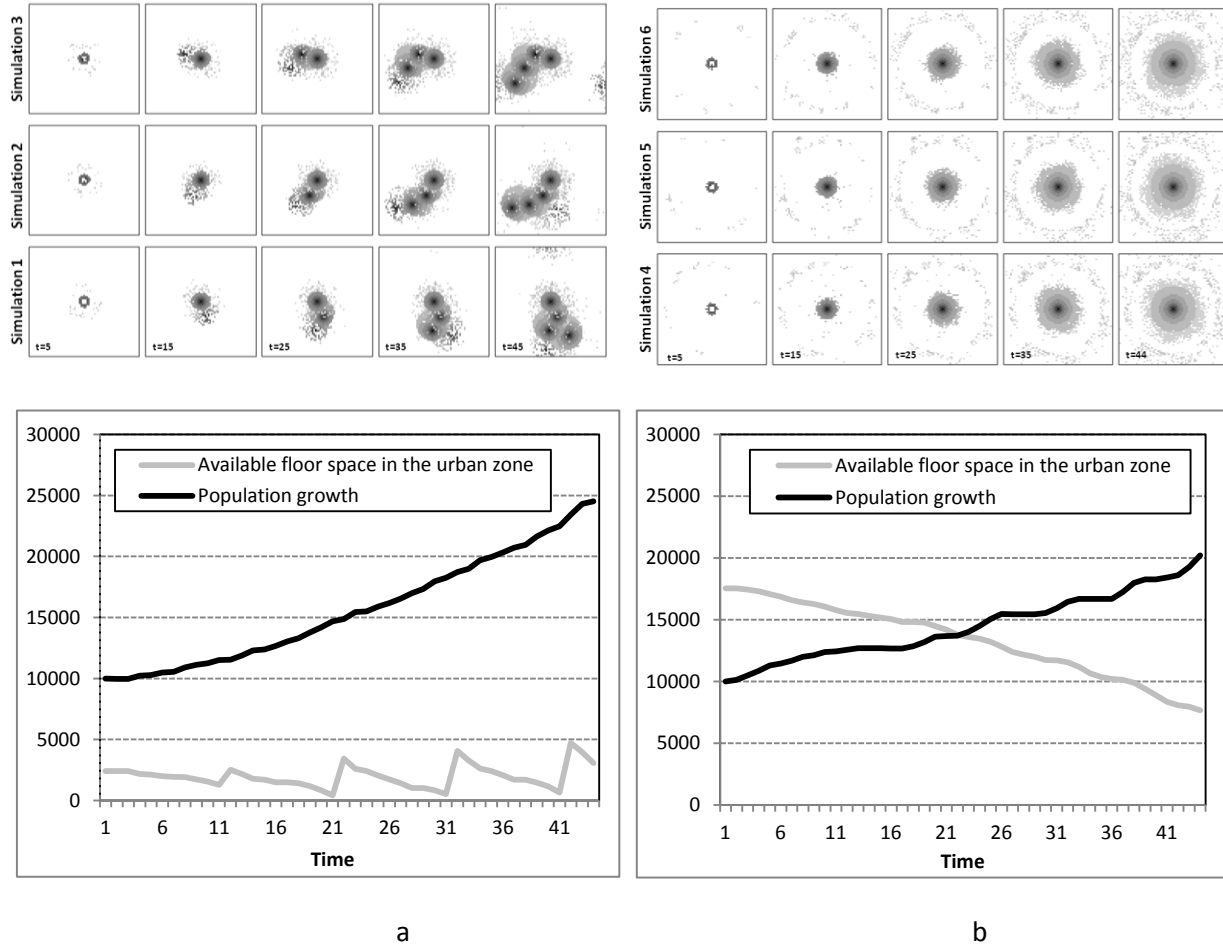
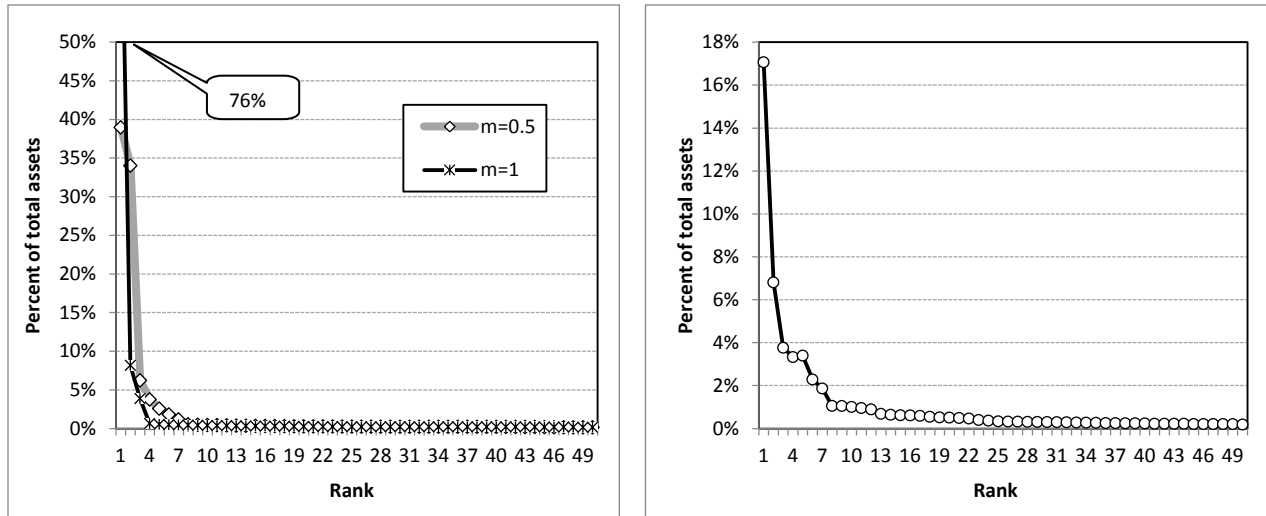


Figure 11: Dynamics of the city pattern, population and planned floor space in the urban zone in case the plan is modified once every 10 years (a) and long-tem plan for 50 years (b). Darker color marks higher density.

4.5. Qualitative comparison to the real data

Our model is a stylized theoretical exercise. However, the obtained model distribution of developers' assets (Figure 12a) obtained for two scenarios in the case of absolute advantage of size ($K = 1$) where $m = 1$ in the first simulation and $m = 0.5$ in the second, strongly resembles the size distribution of the Israeli development firms (Figure 12b). Differently from reality, the model predicts essentially larger share of the largest developers. A possible reason for this difference is that in reality large development firms are involved in other fields of business and therefore divert some of their profits from land development into other activities. With that, we consider the qualitative resemblance of the results as an indication that advantage to size principle governs the Israeli land development Industry.



a

b

Figure 12: Rank-size distribution of developers assets at $t = 50$ as (a) obtained in the two scenario with $m = 1$ and $m = 0.5$, $N_{sp} = 20\%$, $K = 1$ versus (b) rank-size distribution of development firms size in Israel in 2013 according to <http://duns100.dunbd.co.il/ts.cgi?tsscript=/2013h/e40a61>.

5. Conclusions

We study the evolution of the land development industry with an agent-based model that simulates urban development in a planned city. We aim at the economic explanation to the city dynamics and model's major assumption is in "advantage to size" – the larger is a developer, the more advantageous she is in purchasing land and obtaining special construction permits. In the model, this assumption generates positive feedback that causes and re-enforces the divergence between large and small developers.

If land purchases and construction permissions are completely independent of developer's size a uniform distribution of developers' assets is preserved over time. However when advantage to size prevails the land purchase competition, as few developers becomes larger than others, they exploit their size advantages for accumulating more assets and, thus, invest into further purchasing and constructing. The market concentration starts steadily to grow and the market is eventually split between few ever-growing large developers and the rest of the developers.

The more uncertain is the advantage of size that is, the more developers have chances to compete over the purchase of parcels and obtaining special construction permissions, the less concentrated is the

market. The effect of uncertainty is non-linear and to influence market concentration the uncertainty should be significantly high.

Special construction permits for construction on the non-urban parcels strengthen the positive feedback and increase market concentration. The more permissions are issued the more concentrated is a market, fewer developers own most of the assets and the faster the city converges into being controlled by very few large developers who hold larger parts of the market.

Urban development plan aims at governing developers' decisions regarding land purchases and construction. However, planning policy requires flexibility, and plan's modifications entail co-adaptation of regulator and developers. As we demonstrated these processes are history-dependent and thus, hardly predictable. The interaction between developers' decisions regarding the location of land purchases and planner's approvals of piecemeal construction permits and comprehensive updates of zoning result in bifurcations of city structure that occur at times of plan modification and leads to a polycentric city. These interactions can be the reason for the low fit between the plan and actual development (Alfasi et al, 2012).

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