

# A Cellular Automata Simulation of the 1990s Russian Housing Privatization Decision

by

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# **A CELLULAR AUTOMATA SIMULATION OF THE 1990s RUSSIAN HOUSING PRIVATIZATION DECISION**

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## **ABSTRACT:**

The study uses a computational approach to study the phenomenon of housing privatization in Russia in the 1990s. As part of the housing reform flats in multi-family buildings were offered to their residents free of payment. Nevertheless rapid mass housing privatization did not take place. While this outcome admits a number of explanations this analysis emphasizes the fact that the environment in which the decision-making households were operating had a high degree of uncertainty and imposed a high information-processing requirement on the decision-makers. Using the bounded rationality paradigm, the study builds a case for a cellular automata simulation of household decision-making in the context of housing privatization reforms in Russia in the 1990s. Cellular automata is then used to simulate a household's decision to become the owner of its dwelling.

*JEL Classification: C45, C63, P21, R21*

*Keywords: Cellular automata, Complex systems, Housing reform, Russia, Simulation.*

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## **A CELLULAR AUTOMATA SIMULATION OF THE 1990's RUSSIAN HOUSING PRIVATIZATION DECISION**

Privatization of public housing in the form of a transfer of ownership to existing tenants took place in many countries - notably the U.K. in the early 1980s as well as the former Soviet Union and many Eastern and Central European countries a decade later. The largest transfer in terms of absolute number and percent of housing stock subject to privatization was in Russia. Unlike in the other post-socialist countries where housing was sold to the residents at discount prices, in Russia dwellings were offered to their residents free of payment. (Unbounded) rationality suggests that they should have switched to private ownership to become home owners virtually costlessly. In reality majority of the households did not immediately take up the ownership offer. Even though the absolute numbers were high, there was no one-time mass privatization that has taken place in Central and Eastern European transition countries like Slovenia. Privatization has been a gradual process that has stretched well beyond the initial years of transition. At some point households who privatized their dwellings were allowed to transfer housing back to municipal ownership, i.e. deprivatize. Housing privatization is still happening now which makes this paper relevant to contemporary policy-making. Yet the reader is warned that the approach adopted in this paper is most relevant to describe privatization decisions of agent-households under high informational uncertainty at the onset of the economic transition. In this paper we suggest that the observed non-uniform privatization outcomes may fit a number of explanations and concentrate on “process” explanation as opposed to “causal” explanation.

A general typology of research approaches to Spatial Behavioral Modeling offered by Couclelis (1986) identifies two main research approaches: one based on economic rationality that seeks to “establish empirical generalizations through the identification of cause and effect

relationships among explanatory variables and outcomes”. An alternative research approach of computational process models is based on the information-processing paradigm that promotes “process” explanation (Couclelis, 1986; p. 96). Conlisk (1996) describes models that he groups in a category of population distribution models. In these models a population of individuals is distributed over different categories. Over time individuals make adaptive transitions across the categories based on pre-determined rules. These types of models are especially useful for investigating interactions among individuals. Among the interactions considered are imitation, word of mouth communication, fads and fashions, bandwagons, threshold effects, herding, lock-ins, and informational cascades. Conlisk also underscores one of the themes emerging from the population distribution models: the question of whether the population converges to a “well-behaved outcome”, such as the adoption of the best technology.

Another relevant methodological approach to the study of household privatization choice is that of social learning models. The process of social learning involves the diffusion of private beliefs to decision-makers through observing the action choices of other decision-makers. One can argue that under high degree of uncertainty characteristic of the economic and policy environment during the early market reform period people made their housing privatization decisions based on the actions of their neighbors. This reasoning takes the discussion in the purview of bounded rationality (Simon, 1996). Cellular automata simulations (Gilbert and Troitzsch, 1999) have increasingly been used to model the dynamics of social interactions and constitute a rapidly growing body of research in behavioral sciences. We make the case that the informational uncertainty and the resulting complexity of the decision-making makes the computational approach and CA in particular a relevant and instructive way to study household

choice behavior in the context of housing market reforms in Russia. Complexity of privatization decision-choice is illustrated using a cellular automata simulation.

In Section 1 we provide background information about housing privatization and associated housing reforms. In Section 2 we review selected literature on the housing privatization decision and suggest why a process explanation and hence computational approach is relevant to study the privatization decision. In Section 3 we introduce elements of cellular automata and provide a cellular automata model description in Section 4. In Section 5 we describe the results of the simulations and Section 6 concludes with suggestions for extending the analysis to allow more complex behavioral response to the ownership offer.

## **1. INTRODUCTION - THE 1990s RUSSIAN HOUSING PRIVATIZATION**

During the Soviet era, housing in Russia was state-owned and individuals obtained their housing through the state. There was no formal housing market and individuals were able to change their dwellings only through a complex process of exchange that required a double coincidence of wants. Starting in the early 1990s, the Russian government has implemented a policy of housing privatization as part of the broader effort to privatize state assets of the economy. The purpose of housing privatization has been the creation of housing market, in particular a secondary housing market. The process has been governed by the country-wide set of rules that stipulate free-of-charge, one-time privatization by the occupants of the dwelling. The routine execution of housing privatization has been entrusted to the municipalities. The households wishing to privatize their dwellings are to provide a set of documents such as proof of residence and consent of all adult residents to privatization of their dwellings. Later, in 2002, the option for one-time deprivatization, or transferring the ownership back to the municipality, was added to the legal

provisions. In addition to the procedures of becoming owners as well as relinquishing the ownership being virtually costless, the household does not have to pay the municipality, the state or other former institutional owner for the value of the property. The fact that becoming an owner does not involve a monetary transaction differentiates the privatization decision from the decision to buy versus to rent housing that has been extensively studied in the context of western market economies as well as from the right-to-buy of social housing in these countries. By becoming owners, people acquire a valuable tangible asset free of charge. Nevertheless, mass-housing privatization has not been completed despite going on for so long. The government has been setting deadlines for ending the free of charge privatization but then subsequently extended the deadlines several times. The current deadline for ending free-of-charge privatization is set for 2013. Moreover the municipalities continue building municipal housing to accommodate households whose living conditions have been deemed substandard and who have been eligible for improvement of their housing allocation from the time prior to the start of housing market reforms (i.e. those in the so-called housing queue). Because of the practice of deferring maintenance of the housing stock under the socialist housing system many households have been eligible for new comparable apartments<sup>1</sup>. There were about 10 million families comprising 20% of all households in the “housing queue” in 1990. The absolute number and the share of households in the queue went down to about 3 million and 5% in 2008 but only a fraction of the decrease was due to accommodating eligible households in the (new-built) municipally owned housing.

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<sup>1</sup> If the apartment is already privatized when the building is demolished, then the new apartment by law is to be located in the same city district (which is usually an advantage). If the apartment is not privatized when demolished, the new apartment does not have to be located in the same district (which in actuality often means new location at the edge of the city).

Like in other post-socialist countries housing privatization in Russia is largely an urban phenomenon. In rural areas, most of the housing has always been privately constructed and privately owned.

Table 1 shows that privatization accelerated initially to reach its peak in 1993 and continued on throughout the years with privatized stock in 2007 reaching close to 70% of the housing stock eligible to be privatized. Housing eligible for privatization includes housing that used to be state owned and municipally-owned housing constructed since privatization began.

**Table 1. Housing Privatization in Russia, 1989-2008**

	<b>Number of Privatized units, thousands</b>	<b>Privatized units as percent of units eligible for privatization</b>
1989	10	0.03
1990	43	0.1
1991	122	0.4
1992	2631	8
1993	5804	18
1994	2396	9
1995	1529	6
1996	1203	5
1997	1198	5
1998	959	5
1999	896	5
2000	922	4
2001	1302	6
2002	1395	7
2003	897	5
2004	1408	8
2005	1822	11
2006	1624	11
2007	787	n/a
2008	699	n/a
Cumulative in 2007	25838	69

*Source:* State Statistical Agency

Figure 1.1. Cumulative Percent Privatized out of Dwellings Eligible to be Privatized, Russia, 1990-2007

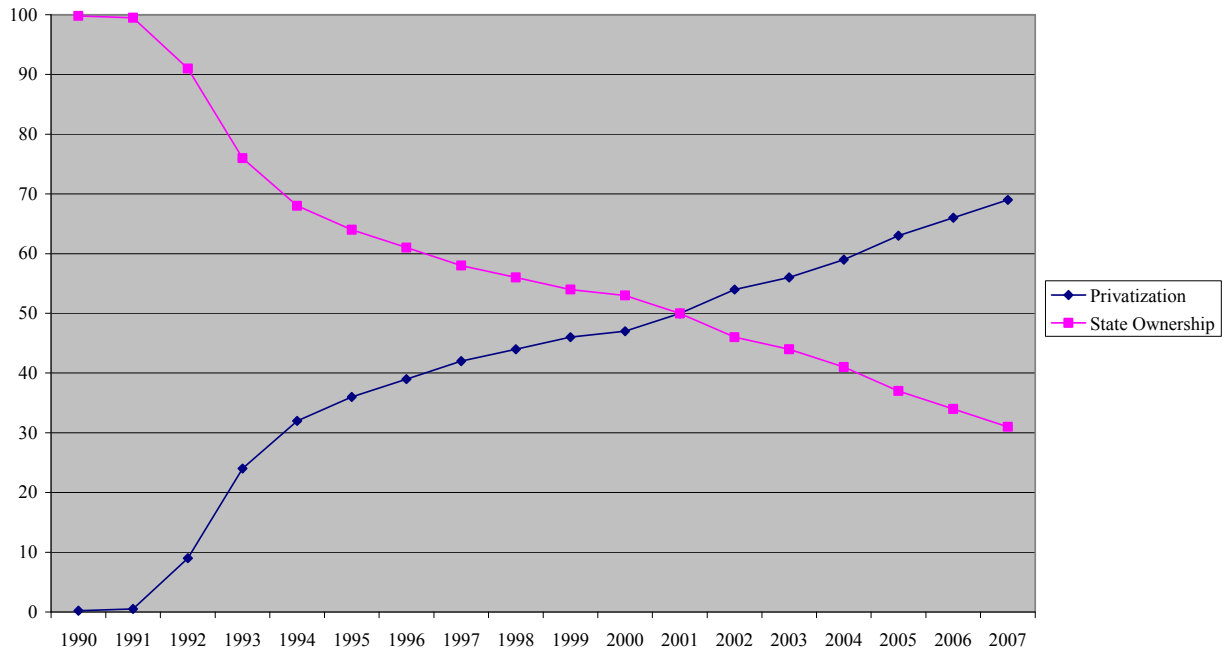


Figure 1.1 shows cumulative distribution of privatized versus non-privatized housing stock out of total stock eligible for privatization.

## 2. THE CASE FOR COMPUTATIONAL APPROACH TO STUDY HOUSING PRIVATIZATION DECISION

A decision to privatize is necessary if a household wants to relocate. Ownership makes it possible to sell the dwelling and buy or rent another one in the desired location. Beside the relocation motive, there are other factors that can influence privatization decision of a household. There are few studies that look at the determinant factors of the decision to become formal owners of the dwelling, versus remaining an occupant and renting from the municipality. These studies belong to the “causal” rather than “process” approach from the dichotomy suggested by Couclelis (1986). Among the existing studies, some explore the socio-economic background of those privatizing their dwellings. Guzanova (1998) notes that the two groups most likely to



privatize their apartments are the pensioners and the relatively well-off. She also suggests that household characteristics such as education are important determinants of the privatization decision. Bater (1994) provides a break-up of privatization status by occupational group. By 1994, the highest share of privatized dwellings by occupation belonged to artistic professionals (53.5%); the second (43%) belonged to pensioners. The smallest share belonged to blue-collar workers (14.2%) and government employees (15.2%). Zavisca (2006) examined the sources and extent of housing inequality in post-reform Russia, and using the data from the Russia Longitudinal Monitoring survey related housing allocation to socio-economic outcomes for households. Plotnikova (2009) identified the determinants of the privatization decision such as (unresolved) issues of major building renovation and operationalized them via household, dwelling and locational characteristics in a regression analysis. Using the data from the Russia Longitudinal monitoring survey she found age to be an important predictor of the decision to become owners, pointing at the importance of the *intent to bequeath*. Households with higher education members were more likely to become owners earlier than comparable households. Living in overcrowded conditions delayed privatization because of continuing policy to provide the residents with municipal housing based on space-per-person norms. The central issue as evidenced by the debate around housing policies and studies of housing privatization informed by this debate (Plotnikova, 2009, Kosareva and Struyk, 1993) is the uncertainty over the future cost of maintenance and major renovation of housing stock that has led to incomplete privatization in Russia. Lack of market-based alternatives for managing common property in multi-family dwellings was also a contributory factor. There were no private property management companies, no established homeowners associations or condominiums. The fact that education was found to be a determinant of the decision to privatize seems to suggest that uncertainty plays a role since the more educated face less uncertainty over maintenance and the policy

environment affecting the outcome of the privatization decision. There was substantial ambiguity in the laws and procedural arrangements relating to privatization, future housing policies, and property taxes. Moreover, during those first few years essential institutional elements such as credit mechanisms, real estate companies, property appraisal were absent or at best in the process of development. Early decision-makers had to act under high degree of uncertainty. The housing market itself was a nascent one and in the process of being created. Hence the assumption of price as a signal and equilibrium may not be realistic in the Russian context in the early 1990s. For example apartment auctions were conducted because there was no going market price for housing units. Because of this we believe that the usual unbounded rationality models relying on market price and the notion of economic equilibrium (e.g. models of tenure choice) may be of limited applicability to study the privatization decision. Albin (1998) notes that “the weakest aspect of economic equilibrium theory is its implicit assumption that information diffusion in the market is costless and instantaneous.” This aspect of the problem is highly relevant to housing privatization in Russia in the early 1990s.

One of the criticisms of the unbounded rationality assumption is the evidence that when such a complex decision is necessary, agents may not be able to perfectly predict the future. Daniel (1997) provides an example of this in her study of housing privatization in Hungary where the majority of households privatized their dwellings. The study provides a cost-benefit calculation showing that ex-post many residents ended up worse off, because the housing expenses of an average household increased considerably following privatization. Essentially, the more poorly maintained a building was, the greater was the ex-post burden on households. She sites newspaper reports of residents demanding the de-privatization option from the municipalities which is direct evidence that some households ex-ante made the wrong decision

with respect to privatization. This same argument applies very well to the Russian case where the share of privatizable housing has been much higher, maintenance is a long-term problem and de-privatization has been taking place.

Because housing is a multi-attribute good, the decision-making household needs to take into consideration many facts when making a decision to become an owner or continue renting from the municipality. For example, the decision-maker needs to take into consideration (the forecast of) future housing prices, property tax, rents of municipal housing, maintenance payments, government subsidy schemes, to name a few. In the face of uncertainty regarding the future state and complex calculations that the decision-making household would need to make, the information-processing requirement of the decision maker may be too demanding.

The notion of bounded rationality responds to these two criticisms. The idea of bounded rationality originates with Herbert Simon and the idea of “satisficing”. Finding the optimal solution requires resources and is costly. As a consequence suboptimal behavior may arise more frequently than we expect. Agents may find it optimal to mimic the behavior of other agents instead of making full calculations in order to decide whether to become owners or rent. Some decision-makers may have more information about the future state and therefore make better decisions. Other decision-makers may find it optimal to follow the “true” optimizers. In this setting then imitative behavior is a cheap alternative to optimizing behavior. Moreover, if the agents can correctly choose who they must imitate, it can allow them to achieve the optimal outcome. In the case of housing privatization some households such as those of policy-makers or intellectual elite who have better information about future policies may make the decision and other households may follow them.

A related approach to study decision choice in an uncertain environment that bypasses the high deliberation cost argument is that of social learning models (Chamley, 2003). When an individual learns from another's action, it is because the action taken is motivated by the knowledge that the decision-maker has about the state of nature that is common to all decision-makers. In the context of Russian housing privatization the state of nature can be characterized by the degree of transition to market, the state of housing maintenance reform, the state of development of condominium associations and other housing management arrangements to name a few. When the state is favorable for privatization, i.e. the decision to privatize leads to a higher payoff than the decision to remain a municipal tenant, privatization is the correct action. Each agent has a private signal about the state. It is reasonable to assume that the signal may not be precise and the degree of precision may also differ across agents (some people are simply better informed). The choice of action is based upon the private information and on learning from observing the decisions of others. As the number of decisions that have been taken increases, the importance of decision history for decision choice grows and the agents rely less on their private information. In this case the outcome will be clustering (privatization rates vary by location which can be an outcome of clustering). Moreover, when the action set is discrete, as in the case of housing privatization, it is harder for information signals to be inferred by observing these discrete actions. Social learning can hence fail in a sense that persistence of wrong choice can arise quite easily. In addition, uncertainty about future government policies, taxes, economy in general may enhance herding behavior with respect to privatization decision, i.e. people basing the decision to privatize on that of their neighbors. Such local interaction is well-suited to be modeled using computational approach and cellular automata in particular. Where the facts suggest that economic agents are complex because they are trying to predict the behavior of a

complex system in which they operate and which they hence affect, Albin (1998) advocates computational process models and cellular automata models in particular. Complexity in cellular automata arises through linked local interaction of agents.

Before moving on to a detailed description of the simulations we want to stress that replication or reproduction of the spread of home-ownership in Russia is not the aim of the simulations. Simulations feature experiments that can not be observed or carried out in reality. They help our fundamental understanding of the process under study, in our case the (social) consequences of uncoordinated individual action. Like other models, a simulation model enables to study aspects of the reality by making assumptions and isolating out the effects stemming from the use of assumptions.

### **3. ELEMENTS OF CELLULAR AUTOMATA**

Traditionally dynamical systems are defined by *i*) the state space in which the system evolves, *ii*) transition rule(s) defining the trajectory of the system over time, and *iii*) a continuous or discrete time horizon determining when the transition rules are activated. If we "discretize" both time and space-state then we obtain a dynamic system called *cellular automaton* (Casti, 2000). Cellular automata consist of a one-dimensional or more commonly a two-dimensional<sup>2</sup> array of cells, each obeying more or less simple rules; cells' interaction produces complex patterns of behavior. A lengthy history of cellular automata dating back to the work of its founders, John von Neumann and Stanislaw Ulam is available in Wolfram (2002, p.876) and Gardner (1983, p.214).

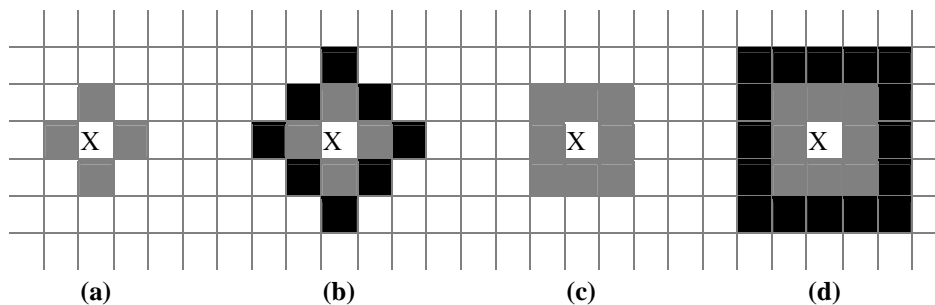
A cellular automata consists of:

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<sup>2</sup> Technically higher dimension are conceivable as well, but for dimensions higher than 3, visualization remains an impediment in many areas of science.

1. A number of identical cells, representing agents in the general meaning of the term, arranged in a lattice of a given size and dimension. Each cell on the lattice takes on one among a finite set of states, such as {on, off}.
2. A discrete time line along which the simulation runs until a structure appears.
3. A set of (deterministic or stochastic) rules determining the state of each cell based on its current state and the state of the cells immediately surrounding it in the considered neighborhood. Traditionally, the state of every cell is updated according to a uniform set of rules (Gilbert and Troitzsch, 1999); however various, more or less intricate, transition rules are possible depending on the phenomena examined.

The size and shape of the neighborhood is essential for the results of the simulations, since the transition rules are defined with respect to it. In addition to linear neighborhood two two-dimensional neighborhoods are of common use, these are the *von Neumann neighborhood* and the *Moore neighborhood* and their extended versions (fig. 3.1). The shape of the cells does not have necessarily to be square; they could be of hexagonal or triangular shape<sup>3</sup>, or any other shape that can be arranged contiguously over a lattice.



<sup>3</sup> Mathematical studies of *tiling* showed that when arranged side by side, the square, the triangle and the hexagon are the only polygons that completely cover the plane (Devlin, 1994).

**Figure 3.1:** (a) von Neumann neighborhood, (b) extended von Neumann neighborhood of size 1, (c) Moore neighborhood, (d) extended Moore neighborhood of size 1.

Cellular automata simulations are used to model the dynamics of social interactions, Gilbert and Troitzsch (1999) note that the use of cellular automata extends to exact sciences as well as to social sciences and they are best suited to investigate "the outcomes at the macro scale of millions of simple micro-scale events", when the interactions are local. Schelling (1971) uses cellular automata to explain the emergence of racial-segregation in urban housing. Meen and Meen (2003) use a cellular automata model to show how local interaction in housing markets results in residential segregation. Cellular automata models have been used to study urban growth (White and Engelen, 1993). Manrubia et al. (1999) use stochastic cellular automata to study the effects of migration on cities' growth. Caruso et al (2007) combine a microeconomic model with a cellular automata base to simulate emergence of urban sprawl.

#### **4. CELLULAR AUTOMATA DESCRIPTION**

A basic CA model can be used to model housing privatization decision assuming that local interaction is the primary driver of decision-making, reflecting the fact that the decision of the neighbors is important in the decision to either rent, purchase, or sell a housing unit. Each decision maker, or collection of agents living in a given housing unit, has to first choose whether to remain in a municipality-owned housing unit, i.e. rent, (state 0) or to become the owner of the housing unit (state 1). The decision is taken if a given number of neighbors of the cell have taken the decision. This set-up can thus capture the extreme case of imitation behavior that is assumed to be the consequence of the fact that deliberation cost of privatization decision is prohibitively high.

The simulations we conduct here view the housing decision as being affected by a combination of factors relating to the surrounding agents' states and informational uncertainty at the beginning of the housing reform. To allow for possibility of differential information about future state with respect to owning vs. renting, consider two types of households, the informed and the uninformed. The proportion  $\beta$  of the informed in the population is taken to be relatively small ( $<10\%$ ) representing the fact that in reality there may have been a small minority of people who in the early 1990s have had an insight into the implications of the privatization decision (e.g. government executives). We also assume for illustrative purposes that privatization is the “right” decision. The informed have a signal about the future state but only a proportion  $\alpha$  have the “right” signal to privatize in the initial period. Or, alternatively  $1-\alpha$  portion of the informed households does not use their information. One can also justify the existence of first-movers in the simulation by the fact that some households became owners of the dwelling because they needed to relocate and/or wanted to sell the dwelling.

Casti (1992) points to two important elements that extend the model of cellular automata beyond the basic elements enumerated above, in particular he mentions the *boundary conditions* and active controls.<sup>4</sup> The boundary conditions require a judgment call, cellular automata are supposed to run on a lattice of infinite dimension, however simulation have to be constrained to a finite size lattice. A simple solution for infinite systems is to assume a periodic boundary condition, also called torus topological transformation, i.e. cells on a boundary of a lattice are assumed to have four neighbor cells on the opposite boundary of the lattice. Although the use of periodic boundaries is justified in many cases, it is not in others. For instance, when dealing with cities and housing if we believe that the whole region is homogenous then assuming periodic

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<sup>4</sup> With active controls, one could envisage transition rules that depend not only on the state of the cells in the neighborhood but also on time or other factors in the model.



boundaries is justified. However, if we are dealing with a city or a region that is not homogenous where the existence of a particular region –a capital or a downtown for example– affects the agents' decisions then a non-periodic boundary seems to be the right choice. We assume that our study-area is homogeneous and adopt a periodic boundary.

Let us consider a square lattice of size 50, where each cell represents a decision maker household. Each household has four neighbors forming a von Neumann neighborhood of order 1 as in Figure 3.1(a). We chose von Neumann neighborhood because it is a simple and commonly used neighborhood structure. The minimum number of neighbors in state 0 (renting from the municipality) to for the agent to switch to state 1 (privatize) is two. In a von Neumann neighborhood this means that the majority of the neighbors need to change the status for a given cell to change its status. We also conduct a simulation where the agent-households that have previously privatized its dwelling are allowed to revert back to the municipal ownership, or deprivatize. The Von Neumann neighborhood structure and the transition rule can be expressed in the following way.

**Definition 4.1:** For a cell  $(i, j)$ , the von Neumann neighborhood of size 1 as in Figure 3.1 (a) is:

$$N(i, j) = \{(k, l) : |i - k| = 1 \text{ and } |j - l| = 1\}$$

In a von Neumann neighborhood of size 1, the state-transition rule of a cell in position  $(i, j)$  is defined by:

$$s(i, j; t+1) = f(s(i, j; t), s(i-1, j; t), s(i, j+1; t), s(i+1, j; t), s(i, j-1; t))$$

where the state of a cell at time  $t$  is  $s(i, j; t) \in \{0, 1, 2\}; \forall t, \forall i, j = 1, \dots, n$ . State 0 refers to municipal ownership, state 1 - to private ownership and state 2 means that the cell reverts from state 1 to state 0, representing deprivatization.

It is possible to adopt transition rules that are different across cells, and are updated in different sequences. For certain applications *random asynchronous* or *incentive-based asynchronous* (Page, 1997) updating maybe justifiable, but in our case we will use a *synchronous* but cell-independent rule meaning that cells are updated simultaneously in time-steps.

**Definition 4.2:** In a von Neumann neighborhood of size 1, a cell  $(i, j)$  is updated according to the following rule:

$$s(i, j; t+1) = 1 \quad \text{if} \quad \left\{ \begin{array}{l} \sum_{(k,l) \in N(i,j)} \text{sgn}(s(k,l;t)) \geq \lambda_{ij} \\ \text{and} \\ s(i, j; t) = 0 \end{array} \right.$$

where  $\lambda_{ij} = 2$

$$s(i, j; t+1) = s(i, j; t) \quad \text{otherwise.}$$

In the above definition, the function  $\text{sgn}(\cdot)$  is the *signum* function, defined by:

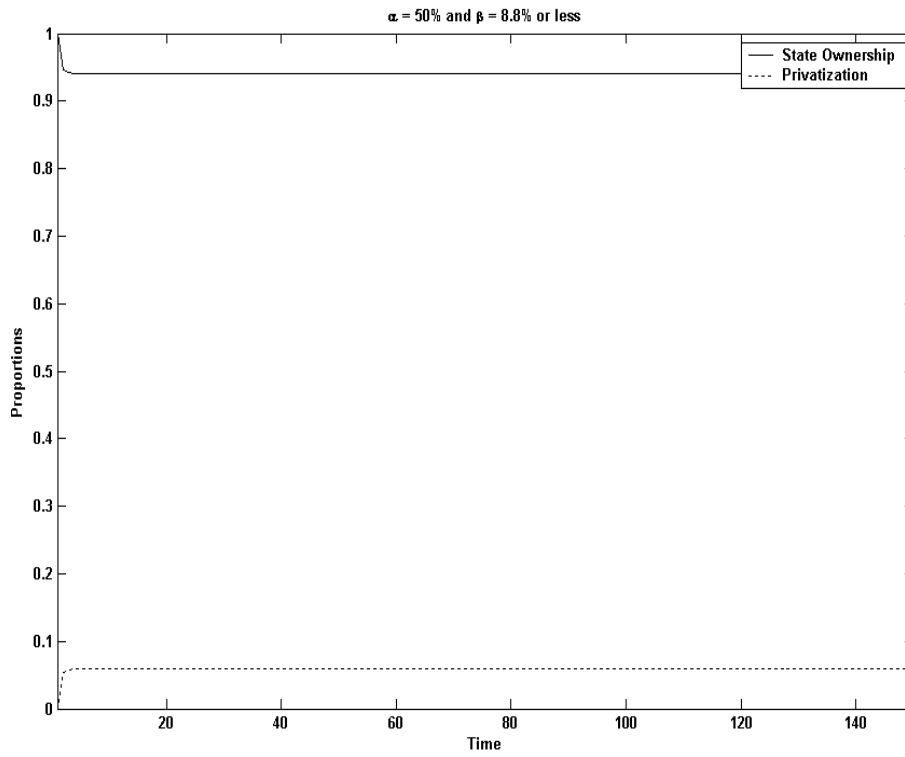
$$\text{sgn}(x) = \begin{cases} 1 & ;\text{if } x > 0 \\ 0 & ;\text{if } x = 0 \\ -1 & ;\text{if } x < 0 \end{cases}$$

## 5. SIMULATION AND ANALYSIS

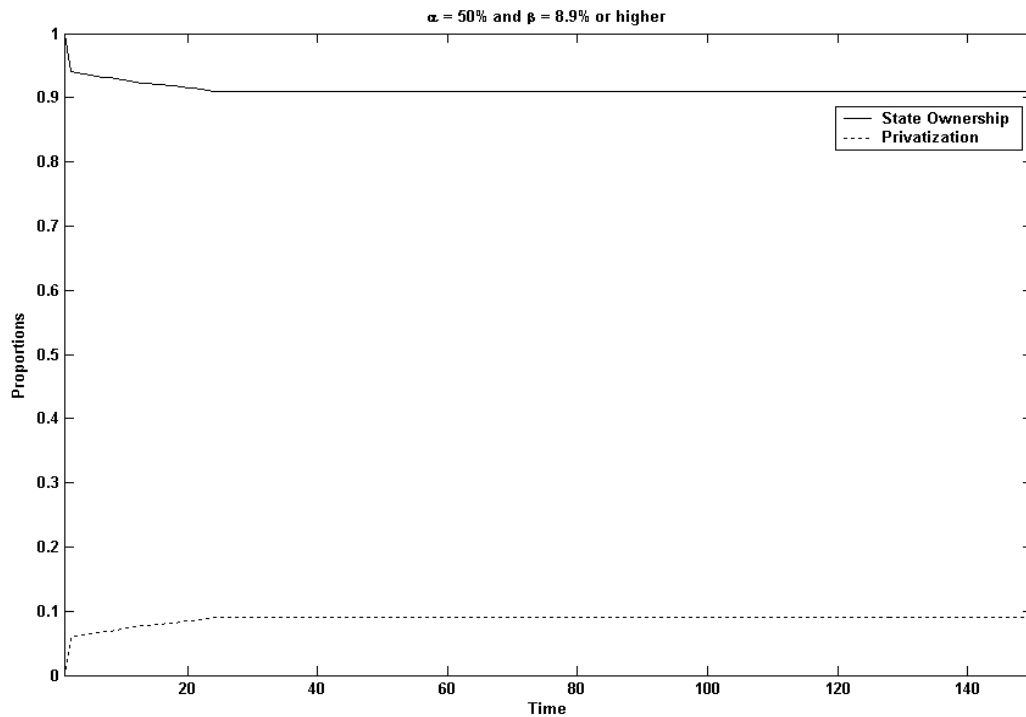
At the start of simulation all the households are renting (state 0). Cells falling into proportion  $\beta$  of informed households are randomly assigned. Then these cells are randomly allocated to  $\alpha$  proportion of cells with the signal to privatize and  $1 - \alpha$  proportion of cells with the signal to remain in the municipal ownership. So the proportion of cells that are informed and receive a

signal that privatization is the correct action is  $\beta * \alpha$ . These cells change their state to 1 in the first period. After the first period the uninformed households base their decision on the decision of their neighbors by observing the households in their neighborhood and switch to state 1 if three or more of their neighbors are in state 1. It is also assumed that the “informed” status is maintained only for the first action-updating period. After the first period those who had a wrong signal start acting like the rest of the households by updating if their neighbors do. The simulations were done in Matlab programming language. We carried out simulations in time steps until the number of cells in each state stabilized.

We first conduct simulations when de-privatization or transferring privatized dwelling back to the municipality is not allowed, i.e. once the status is changed to 1, it can not be changed back to 0. These were followed by a simulation where deprivatization is eventually allowed. This reflects that fact that deprivatization was allowed in Russia in 2002. Different values of parameters  $\alpha$  and  $\beta$  produce different results. The first two simulations depicted on Figures 5.1 and 5.2 have  $\alpha$ , the proportion of the “right” signal among the informed households equal to 0.5, i.e. the informed households are not really “informed” on average. This reflects uncertainty at the start of the privatization period. We report simulation results for break-points in values of parameter  $\beta$  in Figures 5.1-5.4. A break-point for  $\beta$  lies between 8.8 and 8.9 where for values 8.8 and below the equilibrium privatization rate is about 6% and for values 8.9 and above the equilibrium privatization rate is 10% and it takes longer to converge to equilibrium rate. In figures 5.3 and 5.4 the proportion of the right signal  $\alpha$  is increased to 0.85, reflecting better information on average. The same break-point proportions of informed households in the populations,  $\beta=8.8\%$  and  $8.9\%$  are used in simulations with  $\alpha = 0.85$ .

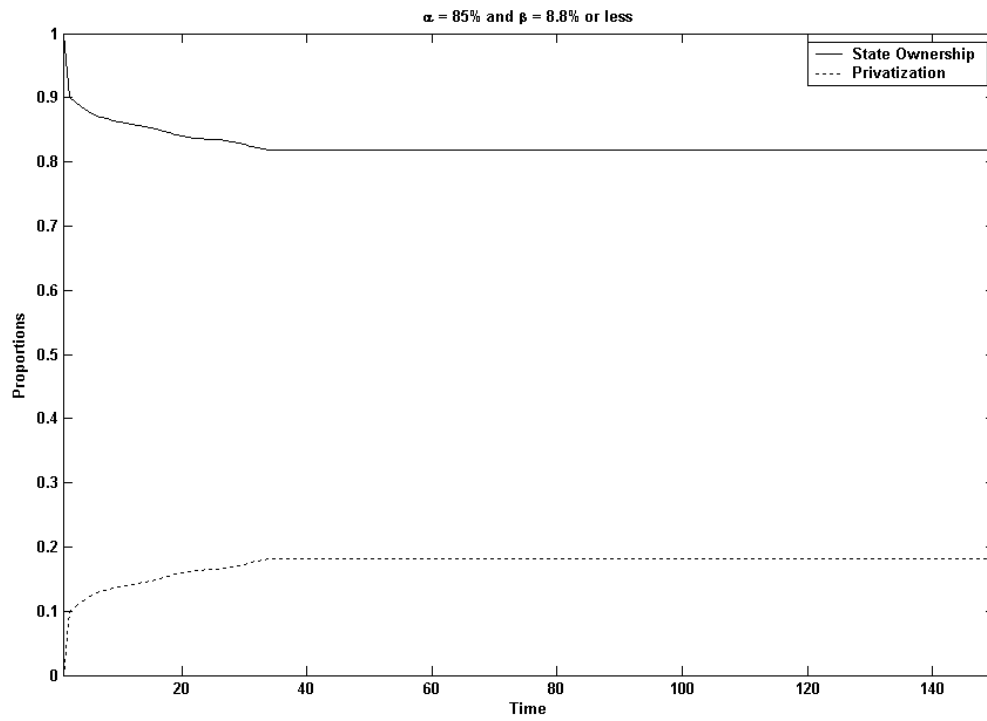


**Figure 5.1. Cellular Automata Simulation: “noisy” signal, lower proportion of informed decision-makers**

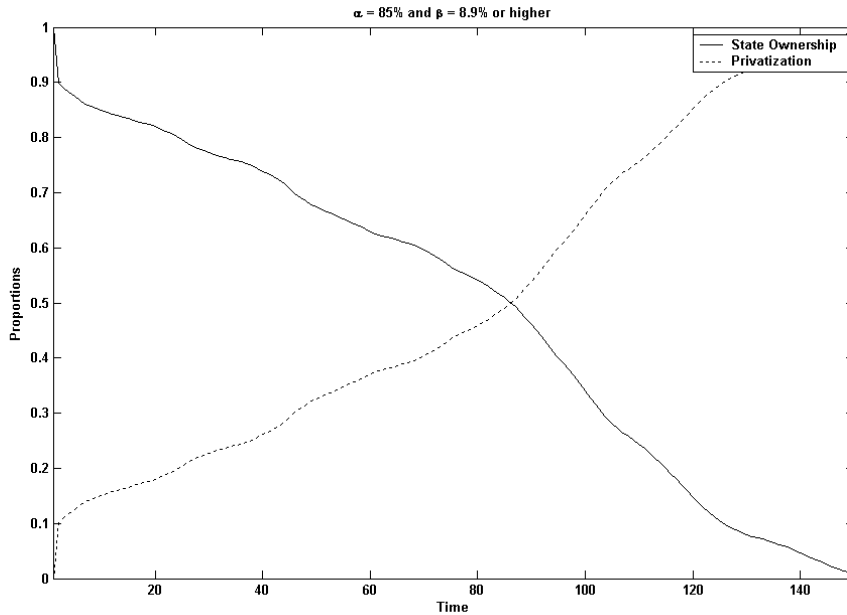


**Figure 5.2. Cellular Automata Simulation: “Noisy” signal, higher proportion of informed decision-makers**

In Figure 5.3 with  $\beta = 8.8\%$  and  $\alpha = 0.85$  the equilibrium privatization rate is just under 20%, but in Figure 5.4 a small change to  $\beta = 8.9\%$  (the proportion of the informed agents) results in complete eventual privatization at the end of the simulation run. In these four simulations cells change status using the same propagation mechanism and the difference in results is due to different initial conditions, that is different initial proportion of cells that were assigned to state 1, privatization. The results did not depend on the initial distribution of cells in state 1.

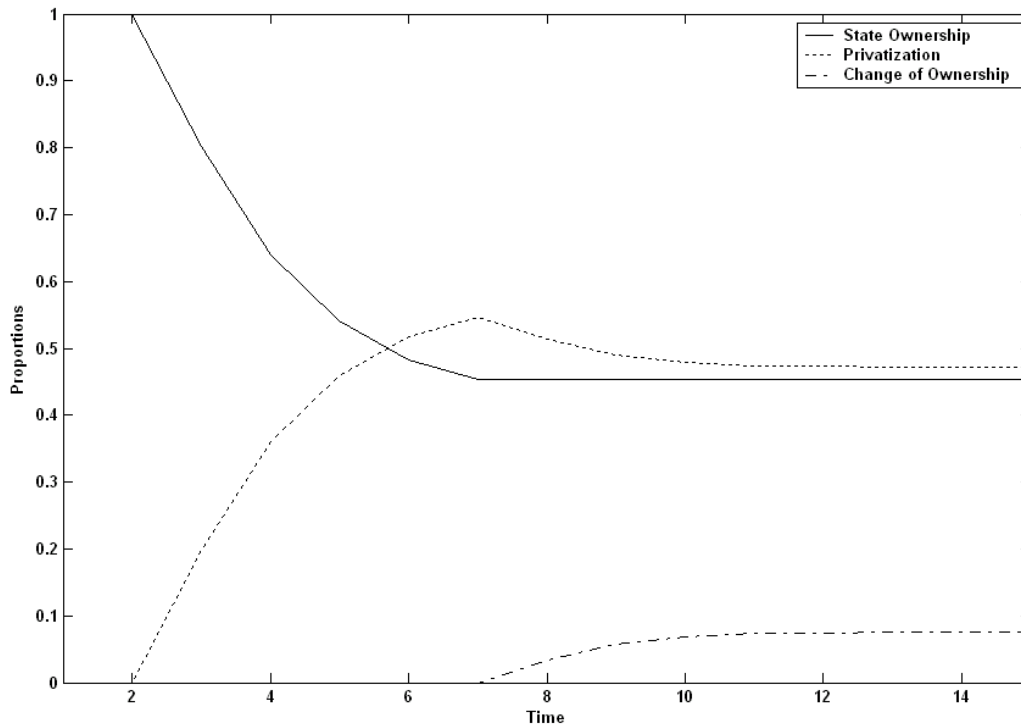


**Figure 5.3. Cellular Automata Simulation: Right signal, lower proportion of informed decision-makers**



**Figure 5.4. Cellular Automata Simulation: Right signal, higher proportion of informed decision-makers**

In our next simulation we allow for deprivatization, i.e. returning of the formerly privatized dwelling back to the municipality. This is operationalized by having a cell switch to state 0 (renting from the municipality) if three or more of its neighbors have state 0. An example in Figure 5.5 shows that introducing the ability to switch back to municipal renting in period 7 prevents complete switch to private ownership as in Figure 5.4. In Figure 5.5 the share of households that privatized and that of the original municipal renters stabilizes at about 47% and 45% respectively and the remaining share – about 8% belongs to deprivatized municipal renters. This pattern of convergence to certain proportions of privatized, municipal and privatized-switched-to municipal ownership holds for various starting periods within the simulation cycle when deprivatization was first allowed.



**Figure 5.5. Cellular Automata Simulation: Right signal, higher proportion of informed decision-makers; deprivatization is allowed from time-step 7 of the simulation period**

## 6. CONCLUSION

In this paper we modeled the spread of the transfer from municipal to private ownership of the housing stock through privatization decisions of households in Russia in the 1990s. Despite being offered to own their dwellings for free, not all households chose ownership, some chose it with considerable delay and some, having become owners eventually transferred the ownership back to the municipalities. The main issue addressed in this paper has been what accounts for differential response to the privatization offer. We chose to focus on boundedly rational models – in particular on models where agents are myopic in the sense that they do not make their own decisions either because of informational or computational reasons. Instead they take into



account the decisions of other agents and learn from them. Such social learning can fail and herding behavior can arise quite easily. To illustrate the notion of complexity present in the privatization decision, we used a cellular automata framework to simulate the privatization decision of households by incorporating elements of bounded rationality and imitation behavior. This was a simple exposition that illustrated one aspect of the phenomenon of privatization decision, mainly reliance on imitation behavior and the introduction of deprivatization.

Our cellular automata simulation was based on a von-Neumann neighborhood of order 1 where a cell changed status if three out of four neighbors changed status. A crucial assumption was the size of the initial proportion of cells that were assigned status 1 representing the households that privatized quickly after privatization was introduced. We reported convergence to different population shares of private and municipal ownership depending on whether parameter values were above or below certain threshold values. As expected, deprivatization, or converting back to municipal ownership prevented complete privatization from happening. Deprivatization was introduced as a reversal of privatization, i.e. household-cells reverted to municipal ownership if three out of four of its neighbors were in municipal ownership. Deprivatization could be introduced without the assumption of imitation behavior, for example through random assignment of household-cells that revert to municipal ownership because, for example, they live in dilapidated buildings.

Another possible extension is using a more complex neighborhood structure such as extended Von Neumann or extended Moore neighborhood to see how results depends on the type of neighborhood structure. A way to introduce informational complexity in an unboundedly rational sense in a CA model would be for each agent to make an explicit calculation of the payoffs from alternative actions of remaining a municipal renter or becoming an owner and the

ensuing possibility to sell and offer properties on the rental market or return the property back to the municipality. The value function would include sale or rent value, maintenance and rent payment to the municipality. Contiguous cells representing buildings of different quality would require different maintenance payment. The deadline for free privatization and the ensuing payment for the ownership of the dwelling can also be incorporated. To ensure different optimal time of adoption across household-cells in a lattice with periodic boundary, heterogeneity can be incorporated (for example, through different probabilities of selling a given dwelling). Alternatively a lattice with a non-periodic boundary will allow for a more realistic representation of a city.

**REFERENCES**

- Albin, P. S., 1998 *Barriers and Bounds to Rationality: Essays on Economic Complexity and Dynamics in Interactive systems*, (Princeton University Press, Princeton, New Jersey)
- Bater, J. H., 1994 "Privatization in Moscow", *Geographical Review*, vol. 84, issue 2, pp. 201-215
- Caruso, G., Peters, D., Cavailhès J., Rounsevell, M., 2007 "Spatial Configurations in a Periurban City: A Cellular Automata-based Microeconomic Model", *Regional Science and Urban Economics*, Volume 37, Issue 5, pp. 542-567
- Casti, J. L., 1992 *Reality Rules I: Picturing the World in Mathematics-The Fundamentals*, (John Wiley & Sons, New York), Ch. 3, pp. 161-249.
- Casti, J. L., 2000 *Five More Golden Rules: Knots, Codes, Chaos, and Other Great Theories of 20<sup>th</sup>-Century Mathematics*, (John Wiley & Sons, New York), Ch. 2.
- Chamley, C., 2003 *Rational Herds: Economic Models of Social Learning*, (Cambridge University Press, Cambridge)
- Couclelis, H., 1986 "A Theoretical Framework for Alternative Models of Spatial Decision and Behavior", *Annals of the Association of American Geographers*, 76 (1), pp. 95-113.
- Daniel Z., 1997 "The Paradox in the Privatization of Hungary's Public Housing: A National Gift or a Bad Bargain", *Economics of Transition*, vol. 5 (1), pp.147-170
- Devlin, K., 1994 *Mathematics. The Science of Patterns* (Scientific American Library, New York)
- Gardner, M., 1983 *Wheels, Life and Other Mathematical Amusements*, (W. H. Freeman & Co., New York), Chapt. 20, 21, and 22, pp. 214-257
- Gilbert, N. and Troitzsch, K.G., 1999 *Simulation for the Social Scientist*, (Open University Press, Buckingham), Chapt. 7.
- Guzanova, A., 1998 The Housing Market in the Russian Federation: Privatization and Implication for Market development, *World Bank Discussion Paper*, The World Bank, Washington, D.C.
- Kosareva N., Struyk R., 1993, "Housing Privatization in the Russian Federation", *Housing Policy Debate*, vol. 4(1), pp. 81-100
- Manrubia, S.C., Zanette, D. H., Solé, R.V., 1999 "Transient Dynamics and Scaling Phenomena in Urban Growth", *Fractals* 7, pp. 1-8.
- MATLAB® software, The MathWorks Ltd, Cambridge, U.K.

- Meen, D. and Meen, G., 2003 "Social Behavior as a Basis for Modeling the Urban Housing Market: A Review", *Urban Studies*, Vol. 40, No. 5-6, pp. 917-935
- Page, S. E., 1997 "On Incentives and Updating in Agent Based Models", *Computational Economics* 10, pp. 67-87.
- Plotnikova, M., 2009 "A Model of Housing Privatization Decision: the Case of Russia", under review in *Housing Economics*
- Schelling, T. C., 1971 "Dynamic Models of Segregation", *Journal of Mathematical Sociology* 1, pp. 143-186.
- Simon, H. A., 1996 *The Sciences of the Artificial*, Cambridge, (The MIT Press, Cambridge, MA) 3<sup>rd</sup> edition
- Tiebout, C. M., 1956 "A Pure Theory of Local Expenditure", *Journal of Political Economy* 64, pp. 416-424.
- White R., Engelen, G., 1993 "Cellular automata and fractal urban form: a cellular modeling approach to the evolution of urban land-use patterns", *Environment and Planning A*, 25, pp. 1175-1199
- Wolfram, S., 2002 *A New Kind of Science*, (Wolfram Media)
- Zavisca, J., 2006 "Housing Divides: The Causes and Consequences of Housing Inequality in Russia", working paper, University of Arizona