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Analyzing the Impact of Planning Regulations on Housing Prices and the Expansion of Informal Settlements

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under the supervision of Professor Heather MacDonald, Associate Professor Song Shi, and Associate Professor Alireza Ahmadian Fard Fini

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Danon Jalali, declare that this thesis is submitted in fulfilment of the requirements for the award of Doctor of Philosophy (Ph.D.), in the School of built Environment, Faculty of Design, Architecture, and Building at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

Signature:
Danon Jalali

Date: **04/02/2023**

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The Ph.D. study is a journey. In its end, we, as Ph.D. students, implicitly love to say, 'I finished it alone and on my own.' However, genuinely, we all know it is not true. There have been hands in this way who showed us the right way, prevented us from falling down the troughs, saved us from being lost in the devious routes of research, grabbed our hands when we fell, and helped us stand again. I believe that I owe a great appreciation to all these hands who have supported me.

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Preface

This preface explains the path I have passed through to reach the point of delivering the result of my four-year Ph.D. research. I struggled to prepare the thesis in the middle of one of the biggest and globally unique calamities of the current century: the outbreak of COVID-19. The main benefit of writing this preface for me is to further justify specific procedures that I followed, particularly in Chapter 5. Also, these few words aim to explain my small contribution to the microhistory of research during the COVID-19 pandemic.

When I started my work as a Ph.D. student at the School of Built Environment at UTS, I made every effort to consider all the risks and identify possible strategies to cope with them. Studying and working in a developing country have taught me that the biggest obstacle to conducting research is the serious shortage of data at the city level. Although there are tonnes of registered data in responsible urban planning and management public organizations in Iran, access to the data is almost impossible. The reason is that, in most cases, the data is not organized, and in a few other cases, it is regarded as confidential. The Statistical Center of Iran and the Central Bank of Iran are two major institutes that provide city-level time series data for a few items and province-level time series data for some others. Therefore, the best way to provide the required information for research in the field of urban planning in Iran is to use survey data in a case study. I adopted this strategy to provide the required data for my thesis. The case study of the thesis was intended to be Eslamshahr, previously known as an informal settlement and now recognized as a city having an informal settlement (Mianabad) adjacent to it. Eslamshahr is probably the most studied informal settlement in Iran. There are several independent studies, research projects, and Ph.D. and master thesis on this settlement and its adjacent informal settlement. Each of these studies could cover part of the data requirements. However, the main data gap, similar to other middle-rank cities in Iran, is the lack of time series data on housing and land prices. During the first year of my Ph.D., I travelled to Iran twice and designed the survey process to gather the required longitudinal data on housing and land transactions and transactors' characteristics.

At the beginning of 2020, when I had planned to implement the survey, the COVID-19 outbreak happened. Australia closed its borders to all incoming passengers, and Iran incurred one of the highest rates of casualties of the disease in the world. In this situation, the only way to conduct the survey remotely was to distribute it through the internet. However, the low level of internet diffusion in informal settlements and deprived areas made this alternative impractical. Hence, I had to change the plan and use the secondary data provided by the Statistical Center of Iran and the Central Bank of Iran. Since the secondary data did not cover all the required items for a city, it was impossible to focus on a specific case to develop the model and internally calibrate it based on that specific case's data. Instead, I developed the model of a hypothetical city in Iran and externally calibrated it by the available secondary data on second-tier metropolises to simulate the behavior of a typical city in that rank. To the best of my knowledge, this study is the first one using simulation by system dynamics to model the effect of planning regulations on housing and land prices and the expansion of informal settlements. The resulted simulation model has performed satisfactorily in answering all the research questions and have yielded interesting results providing refinements for some of the existing theories on the behavior of housing and land markets under the effect of planning regulations and clarifications for the empirical ambiguousness. I derived those results by shifting focus to developing a system dynamics model based on the economic theory. This required adopting a hybrid approach to system dynamics modeling. Hence, the resulting hybrid model is the main contribution of this thesis. Now, I can say that I understand Doctor Frankenstein's feelings toward his creature.

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Abstract

Informal settlements grow or decline as a result of relative levels of deprivation and vulnerability, which in turn are influenced by conditions in formal housing markets. The extant literature on the role of planning regulations in the growth of informal settlements is limited, and studies take varying approaches to three major methodological difficulties in working on regulatory systems: endogeneity, heterogeneity, and temporality. Like most studies on the price-inflationary effect of planning regulations, they use static models and mainly address the effect of one regulation (Minimum Lot Size (MLS)). The effects of other major planning regulations, including Maximum Building Density (MBD) and Urban Growth Boundary (UGB), are not fully explored, and their combined effects over time are overlooked. Consequently, a consensus has not emerged about why and how planning regulations affect the growth or decline of informal housing settlements.

This thesis tests a new methodological approach to answer this question while accounting for the shortcomings listed above. The study uses the System Dynamics method to develop a dynamic non-spatial model of the interaction of the housing market, the land market, and the housing construction sector, constrained by three major planning regulations: MBD, UGB, and MLS. The connections among model elements are based on causal relationships derived from microeconomic theory and the observed causal links between planning regulations and housing and land markets in real-world cases from Iran as a developing country where informal settlements have been growing for more than half a century. The model uses secondary data from the Statistical Center of Iran and the Central Bank of Iran to run simulations on a typical city representing the seven second-tier metropolises in Iran. Based on simulation results, this causal structure demonstrates how planning regulations' incremental effects on formal housing price trends can lead to the expansion of informal settlements. Increases in the housing price may exclude low-income households from formal housing markets because they cannot afford the minimum liveable space without sacrificing other necessities.

Dynamic simulations indicate that changing housing price trends are more important drivers of the marginalization of low-income households, in contrast to changing long-term equilibrium housing prices, as static models suggest. The study finds that MBD can change both the trend and the long-term equilibrium price dramatically, UGB can change the trend dramatically but has only small effects on long-term equilibrium price, and MLS has limited effects on housing price trends. Simulations show that the combined effect of planning regulations is nonlinear. Thus, policymakers in developing countries using these three regulations should be more

cautious in applying MBD than using the other two. The simulation results also demonstrate that factors such as income level, unequal income distribution, the cost of capital, and the price of capital factor (resulting from central government policies), can be more influential than local government's planning regulations on the number of informal dwellers. Therefore, in alleviating the informal settlement problem, national-level policy measures should have higher priority than the local regulatory policy tools.

The simulation model can be used as a policy-making laboratory, allowing policymakers to evaluate the consequences of alternative regulatory and non-regulatory policies on informal settlements' expansion over time. As a collaborative platform for practitioners of different disciplines to explore parameters of interest (including combined effects), the model may contribute to developing smart regulatory policies.

1. Introduction

1-1- Why is it important to understand the causal factors driving the growth of informal housing settlements?

The world is now majority urban, and much future population growth will occur in slums. Although the share of slum-dwellers in the developing world declined from 39 percent to 30 percent between 2000 and 2014, their sheer number increased from 689 million to 881 million between 1990 and 2014 (28 percent growth in absolute number) (UN-Habitat, 2016b: 57-58).

Despite the extensive descriptive literature on the diverse manifestation of informal settlements worldwide, the narrow literature on the informal housing and land markets is concerned about the reaction of these settlements to formalization policies rather than the forces causing these settlements to appear and grow. Thus, our knowledge of why and how this type of settlement emerges and grows is limited. To answer these questions, we must concentrate on the contributing factors in the functioning of formal housing and land markets. Following that, this thesis focuses on one of the major effective factors whose role has been understated: planning regulations. This thesis develops an innovative simulation model focusing on the causal dynamic interrelationships between the formal housing market, the formal land market, and the housing construction industry to determine how and why planning regulations affect the growth of informal settlements. Apart from improving our understanding of how and why informal settlements grow, the simulation model may enable us to evaluate the consequences of alternative regulatory and non-regulatory policies on informal settlements expansion.

1-1-1- What is “the informal settlement”?

United Nations defines slums as:

“residential areas where Inhabitants have no security of tenure vis-à-vis the land or the dwellings they inhabit, with modalities ranging from squatting to informal rental housing. The neighborhoods usually lack, or are cut-off from, basic services and city infrastructure. Moreover, the housing may not comply with current planning and building regulations and is often situated in geographically and environmentally hazardous areas“(UN-Habitat, 2016c: 1).

In the above definition, informality is the key characteristic from which all other characteristics stem. An “informal settlement” can be defined as a settlement where one or more stages of the development process, from subdividing the land lots to constructing the housing unit, has happened in a manner inconsistent with the formal rules and regulations that govern urban development. Residents who occupy land developed outside of the framework defined by planning (and other) regulations may lack a range of urban goods (and rights), including access to "improved water sources, improved sanitation facilities, sufficient living area, housing durability, and the security of tenure" (UN-Habitat, 2016a: 2).

In the previous sentence, I used 'may' since affluent people can develop housing units without complying with the regulations and still not be deprived of those housing services. However, the low-income households living in informal settlements, who are in the lowest three deciles of the income distribution, will be deprived of significant housing services from this list, because they sacrifice those services to afford other needs. Slums are the sub-set of informal settlements that are the most deprived and marginalized and are characterized by the deprivations mentioned above. Since the share of informal developments by the privileged is infinitesimal, one can interchangeably use slums and informal settlements. Lacking basic housing services brings hidden costs and negative externalities. Residing on unplanned land in areas not approved for development, results in a lack of access to improved water and sanitation facilities, and a dense precarious housing stock. Informal settlements residents are the most vulnerable to natural disasters, infectious diseases, and climate change (Adams, 2019). In informal settlements, vulnerable groups, particularly women and children, are more exposed to sexual abuse, violence, and crime. Residents are less likely to have the education and employment skills (and employment prospects) of their counterparts in formal areas (UN-Habitat, 2016a).

Thus, some of the Millennium Development Goals (MDG) and Sustainable Development Goals (SDG) have focused on the alleviation of the self-reinforcing consequences of informal settlements expansion. Goal 7, Target 7D has stipulated that a significant improvement in the lives of at least 100 million slum dwellers should be achieved by 2020, and Goal 11, Target 11.1 of SDG aims to upgrade slums, and ensure the access of all people to adequate, safe, and affordable housing and essential services by 2030 (UN-Habitat, 2016a: 2). Achieving these goals will require constant monitoring and research on this critical phenomenon. Choosing effective strategies requires better understanding of the underlying factors that cause the growth of informal settlements.

1-2- Research problem

The critical role of planning regulations' exclusionary effect on the emergence and the expansion of informal settlements has long been pointed out by scholars in the planning field (Darabi and Jalali, 2019; Harris, 2018; Mehta et al., 1989; Roy, 2005; Sivam, 2002). Mehta et al. (1989) point to the European origin of the master planning system in developing countries and argue that these development plans enforce minimum lot size restrictions and land-use zoning, at a cost that is not affordable for the majority of people in the developing world's cities. Sivam (2002) identifies planning regulations inherited from colonial governments or imported by European architect-planners as a factor that makes land and housing prices unaffordable for low-income groups. Consequently, the shelter choices of low-income households are often limited to the informal sector. Roy (2005) defines the informal housing sector as an affordable housing market due to the lack of planning regulations. Darabi and Jalali (2019) show that the high transaction costs imposed by the formal institutional framework on rural landowners intending to develop their land, force them to do so in the informal rather than formal sector. Harris (2018) concludes the discussion by relating all forms of informality to the inability or unwillingness to comply with or enforce regulations.

However, the planning literature on informal settlements has been predominantly concerned about their diverse manifestations rather than their underlying cause (Alsayyad, 2004; Boamah and Walker, 2017; Chiodelli and Moroni, 2014; Harris, 2018; Rosa, 2017; Ward, 1976). The effect of planning regulations on the expansion of informal settlements has been absent from the mainstream urban economics literature on informal settlements. These studies have been concerned about the magnitude of the effect of legalization on informal housing prices, or the effect of formalization policies on the welfare gain of both formal and squatter residents (Jimenez, 1982; Jimenez, 1984; Jimenez, 1985; Friedman et al., 1988; Hoy and Jimenez, 1991; Turnbull, 2008; Brueckner and Selod, 2009; Brueckner, 2013; Shah, 2014; Posada, 2018).

Urban economists and planning scholars have long been suspicious of the incremental effect of planning regulations on housing prices, and their use as a tool to exclude lower-income households (i.e. the exclusionary effect of planning regulations) (Quigley and Rosenthal, 2005). However, the great majority of the extensive literature on the topic has been based on studies of the United States, and has predominantly focused on measuring the incremental effect of planning regulations on housing prices (i.e. price-inflationary) rather than their exclusionary effect (Pogodzinski and Sass, 1990; Pogodzinski and Sass, 1991; Nelson et al., 2002; Quigley and Rosenthal, 2005; Anthony, 2017). A few works on the effect of urban containment policies on residential segregation in US cities are the only studies in the context of developed countries on the exclusionary effect of planning regulations (Dawkins and Nelson, 2002; Nelson et al., 2004). Only a limited number of studies conducted in the 2000s and the 2010s tried to trace planning regulations' exclusionary effect on the expansion of informal settlements in developing countries (Lall et al., 2007; Duranton, 2008; Biderman, 2008; Souza, 2009; Heikkila and Lin, 2014; Cavalcanti et al., 2019). Despite the difference between the contexts of these two literature themes, there is a shared focus on the exclusionary effect of planning regulations. Both sets of literature also face three important sets of challenges.

1-2-1- Challenges facing models of the impact of planning regulations

The complexities mentioned in the previous section stem from regulations' three characteristics: the endogeneity of regulations, the heterogeneity of regulations, and the temporality of regulations (Quigley and Rosenthal, 2005). The endogeneity problem stems from the interaction between planning regulations as independent variables and the housing price as the dependent variable. The problem results in overestimating the impact of regulations on the housing price. The heterogeneity of regulations refers to the difference between the regulations imposed by different jurisdictions. The heterogeneity of planning regulations makes it difficult, especially for empirical studies, to simultaneously include all types of regulations across a large number of jurisdictions. Therefore, scholars have had to make a trade-off between the number of regulations and jurisdictions. That has also been a trade-off between the number of regulations and the generalization of the results. The temporality of regulations refers to the time needed for the appearance of the regulatory effect. The actual effect of regulations may stay hidden for varying lengths of time. Studies need to capture the time lag between the enforcement and the emergence of its results. Different techniques and approaches are adopted to deal with these difficulties in the broad literature on the incremental effect of regulations on housing prices. The most important techniques and approaches include using instrumental variables to control the endogeneity (Malpezzi, 1999), selecting regulations (Pogodzinski and Sass, 1991; Green, 1999; Zabel and Dalton, 2011), defining comprehensive indices measuring the restrictiveness of the regulatory environment (Malpezzi et al., 1998; Quigley and Raphael, 2005), and applying dynamic modeling methods (Malpezzi, 1999; Capozza et al., 2004; Hwang and Quigley, 2006).

The studies on the effect of planning regulations on informal settlements' growth have adopted some of these approaches and techniques. In dealing with the heterogeneity of regulations, most of these studies have focused on Minimum Lot Size (MLS) regulation. There is limited research on the effect of other major regulations. For instance, Urban Growth Boundary (UGB) (Biderman, 2008) and Maximum Building Density (MBD) (Souza, 2009), are each the focus of only one study. Although empirical works have incorporated a wider range of regulations, they have tested the effect of each regulation separately (Biderman, 2008; Souza, 2009). Thus, analyses have not addressed the combined effect of regulations. Studies dealing with the temporality and the endogeneity of regulations are rare, and each is dealt with in only one study (Biderman, 2008; Souza, 2009).

Moreover, the complexities explained above are increased with an extra tier of analysis introduced by the focus on the causal relationship between housing prices and the expansion of informal settlements. This introduces more endogenous variables, and more variables affected by regulations and change over time. To cope with the extra complexities, scholars have made some simplifying assumptions. Studies with theoretical models have taken land consumption as equivalent to housing consumption. This assumption regards minimum lot size as the most important regulation (Lall et al., 2007; Duranton, 2008; Heikkila and Lin, 2014). The other assumption is that planning regulations have a direct impact on the migration decisions of people, or their housing preferences (Biderman, 2008; Lall et al., 2007; Cavalcanti et al., 2019). This assumption has been made to make the model tractable or eliminate the housing price as an endogenous variable. However, it has some theoretical problems as the following discussion shows.

People choose their living place based on different criteria; housing characteristics are only part of the characteristics considered, and planning regulations can indirectly affect these too (Pogodzinski and Sass, 1991b; Pogodzinski and Sass, 1994). For example, building codes, minimum lot size, maximum building density, and occupation ratio (lot coverage ratio) indirectly affect characteristics such as housing size, number of beds and bathrooms, and number of housing units in the apartment, which can directly affect household preferences. The effect of regulations such as an urban growth boundary, which enforces a limit for the physical growth of a city, is more collective and is felt more indirectly. However, the most direct effect is their amenity effect. They can improve the quality of life in the neighborhood by segregating unpleasant land uses, allocating land to public parks, controlling the population density, and improving the urban viewpoints.

Due to the lag between the enactment of regulations and the emergence of their effect (the temporality of regulations), it is more reasonable to incorporate the neighborhood characteristics rather than regulations into the households' utility function. The time lag exists because new regulations will be effective on a housing unit only when it is being developed or re-developed. Therefore, it will take years to see the indirect effect of regulation on the housing stock. Even then, the old stock can be grandfathered in by waiving compliance with regulations such as minimum lot size. Hence, it is not reasonable to assume the planning regulations enter directly into households' preferences. As Pogodzinski and Sass (1990) pointed out, regulations act as constraints on developers' decisions. Thus, the only situation in which regulations will directly affect demanders' choices is when people build their home themselves, which is likely to be only a small minority the total stock.

The current state of the literature indicates further research is needed to analyze the individual and combined effects of planning regulations on the expansion of informal settlements through time, if we are to reach consensus. The other challenge faced by studies on the price-inflationary effect of planning regulations (and on their exclusionary effect), is how to incorporate planning regulations in models. In both of these themes of study, regulations appear in the specifications either directly or indirectly as restrictiveness indices in a linear additive form, similar to other hypothetically influential variables that may be added to the model. These aggregate statistical models aim to find a correlation between regulations and housing prices and the growth of informal settlements. In the real world, however, regulations act as constraints that dynamically affect developers' decisions, and most likely, they have non-linear effects on housing and land prices, and on the expansion of informal settlements. Thus, a more practical way to capture their individual effects over time, whether their price-inflationary effect or their exclusionary effect, is perhaps to incorporate regulations in a causal model of residential land development. This is the gap that this thesis aims to bridge.

1-2-2- Potential of the System Dynamics modeling method

This thesis uses the System Dynamics (SD) modeling method to develop a dynamic simulation model of a typical city's housing and land markets and construction sector to fill the gap mentioned above. The SD modeling method has advantages in dealing with the difficulties in analyzing the effects of planning regulations on housing and land markets. It is a specific method for modeling the complex systems over time (Forrester, 1985; Sterman, 2000). The dynamic structure of the model helps capture the effect of planning regulations on target variables, namely, the housing price, the land price, and the number of informal dwellers, over time (addressing the temporality of regulations' effect).

The core of the SD modeling approach is based on identifying the causal mutual interrelationships between variables and connecting them based on such causal interrelationships (Forrester, 1985; Sterman, 2000). In other words, an SD model works based on the endogeneity of variables. Therefore, the model explicitly incorporates the endogeneity of housing and land prices and other critical variables such as the optimum building density and the construction profit. The SD modeling method makes it possible to detect the non-linear effect of variables if such effects do exist in the reality (Mohapatra, 1980; Vennix, 2001). The causal relationships among the variables make it possible to incorporate planning regulations into the model as constraints that affect developers' decisions. It helps capture the probable nonlinear behavior of the variables in response to changes in planning regulations.

Moreover, by adding regulations as constraints, it is also possible to simultaneously incorporate different types of regulations into the model and measure their individual and combined effects on the target variables. This means that we can capture the heterogeneity of variables without sacrificing the individual effects of each regulation. Therefore, this thesis has a selective approach to the heterogeneity problem. The selection of regulations depends on the context of the study. Planning systems around the world use numerous regulations. The model this thesis presents has the capacity to incorporate a wide range of planning regulations. The three regulations this study focuses on in this study reflect a hypothetical city case, explained below.

SD models are causality-based simulation models in which one can control the effect of other factors by adding or removing them to or from the model. This characteristic makes SD models great laboratories for a diverse range of scenarios (Forrester, 1985; Sterman, 2000). Based on this, the simulation model of this thesis can function as an urban laboratory to determine the number of factors that should be controlled or combined with other ones. To the best of my knowledge, only one study has used simulation to analyze the effect of planning regulations on housing and land prices. Magliocca et al. (2012) used agent-based modeling to simulate the effect of minimum lot size on housing and land prices in a suburban area of a typical US metropolis. Hence, this research is the first attempt to dynamically simulate the effect of three planning regulations on housing and land markets and the expansion of informal settlements. Since this research intends to analyze both the inflationary and exclusionary effects, its findings could be insightful for studies in the developed world context that mainly consider the price-inflationary effect. The research can, then, be one small step forward the question posed by Roy (2005) in criticizing the contemporary urban studies that "what might be learned by paying attention to urban transformations of the developing world?".

1-3- Research questions

This research intends to answer a critical question at the center of the research problem. This central question is as follows: *How and why do planning regulations affect the growth or decline of informal housing settlements in a city?*

Multiple factors can affect the expansion of informal settlements. This study focuses on the specific effects of planning regulations, based on simulating the interactions of the land and housing markets and the construction industry, using the Systems dynamic simulation model developed in this thesis.

The central question can be unpacked into several main questions. These questions reveal the theoretical framework that structures this study and are about the substantive investigations:

First Question: *What are the individual effects of planning regulations on formal housing prices?*

Second Question: *What are the individual effects of planning regulations on the expansion of informal settlements?*

Third Question: *How can we explain the interaction of different planning regulations, and how they lead to a specific combined effect?*

Fourth Question: *What are the combined effects of planning regulations on formal housing prices?*

Fifth Question: *What are the combined effects of planning regulations on the expansion of informal settlements?*

Since this research adopts an alternative approach of modeling to answer questions, it enables comparison between this approach to modeling and the mainstream approach of neoclassical economics. Answering the following two subsidiary questions leads to the comparison of the two approaches.

First Subsidiary Question: *What are the potentialities and limitations of neoclassical economic modeling as a method of answering the central question of this research?*

Second Subsidiary Question: *What are the potentialities and limitations of the SD modeling approach in answering the central question of this research?*

1-4- Research context

The stylized model developed for this thesis represents a typical second-tier metropolis in Iran. Since the vast majority of the studies on the price-inflationary effect of the planning regulations have been done in the US context, the chosen planning system should have similarities to the US planning context. This makes the result of this study comparable to the substantive body of existing literature on the subject. Iran is well-fitted for this objective. As a developing country, Iran's urban planning system was adopted from the US in the 1960s, and the type of regulations used in Iran is very similar to what is prevalent in the US. However, one major difference between the two is the sizable informal housing sector in these metropolises making it an ideal choice as a case study. Therefore, one can compare this thesis's results for the price-inflationary effect of planning regulations, as the results from a developing country, to results obtained in the US context as a developed one. Also, I have graduated in Urban and Regional Planning from the University of Tehran, Iran, and worked there as an urban planner in both public and private sectors for a decade. The backbone of planning regulations in Iran consists of three regulations, namely, the Maximum Building Density (MBD), the Minimum Lot Size (MLS), and the Urban Growth Boundary (UGB). They are major regulations in the US planning system too and have appeared in the related literature more frequently. The second-tier metropolises comprise the seven most populated ones excluding Tehran as Iran's capital. They are Mashhad, Karaj, Tabriz, Esfahan, Ahvaz, Shiraz, and Qom. The informal settlement growth is more acute in these cities, and the required statistics about them are more accessible than in other cities. Therefore, they are ideal for being a subject of modeling.

As explained in the discussion of the research problem in the previous section, this thesis adopted a selective approach to account for the heterogeneity of planning regulations. The planning system and planning regulations differ across countries. Hence, one cannot develop a stylized model of a typical city entirely disconnected from a specific context. As explained above, I chose Iran’s planning system as the context, and the model represents a hypothetical (typical) second-tier metropolis in Iran. There are many similarities in planning regulations and planning documents managing the urban development in the US and Iran. This similarity in the planning systems makes the results of this thesis comparable with the extensive literature on the price-inflationary effect of planning regulations predominantly produced in the US context (Pogodzinski and Sass, 1991b; Pogodzinski and Sass, 1994; Glaeser and Ward, 2009; Zabel and Dalton, 2011; Ihlanfeldt and Mayock, 2014; Brueckner et al., 2017; Brueckner and Singh, 2020). In this section, I elaborate on Iran’s informal settlements, and the planning system, since both play an implicit but essential role in developing the model presented in this thesis.

Some Iranian scholars believe that informal settlements in Iran emerged after WWII and specifically during the 1950s when the oil industry started playing a major role in Iran's economy (Arefi, 2018; Alaedini, 2015; Piran, 2003; Habibi, 2002). Although this economic change has drastically affected the country's economic and demographic balance between urban and rural settlements for decades, the type of housing in the slums that formed shortly after that was irregular, not informal. Irregular housing has existed throughout the history of Iran, such as sleeping in cemeteries (Arefi, 2018). Taking shelter in the desolated urban areas and living around kilns producing bricks for the construction in the main cities are among the other examples of irregular housings and settlements in Iran's urban history. Informal housing is also a type of irregular housing; however, the reference point to identify housing as informal is not the previously- pervasive traditional norms in cities but the modern norms of complying with the laws and planning regulations. Thus, the search for the inception of informal settlements should begin at the time the modern planning system was established in Iran. The mid-1960s saw the commencement of the comprehensive urban planning in Iran, and this was the period that the first informal settlements appeared at the periphery of the large cities (Shafie and Asef vaziri, 2021; Amakchi, 2003).

Having started from the fringe of a small number of large cities such as Tehran, Isfahan, and Tabriz, informal settlements can now be found in all the provincial centers and mid-sized cities in Iran. Unfortunately, there is no time-series data for the population of informal settlements In Iran. The Statistical Center of Iran, responsible for collecting census data, has never provided such data. Therefore, any reported figure is an estimation. One of the obstacles to accurately estimating informal dwellers is that it is difficult to identify them based on the characteristics of their housing units. The informal settlements in Iran are different from those in other countries in three ways. First, informal dwellers have not invaded and occupied lands. Most informal dwellers obtained quasi-ownership of their land lots through informal transactions. They have informal or even formal deeds for their land lots (Sheikhi, 2002; Piran, 2003; Alaeddini and Aminnaseri, 2009; Zebardast, 2006). The structure of housing units predominantly consists of permanent materials. However, they violate the formal construction rules by building on lands that are not allowed to be subdivided and changed to residential land uses, or by ignoring the building codes. Therefore, they do not have building permits.

The physical quality of housing units is far better than the informal settlements in other countries such as India or Latin American countries (Piran, 1995; Sheikhi, 2002).Thus, many scholars believe that the government's task in incorporating these settlements into the formal boundaries of the city will not be difficult (Piran, 1995). This highlights another characteristic of informal settlements in Iran. They mainly emerge on the agricultural rural-urban fringe of cities and follow two paths in their growth: annexing the central city, or forming an independent city by the conglomeration of their adjacent informal nuclei (Piran, 1995; Sheikhi, 2002). Since they have been formed in the rural-urban fringe of central cities and outside of urban growth boundaries, informal dwellers' demand for land is less likely to "squeeze" the formal land market. In other developing countries, such an effect on the formal land market of the main cities from adjacent informal settlements is more likely (Bruecknet and Selod, 2009). Hence, the informality stems from land lots having been subdivided and illegally sold or leased by their initial owners. As a result, the dwelling units on these land lots are not authorized. Based on these differences, identifying informal settlements requires closer investigation, it cannot be done merely based on the census data.

After adopting enablement as the national strategy to cope with the problems of growing informal settlements in 2004, the National Urban Revitalization Taskforce (NURT) started conducting studies on informal settlements in 110 major cities of the country. These studies provided the best estimation of the number of informal dwellers in Iran. The results show that of the 38.8 million people residing in these cities, at least 6.7 million people live in informal areas (17%of the urban population) (NURT, 2018). However, the actual share of informal dwellers is most likely more than this number. Because some studies, specifically those on the metropolises, were last conducted in 2006, they do not reflect the growth of informal settlements subsequently. Although informal settlements are in all the central cities of provinces, the problem is more acute in the metropolises of the country. In 2006, at least 2 million of the informal population of the country resided in the seven metropolises (excluding Tehran) (MRUD, 2018). These figures consist of the number of informal settlements inside the legal boundary and outside but adjacent to it. Based on another estimation in 2016, the informal population residing in these metropolises increased to nearly 3.5 million. Table (1-1) shows the changes in the number of informal dwellers and total population in these metropolises. In all of these cities, the sheer number of informal dwellers has increased during this period. Except for Mashhad and Ahvaz, where informal dwellers had the highest share of their population in 2006, informal dwellers have grown faster than the total population in all other cities. As a result, the share of informal dwellers increased in most of them. While, in 2006, only four cities had informal dwellers more than 20 percent of their population, in 2011, informal dwellers constituted more than 20 percent of the population in all these metropolises.

Table 1-1: Changes in the number of informal dwellers in the seven second-tier metropolises of Iran

City	Informal Dwellers			Total Population			Share from Total Population (%)	
	2006	2011	Annual Growth Rate (%)	2006	2011	Annual Growth Rate (%)	2006	2011
Tabriz	300,000	500,000	3.5	1,378,935	1,558,693	1.2	21.8	32.1
Esfahan	221,000	448,000	5.2	1,583,609	1,961,260	2.2	14.0	22.8
Karaj	95,000	450,000	11.8	1,377,450	1,592,492	1.5	6.9	28.3
Mashhad	821,286	1,011,798	1.4	2,410,800	3,001,184	2.2	34.1	33.7

City	Informal Dwellers			Total Population			Share from Total Population (%)	
	2006	2011	Annual Growth Rate (%)	2006	2011	Annual Growth Rate (%)	2006	2011
Ahvaz	342,075	390,777	1.0	969,843	1,184,788	2.0	35.3	33.0
Shiraz	184,612	374,000	4.8	1,204,882	1,565,572	2.7	15.3	23.9
Qom	90,000	270,000	7.6	951,918	1,201,158	2.4	9.5	22.5
Total	2,053,973	3,444,575	3.5	9,877,437	12,065,147	2.0	20.8	28.5

Reference: NURT, Statistical Center of Iran (SCI), Mirsaeedi based on NURT

To cope with the problem of informal settlements, Iran's governments, whether pre-or post-revolutionary, have adopted different types of policies in its five-year development plans. Except for the first and second seven-year development plans before the revolution, all others have had a specific section for the housing sector (Athari, 2000; Mashayekhi, 2019). The pre-revolution development plans tried to tackle the problem by direct policies such as eradicating informal settlements and constructing housing units for informal dwellers, or indirect policies such as constructing low-price housing units for the poor, encouraging the owners of factories and industries to build housing units for their workers through the establishment of cooperation companies. However, none of these policies could stop the ever-increasing number of informal dwellers or curb the unbridled housing prices in large cities, especially the country's capital (Mashayekhi, 2019). Also, some of these policies made large cities and industrial poles attractive for rural immigrants and intensified immigration. The dissatisfied dwellers of informal settlements around large cities fueled the socio-political unrests, and riots at the end of the 1970s led to the 1979 revolution (Bayat, 1997).

The new religious regime took power with the slogan of supporting the poor. For ten years after the revolution, there was no development plan for the country. This period was concomitant with the Iran-Iraq war. Over the war period, the government managed urban land supply by enacting urban land laws (1358, 1360, and 1366). The government tried to prevent land speculation in cities. Thus, these laws controlled land prices in the first decade after the revolution (Athari, 2000). However, since the government did not have a specific plan for the housing sector, the country lost the chance to implement an effective policy for the housing of low-income groups (Afagh Pour, 2021). Individual applicants were eligible to buy the government-supplied land, but eligibility requirements put low-priced urban land out of reach of the low-income groups. Requiring conditions such as a 5 to 10-year stay in the city and the collateral to warrant the payment of land-purchase installments, pushed low-income groups towards informal settlements (Amakchi, 1997 cited in Zebardast, 2006; Amackchi, 2003). In addition, the regulatory system ignored agricultural and rural lands outside cities' boundaries. Therefore, for a decade after the revolution, rural nuclei formed a fertile ground for the growth of informal settlements (Bayat, 1997). Some of them grew to the extent that the government had no choice but to recognize them as a city by establishing a municipality.

The post-war plans have aimed to achieve the housing sectors’ objectives through market mechanisms. These development plans deviated from the demand-side policies of the first decade after the revolution and inclined towards the supply-side policies (Majedi, 2010). The resulting policies aimed to encourage mass construction, reduce the floor area of housing units, support the rental market, and free the land market. The government loosened its control on the land market and started supplying its land in the market (Alaedini, 2015). Without a strong production sector in the country, thriving housing and land markets became attractive for investment. As a result, governmental institutes, departments, and banks became involved in housing construction and land speculation. Although the total number of constructed housing units usually fulfilled the assigned objectives of the development plans, it happened at the expense of increasing the average floor area of units (Alaedini, 2015).

The establishment of new towns around large cities was another major policy started in the first development plan after the revolution and followed until the current period. However, the conditions of delivering land to the applicants, unrealistic planning standards, and proposals to sell the prepared land lots to cover the development companies' cost, have been the major reasons hindering the low-income groups from being attracted to these new settlements (Amakchi, 2003). Therefore, these policies' outcomes favored high- and middle-income groups rather than the low-income groups. These policies affected the housing market during the first, second, and third development plans prepared by the Construction State and the Reformist State from 1989 until 2005.

Although none of these plans addressed the informal settlement problem, since the early 1990s, the government realized the necessity of shifting its approach to the problem. The trigger was the over-expansion of spontaneous settlements around metropolises that, in some cases, led to social riots in these newly formalized informal settlements in the 1990s (Bayat, 1997). This change in viewpoint resulted in the adoption of enablement strategy towards the informal settlements as the major long-term strategy to deal with the ever-increasing number of informal settlements. This strategy took steps beyond the mere physical enablement and included other enablement aspects such as legal, social, and economic. This policy shift resulted in the preparation and approval of the Agenda of Enabling Informal Settlements by the government and establishing the National and Provincial Taskforces for Enabling Informal Settlements. These task forces are responsible for coordinating between different ministries and departments to implement the integrated enablement strategy. Despite the importance of changing the long-term viewpoint of governments, enablement is a passive rather than active strategy. It cannot prevent current informal settlements from growing or the emergence of new ones (Afagh Pour, 2021).

At the same time, the reformist government tried to entrench a strategic viewpoint towards the housing sector through the fourth development plan. This plan required the government to prepare the Comprehensive Housing Plan (CHP), which consisted of 55 plans to cover all aspects of the housing problem for the next 20 years, including the low-income groups housing (Mozhdehi and Shafie, 2021). The CHP pointed to the old problem of the high share of land price in the cost of housing development. However, the approach was different from the policies of the first decade after the revolution. One of the plans required the government to develop affordable rental housing units on public urban lands inside cities for the first income-decile households with the cooperation of municipalities. The aim was to omit the land price from the cost of development (Shafie and Asef Vaziri, 2021). However, the next populist government, who was responsible for implementing the plan, changed the plan's target from 20,000 rental housing units per year to nearly 400,000 per year (Mozhdehi and Shafie, 2021). The massive scale of the new plan, called the Mehr Housing Plan, imposed prohibitive costs on the country's financial system. The shortage of financial resources significantly lowered the construction quality and enforced long delays in providing public infrastructure and services. More importantly, in contrast to the original plan, most housing units have been transacted in the housing market and priced far more than their construction costs (Fathi, 2013). Hence, Mehr housing projects could not house the target income groups and became an extra problem for the housing sector.

From the third development plan before the revolution until now, the government has tried to find a national solution for a local problem. All of the development plans[1] were ignorant about the critical role of municipalities in the implementation of housing sector policies. However,

[1] Although the fourth development plan after the revolution is an exception, the reductionist view of the ninth state towards implementing the fourth development plan hindered the incorporation of municipalities.

since the development plan that defined the housing sector policies for the first time, the government implicitly defined a crucial role for municipalities in implementing the housing plans by requiring them to have a comprehensive plan for their urban development. Several other laws comprise the legal foundation of Iran's urban planning system. The first and the most important one is Urban Development and Renovation Law (UDR Law), enacted in 1968 by the national parliament. The UDR Law has been a comprehensive law that considers both the physical and financial aspects of urban planning. The enforcement of UDR Law and the birth of the first comprehensive plan was almost concomitant. Tehran's first comprehensive plan was approved in 1969. A consortium of two consulting companies, one Iranian and the other from the US, prepared the first comprehensive plan.

Based on the origin of the US party, Victor Gruen Associates, the plan was inspired by American master planning (Madanipour, 1998; Mashayekhi, 2019). The plan defined the same regulations applied in the US planning system. Urban legal area, zoning, minimum lot size, maximum building density, and land occupation ratio are among the major regulations borrowed from the US system. Before Tehran, the Plan and Budget Organization, which was responsible for preparing development plans for the country, prepared three development plans for a few other cities with the cooperation of foreign consulting companies (Farhoodi et al., 2009). However, Tehran's first comprehensive plan provided a pattern for other cities, which UDR Law obliged to prepare a comprehensive plan.

In 1974, the Ministry of Housing and Urban Development became responsible for preparing comprehensive and detailed plans for all cities. Despite this decision treating housing development and urban development as two interrelated responsibilities of one organization, there has been a lack of coordination between the policies in these two areas. In this situation, while the government has been straying from one housing policy to another intermittently, municipalities have been affecting local housing and land markets by their solid urban development policies constantly. The latter is reflected in the solid planning regulations used in them. Although the framework of plan preparation has changed several times, all these plans rely on the same types of planning regulations. Investigating different Iranian cities' comprehensive and detailed plans demonstrates that UGB, MBD, MLS, and land use zonings have been the main planning measures in the hand of Iranian planners for half of a century.

Planning regulations' role as the tools to implement urban development policies have attracted the attention of scholars, as one of the main culprits of the creation of informal settlements. Amakchi (2003) believes that the preparation of the first comprehensive plans from the end of the 1960s caused the emergence of informal settlements. These plans defined a legal boundary around cities that prohibited the construction outside it, and enforced planning regulations on the construction inside it. Moreover, the residents inside the legal boundary benefited from the public services provided by municipalities and other public institutions. These benefits are capitalized in land and housing prices and cause them to increase inside the legal boundary compared to the outside. As a result, land-use zoning and planning regulations forced those who could not afford to comply with them to leave the formal market to find housing in the informal land and housing market. Regarding the Tehran Urban Region, Athari (2000) mentions the MLS restriction, which was passively adopted from developed countries by the Tehran Comprehensive Plan as a reason for the exclusion of low-income groups from Tehran. Also, Arefi (2018) inferred the same point by comparing the range of minimum lot size restrictions set in the major cities and the average size of subdivided land lots in informal settlements.

Few studies addressed the overall role of planning regulations on informal settlements' growth more systematically in Iran. Rafiei and Athari (1995) argue that urban development plans have ignored the financial capabilities of low-income groups in setting regulations. Therefore, those who could not afford the price of housing units complying with planning regulations had to resort to the informal land and housing market to meet their need. The emergence of informal settlements in Iran is concomitant with the establishment of the urban planning system and the inception of the preparation and implementation of comprehensive plans (cited in Zebardast, 2006). To prove this point, Rafiei and Athari (1995) investigate the formation of informal settlements in 10 cities of Iran. After implementing urban development plans, they noticed that all of these cities had higher rates of informal settlements' growth on their rural-urban fringe (cited in Zebardast, 2006). Piran (1995) addresses the change in the population distribution among different regions inside and outside Mashhad after implementing its master plan. He shows that those regions, whether inside the city's boundary or outside, that absorbed more than the predicted population accommodated lower-income groups. More than half a million people from low-income groups live outside the city's legal boundary. He interprets it as a sign that more than half a million people could not afford shelter through the formal housing and land markets. Thus, they moved to the informal sector and found a place to live outside the city's boundary. In contrast, the regions with less population than predicted accommodate affluent people and have higher standards. According to Piran, in most Iranian cities, the same story is going on regarding the urban development plans.

The studies mentioned above consider the overall effect of planning regulations. They do not address the possible effect of each of the three critical types of planning regulations on the emergence of informal settlements. Their method is an uncontrolled quantitative comparison which does not necessarily lead to robust inferences about the causal relationship between the enforcement of planning regulations and the expansion of informal settlements. The scholars mostly blame the unrealistic MLSs for the marginalization of the low-income groups and ignore the possible effect of MBD or UGB. Using the SD modeling method, this thesis analyzes the individual and combined effects of the three planning regulations on the housing price and the expansion of informal settlements.

1-5- Structure of the thesis

This thesis consists of six chapters. This first chapter introduces the research problem and concisely explains the methodological approach. The first chapter also enumerates the central question of the research and then breaks it down into five specific questions and two subsidiary methodological questions. Lastly, it describes the context in which the research problem has arisen, and the model is devised based on that.

Chapter 2 is the literature review and has two parts. The first part reviews the literature on the effect of three types of planning regulations on housing and land prices. The second part investigates the limited number of works that have been conducted on the effect of regulations on the expansion of informal settlements. These two parts correspond with the two contexts of research discussed in the research problem. The objective is to summarize their findings, show the level of consensus, and enumerate assumptions that these studies have made.

Chapter 3 is devoted to the methodology. However, it starts from a broader context of dynamic economic modeling and then reaches the dynamics modeling of the property markets. Finally, it discusses the system dynamics modeling as the specific approach and method adopted and applied in this thesis to analyze the problem. This chapter aims to find the common roots of both the mainstream approach of dynamic economic modeling and the system dynamics as an alternative approach and their discrepancies. This chapter also explains the key elements of system dynamics models and the process of modeling.

Chapter 4 explains the stages of developing the model of the thesis. The model integrates three sub-models: the housing market sub-model, the construction sector sub-model, and the land market sub-model. The chapter expounds each sub-model separately by combining property economics theories and modifications imposed by real-world obligations and constraints and translating them into system dynamics modeling elements. The remaining sections of the chapter address the behavioral validation of the simulation model. Several tests are performed to test the model's behavior against proven theories.

Chapter 5 contains the analyses of the research. Before commencing the analysis section, the chapter explains the process of calibrating the model to represent a typical metropolis in Iran. After that, there is a discussion about the data used for feeding the model and its sources. The analysis section is organized in accordance with the main research questions. In the first part, the results of simulating the effect of non-regulatory factors are analyzed and represented. The second part analyzes the simulation results of the individual effect of the three types of regulation. The final part analyzes the results of simulating the combined effect of each pair of regulations on housing prices and the number of households marginalized to the informal housing sector.

Chapter 6 organizes the findings of the thesis and answers the research questions. It also discusses the theoretical contributions of the thesis and the potential use of the developed model in practice. Since the analysis is not focused on an actual place, addressing the policy implications makes no sense in the scope of this thesis. The discussion goes only so far as explaining the model as a tool, which can also be used for designing policies and testing their implications. The final section of the chapter enumerates the possible avenue of research that can enrich the current model.

2. The Review of Literature on Planning Regulations Effects

2-1- Introduction

The discussion of the research problem in Chapter 1 presented an overall review of the broad literature on the effect of planning regulations on housing and land prices. It was organized based on other comprehensive reviews and delved into some of the critical works in the field to provide examples clarifying the problem. As mentioned in Chapter 1, the approach of this thesis to dealing with the heterogeneity of regulations is selective. However, instead of focusing on a single type of regulation, three planning regulations shaping the backbone of the Iranian planning system have been chosen. This chapter investigates studies that specifically analyze the effect of these three planning regulations, namely, minimum lot size (MLS), maximum building density (MBD), and urban growth boundary (UGB). However, before reviewing this literature, the first section of the chapter addresses theoretical aspects of the application of planning regulations. These provide justifications for the enforcement of regulations, and explanations for the various ways that planning regulations can affect housing prices.

The literature review has two parts. The first part concentrates on the modeling efforts analyzing the price-inflationary effect of regulations. Each subsection addresses one of the three regulations, including 23 studies covering the 1970s to 2010s. The second part investigates the specialised literature on the effect of planning regulations on the growth of informal settlements. There are very few studies developing this focused theme (only seven works), and they are addressed chronologically. This discussion identifies the gap in the literature that this thesis aims to fill. The final section of the chapter discusses this gap.

2-2- Planning regulations: justifications and effects

The traditional justification for applying planning regulations has been to improve the health, safety, and general welfare of residents of a community or, more concisely, to promote the quality of life of a community's residents. In economic terms, planning regulations are necessary to correct the market failures in providing merit goods or preventing physical externalities (Katz and Rosen, 1987; Quigley and Rosenthal, 2005). Construction codes and standards are devised, imposed, and monitored for guaranteeing the provision of housing as a merit good that can affect the public health, safety, and welfare of its residents. The solution for preventing physical externalities has been to segregate the nonconforming from conforming land uses. Typical examples are assigning a separate zone for industrial activities or segregating hospitals from land uses causing noise and pollution. These are the traditional forms of zoning. However, zoning can differ between different structures with seemingly the same land use. Assigning different zones for single-family homes and apartment buildings is the best example. Here, protecting the residents of the single-family homes from the negative externalities such as noise, over-shadowing, traffic, and lack of safety, specifically for children, stemming from adjacent apartments, has been the justification for segregation. Since, at this time, segregation takes place in a single category of land use and not between two different types of land use, one characteristic or a combination of different characteristics, including lot size, construction density, or number of families in the building are used to define different zones. Therefore, each zone defines a set of restrictions for each characteristic, to accommodate homogeneous residential buildings.

After WWII, the vast suburbanization in the US showed another externality stemming from urban growth. Losing the natural viewpoints and the quality of life, and the high cost of providing urban infrastructures due to leap-frog suburban development provoked growing suburban communities to control their growth. Based on this, from the beginning of the 1960s until now, new forms of planning regulations were introduced and adopted to cope with this growth. Anthony (2017) divided these regulatory measures into two categories based on the time of their dominance. In the beginning, the inclination to control the urban growth was to the extent that, as Quigley and Rosenthal (2005) stated, the urban growth via population growth and building new houses of any kind was considered a threat. This inclination led to applying a group of regulatory tools known as the growth control regulations during the 1960s and 1970s. They have been time-based set capacities for the population number of a town or the number of permits for developing housing units. Suspicion about their inflationary effect on housing and land prices has limited their usage or even led to their abandonment. During the 1980s and early 1990s, other regulatory measures were adopted, mostly managing the growth rather than hindering it. The primary objective of these growth-management regulatory tools has been to manage urban growth to minimize its deleterious effects on natural environments and the quality of urban life. Urban growth boundaries, impact fees, and sensitive area moratoria are some of the main growth management measures. Although they may improve the efficiency of public investment, even these measures raised concern about their incremental effect on housing and land prices, leading to a decline in their application (Quigley and Rosenthal, 2005).

Over time, new issues have led planning regulations to evolve into more complicated forms. The identification of fiscal externalities has been one of the most significant cases. Fiscal externalities happen when two income groups, which live in different value housing units and the same jurisdiction, pay the identical property tax rate to the municipality. Therefore, the contribution of the higher income group to public expenditures in the form of the tax paid is more than the low-income group (who are thus considered free-riders). The efficient solution again is the spatial segregation of these types of the housing accommodating different income groups. The same regulations have been used to separate different housing types (Quigley and Rosenthal, 2005). A corollary of fiscal zoning has been income segregation or even social segregation (racial segregation) due to the coincidence between social and income groups. The exclusionary aspect of fiscal zoning was concerning to the extent that civil rights advocates referred to it as exclusionary zoning (Quigley and Rosenthal, 2005). As Fischel (2002) argued, from the early 20th century, the possibility of segregation by using zoning ordinances has been limited by federal and state laws. However, suburban communities opt for restrictive zoning more to exclude low-income groups rather than ethnic ones. Fischel bases this argument on the observation that even in communities with a lower fraction of minorities, the residents have favored restrictive zoning (Fischel, 2002). On this basis, there has been a growing concern that more affluent communities may use the likely incremental effect of planning regulations to prevent low- and even middle-income groups from living in those communities (Katz and Rosen, 1987). Although exclusionary zoning may be in the process of being consigned to history, it has triggered broad research on the price-inflationary effect of planning regulations.

Planning regulations can affect housing prices in different ways, which scholars have tried to identify. For example, Downs (1991) enumerated three channels through which planning regulations can increase housing prices. First, regulations can directly restrict the housing supply by setting caps on building permits, limiting the developable lands, setting density limits, and restricting multifamily housing zones. Second, regulations can directly increase the construction cost by imposing expensive building codes, forcing developers to purchase larger lots, and receiving fees from developers to compensate for the harmful effects of extra development. Third, imposing regulations can cause delays in the process of development. A good example is the required time for issuing development permits.

Anthony (2017) provided a complete list by expanding the number of paths through which the imposition of planning regulations can lead to the uplift in housing prices to five. Also, he categorized them based on their effect on the supply of housing or the demand for it. The first four are supply-side effects, and the fifth affects the housing demand. First, regulations can restrict the supply of developable land in different ways, including limiting the amount of undeveloped land that can be converted to urban use and requiring developers to meet a specific level of infrastructures for developing their land lots. Second, regulations can increase the construction cost through increasing the impact fees or development exactions or by imposing higher standards of construction or amenities that can increase the cost. Third, compliance with the regulatory procedures is time-consuming and imposes opportunity costs to developers. Fourth, planning regulations can directly affect the housing supply by setting quota restrictions on annual building permits. Fifth, since planning regulations can improve the quality of environmental amenities, the willingness of people to reside in those communities applying regulations may increase, which comes with higher prices. The amenity effect is indeed the one side of an overall effect Pogodzinski and Sass (1990) name the Tiebout effect. This means demanders respond to regulations by changing the jurisdiction where they live. As a result, people may leave the jurisdiction in response to a particular regulation, which may decrease the total demand in that place. The overall effect on the housing price would result from combining each of these effects. Each planning regulation may demonstrate one or more of these effects. Therefore, modeling the overall effect of planning regulations on housing prices can have different results depending on the number of the effects mentioned above and their interaction.

2-3- Complexities and approaches to measuring the price-inflationary effect of planning regulations

Despite numerous studies on the incremental effect of planning regulations on housing and land prices, the real-world complexities of the subject and discrepancies among approaches to overcome the difficulties have hindered consensus (Pogodzinski and Sass, 1990; Pogodzinski and Sass, 1991a; Nelson et al., 2002; Quigley and Rosenthal, 2005; Anthony, 2017). There are three main complexities stemming from the nature of planning regulations: the endogeneity, the heterogeneity of regulations, and the temporal dimension of regulations' effect. Attitudes towards these complexities and strategies for dealing with them have differed.

The endogeneity problem stems from the mutual interrelationships between planning regulations and housing and land prices. Jurisdictions may impose a level of restriction based on the current price of properties in a region. For example, a municipality may try to broaden its tax base by delineating the UGB to annex areas with higher housing and land prices. Similarly, higher housing prices may trigger the municipality to set more restrictive MBD to receive more extra-development fees. Therefore, ignoring the mutual relationships will overestimate the effect of planning regulations on housing and land prices (Malpezzi et al., 1998). The endogeneity problem has been addressed using statistical methods such as instrumental variables or quasi-experimental analysis to eradicate any possible mutual interrelationship between regulations and housing and land prices. However, the heterogeneity of regulations and their temporal effect has attracted attention during the last two decades, dividing the literature based on approaches toward these problems (Jackson, 2016).

The heterogeneity of regulations stems from the fact that the regulatory systems, specifically in the US (the research context for most studies), are heterogeneous. Each jurisdiction imposes a different set of regulations. Therefore, scholars have to make a trade-off between the jurisdictions number and the types of regulations in their analysis. Two approaches have emerged, namely: the selective and the comprehensive. The selective approach restricts the investigation to analyzing the impact of one or a selection of regulations on housing and land markets in a limited number of jurisdictions with similar regulatory systems. The primary issue with studies adopting this approach is that scholars have usually addressed the effect of a single regulation such as Minimum Lot Size (Zabel and Dalton, 2011), Urban Growth Boundary (Grout et al., 2011; Mathur, 2014; Mathur, 2019), or Coastal Zone Boundary (Severen and Platinga, 2018). Few studies have analyzed a set of regulations' combined effect (Pogodzinski and Sass, 1991b; Green, 1999; Jackson, 2016). Thus, it is difficult to generalize from them.

On the other hand, the comprehensive approach uses indices that measure the restrictiveness of regulatory environments at the national level or lower spatial scales instead of using individual variables for each type of regulation (Noam, 1983; Malpezzi, 1996; Malpezzi et al., 1998; Quigley and Raphael, 2005; Ihlanfeldt, 2007; Sunding and Swoboda, 2010; Huang and Tang, 2012; Turner et al., 2014; Kok et al., 2014; Jackson, 2018).

For example, Malpezzi et al. (1998) developed an index which was the unweighted average of seven variables to measure the stringency of the regulatory environment. These seven variables measured in ordinal scale (from 1 to 5) were as follows: “1) the change in approval time (zoning and subdivision) for single-family projects between 1983 and 1988, 2) the estimated number of months between application for rezoning and issuance of a permit for a residential subdivision less than 50 units; 3) A similar variable, but based on the time for single-family subdivision more than 50 units, 4) A quantitative assessments of how the acreage of land zoned for single-family compares to demand, 5) the amount of acreage of land zoned for multifamily compared to the demand for multifamily, 6) the percentage of zoning changes approved, 7) the adequacy of infrastructure (roads and sewers) compared with demand” (Malpezzi et al., 1998: 247-248).

The other method of devising such indices has been to sum up the number of regulations used by each jurisdiction with a subjective weight assigned to each restriction. Ihlanfeldt (2007) applied this method to measure the overall stringency of the regulatory environment of the jurisdiction in Florida by using 13 types of restrictions. This method makes it possible to compare jurisdiction with few imposed restrictions in common.

As a more recent example, Jackson (2018) used the famous California Land Use Regulatory Index (CaLURI) to measure the overall stringency of the regulatory environment in each jurisdiction of California. The regulatory index consists of several sub-indices; each measures the stringency of a group of regulations. These sub-indices were standardized before aggregating them in the overall stringency index. The sub-indices were as follows: Low-Cost Alternative Index, Residential Structure Requirement Index, General Residential Zoning Index, Political Tension Index, Development Uncertainty Index, Regulatory Delay Index, Building Limitations Index, Non-Residential Building Limitations Index, and Affordable Housing Index (Jackson, 2018: 132-133). Each of these sub-indices was yielded by summing the volume of its constituent regulations or the standard deviation of its constituent regulations for each jurisdiction. As Jackson (2016) points out, the second approach dominates the literature and may offer more potential for generalizability. However, these indices' subjective and arbitrary nature limits their application in policymaking. For instance, they mask the individual impact of regulations on housing and land prices. Since these indices aggregate the effects of regulations, any offsetting effects of regulations can be wrongly interpreted as no effect (Jackson, 2016).

The temporality of regulations' effects stems from the time needed for the emergence of the regulation's effect on agents' decisions in the market. There are two approaches to dealing with the temporal effect of planning regulations on housing and land markets: the static and dynamic approaches. Most studies have adopted the static approach and did not consider any lag between the enforcement time and the price (Pogodzinski and Sass, 1991b; Green, 1999; Ihlanfeldt, 2007; Turner et al., 2014; Kok et al., 2014). Some studies considered time in their analysis based on the nature of the method they applied, including those that used semi-experimental methods such as difference-in-differences (Zabel and Dalton, 2011; Jaeger et al., 2012; Ball et al., 2014). These predominantly analyze the effect of one type of regulation. Although they incorporate time in their model, the approach is not dynamic. They use time series data split by a time section to divide the cases into the control and treatment groups in order to identify causality.

The dynamic approach has been used extensively in studying property markets, including the housing market (De Leeuw and Ekanem, 1973; DiPasquale and Wheaton, 1994; Alm and Follain, 1994; Malpezzi, 1999; Malpezzi and Maclennan, 2001; Capozza et al., 2004; Riddel, 2004; Malpezzi and Wachter, 2005; Hwang and Quigley, 2006; Edelstein and Tsang, 2007; Caldera and Johansson, 2013; Stevenson and Young, 2014; Zabel, 2016; Oikarinen et al., 2018). Most studies have been concerned about explaining the fundamental reasons behind housing price instability and fluctuations by using partial adjustment or error-correction modeling. Among these, few studies account for the role of regulations (Malpezzi, 1999; Capozza et al., 2004; Hwang and Quigley, 2006). The results are partly contradictory. In error-correction models, long-run equations showed the significant negative effect of regulations on housing prices. However, there is no meaningful relationship in the short-run equations with the sign (Malpezzi, 1999) or significance (Capozza et al., 2004). On the other hand, only the VAR (Vector Auto-Regressive) model provided a robust result regarding short-run relationships (Hwang and Quigley, 2006). Among these few dynamic studies, two works used compound indices (Malpezzi, 1999; Hwang and Quigley, 2006), and one entered a selection of regulations directly (Capozza et al., 2004). Table (2-1) shows the distribution of studies in the literature adopting different combinations of approaches towards the complexities of the subject. Given the small number of studies and their contradictory results, further research is required to explore the individual effect of regulations on housing and land prices through time and thus pave the way for a consensus.

Table 2-1: the share of studies in the literature adopting different combination of approaches towards the heterogeneity of regulations and their temporal effect

Problem		Heterogeneity	
	Approach	Comprehensive	Selective
Temporal Dimension	Static	High	High
	Dynamic	Low	Low

2-4- The literature on the effect of three major planning regulations on Housing and Land Prices

The literature on each of the three regulations' effects on housing or land prices is reviewed in the following subsections. These studies consist of both theoretical and empirical ones and cover the period from the 1970s until now.

2-4-1- Maximum building density

MBD defines the maximum amount of floor space that can be built on a land lot in an urban area. Higher densities are assumed to be associated with traffic congestion, air pollution, noise, and extra pressure on public facilities and infrastructures. MBD is imposed to prevent these adverse effects of high densities and preserve life quality (Leibowicz, 2017).

There have been several attempts to analyze the effect of maximum building density on housing and land markets. Some of these works have addressed the issue by theoretical modeling. The developed models have been solved analytically or numerically. Scholars developed a general equilibrium model of the city with or without considering the spatial distance in both cases. The former was the case of a numerically solved model, and the latter was the case of analytically solved ones. Moss's (1977) work is probably one of the pioneers in analytical modeling[2]. His analytical model represented a geographically multiple-sector city with inelastic land supply, and demonstrated that the imposition of restriction would increase housing and land prices and expand the metropolitan area into rural areas.

In the same analytical category, Grieson and White (1981) developed a housing and land markets model divided into multiple types of structures with inelastic land supply and zero cross-price elasticities between the structures. By imposing the minimum lot-size restriction on one type of structure in the two-type-structure version of the model and differentiating, they showed that more restriction on the building density of a structure increases that structure's unit price. However, the effect of change in maximum building density on the price of other structures and land price is ambiguous.

The analytical category of general equilibrium modeling accounting for distance is the modified version of urban economics' classic monocentric city model. The land supply is completely elastic in contrast to the non-spatial models. Differences are mainly associated with the utility functions, housing attributes incorporated into the model, and construction cost functions. For example, in Arnott and MacKinnon (1977), the housing-related sources of utility are the housing floor area and recreational land. Buttler (1981) added to the attributes by considering the floor area, the finishing cost of a dwelling, the garden space, and the height of the building. Bertaud and Brueckner (2004) only considered the floor area. Despite these differences, the numerical solutions have yielded the same results. The restricted city's housing price gradient is higher than that of the unrestricted city (Buttler, 1981; Bertaud and Brueckner, 2004). The land rent in the CBD and nearby was lower in the restricted city than the unrestricted one. On the other hand, the restricted city expanded more, and after a certain distance, the land rent gradient in the restricted city was above the gradient of the unrestricted city (Arnott and MacKinnon, 1977; Buttler, 1981; Bertaud and Brueckner, 2004). While Arnott and MacKinnon (1977) interpreted the latter as an increase in the total land rent, Bertaud and Brueckner (2004) took the cautious way and mentioned that the result of a change in the land price curve and the differential land rent are ambiguous, and the incremental effect derived from simulation cannot be generalized.

[2]Although he originally wanted to examine the effect of minimum lot size, his way of representing minimum lot size turned his model towards analyzing the effect of MBD. He entered MLS restriction in the form of the minimum amount of land that should produce one output unit. One can convert such a restriction to the maximum building density.

The empirical works have been chiefly concerned with the effect of MBD on land prices rather than housing prices. The theoretical discussion and the derived empirical specification were on the parcel level and for an individual developer. Following that, the prevailing method in empirical studies has been hedonic modeling, and results have been related to the parcel level effects. However, along with individual effects, the imposition of MBD has a critical effect on the whole city, which can raise both housing and land prices (Arnott and MacKinnon, 1977; Brueckner et al., 2017).

Gao et al. (2006) developed a hedonic model using data on land prices in Tokyo. They incorporated FAR as three categories in the model. The results were not straightforward. The first and third categories were negative, and the effect of being in the second category was zero. They justified this pattern by referring to the offsetting effect of MBD's other impacts. In the lowest category, the cramped situation for living due to small lot sizes outweighed the environmental desirability of low-density areas. The undesirable environment in the higher density category outweighed the more developable space due to the higher effective FAR.

Brueckner et al. (2017) defined a new indicator to measure the level of stringency of MBDs and devised a procedure to calculate the indicator. As part of this procedure, they regressed the natural logarithm of land prices to FAR restrictions at the parcel level using panel data on more than 200 Chinese cities between 2002 and 2011. The estimated elasticity of land price with respect to the MBD in all regression models was significant and positive, implying that by relaxing the MBD for a land lot, its price will increase due to the higher profitability developers would expect when constructing more on a standard size land parcel. Brueckner and Singh's (2020) recent study on five US cities based on the same methodology showed the positive relationship between the average price of land lots and MBDs imposed on those cities.

2-4-2- Minimum lot size

MLS is the minimum size requirement for the subdivision of lands for future urban development. It is binding for undeveloped lands, and developed lands are usually grandfathered in. The original reason for applying MLS was its exclusionary effect, which prevents other socioeconomic groups from entering the single-family home suburbs that enacted and imposed MLS (Moss, 1977).

Studies on the effect of MLS on housing and land markets can be categorized in similar ways to the studies of MBD effects discussed in the previous section. However, here, the share of empirical works is considerable. White (1975) developed a two-sector model of an urban area in which households had identical income and utility levels. The model omitted the housing production sector, and households gain utility from the land and capital as production factors and other goods. This simplification offered the possibility of imposing MLS[3] directly on the households and incorporating them into household utility functions. Hence, by calculating and comparing households' utility change in the suburbs and center city as a result of imposing the restriction on the suburb, it is possible to define the direction of movement from suburb to center or center to suburb, or even no movement in the case of no difference in the utility change. However, to implement this method, it was necessary to assume that the city's size and the price of fringe land would not change at the point the regulation was introduced. Owing to the complexity of the general evaluation, White had to use a numerical solution. The results were parameter-sensitive. Hence, the effect of zoning on metropolitan area size was ambiguous. She then analyzed the effect of zoning on the overall land value in each of three cases: increase, decrease, and no change in the city size. In the case of constant or increased city size, the overall land value increased. However, in the case of a reduction in city size, the overall land value change was ambiguous.

Grieson and White (1981) used the same model described above to find the effect of MLS. They found that the direction of change in land and housing prices is ambiguous with respect to the direction of change in the lot size restrictiveness.

Bucovetsky (1984) developed a simple model of a small city where land supply is inelastic and prospective residents are entirely mobile. He showed that more restrictive MLS would increase the value of new houses and decrease land prices.

Pasha (1996) developed a model of a semi-closed city with two income groups. The low-income group lives in the city and the high-income group resides in the suburbs. Each group's population is fixed; however, the boundaries of each zone in which these groups reside are variable. He assumed that all the residents maximize their utility by consuming a composite good and land. This assumption implies that land and housing consumption were considered the same, and the whole city comprises single-family homes. Using the comparative statics, he showed that the imposition of MLS in the suburbs would expand the metropolitan area and decrease the land value in the center city. However, its effect on the value of suburban land is ambiguous. Therefore, its effect on the overall price of land can be regarded as ambiguous.

[3] One of the problematic aspects of White's model is the way of interpreting MLS. She interpreted it as increasing the size of all land lots by K%, which is entirely different from the absolute amount used in the real world.

In the empirical ambit, the MLS effect on housing and land prices has been examined individually or with other regulations. Pointing to the shortcoming of the previous study in capturing the effect of regulations only through dummy variables, Pogodzinski and Sass (1991) incorporated the effect of different types of zoning regulations and their interaction with housing characteristics. For MLS, they entered its interaction with the living area. Estimating the model using the transaction data of 11 cities showed that setting a higher restriction on MLS increases the total housing price. On the other hand, its effect through the implicit price of living area is negative. However, the net effect of minimum lot size is positive. Later on, Pogodzinski and Sass (1994) developed another model controlling the endogeneity of demographics and zoning regulations. The estimation of the model demonstrated that contrary to their previous work, MLS had a negative effect on single-family housing prices, and its interaction with the living area was not significant. They attributed this negative effect to the negative effects of MLS on other unmeasured housing characteristics that lowered the quality of housing, which compensate for the higher payments for larger land lots.

Glaeser and Ward (2009) studied the effect of four types of regulations, including MLS, on new construction and housing prices in 187 cities of Greater Boston through time. They developed simple regression models to examine the effect of MLS on the number of housing permits and housing prices separately. Regarding the effect on housing prices, they found a marginally significant increasing effect for MLS without demographic and density controls. However, entering those controls showed no significant effect. They interpreted this finding as showing how the existence of close substitutes in a region can prevent the increasing effect of MLS on housing prices from emerging, in a town with a higher MLS level.

Zabel and Dalton (2011) developed a model using the difference-in-differences estimator to isolate the causal effect of MLS on the price of housing. They estimated four models to show how using this method could change the magnitude of the effect of MLS restriction on housing prices and its direction. The first model used the cross-sectional data and entered MLS as the current value. The result was not significant at the 5% level, and the direction was negative, which means housing units with lower prices are in towns with higher MLS restrictions. Then, they estimated three regression models with difference-in-differences estimators accounting for zoning districts' fixed effects, and community zoning power. In all models, increasing the MLS resulted in uplifts in housing prices.

Adopting a bottom-up modeling approach, Magliocca et al. (2012) developed an agent-based model to simulate the effect of large-lot zoning on housing and land prices in a hypothetical exurban area. Imposing MLS can increase the land price (per acre) in both zoned and unzoned areas, but more restrictive MLS can have the opposite effect. Results showed that imposing the more restrictive MLS increases the average housing rent (per home) in the exurban area, and its effect on the zoned area is significantly higher than the unzoned area.

Ihlanfeldt and Mayock (2014) conducted a two-step analysis first to investigate the effect of the price elasticity of land supply on housing prices during boom-and-bust cycles and then address the role of different contributing factors in determining the housing supply elasticity. To represent regulatory restrictiveness, they analyzed the effect of measurement of MLS on the housing supply elasticity. The regression model result showed that larger MLSs led to lower supply elasticities, resulting in a considerable increase in price appreciation.

2-4-3- Urban growth boundary

An UGB is a boundary demarcated around urban areas to limit the urban development to the areas inside the boundary and prevent urban growth outside of it (Mathur, 2019; Leibowicz, 2017). UGB is deemed an effective regulation that hampers the urban sprawl and destruction of agricultural lands, forests, and open spaces in exurban hinterlands. Other titles for an UGB are urban limit line and urban service boundary (Dawkins and Nelson, 2002). Compared to the other two regulations, the price effect of UGB has been the subject of empirical studies rather than theoretical ones. Moreover, most of the works have focused on UGB's effect on the land market.

Knaap (1985) conducted one of the first studies on the effects of UGB on land prices. Using the simple theoretical partial equilibrium model, he argued that by determining when a non-urban land lot will be permitted to be used as urban land, UGBs affect the price of a non-urban land lot inside the UGB by changing the stream of its future expected rental revenues. His empirical model confirmed that the UGBs positively affected the prices of non-urban land lots inside the UGBs. Although he mentioned the possible effect of imposing a UGB on urban land inside a UGB, he accounted for no effect on urban land in his theoretical model. He could not measure this effect empirically since, in practice, no urban land existed outside the UGB for comparison. Moreover, he did not consider the endogeneity effect, which is the probability of pre-UGB land prices' having an effect on the delineation of UGB, with high-priced land lots being included within the UGB. Finally, he did not consider the effect of the UGB on land prices by preventing the city's outward development.

Brueckner (1990) developed a dynamic model of a monocentric city to examine the amenity effect of UGB on developed and undeveloped land prices. Here, the population number was taken as the source of disamenity and entered in the utility function. He made the demand side of the model as simple as possible by treating most of the variables such as income level, utility level, and household land consumption (as the equivalent of housing consumption) as exogenously defined. The model determines the time of converting a rural land lot with a distance x from the CBD and shows how the city expands and population increases over time. Instead of a fixed physical boundary around the city, Brueckner defined the UGB as a tool redefining the city's growth trend (path). After its imposition, a city's growth trend would be lower than the free market trend. His analysis showed that the amenity effect of the growth control increases the developed land value in all locations. However, its effect on undeveloped land value is ambiguous. He explained this indeterminacy by referring to the decreasing effect of delay on developments and the increasing effect of amenity due to the growth control measure.

Bigelow and Plantinga (2017) tried to evaluate both the amenity and scarcity effects of UGB. First, they developed a simple theoretical model of a linear city to demonstrate the effects of imposing UGB on the difference between land (housing) prices in the urban and exurban areas. The model was kept simple in order to be tractable, by assuming equivalency of housing and land consumption and that all residents had fixed and identical housing unit consumption. They divided people into two categories based on their preferences for urban and exurban amenities. The comparative statics showed that the imposition of the UGB increases land (housing) prices both inside and outside the UGB. However, the price increment effect of the UGB in the latter was higher than in the former. The difference in the price increase stems from the scarcity of land in the exurban area and the disamenity of population growth inside the UGB. They tried to test their theoretical findings empirically by estimating a hedonic model of land prices using the panel data of cities in Willamette Valley in Oregon, US. The estimation demonstrated that the average land price appreciation rate outside the UGB was higher than the rate for the land parcels inside it. Since the evidence of a quality effect was not strongly significant, they attributed the discrepancy in the land price appreciation inside and outside the UGB mainly to the scarcity effect. However, their empirical model did not gauge the impact of the UGB on the total land or housing price increase in the urban areas since the model used the data from all cities with the UGB in place.

Ball et al. (2014) devised a quasi-experimental analysis by estimating the difference-in-differences estimator capturing the effect of enacting Melbourne UGB on land prices inside the UGB. They used the cross-sectional data on land lot transactions from 1996 to 2007 in the Melbourne Metropolitan fringe. Two models were estimated: one with a fixed coefficient as the effect of UGB for all periods and the other with variable coefficients for each quarter. Estimating the models demonstrated that land prices inside the UGB surged significantly, and the effect was constant throughout the enforcement period. Also, they showed by calculation that this 65% increase in the price of residential land lots was responsible for a 21% uplift in the price of a housing unit built on an average-sized land lot.

Mathur (2014) estimated four models using data on single-family land lots and housing unit transactions in King County, Washington, US, from 2004 to 2006 to capture the effect of UGB on housing and land prices. Controlling for spatial and temporal fixed effects, lot sizes, along with other structural and place-based attributes, the results demonstrated that the UGB increased the average price of land lots inside the UGB in comparison to land lots outside it. Due to controlling for amenities, he attributed the estimated incremental effect to the scarcity effect of the UGB on the land supply. On the other hand, despite the inflationary effect of the UGB on housing values through the lot size variable, estimating the coefficients of the UGB dummy variable in the housing price model showed the negative effect of the UGB to the extent that it provided an overall negative effect of the UGB on housing prices. Later on, Mathur (2019) estimated similar hedonic models, this time for each decile of housing prices in King County, Washington, to measure the UGB effect on the housing price of single-family homes. He derived the similar decreasing effect of UGB on total housing prices and increasing effect on price per square meter of land for all models.

Mathur justified this decreasing effect of the UGB on housing prices by referring to other supporting policies increasing the housing supply elasticity despite higher land prices. However, it may be related to the fact that while the dependent variable in the land price model was the price per square foot of land, it is the total price of a single-family housing unit in the housing price model. Thus, it is possible that if one estimates the model for the total land price, the effect of the UGB on the total price of an average land lot might be negative. Moreover, the smaller lot size inside the UGB can reduce the average housing sizes inside the UGB. Hence, it is possible that the impact of the UGB on total price was negative, but simultaneously, the price per square meter of housing space was higher inside the UGB than the outside. Hence, the results for the effect of the UGB on housing prices remain infused with doubt.

Table (2-2) summarizes the literature reviewed in this section. Relatively, results on the effect of UGB show the highest level of consensus among others. All the studies confirmed the incremental effect of UGB on the land price. However, except for two studies, the others did not examine the effect of UGB on the housing price. Also, the two studies showed the negative effect of UGB on the total housing price and not the price per square meter. As Dawkins and Nelson

(2002) mention, UGBs, depending on their level of pervasiveness, can be nationalized, state-mandated, state-supported, or localized[4]. Regardless of their implementation, UGBs affect land prices positively. However, their effect on housing prices depends on the other planning regulations being enforced within UGBs. After the findings of studies on UGB's impacts, studies on the effect of MBD stand in second place with respect to the level of agreement among their results. This is evident in theoretical works' findings on the effect of MBD on housing prices. However, none of the empirical works addressed the effect of MBD on housing prices. Regarding MBD's effect on land prices, while theoretical works show positive or ambiguous effects, few empirical studies show negative or ambiguous effects. Results on the effect of MLS exhibit the lowest level of consensus. From negative to positive and ambiguous, all types of results can be seen. Judging based on the most common result, one can argue that the effect of MLS on the housing price is positive, but its effect on the land price is ambiguous. Moreover, almost all of the studies addressed only the effect of one type of regulation. The two theoretical studies that analyzed the effect of more than one regulation examined the effect of each regulation separately. Only two empirical studies incorporated more than one regulation in their model. Finding the concurrence regarding the effect of regulations on housing and land prices is difficult.

Table 2-2: The summary of the literature on the effect of MBD, MLS, UGB on housing and/or land prices

Type of regulation	Study	Type of model	Method/ Technique	Effect on the housing price	Effect on the land price	Considerations and assumptions
MBD	Moss (1977)	Theoretical	Analytical	+	+	
	Arnott and MacKinnon (1977)	Theoretical	Numerical	+	+	housing floor area and recreational land as the utility source
	Grieson and White (1981)	Theoretical	Analytical	+	+/-	
	Büttler (1981)	Theoretical	Numerical	+	+	floor area, the finishing cost of a dwelling, the garden space, and the height

[4] The central government in Iran determines the set of planning regulations that municipalities should apply in their development plans. Therefore, UGB is a nationally mandatory regulation. However, each municipality has its own considerations in delineating the urban boundary around its city.

Type of regulation	Study	Type of model	Method/ Technique	Effect on the housing price	Effect on the land price	Considerations and assumptions
						of the building as the utility source
	Bertaud and Brueckner (2005)	Theoretical	Numerical	+	+/-	floor area as the utility source
	Gao et al. (2006)	Empirical	Hedonic regression	N	+/-	
	Brueckner et al. (2017) defined	Empirical	Hedonic regression	N	-	
	Brueckner and Singh's (2020)	Empirical	Hedonic regression	N	-	
MLS	White (1975)	Theoretical	Numerical	N	+/-	No production sector, Considering land, capital (production factors) as the source of households' utility, identical income and utility
	Grieson and White (1981)	Theoretical	Analytical	+/-	+/-	
	Bucovetsky (1984)	Theoretical	Analytical	+	-	
	Pogodzinski and Sass (1991b)	Empirical	Hedonic regression	+	N	Single-family homes
	Pogodzinski and Sass (1994)	Empirical	Hedonic regression	-	N	Single-family homes
	Pasha (1996)	Theoretical	Analytical	N	+/-	Land consumption ≡Housing Consumption, Single-family homes, Two income groups, Two sectors (City and suburb)

Type of regulation	Study	Type of model	Method/ Technique	Effect on the housing price	Effect on the land price	Considerations and assumptions
	Glaeser and Ward (2009)	Empirical	Multi-variable regression	0	N	
	Zabel and Dalton (2011)	Empirical	Difference-in-differences	+	N	Single-family homes
	Magliocca et al. (2012)	Theoretical	Agent-based simulation	+	+/-	Single-family homes, Effects on total rent per home and price per acre of land, effect on average price of all lands was not reported
	Ihlanfeldt and Mayock (2014)	Empirical	Multi-variable regression	+	N	Single-family homes
UGB	Knaap (1985)	Theoretical	Analytical	N	+	Effects on non-urban land inside UGB, Did not account for the endogeneity effect
		Empirical	Hedonic regression	N	+	
	Brueckner (1990)	Theoretical	Analytical	N	+	Land consumption ≡Housing Consumption, Population as the source of disamenity, exogenously defined income and utility level, exogenously defined land consumption per household
	Ball et al. (2014)	Empirical	Difference-in-differences	N	+	

Type of regulation	Study	Type of model	Method/ Technique	Effect on the housing price	Effect on the land price	Considerations and assumptions
	Mathur (2014)	Empirical	Hedonic regression	-	+	Single-family homes, Effects on price per square meter of land and total price of housing
	Bigelow and Plantinga (2017)	Theoretical	Analytical	N	+	Land consumption ≡Housing Consumption, Fixed and identical consumption of land/housing
	Mathur (2019)	Empirical	Hedonic regression	-	+	Single-family homes, Effects on price per square meter of land and total price of housing

(+) Increasing effect

(-) Decreasing effect

(+/-) Ambiguous effect

(0) No effect

(N) Not addressed

2-5- The Literature on the economic modeling of informal settlement growth

The literature on the economic modeling of informal settlement growth can be divided into two threads. The older thread focuses on the interaction between the squatter and the landowner to model the size of a typical informal settlement. The newer thread analyses the effect of institutes in the formal housing market, specifically the planning regulations, on the expansion of informal settlements. Following sub-sections address studies in these two threads.

2-5-1- Squatter-landowner interaction

Prior to reviewing the literature on the effect of regulations on informal settlements' growth, it is necessary to address another stream of literature that has analyzed the expansion of informal settlements without considering the role of planning regulations. This rich theoretical literature has focused on modeling the informal housing or land market in a typical squatter settlement. The primary incentive has been to analyze the effect of formalization policies on the welfare gain of squatters or formal residents or both of them (Brueckner and Selod, 2009). These models' structure is based on the interaction between squatters and landowner/landowners whose lands are squatted. However, several efforts have modified this general structure by incorporating other actors to better reflect the actual situations.

As the earliest work in this domain, Jimenez's (1985) model introduced the view of squatting as a tenure choice. The model is based on the government-squatter interaction. Later, Hoy and Jimenez (1991) replaced the government with a private sector landowner. In their model, the landowner chooses the eviction strategy (the combination of eviction and preventing further addition to housing capital by squatters) to maximize the expected value of the owned land lots. Squatters choose the amount of housing stock they consume based on the risk of eviction, the housing rent, and their income. Turnbull (2008) continued this stream of works by considering that the squatting exists as long as the landowner finds the preemptive measures such as enclosing the land or continually monitoring it costlier than eviction at the time of developing the land. Brueckner and Selod (2009) incorporated a benevolent organizer who defines the number of squatters and their land consumption to control the squeezing effect of the squatter settlement on the formal land market. In their model, formal and informal households compete in the land market, and informal land consumption squeezes the formal households when squatters pay higher prices. The squeezing effect invites formal households to choose the eviction strategy. In later work, Brueckner (2013) replaced the benevolent organizer with rent-seeking ones. Shah (2014) maintained the same analytical structure and replaced the private landowners with the government. Posada (2018) expanded the land-owner-squatter version by incorporating formal-informal dichotomy in the land market, housing production sector, and households residing in a mono-centric linear city. He intended to show the spatial structuring of formal and informal housing construction.

Assuming that squatters come from somewhere, the squatter-landowner models mainly focus on the informal market as the destination, rather than the formal market as the origin, of squatters and the driving forces behind changes in numbers of squatters. The eviction strategy or the formalization policy can change a single informal settlement's number of residents. The eviction strategy eliminates the squatters from the modeled settlement, but since everyone must live somewhere, the re-marginalized dwellers squat somewhere else in reality. Putting these policies in a broader context of a metropolitan area, they cannot stop the marginalization process unless policymakers take the driving force of the formal market into account.

2-5-2- The effect of planning regulations on the expansion of informal settlements

The newer stream of studies analyzing the effect of planning regulations on informal settlements' growth has altered the focal point to the formal market as the source of informal dwellers. Limited research has attempted to study the effect of planning regulations on the expansion of informal settlements.[5] This section addresses the extant studies in this ambit in more detail, since their advent in the mid-2000s.

Lall et al. (2007) provided the first simultaneously analytical and empirical economic modeling to study the effect of planning regulations on slum formation. People choose to build informal housing instead of formal housing whenever the total cost of housing construction is much higher than the household's budget constraint (income). The total cost of constructing a formal housing unit in the efficient market equates to its total price. Therefore, they implicitly used the prevailing concept of housing affordability. Based on this definition, a housing unit is affordable for a household with a certain income if the housing price-to-the-household income ratio does not exceed a specific threshold (Stone, 2006). If planning regulations increase housing prices more than the affordable threshold, the household will choose to build an informal housing unit over the formal housing. Lall et al. hypothesize that slums are responses to the failure of the formal housing market to meet market demand, which stems from restrictive land-use regulations. They test the hypothesis both analytically and empirically. Analytical modeling of partial equilibrium shows that regulations and income have an ambiguous effect on slum formation. The behavioral assumption of the analytical model was that people directly consider the restrictiveness of regulations in their choice of a city as their migration destination. This is only the case when self-construction is the dominant mode of housing construction. On this basis, both planning regulations and housing price, which is affected by regulations, appeared on the right-hand side of the equation, determining the change in the number of formal households. By deriving the specification from the analytical model, they estimated the analytical equations to find the impact of regulations on the slum formation in a real case. The empirical results demonstrated that in contrast with the conventional wisdom that decreasing

[5] Biderman (2008) directly points to this rarity.

minimum lot size will reduce the size of the informal housing sector, the relationship is in the reverse direction, and this study has found a significant increase in slum growth.

Biderman (2008) tried to empirically test the effect of different types of planning restrictions on slum growth. These regulations included building codes, urban growth boundaries, zoning, and parceling. His fundamental theoretical assumption was that planning regulations directly affect the decision of the housing demanders. Based on this assumption, along with the difference between the aggregate characteristics of each city's households and their formal and informal dwellings, the relative market share of informal housing depends on the difference between city-level features, including the planning regulations. By estimating difference-in-differences estimators, Biderman showed that all the planning restrictions slowed the declining informal housing share in a municipality that enacted regulations compared to an unregulated one. However, the significance levels of most of the estimates are problematic.

Duranton (2008) adopted the diagrammatic framework of demonstrating optimal city size to explain the impact of regulation on the emergence of squatter settlements in the cities of developing countries. He used the overlay of the net wage curve and labor supply curve and their intersection to define the equilibrium size of the city. He postulated that the slope of living cost in informal settlements is not as steep as that in formal settlements, and imposing the minimum lot size increases the cost of living in formal housing. Based on these assumptions, Duranton showed that after a certain population threshold, living in informal settlements would be cheaper than living in the formal part of the city, due to the imposition of minimum lot size restrictions. Duranton's analysis depicts how the potential informal market would become activated by the growth of the city and the imposition of regulations. The implicit assumption in the analysis is that land consumption is equivalent to housing consumption.

Using empirical data from Brazil, Souza (2009) has studied the relationships between the six types of land use regulations, housing prices, and the growth of informal settlements. She developed a three-stage regression model to account for the endogeneity of the regulatory variables and the formal housing price. The derived relationships determine how different land-use regulations affect housing prices and how the increase or decrease in housing prices can influence informal housing growth. The results demonstrated that increasing minimum plot area, minimum front setback, and minimum frontage had an incremental effect on formal housing prices. In contrast to expectations, increasing the maximum number of floors and the floor area ratio resulted in a decline in formal housing prices. On the other hand, the price of formal housing negatively affects the number of informal dwellings in the corresponding location but positively affects the number of informal dwellings in adjacent and more distant areas. The separate estimation of each regulation's effect does not enable one to estimate their combined effect.

Heikkila and Lin (2014) developed a model without an a priori informal housing sector. By assuming the equivalency of land consumption and housing consumption and applying the linear expenditure system, they showed that the imposition of minimum lot size could marginalize those households who could not afford the binding minimum consumption of land. In the linear expenditure system, there is a minimum level of consumption for each good, which guarantees a person's survival. Based on this concept, Heikkila and Lin (2014) explained that the process of marginalization of households to the informal sector happens when low-income households are unable to afford the minimum survival level of the housing space in the formal market. They are forced to obtain housing in the informal market, which is not subject to the restrictive rules of the formal market. Like Lall et al. (2007), Heikkila and Lin (2014) related the marginalization of households to the housing affordability concept. However, they used the residual income approach's definition of housing affordability, theoretically more robust than the ratio approach's definition (Stone, 2006). Based on that, a housing unit is affordable for households of a certain income group if the household can pay the housing rent without sacrificing their basic needs for non-housing goods (Stone, 2006). In Heikkila and Lin's (2014) application of this definition, if a household cannot afford its basic needs to housing space in the formal housing market without sacrificing other basic needs, it will resort to the informal housing market. This model is the first analytical one that considered the informal settlement as a last resort rather than a choice. Heikkila and Harten (2019) expanded this analytical framework in conjunction with Tiebout's and Alonso's locational models in a metropolitan area and a city, respectively, in a more descriptive way.

Cavalcanti et al. (2019) built a general equilibrium model to explain the mechanisms through which poverty, population, and regulations act as three contributing factors affecting slum growth. They introduced the governmental sector with property and income taxes as revenues and expenditures on public facilities, a housing production sector, a non-spatial goods production sector paying wages to households, and households with heterogeneous incomes maximizing their utility by consuming non-housing goods and housing services. The housing services stem from the housing space and public goods around the housing unit. The latter differs for the formal housing and the informal housing units. Therefore, people choose between formal and informal housing units to maximize their utility. By choosing informal housing, on the one hand, the household receives a lower amount of public goods, reducing its utility, and faces the cost of protecting its property and on the other hand, the informal household does not pay the property tax and does not have to comply the minimum consumption of housing. Simulations using data in the Brazilian context demonstrated that the enforcement of MLS regulation might increase the share of slums, and upgrading policies might attract more people to slums. The model is unique because it considers income heterogeneity. However, there are some simplifying and unrealistic assumptions behind it. First, both formal and informal housing sectors use the same housing production function. This assumption is problematic, especially in the case of South American informal settlements. Posada (2018) developed a theoretical model in the same context and used different production functions for formal and informal housing sectors. Instead of incorporating MLS as a constraint for developers in the formal market, it is incorporated in the form of housing demanders who maximize their utility subject to MLS. While Cavalcanti et al. apparently consider housing consumption to be a different phenomenon from land consumption, it seems for purposes of simplicity they defined MLS as a minimum liveable space rather than the minimum plot of land. Even in this form, it will have implications for the housing production function.

Table (2-3) summarizes the main aspects of the articles reviewed in this section. Half of the studies investigated the effect of selected variables. The other half, based on theoretical models solved analytically or numerically, focused on one type of regulation, i.e., MLS. Two empirical studies, Lall et al. (2007) and Souza (2009), which addressed the effect of MLS, found contradicting results. Only the theoretical models yielded consistent results. However, among the three, while Cavelcanti et al. (2019) did not use housing and land consumption as equivalent concepts, they incorporated MLS as a minimum liveable space rather than the minimum area of the land lot. The other contradictory results are related to general zoning regulations, for which Lall et al. (2007) found no relationship while Biderman (2008) found a positive one. Regarding UGB and MBD, the two other regulations that this thesis examines, Biderman (2008) found a positive effect of UGB on the expansion of informal settlements; however, Souze (2009) estimated that more restrictive MBD had a surprizing negative effect on housing prices and consequently on informal dwellers' growth. None of the theoretical models analyzed the effect of UGB and MBD. As can be seen, the results are far from indicating a consensus, and more research is required to analyze the effect of planning regulations, other than MLS, on informal settlements and the marginalization of low-income households.

Table 2-3: Summary of reviewed literature on economic modelling of informal settlements

Study	Type of Model	Method/Technique	Regulatory Variables	Effect of the dependent variable	Dependent variable	Considerations and assumptions
Lall et al (2007)	Theoretical	Analytical	A general variable representing Planning regulations	(+/-)	Share of informal dwellers	Direct effect of regulations on people's choice
	Empirical	Log-linear regression	Minimum lot size	-	Number of informal dwellers	
			General zoning regulation	0		
Duranton (2008)	Theoretical	Analytical	Minimum lot size	+	Number of informal dwellers	Imposition of minimum lot size increases the cost of living
Biderman (2008)	Empirical	Difference-in-difference	Building codes	+	Number of untitled housing units	Direct effect of regulations on people's choice, Effect of regulations was measured separately. Most of estimations are not significant at 90 percent level.
			Urban growth boundary	+		
			Parceling	+		
			Zoning	+		
Souza (2009)	Empirical	Three stage least square regression	Minimum plot area	+	Number of informal dwellings	Effect of regulations was measured separately
			Maximum number of floors	-		
			Minimum front set-back	+		
			Minimum frontage	+		
			Occupation ratio	+		

Study	Type of Model	Method/Technique	Regulatory Variables	Effect of the dependent variable	Dependent variable	Considerations and assumptions
			Floor area ratio	-		
Heikkila and Lin (2014)	Theoretical	Numerical	Minimum lot size	+	Number of informal dwellers	Land consumption ≡Housing Consumption
Cavalcanti et al (2019)	Theoretical	Numerical	Minimum lot size	+	Share of population in slums	Imposing minimum lot size to residents instead of developers Minimum lot size≡ Minimum housing space

(+) Increasing effect

(-) Decreasing effect

(+/-) Ambiguous effect

(0) No effect

2-6- Conclusions

This chapter looked at the concept of planning regulations and their effects. Planning regulations have been justified as a way to correct market failures such as physical and fiscal externalities. However, there has been a growing concern that the likely price-inflationary effect of planning regulations may be used by high-income households to exclude lower-income groups. This has led to a significant amount of literature aiming to identify and measure the incremental effect of planning regulations on housing and land prices. There are several potential ways that planning regulations might affect housing price. The effects can be divided into two broad categories: supply-side and demand-side. On the supply side, regulations can decrease the land supply (land scarcity effect), increase the construction cost, impose time-related costs, and reduce the supply of housing space. On the demand side, they can increase the demand and willingness to pay by improving the local amenities, or decrease it by provoking people to move.

Moreover, there are complexities in measuring the effects of planning regulations on housing and land prices. These complexities stem from three characteristics of regulations: endogeneity, heterogeneity, and temporality. The endogeneity of regulations refers to the mutual relationships between the property prices and the level of regulatory restrictiveness chosen by local governments. The heterogeneity of regulations points to the diversity of jurisdictions in using different types of regulations which hinders studies adopting a more general cross-sectional analysis. The temporality of regulations refers to the time lag between the enforcement of regulations and the emergence of their effect. To cope with these difficulties, scholars have adopted different techniques and approaches which have fragmented the extant literature and hindered a consensus. The pervasive technique to account for the endogeneity of regulations has been to use instrumental variables. Difficulty in finding appropriate instrumental variables has led scholars to economize on the number of regulations included in studies. Hence, most of the studies have addressed the effect of one regulation (selective approach) or the effect of a compound index representing the stringency of the regulatory environment (comprehensive approach) without considering the temporality of the effect (static approach). However, we need to improve our understanding of both the individual and the combined effects of planning regulations throughout time, for policymaking purposes.

The literature review on the individual effect of three major planning regulations shows no robust consensus, and depending on the type of regulation, the level of consensus can differ. The results on the effect of UGB show the highest level of (relative) consistency among the studies. However, most of them have not addressed the effect of UGB on housing prices. MBD results provide the next highest level of consensus, even though there is an apparent inconsistency between theoretical and empirical results. Finally, studies on MLS effects have provided the most inconsistent results.

The literature on the economic modeling of informal settlements growth is not extensive. The richer threads within this theme focus on the informal housing/land market as the destination, and approach questions about informal sector expansion through modeling the interaction between the landowner and the squatter. In contrast, a secondary thread within this theme seeks the source of the problem in the formal housing market as the origin, and analyzes the role of planning regulations in the expansion of informal settlements. A limitation of many of these studies is their focus on only one regulation (MLS), and their results are not convincingly robust. Moreover, the effect of the other two regulations of interest in this thesis, MBD and UGB, is under-explored, with only one study on each of these. These studies must deal with the same three difficulties (endogeneity, heterogeneity, and temporality) that the extensive literature on the price-inflationary effect of regulations has to address. They too use the predominant approaches - the static and the selective. None of these studies have analyzed the combined effect of a set of planning regulations over time. This is the gap that the thesis intends to fill, by using the systems dynamics (SD) simulation method, which offers a way to address all three complexities of modeling the effects of planning regulations. The following chapter discusses the SD method in connection to the dynamic modeling method in economics and property economics.

3. Theoretical Foundation of the Methodology

3-1- Introduction

As identified in the literature review in Chapter 2, the dominant share of literature on the effect of planning regulations on housing prices and the expansion of informal settlements have adopted the static approach of modeling. However, since regulations affect the housing market through the new supply, their effect gradually appears. Over the time that the effect of regulations emerges, the course of the housing price can change, and consequently the trend of informal settlements may change. Therefore, the dynamic modeling of the housing market can provide more insightful results than those derived from analysis based on comparative statics. Dynamic economic modeling, specifically when it comes to empirical methods of estimating dynamic specifications, is a vast part of the econometrics literature.

This chapter does not intend to thoroughly investigate all the developed econometric methods of estimating dynamic models. The main objective here is to identify the theoretical core of those models that have used econometrics to reach their dynamic specifications. The chapter starts by explaining the adjustment process and its configuration in partial adjustment models. It explains how the transformation of the partial adjustment model can result in theory-based specifications for empirical estimation and testing. It is followed by a section reviewing the dynamic models of the housing market. There are two objectives for investigating these studies. First, to clarify how the partial adjustment structure has been applied in these models, and second, to find the way planning regulations have been incorporated in these models.

This methodological review includes 22 studies covering the period from the 1970s to 2010s. The section after that connects the dynamic modeling in housing economics to a broader context of closed-loop systems' dynamic modeling. Subsequently, System Dynamics (SD), as a well-known methodology for modeling those systems, is explained. The theoretical roots of system dynamics, and its methodological tools, and modeling approaches are addressed. Further, this thesis' approach in applying SD methodology for developing the theoretical model of the research is explained. The chapter ends with concluding remarks.

3-2- The Adjustment Process

The essential mission of dynamic economic modeling is to provide a plausible narration of what is happening between the two stable situations of a market, when displacement occurs. The adjustment process or the disequilibrium adjustment process is the notion through which scholars have tried to explain movement from one stable equilibrium to another (Fisher, 1998). There are different types of adjustment processes, such as Marshall’s adjustment process and

Cobweb adjustment process. In Marshall's adjustment process, there are supply prices and demand prices; the difference between them is the force that alters the supply. Suppose the demand price exceeds the supply price, the supply increases, and vice versa. In the Cobweb model, the price adjusts instantly to demand shock and vice versa; however, the supply reacts to the price with a lag (Samuelson, 1971). However, the most famous and essential adjustment process is the price adjustment process. It is also known as the Walrasian adjustment process since Leon Walras first introduced the process necessary for defining the general equilibrium condition. Changes in the price of a commodity depend on the difference between the demand for and supply of that commodity. In turn, both demand and supply depend on the price level in each period. The price adjustment process can be mathematically represented by following differential equation (Samuelson, 1971: 263; Arrow and Hurwicz, 1958: 526):

$$dp/dt = f(p) = h[D(p) - S(p)] \qquad (3\text{-}1)$$

where, $h(0) = 0$, $h' > 0$[6], and $f(p)$ is known as the excess demand function. This simple equation means that whenever demand exceeds supply, the price rises, and when supply exceeds demand, the price falls. Only when supply equates demand, the price will not change. The latter is the equilibrium condition. One can rewrite equation (3-1) in the difference equations format treating time in a discrete form:

$$\Delta p_t = p_t - p_{t-1} = p_t^* - p_{t-1} = h[D(p_{t-1}) - S(p_{t-1})] \qquad (3\text{-}2)$$

If there is excessive demand, the excess demand function will convert it into the house price increase. This increase will be added to the price level at the end of the previous period to give the price level at the end of the current time. It is an instant adjustment in which it is assumed that the price will increase in so far as the supply in the current period equates to the demand. In other word, the price instantly adjusts to the equilibrium price level ($p_t = p_t^*$). However, in the real world, depending on the type of commodity, the adjustment might be costly and time-consuming. Referring to Walras's phrase, it involves the auctioneer as a price adjuster. Regarding the property market, real estate agents are involved in this process since they have the most updated information about the property market. They are engaged with both sides of the market and can estimate excess demand. The existence of agents is a sign of the costliness of the transaction. Hence, the adjustment is a process, and it happens partially rather than instantaneously. The speed of adjustment depends on the amount of the cost of adjustment

[6] The symbol ' here denotes the first derivative of function h.

which is the raison d'être for the adjustment process (Maccini, 1998). The more the adjustment cost, the slower is the adjustment process. The adjustment process is also evident for other variables in the market.

3-3- Partial Adjustment Models

A partial adjustment model explains how a dependent variable inclines over time to its desired level, i.e. its value in the next equilibrium. It is called partial since the dependent variable can move part of the way from its actual level in the previous period to the desired level in the current period (Ferguson and Lim, 2005). Structurally, all partial adjustment models consist of two equations. The first equation describes the long-run relationship between the dependent variable and other exogenous variables. This equation yields the dependent variable's equilibrium value, given the value(s) of the exogenous independent variable(s). The second part of the model illustrates the adjustment of the dependent variable and its movement from its actual level towards the long-run equilibrium level. The mathematical form of a typical partial adjustment model is as below:

$$y_t^* = \alpha^0 + \sum_{i=1}^{n} \alpha^i . x_t^i \tag{3-3}$$

$$y_t - y_{t-1} = \delta . (y_t^* - y_{t-1}) \qquad 0 < \delta < 1 \tag{3-4}$$

The dependent variable seeks its equilibrium value over time. This inclination can be disturbed by changes in exogenous variables. Therefore, the equilibrium value can be a moving target.

Back to the Walrasian price adjustment process, it is possible to define it as a partial adjustment process. One can rewrite equation (3-4) based on prices where γ is the adjustment parameter which defines the speed of adjustment. On this basis, equation (3-2) should be rewritten as equations (3-6):

$$p_t - p_{t-1} = \gamma . (p_t^* - p_{t-1}) \tag{3-5}$$

$$p_t - p_{t-1} = \gamma . (p_t^* - p_{t-1}) = \gamma . h[D(p_{t-1}) - S(p_{t-1})] \tag{3-6}$$

One famous example of the partial adjustment model is the capital stock adjustment model or the flexible accelerator model. This model is based on the acceleration principle, which is the theory behind the demand for investment and capital goods supply. Based on the acceleration principle, the optimum amount of capital goods in each period (K_t^*) can be defined by the required output in the same period (Y_t). Considering the capital goods as a production factor, the demand for capital goods is a derived demand dependent on the level of output. Through this simplification, the acceleration principle omits the intermediation of the price of capital goods and production inputs for which it has been criticized (Junankar, 1998). Equation (3-7) shows this simple relationship in which ϑ is the capital-output ratio or the accelerator. The investment demand relationship will be yielded as equation (3-8) by differencing the two consecutive periods' equations. In other words, the increase in the required output will accelerate the investment.

$$K_t^* = K_t = \vartheta . Y_t \tag{3-7}$$

$$I_t = K_t^* - K_{t-1}^* = K_t - K_{t-1} = \vartheta . Y_t - \vartheta . Y_{t-1} = \vartheta . \Delta Y_t \tag{3-8}$$

Due to the poor empirical support for the second relationship with estimated accelerator coefficients smaller than the average capital-output ratios, equation (3-8) has been improved by incorporating the adjustment process (Evans, 1969). Equation (3-9) shows the adjustment process in the capital stock. This reformulation converts the model to the familiar partial adjustment model and states that the capital stock cannot be adjusted instantaneously. Putting (3-7) inside (3-9) will yield equation (3-10). Considering that b is between zero and one, α, the product of b and ϑ, which is the coefficient in the investment function, becomes smaller and more consistent with the empirical results (Evans, 1969).

$$I_t = K_t - K_{t-1} = b.(K_t^* - K_{t-1}) \tag{3-9}$$

$$I_t = K_t - K_{t-1} = b.\vartheta . Y_t - b.K_{t-1} = \alpha . Y_t - b.K_{t-1} \tag{3-10}$$

3-4- Empirical Specifications Derived from Theoretical Adjustment Process

There are two sources for determining the specification of an empirical model: data and theory. The empirical model means a model should be tested by the empirical data. The adjustment process provides the theoretical basis for the specifications of a large body of time series econometrics models (Judge et al., 1985). The following two subsections investigate two main categories of time series specifications in which the partial adjustment process plays a central determining role.

3-4-1- Auto Distributed Lag Models

The theoretical partial adjustment mechanism represented through equations (3-3) and (3-4) is hidden in the real-world data. Revealing it by estimating the parameters, specifically the adjustment parameter, is an empirical work's main objective. Since the equilibrium values of dependent variable y_t^* are unknown, there is no direct way of estimating equations (3-3) and (3-4). However, one can place equation (3-3) into equation (3-4) and substitute y_t^* in equation (3-4) with equation (3-3). By eliminating the equilibrium value of the dependent variable, the reduced form model will be as follows (Ferguson and Lim, 2005):

$$y_t = \delta.\alpha^0 + \delta.\sum_{i=1}^{n} \alpha^i.x_t^i + (1-\delta).y_{t-1} \tag{3-11}$$

Replacing the product of the parameters with the new set of notations results in equation (3-12) as below:

$$y_t = \beta^0 + \sum_{i=1}^{n} \beta^i.x_t^i + \beta^{n+1}.y_{t-1} \tag{3-12}$$

Equation (3-12) is a specific form of the auto-distributed lag model from which the other lags of the dependent variable have been excluded. By estimating the coefficients of equation (3-12), estimating the long-run parameters of the original partial adjustment model's coefficients is possible. The adjustment parameter δ can be calculated by equating the estimated coefficient of the dependent variable's lagged value in equation (3-12) and its coefficient in equation (3-11). In the long-run equilibrium, all the dependent variable values converge to a specific long-run equilibrium value. Hence, the dependent variable and its lagged value should be equal. Setting y_t equal to y_{t-1}, equation (3-12) can be written as below:

$$y_t = \beta^0 + \sum_{i=1}^{n} \beta^i.x_t^i + \beta^{n+1}.y_t \tag{3-13}$$

In this case, y_t is equal to y_t^* which is the equilibrium value of the dependent variable. Therefore, one may supplant y_t with y_t^*. Writing equation (3-13) based on y_t^*, equation (3-13) can be written as follows:

$$(1-\beta^{n+1})y_t^* = \beta^0 + \sum_{i=1}^{n} \beta^i.x_t^i \tag{14}$$

$$y_t^* = \frac{\beta^0}{(1-\beta^{n+1})} + \sum\nolimits_{i=1}^{n} \frac{\beta^i}{(1-\beta^{n+1})} . x_t^i \tag{15}$$

Equation (3-15) is the estimation of equation (3-3), and it will yield the coefficients of the long-run relationship between the independent exogenous variables and the dependent variable (Ferguson and Lim, 2005).

3-4-2- Error-Correction Models

Equation (3-12) resulting from the partial adjustment theoretical model is a limited form of the dynamic econometrics model specification known as auto-distributed lag models. The previous form did not have any lag of independent variables. Adding the lag of the independent variable yields a version of the auto-distributed lag model known as the general dynamic form. It is worth noting that the transformation process in this subsection follows Banerjee et al. (1996) and Ferguson and Lim (2005) with minor modifications in parameters and indices.

$$y_t = \beta^0 + \sum\nolimits_{i=1}^{n} \beta^i . x_t^i + \sum\nolimits_{i=1}^{n} \beta'^i . x_{t-1}^i + \beta^{n+1} . y_{t-1} \tag{3-16}$$

Equation (14) can be converted by adding y_{t-1} to the both side of it:

$$y_t - y_{t-1} = \beta^0 + \sum\nolimits_{i=1}^{n} \beta^i . x_t^i + \sum\nolimits_{i=1}^{n} \beta'^i . x_{t-1}^i + \beta^{n+1} . y_{t-1} - y_{t-1} \tag{3-17}$$

$$\Delta y_t = \beta^0 + \sum\nolimits_{i=1}^{n} \beta^i . x_t^i + \sum\nolimits_{i=1}^{n} \beta'^i . x_{t-1}^i + (\beta^{n+1} - 1) . y_{t-1} \tag{3-18}$$

Then, subtracting and adding $\sum_{i=1}^{n} \beta^i . x_{t-1}^i$ to the left-hand side of equation (3-15) and reorganizing the terms result in the below equations (Banerjee et al., 1996; Ferguson and Lim, 2005):

$$\Delta y_t = \beta^0 + \sum\nolimits_{i=1}^{n} \beta^i . x_t^i + \sum\nolimits_{i=1}^{n} \beta'^i . x_{t-1}^i + (\beta^{n+1} - 1) . y_{t-1} - \sum\nolimits_{i=1}^{n} \beta^i . x_{t-1}^i + \sum\nolimits_{i=1}^{n} \beta^i . x_{t-1}^i \tag{3-19}$$

$$\Delta y_t = \beta^0 + \sum_{i=1}^{n} \beta^i . x_t^i + - \sum_{i=1}^{n} \beta^i . x_{t-1}^i + \sum_{i=1}^{n} {\beta'}^i . x_{t-1}^i + \sum_{i=1}^{n} \beta^i . x_{t-1}^i + (\beta^{n+1} - 1). y_{t-1} \tag{3-20}$$

$$\Delta y_t = \sum_{i=1}^{n} \beta^i . \Delta x_t^i + \left[(\beta^{n+1} - 1). y_{t-1} + \beta^0 + \sum_{i=1}^{n} (\beta^i + {\beta'}^i) . x_{t-1}^i\right] \tag{3-21}$$

$$\Delta y_t = \sum_{i=1}^{n} \beta^i . \Delta x_t^i + (\beta^{n+1} - 1). \left[y_{t-1} + \frac{\beta^0}{(\beta^{n+1} - 1)} + \sum_{i=1}^{n} \frac{(\beta^i + {\beta'}^i)}{(\beta^{n+1} - 1)} . x_{t-1}^i\right] \tag{3-22}$$

$$\Delta y_t = \sum_{i=1}^{n} \beta^i . \Delta x_t^i + (\beta^{n+1} - 1). \left[y_{t-1} - \frac{\beta^0}{(1 - \beta^{n+1})} - \sum_{i=1}^{n} \frac{(\beta^i + {\beta'}^i)}{(1 - \beta^{n+1})} . x_{t-1}^i\right] \tag{3-23}$$

Substituting the coefficients inside the brackets with γ^i as a new representative results in equation (3-24) below:

$$\Delta y_t = \sum_{i=1}^{n} \beta^i . \Delta x_t^i + (\beta^{n+1} - 1). \left[y_{t-1} - \gamma^0 - \sum_{i=1}^{n} \gamma^i . x_{t-1}^i\right] \tag{3-24}$$

$$\Delta y_t = \sum_{i=1}^{n} \beta^i . \Delta x_t^i + (\beta^{n+1} - 1). \left[y_{t-1} - (\gamma^0 + \sum_{i=1}^{n} \gamma^i . x_{t-1}^i)\right] \tag{3-25}$$

The term inside the parenthesis in the equation (3-25) is indeed the long-run equilibrium relationship similar to equation (3-3) and (3-15). By substituting the term in the parenthesis with y_{t-1}^*, equation (3-25) can be rewritten as below:

$$\Delta y_t = \sum_{i=1}^{n} \beta^i . \Delta x_t^i + (\beta^{n+1} - 1). [y_{t-1} - y_{t-1}^*] \tag{3-26}$$

Equation (3-26) is a form of dynamic econometrics models known as error-correction models. It means that the change of the dependent variable between two consecutive periods depends on the changes in exogenous variables as well as the discrepancy between the dependent variable's actual value and its equilibrium level in the previous period. The latter term is known as the error correction term, which shows the dependent variable's tendency to cover the existing gap between its actual value and desired value. In equilibrium point, y_{t-1} equates y_{t-1}^*, and there would be no error and no need to change. Therefore, change terms would equate to zero too. If one sets the coefficients of lagged independent variables (${\beta'}^{i}$) to zero, the lagged version of independent variables is not entered into the model and thus, γ^{i} coefficients will be the same as coefficients in equation (3-15). This identity implies that error-correction form is the transformation of the partial adjustment model.

3-5- Dynamic Models of Property Market

De Leeuw and Ekanem (1973) developed one of the first dynamic models of the housing market. Their purpose was to analyze the effect of three major housing market components' adjustment speed on the emergence of different behavioral patterns in the rental housing market. The three Types of decision-makers whose behavior affects the housing market behavior are households, landlords, and developers. The speed of decision making and implementation in each of these groups affects the housing market output. Therefore, different combinations of components' speed will result in different housing market behavioral patterns to approach the long-run equilibrium. The main theoretical tool to model the behavior of each market component is the partial adjustment mechanism. Thus, first, they specified a behavioral model that determines the equilibrium/desired level of variables upon which each component intends to decide. These variables are housing service consumption and housing rent. Second, they defined an adjustment mechanism through which it is possible to capture each components' behavior in decision making, by changing the adjustment parameters. The adjustment mechanism was defined for the housing service consumption, housing rent, and housing stock. The model structure is discussed for each component of the housing market below. Equation (3-27) and (3-28) define the partial adjustment of housing demand.

$$S_t^* - H_t = \alpha + \beta_1 . Y_t - \beta_2 . (R_t - P_t) \tag{3-27}$$

$$\Delta(S_t + K_t - H_t) = \lambda_1 . [(S_t^* - H_t) - (S_{t-1} + K_{t-1} - H_{t-1})] \tag{3-28}$$

In which, S_t^* and H_t stand for the equilibrium level of housing services and the number of households, respectively. Since all the variables are in the logarithmic format, $S_t^* - H_t$ represents the equilibrium level of housing service per household in period t. Y_t stands for real income per household. R_t and P_t represent the price of housing services and all other goods and services in general, respectively. Hence, the term $R_t - P_t$ is the relative price of housing services in terms of other goods and services in period t. Equation (3-28) defines the adjustment process of actual housing services per household towards its equilibrium/desired level determined by equation (3-27). Thus, the parameter λ_1 is the speed of demand adjustment. In equation (3-28), K_t is the fraction of housing stock available in period t to provide housing services. Therefore, the term $S_t + K_t - H_t$ is the actual housing services per household in period t and with Δ, the whole right-hand side of equation (3-28) represents the change of this term between two consecutive periods.

Equation (3-29) is a behavioral equation for the rent component similar to other partial adjustment models in which, R_t^*, Po_t, Pc_t, and $S_t - H_t$ represent the equilibrium housing rent, the price of operating inputs, the price of capital inputs, and the housing services per household in period t. The reason for including these variables in the rent equation is that in the equilibrium, the rent level should be equal to the marginal cost of each factor in producing housing services. However, de Leeuw and Ekanem (1973) introduced some modifications, specifically in the adjustment equation. Two terms were added to the rent adjustment equation. The term in the bracket is comprised of Pc_t and $\overline{Pc}_t$ with the latter one being the weighted average of capital input price of the current period and previous periods. They include this term to offset the effect of the current capital input price on the equilibrium rent. If the house has been built or remodeled recently, the effect of capital input price should be weakened in the equilibrium rent. The last term represents the effect of utilized housing stock for providing housing services. Including this term is an attempt to incorporate the effect of vacancies in changing the rent level. When all the stock is utilized by the household, which happens in equilibrium, the term will be zero (since it is the logarithm of one) and has no effect on changing the rent.

$$R_t^* = \beta_0 + \beta_1 . Po_t + \beta_2 . Pc_t + \beta_4 . (S_t - H_t) \tag{3-29}$$

$$\Delta R_t = \lambda_2 . (R_t^* - R_{t-1} - \beta_3 . [Pc_t - \overline{Pc}_t]) + \alpha_1 . K_t \tag{3-30}$$

$$\overline{Pc}_t = \gamma_2 . Pc_t + (1 - \gamma_2) . \overline{Pc}_t \tag{3-31}$$

The last equation of the model defines the change in the current housing stock based on the housing market profitability. Since the equilibrium rent defines the level of rent, which is equal to the marginal cost of housing services production, it can be regarded as the marginal cost of production. Hence, the difference between the equilibrium rent and the actual rent defines marginal profit in the housing market. The stock will increase until the period in which the actual rent equates the equilibrium rent (marginal cost of production), and the profit is zero. Equation

(3-32) is indeed a Marshallian type of market adjustment. Their model is symmetrical regarding the construction of new stock and the depreciation of old stocks.

$$S_t - S_{t-1} = \lambda_3.(R_t - R_t^*) \tag{3-32}$$

De Leeuw and Ekanem (1973) run simulations using empirical data on some of the parameters, setting the range of values for adjustment parameters, and defining a change in four exogenous variables in the model. The four exogenous variables were income level, number of households, capital inputs prices, and operating inputs prices. De Leeuw and Ekanem (1973) administered shocks to the model by changing these sets of exogenous variables one by one and considering two modes of speed for adjustment parameters, namely, slow and fast for each one. To validate the results, they built a regression model based on panel data of four metropolitan areas in the USA. They regressed the changes of rents to lagged values of changes in the four exogenous variables in the theoretical model used for simulation. The cumulative effect of the change in each independent variable compared with the effect of the same variable on the changes in rent level after three years (the long-run period in the model) under different assumptions about the speed of adjustment parameters. For nearly all adjustment parameters, the slow adjustment values provided more consistent results with the regression analysis. Moreover, they ran simulations using real data from four metropolitan areas and compared to the real rent trends in them. The overall trajectories were similar, with less variation.

Barras (1983) is probably the first who applied the accelerator principle of investment to build a dynamic model of the office market. Although his work is on the office market, he expanded this model in his subsequent works to explain the building cycles in all sorts of the property market, including the housing market. Therefore, it is worthwhile to ponder on his work. As the accelerator principle has been used successfully to explain the business cycles, he used it to determine the main parameters that provide the office market's endogenous cycles. On this basis, the capital good is the office market's floor area, for which the demand depends on firms' output level as an exogenous variable. Hence, the first two equations of the model are the same as the flexible accelerator model discussed above (see equations (3-36) and (3-37)). He expanded the model by defining the total development orders as the summation of the order for the new development and replacing the depreciated stock (see equation (3-38)). Based on this, the model is asymmetric with regard to the building of new stock and the depreciation of the old stock. He introduced an r-period lag between the total development orders and the completion of orders (equation (3-39)). In the end, the current total stock is the previous stock plus the completed development orders minus the depreciated part of the previous period stock (see equation (3-40)):

$$K_t^* = \alpha . Q_t \tag{3-36}$$

$$D_t^n = \mu . (K_t^* - K_{t-1}) \tag{3-37}$$

$$D_t = D_t^n + \delta . K_{t-1} \tag{3-38}$$

$$C_t = D_{t-r} \tag{3-39}$$

$$K_t = (1 - \delta). K_{t-1} + C_t \tag{3-40}$$

By combining equations (3-36) to (3-40), the model is reduced to equation (3-41) and its equivalent equation (3-42).

$$K_t - (1 - \delta). K_{t-1} + (\mu - \delta). K_{t-r-1} = \alpha . \mu . Q_t \tag{3-41}$$

$$D_t - (1 - \delta). D_{t-1} + (\mu - \delta). D_{t-r-1} = \alpha . \mu . [Q_t - (1 - \delta). Q_{t-1}] \tag{3-42}$$

By setting r equal to one, the difference equation model is analytically solved. The analytical solution leads to identifying the contributing parameters responsible for the change in the office market's cyclical behavior. These parameters are the construction time, depreciation rate, and capital adjustment rate.

The model has the same limitations as the flexible accelerator model. The output price (the price of Q) and the rental price of office space, which defines the profitability of the production sector (the production of Q), may affect the demand for output. The model assumes the output demand as an exogenous variable. Omitting the price mechanism from the demand part of the model (equation (3-36)) converts the capital adjustment mechanism in equation (3-37) to an approximation of the development process, accounting for the effect of profitability on the new development. Omitting the office rental price as a contributing factor in equation (3-36) leads to the omission of the construction costs and land price. Hence, the nonlinear relationship between the components of profitability is reduced to the linear relationship between excess capital demand and new development (Barras, 1983: 1392). When the output demand is high and its production needs more capital goods (floor area of office space) than the status quo office space, the development of new office space is profitable. The other point is related to equation (3-38). The implicit assumption behind this equation is that the depreciated stock of the previous period will be compensated for by reconstruction in the current period. This is not a binding assumption, and one can omit the term $\delta.K_{t-1}$ from equation (3-38) since its effect is incorporated into the model by entering the term in equation (3-40).

In further developing the above model, Barras and Ferguson (1987a) provided a more robust theoretical base prior to the theory of the accelerator principle. They moved from a more comprehensive theoretical model as a base and reduced it to the accelerator principle. They tried to connect the accelerator principle and the general microeconomics theory of the property market. In their static theoretical model, the market of all property types (commercial, residential, and industrial) consists of two submarkets: the investment market and the user market. In the supply side of the investment market, developers develop new buildings. On the demand side of the investment market, the financial institutions invest in the newly developed property as assets. The construction level by developers d^{S} depends on the profitability of development, which is defined by the property price u including labor costs, interest rate, and land prices. The amount of new constructions d^{D} on which the institutions decide to invest depends on their yield (r/v) in the property market compared to the expected yield w from the other rival markets and the supply of the financial capital f for investment. The mathematical expression of the investment market is as follows.

$$d^{\mathrm{S}} = \mathrm{d}^{\mathrm{S}}(v, u) \tag{3-43}$$

$$d^{\mathrm{D}} = \mathrm{d}^{\mathrm{D}}(v, r, f, w) \tag{3-44}$$

The financial institutions are on the supply side of the user market. They lease the completed new buildings to the users. Hence, the supply of completed constructions depends on the same variables as in equation (3-44). On the other side of the user market, demand for the property depends on the users' income and the rent they pay. The mathematical expression of the user market is as follows.

$$c^{\mathrm{S}} = \mathrm{c}^{\mathrm{S}}(v, r, f, w) \tag{3-45}$$

$$d^{\mathrm{D}} = \mathrm{d}^{\mathrm{D}}(r, q) \tag{3-46}$$

The equality of demand-side and supply-side equations in each submarket leads to two equations for the property's rental price in the two submarkets. Barras and Ferguson (1987a) called them yield relationships since they give the relationship between the rent and the property's value:

$$r = y_d(v) \tag{3-47}$$

$$r = y_c(v) \tag{3-48}$$

As an equilibrium condition, setting equation (3-47) and (3-48) equal, the equilibrium price and rent can be defined. This kind of equilibrium does not mean that the quantity demanded and supplied are also in equilibrium. All the equations (3-43) to (3-46) should be set as equal to each other in the long-run. Combining the equations yields equation (3-49) expressing the long-run equilibrium new construction as a function of property value, rent, the supply of investment capital, construction input costs, alternative investment market yield, and user income.

$$b = \mathrm{b}(v, r, q, f, u, w) \tag{3-49}$$

Barras and Ferguson (1987) concluded that by assuming the constant value for all explanatory variables except the user income, the equilibrium relationship could be limited to equation (3-50).

$$b = \mathrm{b}(q, x) \tag{3-50}$$

Considering that the user income depends on the user activity and its level of output, equation (3-50) is indeed the equivalent of equation (3-36) in Barras's (1983) original model. They used that model as a base for defining the specification of the empirical model they intended to estimate. Considering equation (3-42) as Barras's (1983) model, they converted it to an error-correction model by expanding and regrouping the variables.

$$\Delta D_t - (\mu - \delta).D_{t-1} = \alpha.\mu.\Delta Q_t - \mu.(D_{t-1} - \alpha.\delta.Q_{t-1}) \tag{3-51}$$

The term in the right-hand side parenthesis is an error term defining the long-run relationship between the amount of new development and the output level in the long-run equilibrium. Further, they transformed this basic specification into a logarithm format. In the final version, they expanded it by adding more lags of change in output ΔQ and lags of changes in other variables Δx omitted from the theoretical model due to using the accelerator principle. These lags were added to show that the dynamic relationship between changes in the dependent variable and independent variables can last over several periods (Barras and Ferguson, 1987a: 365). Barras and Feguson's (1987a) work is an important contribution to dynamic modeling of the property market. It is the first work to explicitly derive the error-correction specification from a theory related to the property market, and to empirically estimate the specified relationships (Barras and Ferguson, 1987b).

DiPasquale and Wheaton (1994) developed a dynamic model of the owner-occupied housing market in the United States and revised the conventional stock-flow models of the housing market. The general structure of these models is in the form of a two-equation model. The first equation is a stock equation resulted from equating the demand equation with the amount of supply. This equation yields the equilibrium price of the housing market. The second equation is a flow equation determining the change in supply due to new construction and stock depreciation. Hence, the implicit assumptions behind these models have been that this is the supply of housing that gradually changes through new construction and depreciation, while the housing price adjusts instantaneously to equate demand with the supply of housing (existing stock). Applying the original symbols used by DiPasquale and Wheaton (1994), the typical structure of a housing stock-flow model is as follows.

$$D(X_1, P, U, R) = S \quad (3\text{-}52)$$

$$\Delta S = C(X_2, P) - \delta S \quad (3\text{-}53)$$

In which, the housing demand D depends on the real price level of housing P, the user cost of homeownership U, alternative cost of renting (this is the annual cost of the owner-occupied only alternative) R, exogenous variables X_1 (such as demographic characteristics and real permanent income). On the other hand, the existing stock S changes by new construction C depending on exogenous variables being effective on supply, including production factors' prices and interest rates X_2 and housing prices, and by depreciation rate δ. Representing in the conventional difference equation format turns the above equations as below.

$$D_t(X_{1t}, P_t, U_t, R_t) = S_t \quad (3\text{-}54)$$

$$\Delta S = S_t - S_{t-1} = C_t(X_{2t}, P_t) - \delta S_{t-1} \quad (3\text{-}55)$$

Their revision of the stock-flow model of the housing market is based on the evidence from empirical works contradicting the model's assumption of the instantaneous clearing of the market by price. The empirical evidence showed serial correlations in the housing prices time series, implying the gradual movement of housing prices rather than an instant change to a market-clearing value. To incorporate the gradual adjustment of housing prices, DiPasquale and

Wheaton (1994) added a partial adjustment equation to the conventional structure of the stock-flow housing models.

$$\Delta P = \tau[P^* - P] \tag{3-56}$$

Moreover, regarding $C(X_2, P)$ in equation (3-53) and (3-55), they pointed out the lack of economic theory about the new construction or construction flow. On this basis, they used a partial adjustment structure in the supply side of the model, similar to the main structure of Barras's model. However, instead of using the accelerator principle, they wrote the equation for the total equilibrium supply of housing S^* as a function of prices and exogenous variables (Equation (3-59)). The term inside the bracket and its coefficient is the reduced form of the familiar partial adjustment model. It is different from Barras's model since DiPasquale and Wheaton (1994) added the price and cost shifters as the independent variables instead of counting on the output level. The reason is that in Barras's model of the office market, the output level encompassed all the changes in the demand side, but in DiPasquale and Wheaton's model, the demand was separately modeled, and supply was modeled using the supply-changing variables. For clarity, equations (3-57) and (3-58) are added to their original formulation.

$$S^* = S^*(X_2, P) \tag{3-57}$$

$$C = \alpha.(S^* - S) \tag{3-58}$$

$$\Delta S = C - \delta S = \alpha.(S^* - S) - \delta S \tag{3-59}$$

They estimated the model's equations and used it to forecast the movement of price and construction in the owner-occupied housing market.

Alm and Follain (1994) developed a structural model of the rental housing market to evaluate the impact of major shocks like tax policies on the asset price of rental housing. To avoid previous studies' ad hoc assumptions about the adjustment speed, Alm and Follain tried to clarify the impact of adjustment speed on tax policies' effect on the asset price of rental housing.

Their model consists of four equations, some of which change due to the alteration of assumptions. The demand equation specifies the demand for rental housing as a function of income Y_t and the rent R_t. This equation is an inverse demand function which defines the rental price based on the income level and the demanded stock (equation (3-60)).

$$R_t = a_0 + a_1.K_t + a_2.Y_t \tag{3-60}$$

Based on the stock adjustment equation, the total stock in each period is equal to the previous period stock modified by the new construction C_t and the depreciation of the previous period stock. Equation (3-61) is the same as equation (3-55). In which, d is the depreciation rate.

$$K_t = (1 - d).K_{t-1} + C_t \tag{3-61}$$

Equations (3-60) and (3-61) define the supply of and demand for housing. The assumption behind these equations is that the market clearance happens in each period due to the instant rental adjustment, to equate the amount demanded with the existing stock of rental housing K_t.

The construction equation defines the construction as a function of the difference between the asset price of housing and the replacement cost P^* (equation (3-62)). The discrepancy between the actual price and the replacement cost is, indeed, the construction profit. In equation (3-62), α is defined as the responsiveness of the construction per period to the construction profit. When the profit is positive, developers embark on construction, and when it is zero, the construction is zero. This negative profit in the first version of the model is interpreted as changing the rental stock to owner-occupied stock or non-residential properties (Alm and Follain, 1994: 123). Equation (3-62) is similar to DeLeeuw and Ekanem's formulation for construction, however, with two differences. In the latter, the negative construction also encompassed the depreciated stock. The other difference is related to the replacement cost. In the former, the long-run replacement cost, which is the long-run equilibrium housing price, is defined by a behavioral equation. However, in the latter, it is defined exogenously, which implicitly means it is assumed to be fixed.

$$C_t = \alpha.(P_t - P^*) \tag{3-62}$$

The fourth equation yields the asset price of rental housing (equation (3-63)). The asset price is written as the present value of the expected flow of future net income of the asset. In their formulation, the net income is equal to future rents minus the depreciated asset value of the housing stock. Here, r is the interest rate.

$$P_t = \sum_{i=1}^{\infty} \left[(R_{t+i} - d.P_t)/(1 + r)^i \right] \tag{3-63}$$

Alm and Follain (1994) solved this system of equations analytically and numerically under different assumptions about the market clearing, the possibility of negative new construction, and the formation of expectations about the future rents. In the first set of assumptions, they assumed that people have perfect foresight about the future rents, which means predicting the future stream of rents as they will emerge. Also, rents adjust so that the market clears in each period. Lastly, volumes of new construction can be both negative and positive. Then, they changed each of these assumptions and solved the model. These three assumptions change three equations of the model. The perfect foresight assumption affects equation (3-63), which means that people can predict the movement of the market. Hence, the expected future is equal to the actual future net income. This assumption turns the equation (3-63) to equation (3-64).

$$P_t = (1 + r).P_{t-1} - [r/(d + r)].R_t \quad (3\text{-}64)$$

Regarding the non-market clearing model, they distinguished between the demanded stock and supplied stock. Moreover, they added the Walrasian adjustment process with regard to rent levels. This process means that the housing rent will not adjust instantly to equalize the demand and supply and clear the market. By incorporating equation (3-65), the model turns to a disequilibrium model. Following this change, equations (3-60) and (3-61) change to substitute K_t with K_t^D and K_t^S, respectively.

$$(R_t - R_{t-1}) = \emptyset.(K_t^D - K_t^S) \quad (3\text{-}65)$$

Alm and Follain (1994) set the perfect foresight expectation aside and supplanted it with the partial rent adjustment: the rent in each period adjusts partially towards the equilibrium rent level. They did not address the myopic expectation as an alternative for the perfect foresight. However, a problem with this model is the assumption of fixed replacement cost, which leads to the fixed equilibrium rent level.

Malpezzi (1999) is most likely the first work that investigated the effect of regulations on the dynamic behavior of the housing market. In order to address this issue, he used the error-correction format for his model. However, his application of the error-correction format is different from that in other studies. Importantly, the variable used in the long-run equilibrium relationship and the error-correction term is not the same as the dependent variable in the error-correction equation. In Malpezzi's model, the former is the house-price-to-income ratio, and the latter is the change in the housing prices. Based on the equilibrium equation, there is a long-run relationship between the house-price-to-income ratio and its determinants, including regulations (equation (3-66)).

$$k_t^* = \delta . Z_t \tag{3-66}$$

In which, k_t^* is the equilibrium level of housing price-to-income ratio in period t, Z_t denotes a vector of determinants of k, and δ is a set of corresponding parameters. Having the long-run relationship, Malpezzi wrote the dynamic relationship in two versions as below:

$$\Delta P_t = \beta_0 + \sum_{i=1}^{n} \beta_i . \left(\frac{P_{t-i}}{Y_{t-i}} - k_{t-1}^* \right) + \alpha . X_t \tag{3-67}$$

$$\Delta P_t = \beta_0 + \sum_{i=1}^{n} \beta_i . \left(\frac{P_{t-i}}{Y_{t-i}} - k_{t-1}^* \right) + \sum_{i=1}^{n} \gamma_i . \left(\frac{P_{t-i}}{Y_{t-i}} - k_{t-1}^* \right)^3 + \alpha . X_t \tag{3-68}$$

He incorporated more lags of the error term and added its cubic form to test how much the departure from the equilibrium can affect the price change. In equations (3-67) and (3-68), Y_{t-i} is the income level ith period before the current period, X_t is a vector of market conditions including the regulatory environment, and α is a set of parameters in correspondence with the vector of market conditions. Other variables in X_t are geographical variables (in dummy variable form), per capita income and its growth rate, population and its growth rate, and the nominal mortgage interest rate.

His estimation of the equilibrium relationship satisfied the theoretical expectations about the significance and sign of the parameters. Specifically, the more stringent regulatory environment is tied to higher housing price-to-income ratio. Regarding the error-correction equation, the preliminary estimations showed that the simple error-correction model with one lag and without cubic terms was the most proper specification. Estimating this simple error-correction version showed that all the variables in the error-correction model have the expected sign and significance except the regulation index. Malpezzi (1999) attributed this unexpected result to the application of instrumental variables instead of the direct usage of the regulation stringency index and the incorporation of fixed effects, which may capture the effect of each city's regulations. The other hypothesis that Malpezzi (1999) tested was the effect of the restrictiveness of the regulatory environment on the speed of the adjustment of housing prices towards equilibrium. He found that with a more restrictive regulatory environment, the adjustment process would be slower. He tested this hypothesis in two ways; first, by estimating two different models for two samples by splitting the original sample based on the stringency of regulations, and second, he used the interaction between the disequilibrium term and the regulation index.

Tu (2004) developed a dynamic model of the housing market, structurally based on Dipasquale and Wheaton's (1994) work with some modifications. He took the adjustment parameter of housing stock (α in equation (3-58)) as a function of housing price changes through the time. The reason for this choice is that in higher housing prices, the speed of adjustment with which housing stock adjusts towards the equilibrium level increases. He also applied the log-form of variables for the new construction equation. Hence, all the coefficients can be interpreted as elasticities. However, Tu (2004) did not consider the standard formulation of the partial adjustment models since instead of using the lagged value of the housing stock, he used the current stock. These modifications are represented in the below equations of new construction.

$$C_t = \lambda_t(P_t).[S_t(P_t^*) - S_t] \quad (3\text{-}69)$$

$$\log(C_t) = \log[\lambda_t(P_t)] + \log\{[S_t(P_t^*) - S_t]\} \quad (3\text{-}70)$$

$$\log(C_t) = \gamma_0 + \gamma_1.P_t + \rho.S_t + \gamma_2.X_{2t} \quad (3\text{-}71)$$

In which, $\lambda_t(P_t)$ represents the adjustment variable as a function of the current price. Equation (3-71) is the completed transformed version in which all the right-hand side variables are in the logarithmic version of the variables in equation (3-70). The other difference between the two works is related to the procedure of estimation. Reducing the model to two equations, one for the housing price and the other for the new construction, Tu (2004) applied the error-correction modeling in which the theoretical specifications derived for housing prices and new construction served as the co-integration vector. The reason was the non-stationarity of the data, and that all the variables were cointegrated of order one.

Malpezzi and Maclennan (2001) introduced a dynamic model of the housing market to estimate the price elasticity of new supply. Their model uses the partial adjustment mechanism as its backbone and, in this sense, shares a common ground with DiPasquale and Wheaton's (1994) work. However, the two models are slightly different. As DiPasquale and Wheaton (1994) mentioned, since there is no specific theory about the new construction, they used the partial adjustment mechanism between desired total stock and actual stock in which the latter adjustment towards the former yields the new construction (Equation (3-58)). Tu (2004) modified it by setting the adjustment parameter as a function of the housing price level (Equation (3-69)).

Malpezzi and Maclennan (2001) defined the new construction Q_{St} as a direct linear function of the housing price P_t (Equation (3-73)). They set the adjustment mechanism equal to excess demand Q_{Dt} (Equation (3-71)) instead of new construction as it is in DiPasquale and Wheaton's model. Its equality with new construction is a condition for long-run equilibrium in Malpezzi and Maclennan's model. The other difference is the lack of price adjustment mechanisms in Malpezzi and Maclennan's model. Here, the housing price adjusts instantaneously to equate the excess demand with the new supply. Hence, the market clears instantly. The new market-clearing price determines the desired level stock K_t^* (Equation (3-72)) being both long-run equilibrium supply and demand and the trigger for the demand adjustment process.

$$Q_{Dt} = \delta.(K_t^* - K_{t-1}) \tag{3-71}$$

$$K_t^* = \alpha_0 + \alpha_1.P_t + \alpha_2.Y_t + \alpha_3.D_t \tag{3-72}$$

$$Q_{St} = \beta_0 + \beta_1.P_t \tag{3-73}$$

$$Q_{Dt} = Q_{St} \tag{3-74}$$

In which, δ, Y_t, and D_t stand for the demand adjustment parameter, household income, and the number of population in period t.

Further, Malpezzi and Wachter (2005) used Malpezzi and Maclennan's model as a base to develop a new model for testing whether speculation is the symptom of price cycles in the real estate market or a cause of it. They provided two versions of the model. The first version was similar to the original one except for adding a lagged value of the housing price in the new supply equation. They also simplified the desired stock equation by assuming that for the known level of income and population number, there is a known demand D, which is subject to exogenous shocks. Moreover, for simplicity, they dropped the intercepts. Although this is not technically problematic since it makes all the difference equations homogeneous, it can be conceptually problematic for the equation of new supply. This equation states that the quantity of new supply depends on the housing price level. Without an intercept, it means there will always be the new supply except for the zero-price situation, which is theoretically impossible. Hence, equation (3-77) is conceptually correct only with a negative intercept. The last change to the original model was using the logarithmic version of all variables except for the actual and desired stocks. The first version of the model without accounting the specification is as follows:

$$Q_{Dt} = \delta.(K_t^* - K_{t-1}) \tag{3-75}$$

$$K_t^* = D_t + \alpha_1.P_t \tag{3-76}$$

$$Q_{St} = \beta_0 P_t + \beta_1.P_{t-1} \tag{3-77}$$

$$Q_{Dt} = Q_{St} \tag{3-78}$$

Reducing all the equations gives the following difference equation.

$$P_t = \left(\frac{-\beta_1}{\beta_0 - \delta.\alpha_0}\right).P_{t-1} + \left(\frac{\delta}{\beta_0 - \delta.\alpha_0}\right).D_t - \left(\frac{\delta}{\beta_0 - \delta.\alpha_0}\right).K_{t-1} \tag{3-79}$$

In the second version of the original model, Malpezzi and Wachter (2005) incorporated the notion of speculation. For this purpose, they changed the demand equation by adding the effect of price change. On this basis, the long-run demand is the negative function of the price level and the positive function of the recent price change (Equation (3-80)).

$$K_t^* = D_t + \alpha_1.P_t + \alpha_2.(P_t - P_{t-1}) \tag{3-80}$$

Replacing equation (3-76) with (3-80) and reducing the equations yields the following difference equation for the speculative version of the dynamic model:

$$P_t = \left(\frac{-\beta_1 - \delta.\alpha_2}{\beta_0 - \delta.\alpha_0 - \delta.\alpha_2}\right).P_{t-1} + \left(\frac{\delta}{\beta_0 - \delta.\alpha_0 - \delta.\alpha_2}\right).D_t - \left(\frac{\delta}{\beta_0 - \delta.\alpha_0 - \delta.\alpha_2}\right).K_{t-1} \tag{3-81}$$

Through the simulation, by giving a demand shock, they found that the market is more volatile in the inelastic case. By volatility, they meant the amplitude of price changes due to the initial shock rather than the number of fluctuations. However, considering the number of fluctuations, it is clear that the inelasticity of supply reduces the number of oscillations. Moreover, in the inelastic supply case of the market, speculation has no significant effect on the volatility. Based on this, speculation matters only in the inelastic housing markets, and policies should focus on the efficiency of the supply side (in their viewpoint, the supply of land) and regulatory environment. Despite pointing out the inelastic supply as responsible for the market volatility, its effect is not decomposed to its assumed elements, the supply of developable land (elasticity of land supply) and stringency of the regulatory environment.

To reveal the underlying factor behind the cycles of the property market, Wheaton (1999) developed a stock-flow model of the office market through experimentation. However, his model is entirely different from Barras's work. He based it on the supply and demand principle rather than the accelerator principle. The demand for office space depends on the rental price of the office space as an endogenous variable, and the employment level as an exogenous factor (equation (3-82)). Following the stock-flow conventional form as described in DiPasquale and Wheaton (1994), he set the demand equal to supply for deriving the equilibrium rent (Equation (83)). The exogenous component of the demand was taken as constant to give a one-time shock to the demand in the simulations. The office stock varies by the two sources of change: depreciation rate and the new construction (Equation (3-84)). Here, Wheaton (1999) tried to base the new construction on a basis different from that DiPasquale and Wheaton (1994) used in their model. Similar to Malpezzi and Maclennan (2001), the new construction depends on the price level. However, instead of the absolute level of new construction, the rate of new construction is in a proportional relationship with the price level. In other words, the growth rate of the stock of space depends on the price of the space (Equation (3-85)). Although he pointed out the lack of floor (minimum) price which is indeed the construction costs of the space, Wheaton did not enter it into the formulation due to the mathematical convenience.

The other difference is related to the equation in which price affects the new construction. In the previous models, the price at the time of starting the construction affects the new construction. In Malpezzi and Wachter (2005), price levels in previous periods can affect the new supply in period t. Wheaton (1999) incorporated expectations about prices to show how rational expectations compared to myopic behavior can affect market behavior. He first proved that rational expectation would not lead to oscillations in the prices unless the exogenous variable has an oscillatory behavior. However, the myopic behavior leads to an equation with higher-orders depending on the construction lags, which can result in oscillatory behavior even if the exogenous behavior does not show a fluctuating trajectory. In the format of myopic expectation Wheaton used, people expect the price level in the period of completed construction to be the same as the price level at the start. The price in n period before the completion of the construction was estimated using the rent in the same period. On this basis, the expected price level, which affects the construction rate, is yielded by equation (3-86).

Combining equation (3-83) to (3-86) yields the final model (equation (3-87)). Due to the complexities of the model preventing the analytical solution, Wheaton used numerical solutions and simulated the behavior of the office market under different assumptions about market elasticities, the construction lag, and the depreciation rate. To calibrate the remaining parameters, he first defined a steady-state mirroring the aggregate office market of the largest 54 U.S. metropolitan areas and, secondly, scaled up the two remaining parameters (α_1, α_2). Results of simulations demonstrated that oscillations are more frequent in the event of higher supply elasticity in comparison with demand elasticity, longer development lags, and lower asset durability.

$$D_t = \alpha_1 . E_t . R_t^{-\beta_1} \tag{3-82}$$

$$R_t = (S_t/\alpha_1 . E_t)^{-1/\beta_1} \tag{3-83}$$

$$\frac{S_t}{S_{t-1}} = 1 - \delta + \frac{C_{t-n}}{S_{t-1}} \tag{3-84}$$

$$\frac{C_{t-n}}{S_{t-1}} = \alpha_2 . P_t^{\beta_2} \tag{3-85}$$

$$P_t = R_{t-n}/r \tag{3-86}$$

$$(P_{t+n}/P_{t+n-1})^{-\beta_1} = 1 - \delta + \alpha_2 . P_1^{\beta_2} \tag{3-87}$$

Barras's (2005) new model is the expansion of his original work (1983). Barras (2005) made some changes to his first model (Barras, 1983). One of the changes was dividing the total investment I_t into two types of investment, known as the induced investment I_t^n and the replacement investment I_t^r. The induced investment is the required investment to cover the new demand for space and the replacement investment is the required investment to replace the depreciated capital stock $\delta . K_{t-1}$. Instead of defining the total investment as the result of the partial adjustment of the previous period's capital stock towards the present desired level (equation (3-37)), he set the total investment to instantly adjust towards the discrepancy between the desired and the actual level of capital stock (equation (3-91)). The new development starts S_t partially adjusts towards the new investment through a coefficient called by Barras the reaction coefficient γ (Barras, 2005: 74). The accelerator principle is indeed applied to the total investment. In the first version, the accelerator principle was applied just to the induced investment.

$$I_t = I_t^n + I_t^r \tag{3-88}$$

$$I_t^n = K_t^* - K_{t-1} \tag{3-89}$$

$$I_t^r = \delta . K_{t-1} \tag{3-90}$$

$$I_t = K_t^* - (1-\delta) . K_{t-1} \tag{3-91}$$

$$S_t = \gamma . (K_t^* - (1-\delta) . K_{t-1}) \tag{3-92}$$

After that, he incorporated the vacancy as an intermediary connecting the building start rates to the rent. Through an extensive process of transforming difference equations, Barras demonstrated that the incorporation of rent will not change the model compared to the model that he had built based on the accelerator principle. He argued that such an identity between the results of the two models happens because of the assumption of inelastic demand, which implicitly means that the feedback relationship between the rent and demand for new space is omitted. He provided another version of the model that incorporated this feedback resulting in more complex behavior. On this basis, the second version of Barras's model is similar to Wheaton's model that has a feedback relationship.

Along with Tu (2004), Riddel (2004) tried to reformulate Dipasquale and Wheaton's (1994) partial adjustment model in the error-correction format. The difference was the decomposition of the supply-side and the demand-side effects on the housing market. Riddel wrote separate equations for the long-run equilibrium supply and demand based on the variables affecting each of them. The model is a multiple error-correction model. In equations (3-93) and (3-94), S_t^e is the long-run housing stock (housing supply and demand), P_t is the housing price in period t, $X_{s,t}$ is the vector of supply-shifter variables, and $X_{d,t}$ is the vector of demand-shifter variables.

$$S_t^e = S(P_t, X_{s,t}) \tag{3-93}$$

$$S_t^e = D(P_t, X_{d,t}) \tag{3-94}$$

Riddel (2004) further developed the critique for models that connected the new construction to the level of housing prices. Referring to Wheaton and DiPasquale (1994), she argues that the divergence from the equilibrium stock is the crucial factor for embarking on the construction. The zero-profit condition in long-run equilibrium is the reason for zero new construction or the construction which just compensates for the depreciated stock. Therefore, it is quite possible that cities with the high housing price level have lower construction rates than the construction rate of cities with lower housing price levels which is far from the equilibrium. Such reasoning is not new and as explained DeLeeuw and Ekanem (1973) incorporated it in their model previously. Based on this argument, Riddel followed DiPasquale and Wheaton (1994) in formulating the new construction as the stock adjustment process through which the total supply in the previous period moves to catch the long-run equilibrium stock defined in equations (3-93) and (3-94) separately by using the supply-side and the demand-side variables, respectively. The difference between their model and that of DeLeeuw and Ekanem is that the latter modelled the equilibrium price, in which the discrepancy between the current price and the equilibrium price is the force behind the change in the housing stock. Also, Riddel's model has one difference in the new supply equation with DiPasquale and Wheaton's work. She did not enter the depreciation rate separately. Hence, the difference between actual stock and equilibrium stock captures both the new construction and depreciation (equation (3-95)). In equation (3-95), α is the speed of stock adjustment. The price adjustment part of the model is exactly the same as DiPasquale and Wheaton's model (equation (3-96)).

$$\Delta S_t = \alpha.(S_t^e - S_{t-1}) \tag{3-95}$$

$$\Delta P_t = \tau.(P_t^e - P_{t-1}) \tag{3-96}$$

In order to make the source of disequilibrium clearer, Riddel (2004) wrote the stock adjustment and price adjustment equations in a multiple error-correction in which, ε_{t-1} and v_{t-1} are the disequilibrium terms for demand-side and supply-side, respectively. More precisely, each of these terms explains the discrepancy between the actual stock and the equilibrium (desired) demand and supply. 'γ_i's are coefficients representing the speed of stock adjustment towards its equilibrium level due to dis-equilibrating demand and supply shocks. ΔX_t is a vector of short-term changes in the other market variables. A similar equation based on the error-correction mechanism was defined for the price changes. Equations (3-99) and (3-100) are the disequilibrium terms.

$$\Delta S_t = \gamma_1.\varepsilon_{t-1} + \gamma_2.v_{t-1} + a'.\Delta X_t \tag{3-97}$$

$$\Delta P_t = \delta_1.\varepsilon_{t-1} + \delta_2.v_{t-1} + c'.\Delta X_t \tag{3-98}$$

$$\varepsilon_t = S_t^D - (\beta_{10} + \beta_{11}.P_t + \beta_{12}'.X_{d,t}) \tag{3-99}$$

$$v_t = S_t^S - (\beta_{20} + \beta_{21}.P_t + \beta'_{22}.X_{s,t}) \quad (3\text{-}100)$$

Capozza et al. (2004) developed a simple theoretical model based on the error-correction specification to discover the theoretical effect of mean-reversion and serial correlation parameters on the dynamic behavior of the housing market. Further, they estimated the model, letting parameters interact with factors theoretically expected to affect them using panel data of 62 metropolitan areas from 1979 to 1995. As explained before, the typical specification of error-correction models is of the below form.

$$\Delta P_t = \alpha.\Delta P_{t-1} + \sum_{i=1}^{n} \beta^i.\Delta x_t^i + \delta.(P_{t-1}^* - P_{t-1}) \quad (3\text{-}101)$$

Based on partial adjustment formulation from which the error-correction specification is derived, there is a long-run relationship between a vector of exogenous variables X and the price level (equation (3-102)). According to equation (3-15) and omitting the intercept for mathematical convenience, the long-run relationship can be written as below.

$$P_t^* = p(X_t) = \sum_{i=1}^{n} \frac{\beta^i}{(1-\beta^{n+1})}.x_t^i \quad (3\text{-}103)$$

Taking the first difference of equation (3-103) and rewriting it based on ΔX_t yields equation (104).

$$\Delta P_t^* = \sum_{i=1}^{n} \frac{\beta^i}{(1-\beta^{n+1})}.\Delta x_t^i \quad (3\text{-}104)$$

$$(1-\beta^{n+1}).\Delta P_t^* = \sum_{i=1}^{n} \beta^i.\Delta x_t^i \quad (3\text{-}105)$$

$$\gamma.\Delta P_t^* = \sum_{i=1}^{n} \beta^i.\Delta x_t^i \quad (3\text{-}106)$$

Replacing lagged exogenous variables in equation (3-106) with $\gamma.\Delta P_t^*$, the error-correction model changes as below.

$$\Delta P_t = \alpha.\Delta P_{t-1} + \gamma.\Delta P_t^* + \delta.(P_{t-1}^* - P_{t-1}) \quad (107)$$

Assuming that the equilibrium price is constant, Capozza et al. (2004) rewrote the equation (3-107) based on the equilibrium price. They solved the resulting second-order difference equation based on the model's parameters. They found that different combinations of parameters responsible for the mean-reverting and auto-correlated behavior of the price level define different types of the dynamic behavior of housing prices. The four types of behavior are convergent with oscillations, divergent with oscillation, convergent without oscillations, and divergent without oscillations.

They used equations (3-103) and (3-107) for estimating the autocorrelation and mean-reversion parameters. As Capozza et al. (2004) pointed out, there is a lack of well-developed theory for explaining mean-reverting and auto-correlated behavior of housing prices. However, they provided arguments in favor of the effectiveness and the direction of the impact of three factors on the adjustment process of housing prices. These factors include information costs, supply costs, and constraints, and expectations. For each of these factors, they introduced theoretically appropriate proxies to measure their effect. These proxies included population number, real income growth, real construction costs, and regulations. They hypothesized that "higher real income and population growth and a high level of real construction costs and regulation are expected to increase serial correlation. Higher real income growth, larger metro area size (population), and a lower level of real construction costs/regulation should increase mean reversion." (Capozza et al., 2004: 12).

For the estimation of equation (3-107), they used the result of estimating the long-run relationship to calculate the error-correction term and the first difference of equilibrium prices. To test the effect of three different factors varying across the metro areas and through the time, they modified equation (3-107). They incorporated three factors by interacting them with the main coefficients to capture the effect of place and time (equation (3-108)).

$$\Delta P_{kt} = \left(\sum_i \alpha_i . \left(Y_{i,kt} - \bar{Y}_i\right)\right) . \Delta P_{kt-1} + \left(\sum_i \beta_i . \left(Y_{i,kt} - \bar{Y}_i\right)\right) . \left(P^*_{kt-1} - P_{kt-1}\right) + \gamma . \Delta P^*_{kt} \qquad \text{(3-108)}$$

In which, $Y_{i,kt}$ is a vector of independent variables (factors), where i, k, t index the variable, city, and time, respectively. And $\bar{Y}_i$ represents the mean value of Y_i in the sample.

Estimating the equilibrium relationship showed that all the variables had the expected signs, and many had the expected magnitude. However, it was just the land supply index that had a significant negative effect on the equilibrium housing prices, and all other variables were not significant among regulation variables.

Estimating equation (3-108) demonstrated all the hypothesized relationships between three factors on the one hand and the mean-reversion and serial correlation parameters, on the other hand. However, the coefficients of regulatory variables interactions were not significant, and in the case of the land supply index, the sign of the coefficient contradicted the theoretical expectations. Furthermore, they used the estimated parameters of mean-reversion and serial correlation in the first theoretical model to simulate the housing market behavior when each of the two parameters deviates from their mean values.

Investigating previous works on the structural models of housing markets, Hwang and Quigley (2006) discerned three shortcomings, including ignoring the role of vacancies, unsatisfactory supply equations, and using national level time-series data for estimation. They built a structural model to account for all the three shortcomings of the previous works. The model consisted of three equations determining changes in housing prices, housing supply, and housing vacancies in the owner-occupied market. They estimated the model using panel data for 74 metropolitan areas for 14 years. The core of their model is DiPasquale and Wheaton's (1994) work. Hwang and Quigley (2006) used the same demand equation in Dipasquale and Wheaton's work.

$$D_t = D(P_t, UC_t, R_t, X_t^D) \quad (3\text{-}109)$$

Where D_t is the share of households with demand for owner-occupied housing in time t and is a function of housing price P_t, user cost UC_t, housing rent R_t, and a set of demand shifter variables X_t^D. However, in the equality of demand and supply, they incorporated vacancies.

$$H_t . D_t = OC_t = S_t - V_t = S_{t-1} + N_t - V_t \quad (3\text{-}110)$$

In which, H_t is the number of households in time t, S_t is the stock of housing in time t, V_t denotes vacancies, and N_t is the new construction in time t. Assuming log-linear form for equation (3-109), they took the logarithm of both sides of equation (3-110) and set these two equations equal and solve it for the market-clearing price. The resulting equation is the same as equation (3-54) in DiPasquale and Wheaton's model. However, they did more transformation by taking the first difference of the resulted equation which resulted in equation (3-111). They did the same transformation for other two main equations of their model.

$$\Delta p_t^* = \alpha_1^* . \Delta s_t + \alpha_2^* . \Delta v_t + \alpha_3^* . \Delta uc_t + \alpha_4^* . \Delta r_t + \alpha_5^* . \Delta h_t + \alpha_6^* . \Delta x_t^D \quad (3\text{-}111)$$

In which, all the lower-case variables are the logarithmic form of variables mentioned in equations (3-109) and (3-110). They also assumed the log-linear form for the price adjustment equation as below.

$$\log P_t - \log P_{t-1} = \delta.(\log P_t^* - \log P_{t-1}) \tag{3-112}$$

Taking the first difference of equation (3-112) and rewriting it using equation (3-111) yields the below equation for the housing price.

$$\Delta p_t = \alpha_1.\Delta s_t + \alpha_2.\Delta v_t + \alpha_3.\Delta uc_t + \alpha_4.\Delta r_t + \alpha_5.\Delta h_t + \alpha_6.\Delta x_t^D + \alpha_7.\Delta p_{t-1} \tag{3-113}$$

In which, for $i = 1, 2, 3, \dots, 6$, $\alpha_i = \delta.\alpha_i^*$ and $\alpha_7 = 1 - \delta$.

Regarding the new housing supply, Hwang and Quigley (2006) defined new supply as a function of changes in housing prices and changes in construction costs and macroeconomic conditions. On this basis, the new housing supply equation in their model is as follows.

$$\Delta s_t = \beta_1.\Delta p_t + \beta_2.\Delta v_t + \beta_3.\Delta c_t + \beta_4.\Delta f_t + \beta_5.REG_t + \beta_6.\Delta x_t^S + \beta_7.\Delta p_{t-1} \tag{3-114}$$

Where c_t, f_t, and x_t^S stand for construction costs, financing costs, and set of other supply shifters all in logarithmic form. Moreover, REG_t denotes the restrictiveness of local regulations. The third equation of their model modelling vacancies used the difference format of variables following the two other equations. They related the change in vacancies to changes in current prices, expected changes in future prices $E(\Delta p_{t+1})$, the variance of future price changes $V(\Delta p_{t+1})$, the level of new construction N_t, and a set of the other shifters of vacancies x_t^v.

$$\Delta v_t = \gamma_1.\Delta p_t + \gamma_2.N_t + \gamma_3.E(\Delta p_{t+1}) + \gamma_4.V(\Delta p_{t+1}) + \gamma_5.\Delta x_t^v \tag{3-115}$$

They added equation (3-115) since they expanded DiPasquale and Wheaton's model by incorporating vacancies as an endogenous variable. Estimating the three equations, most of the coefficients showed the expected signs and significance. Especially, the regulation index in the new supply equation had the expected negative sign. Another significant result was that in contrast to many previous studies before them, they empirically demonstrated the negative and significant effect of construction costs on the supply of new housing. Moreover, they run simulations using the simulated model to measure and compare the behavior of different housing markets in response to income shocks. They attributed the difference between the responses of the markets to the local supply condition affected by regulations. In markets with more stringent regulations, housing prices rise more in response to shocks and persist more over time. Besides, the new supply reacts more intensely in markets with less restrictive regulations.

Edelstein and Tsang (2007) developed a theoretical dynamic model of the residential housing market to reproduce the price dynamics and empirically test it. They intended to find which fundamental factors (and on what level along the national-local spectrum) have the highest impact on the housing market cyclical behavior. In their viewpoint, one of the weaknesses of previous studies on housing market dynamics has been the weak relationship between the theoretical model and the econometric specification used for the empirical estimation.

They developed a dynamic model that is based on the relationship between the housing rent, housing price, housing investment, and some exogenous macro-economic variables affecting demand for and supply of housing. Their model consists of three equations. The first equation is derived from the equilibrium relationship between housing rental and asset value (equation (3-116)). By taking a natural logarithm from both sides of the equilibrium relationship, they wrote it as a linear one (equation (3-117)). Considering that such equality holds in the long-run equilibrium, to hold the equality between the long-run equilibrium rent and the market price of housing in the short-run, they added two elasticity parameters for rent with respect to the price and capitalization rate (equation (3-118)). Taking the first difference of the equation (3-118) will yield the equation (3-119).

$$V = R/c \tag{3-116}$$

$$\ln R_t^* = \ln V_t + \ln c_t \tag{3-117}$$

$$\ln R_t^* = \delta_v . \ln V_t + \delta_c . \ln c_t \tag{3-118}$$

$$\Delta \ln R_t^* = \delta_v . \Delta \ln V_t + \delta_c . \Delta \ln c_t \tag{3-119}$$

The second key equation is a rental adjustment equation, which relates the change in the rents from one period to another with the gap between the market rent and the equilibrium rent and other fundamental demand shifters. This specification's logic is that in the short-run that supply is inelastic, the rent level depends on the demand-side shock and the amount of discrepancy between the equilibrium rent and the actual rent. These two effects are shown in the equation (3-120).

$$\Delta \ln R_t^* = f(D_{t-1}) + w . (\ln R_t^* - \ln R_t) \tag{3-120}$$

The third equation of the model determines the supply side of the housing market. To reach the equation, they relied on Topel and Rosen's (1988) housing investment function, which is defined on the value of the property and the supply shifters with one lag (equation (3-121)).

$$I_t = \alpha . V_t + \beta . f(S_{t-1}) \tag{3-121}$$

Combining equations (3-119) and (3-120) and rearranging them based on putting the actual rent on the left-hand side yields equation (3-122). These two equations comprise the whole theoretical dynamic model.

$$\ln R_t = \delta_v . \ln V_t + \delta_c . \ln c_t - (\delta_v / w) . \Delta \ln V_t - (\delta_c / w) . \Delta \ln c_t + (1/w) . f(D_{t-1}) \tag{3-122}$$

This model has been partially specified since there is no housing investment feedback to the housing supply and later to the housing rent. The investment was defined as the number of new single-family housing units starts in each period. Despite this lack of theoretical specification, Edelstein and Tsang (2007) used it as a base for the empirical estimation of coefficients.

Following Shiller's argument about the dominant role of behavioral over fundamental factors in the dynamics of housing markets' boom and bust cycles, Diece and Westerhoff (2012) focused on speculative behavior in the demand side of the typical dynamic model of the housing market. Inspired by recent works on financial markets, they considered behavioral heterogeneity, which means agents in the market are heterogeneous regarding their speculative behavior and strategies. They considered two types of expectation formation mechanisms that stem from the bounded rationality of agents. One has the tendency to extrapolate based on past events, and the other tends to force the agents to consider the position of the market variables compared to their fundamental values. The former persuades agents to behave based on the continuation of the status quo trend; the latter provokes them to behave based on the increasing possibility of market regression following the distance of market variables from their fundamental values.

The core of their model is a disequilibrium model consisting of three equations. The first equation is a Walrasian price adjustment mechanism (equation (3-123)). The demand equation shows the real demand D_t^R as a function of the housing price P_t (Equation (3-124)). In the housing supply equation, the housing stock is modified by the new construction and the depreciation of the previous period stock (equation (3-125)). The supply equation defines the new construction as a mere function of the housing price in the current period ($e.P_t$). The term $(1-d)$ stands for depreciation rate. At first, it is assumed that there is no speculative demand, and all the total demand is equal to real demand ($D_t = D_t^R$).

$$P_{t+1} = P_t + \alpha.(D_t - S_t) \tag{3-123}$$

$$D_t^R = b - c.P_t \tag{3-124}$$

$$S_t = S_{t-1} - (1-d).S_{t-1} + e.P_t = d.S_{t-1} + e.P_t \tag{3-125}$$

They expanded this core by adding speculative demand. Therefore, equation (3-124) can be written as below to include the speculative demand D_t^S.

$$D_t = D_t^R + D_t^S \tag{3-126}$$

The real demand D_t^R depends on the current level of price. It is the speculative demand that hinges on the expectations about the future. Based on the two types of the mechanism being at work in the formation of speculative expectations, the speculative demand can be assumed as a result of two speculative demand components stemming from each of these mechanisms. The extrapolating mechanism drives the first component. The extrapolating component D_t^E is the positive function of the discrepancy of the current price and the fundamental price $\bar{P}$. In equation (3-127), f is the reaction parameter.

$$D_t^E = f.(P_t - \bar{P}) \tag{3-127}$$

The mean-reverting mechanism drives the second component. The mean-reverting component can be written as a positive function of the discrepancy between the actual and fundamental prices. However, here, the discrepancy term is defined as the fundamental price minus the actual price. These two components use the variables in the discrepancy term in reverse order, which proves the reverse direction of these two mechanisms. Parameter g in equation (3-128) determines the amount of the mean-reverting component's reaction towards the discrepancy.

$$D_t^{MR} = g.(\bar{P} - P_t) \tag{3-128}$$

Dieci and Westerhoff (2012) combined the two components of the speculative demand to account for their intertemporal effects. The relative importance ($W_t, 1 - W_t$) of each of these competing mechanisms changes due to market situations in each time step. They showed each component's intertemporal effect as a weight in the weighted average of two components (equation (3-129)).

$$D_t^S = W_t . D_t^E + (1 - W_t) . D_t^{MR} \tag{3-129}$$

The impact of the extrapolating component in each time step is defined as the function of the reverse of the discrepancy between the current and fundamental prices (equation (3-130)).

$$W_t = \frac{1}{1 + h . (P_t - \bar{P})^2} \tag{3-130}$$

This functional form captures the effect of distancing from the fundamental price on the change in the speculators' forecasting strategy. The more market prices are far from their long-run steady-state situation (equilibrium), the more influential the mean-reversion mechanism of predicting the market, which means more agents expect that it is most likely that the price would regress towards its fundamental value. Parameter h defines the speed of change in the power of the mechanisms. Moreover, to account for the possible stop in construction and the asymmetric response of the construction sector to changes in prices, Dieci and Westerhoff (2012) defined a minimum price below which no one embarks on construction. This manner of incorporating profit as a decision factor is ad hoc. Defining the parameters and running the simulations with it showed the model's capabilities in producing complicated movements containing boom and bust cycles in the housing market.

Caldera and Johansson (2013) derived an error-correction specification from the traditional stock-flow model of the housing market to estimate the long-run relationships yielding housing prices and housing investment and the short-run dynamics of the change in these variables for 21 OECD countries. The stock model is the long-run equilibrium relationship between housing demand D and its determinants X_1. These determinants are the real income, the share of the age cohort 25-44 in the population (as a demographic variable), and the real interest rate (as a representative of the user cost of homeownership). The flow equation shows the housing stock changes due to the new investment I and the depreciation of the previous stock ∂S. The housing investment was written as a function of the first lag of the real house price and other independent variables, including the first lag of construction costs and the share of the age cohort 25-44 in the population (as a demographic variable).

$$D(X_1, P) = S = \int_o^T dS \tag{3-131}$$

$$dS = I(X_2, P) - \partial S \tag{3-132}$$

They rewrote equation (3-131) as an invert demand function. This equilibrium relationship yields the equilibrium price level. Adding an error term to it gives the actual level of price in each period. The same process followed for the equilibrium housing investment relationship to get the actual investment level in each period. The estimated error-term of these two relationships is used to estimate the error-correction models of the changes in housing prices and investments. Using the long-run relationships, they estimated the long-run price elasticity of new supply and categorized the countries on this basis. Although they did not enter any variables representing the OECD countries' regulatory environment in their model, they found a negative correlation between the new housing supply elasticities and the number of days to obtain the building permit as a proxy for the restrictiveness of the regulatory environment. Moreover, they did not take a further step to discover any possible empirical relationship between adjustment parameters and the OECD countries' regulatory environment.

Stevenson and Young (2014) developed a housing market model in Ireland by applying the multiple error-correction modeling similar to Riddel's (2004) work. However, there are some differences between the two works. The two long-run equilibrium relationships in Riddel's model were developed for equilibrium supply and demand (equilibrium stock) using supply and demand shifters for each of them. In Stevenson and Young's model, these relationships were built for the equilibrium new supply and the invert demand function. They found that changes in [new] supply respond to the [new] supply disequilibrium term but do not react to the price disequilibrium. They interpreted it as a sign of inelastic supply. Except for the real income level, none of the fundamental independent variables significantly impacted the short-term dynamics models (the error-correction models). Moreover, they did not consider the effect of planning regulations or the stringency of the regulatory environment.

Zabel (2016) developed a dynamic housing market model in which he used vacancies in the error-correction mechanism. He used the panel data of U.S. housing from 1990 to 2011. Zable (2016) first demonstrated the natural level of vacancies by using a simple difference equations model. He assumed that there is always some vacant stock due to the heterogeneity of the housing and searching process. Considering that the owner of these vacancies offers r_a as the acceptable rent level, the probability of getting an offer greater than r_a is $p(r_a)$. The probability of vacating a housing unit by its owner to move to a more preferred location in each period is α. On this basis, the total number of vacancies in each period consists of those vacant stock remaining from the previous period, which have not received an acceptable offer, and those which have been newly vacated (equation (3-133)). Zabel (2016) showed that this difference equation has a steady-state solution (equilibrium point), which after the imposition of shocks, the vacancy level will settle down on it (equation (3-134)). Similar to the Walrasian adjustment process, the rent level changes when the vacancy deviates from its natural level or the equilibrium value (equation (3-135)). This concept was first applied in the property market modeling by Rosen and Smith's (1983)

$$V_t = \big(1 - p(r_a)\big).V_{t-1} + \alpha.\big(1 - p(r_a)\big).(1 - V_{t-1}) + e_t \tag{3-133}$$

$$V^N = \frac{\alpha.\big(1 - p(r_a)\big)}{\alpha.\big(1 - p(r_a)\big) + p(r_a)} \tag{3-134}$$

$$\Delta R_t = g.(V^N - V_t) \tag{135}$$

Following the above theoretical argument, Zabel wrote two error-correction models, one for price changes and the other for new construction, which is indeed the change in the housing stock. In both of them, he used the deviation of the actual vacancy from the natural vacancy as the error-correction term along with lags of dependent variables and changes in demand and supply shifters.

Oikarinen et al. (2018) defined a simple equilibrium housing market model relating three independent variables: the real income level, the real mortgage interest rate (representing the opportunity cost of capital), and construction cost to equilibrium housing prices. They used it as a base of the deviation mechanism in an error-correction specification using the lagged version of differenced values of the same variables. To capture the spatial heterogeneity of the housing market, Oikarinen et al. (2018) estimated the model using the latest advances in panel data. These advances give the possibility of considering the cross-sectional dependence and non-stationarity of the data. Although the model did not incorporate planning regulation explicitly, its results demonstrated that the magnitude and duration of house price bubbles in housing markets with inelastic housing supply are higher than those regional markets with a more elastic housing supply. It is now well-acknowledged that the housing supply elasticity is largely affected by national and local policies and planning regulations.

Table (3-1) summarizes the review of dynamic housing market models. Tracing the housing market dynamic modeling shows that most of the works define the adjustment mechanism for the housing price or rent along with housing stock or alone. Few models use the adjustment mechanism for only housing stock. Also, some works focus on vacancies or house price-to-income ratio as variables that their adjustment triggers changes in the dependent variables. All the studies are concerned about those factors determining long-term housing prices and those affecting short-term housing price dynamics. Most of these studies did not consider the land price effect and a few that considered it did not take it as an endogenous variable.

Most importantly, few studies have tried to incorporate planning regulations into model's equation. Studies with error-correction specification include regulations restrictiveness index as a variable in the long-run relationship and error-correction model. In all the long-run equilibrium relationships, estimates demonstrate the negative impact of the regulations' restrictiveness index on housing prices. However, estimating the error-correction models shows contradicting results. In that, neither the sign nor the significance of the regulation index, whether as a dependent variable (in Malpezzi's model (1999)) or as a variable interacting with the error-correction term (in Malpezzi's model (1999) and Capozza et al. (2004) model) are meaningful. The only promising result in Malpezzi's work is that the adjustment process is slower in cities with more restrictive regulations. Only Hwang and Quigley's (2006) model fulfils the theoretical expectations in that the regulation index has a negative impact on the new supply. Moreover, their simulations based on estimated parameters and under different restrictiveness conditions demonstrate that housing prices increase more in cities with more restrictive regulations and take more time to settle down in reacting to demand shocks. Except for Capozza et al. (2004), all other studies use the regulations restrictiveness index to represent the whole regulatory environment.

Table 3-1: Summary of theoretical housing market dynamic models

Author (Date)	Endogenous variables/ dependent variables	Exogenous variables	Variables with adjustment	Type of regulations	Type of specification	Type of analysis
De Leeuw and Ekanem (1973)	Housing Demand, Housing Rent, Housing Stock	Income, Household Number, Price of Operating Inputs, Price of Capital Inputs, Composite Price of Other Goods and Services	Housing Rent, Housing Demand, Housing Stock	-	Partial Adjustment	Empirical
Barras (1983)	Office Stock, Building Starts, Building Completions	Output Level, Depreciation Rate	Building Starts	-	Partial Adjustment	Theoretical
Barras and Ferguson (1987)	Building Starts, Building Completions	Output Level, Vector of Different Factors, Depreciation Rate	Building Starts, Building Completions	-	Error-Correction	Theoretical
DiPasquale and Wheaton (1994)	Housing Stock, New Construction, Housing Price	User cost of home ownership, Housing Rent, Demographic Characteristics, Real Permanent Income, Cost of construction financing, construction Cost Index, Land Cost Index, Depreciation Rate	Housing Stock, Housing Price	-	Partial Adjustment	Empirical
Alm and Follain (1994)	Housing Stock, Housing Rent,	Replacement Cost, Interest Rate, Depreciation Rate, Income	Housing Stock, Housing Rent	-	Partial Adjustment	Numerical

Table 3-1: Summary of theoretical housing market dynamic models

Author (Date)	**Endogenous variables/ dependent variables**	**Exogenous variables**	**Variables with adjustment**	**Type of regulations**	**Type of specification**	**Type of analysis**
	Housing Price, New Construction					(Simulation using existing empirical data)
Tu (2004)	Housing Stock, New Construction, Housing Price	User cost of home ownership, Housing Rent, Demographic Characteristics, Real Permanent Income, Cost of construction financing, construction Cost Index, Land Cost Index, Depreciation Rate	Housing Stock, Housing Price	-	Partial Adjustment	Empirical
Malpezzi and Maclennan (2001)	Housing Price, Housing Stock, Housing Demand	Income, Population Number	Housing Stock	-	Partial Adjustment	Empirical
Malpezzi and Wachter (2005)	Housing Price, Housing Stock, Housing Demand	Income, Population Number (Both of them were converted to a known demand)	Housing Stock	-	Partial Adjustment	Numerical (Simulation using existing empirical data)
Wheaton (1999)	Office Rent, Office Space Price, Office Stock, New Construction	Employment, Depreciation Rate, Capitalization Rate	Office Stock	-	Traditional Stock-Flow	Numerical (Simulation using existing empirical data)

Table 3-1: Summary of theoretical housing market dynamic models

Author (Date)	**Endogenous variables/ dependent variables**	**Exogenous variables**	**Variables with adjustment**	**Type of regulations**	**Type of specification**	**Type of analysis**
Riddel (2004)	Change in Housing Price, Change in Housing Stock	Set of Housing Demand and Supply Shifters	Housing Stock, Housing Price	-	Error-Correction	Empirical
Barras (2005)	Office Rent, New Construction Starts, Vacancy	Output, Output Growth, Turnover Rate, Depreciation Rate, Natural vacancy Rate	Office Stock, Office Rent,	-	Partial Adjustment	Empirical
Diece and Westerhoff (2012)	Housing Price, Housing Stock, Real Housing Demand, Speculative Housing Demand, Relative Importance of Speculative Demand Components	Depreciation Rate, Fundamental Price (in speculative model), Minimum Price Level for Construction	Housing Price	-	Partial Adjustment	Numerical
Zabel (2016)	Change in Housing Price, New Construction	User Cost of Housing, Rent, Income, Number of Households and Employment	Vacancies, New housing supply, Housing price	-	Error-Correction	Empirical
Oikarinen et al. (2018)	Changes in housing prices	Real income growth, Changes in real interest rate, Real construction costs growth	Housing price	-	Error-correction	Empirical

Table 3-1: Summary of theoretical housing market dynamic models

Author (Date)	**Endogenous variables/ dependent variables**	**Exogenous variables**	**Variables with adjustment**	**Type of regulations**	**Type of specification**	**Type of analysis**
Caldera and Johansson (2013)	Changes in housing prices, Changes in housing investment	Real income growth, Changes in real interest, Changes in the stock of dwelling units, Changes in construction costs, Changes in the share of the age cohort 25-44 in population	Housing price, Housing investment	-	Error-correction	Empirical
Stevenson and Young (2014)	Changes in housing completion, Changes in housing prices	Changes in real building costs, Changes in real after-tax interest rate, Population growth, Changes in real disposable per capita income, Changes in per capita housing stock	Housing price, Housing completion	-	Error-correction	Empirical
Edelstein and Tsang (2007)	Observed market rent (adjusted for inflation), Real housing investment	Property value index, capitalization rate, real growth in state income, Employment growth rate, Unexpected employment growth, Prime interest rate, Credit spread, Long-term interest rate, Changes in construction costs	Housing rent	-	Partial Adjustment	Empirical
Malpezzi (1999)	Housing price-to-income ratio,	Changes in real income per capita, Changes in population, Mortgage interest rate,	Housing price- to-income ratio, Housing price	Regulation stringency index	Error-correction	Empirical

Table 3-1: Summary of theoretical housing market dynamic models

Author (Date)	**Endogenous variables/ dependent variables**	**Exogenous variables**	**Variables with adjustment**	**Type of regulations**	**Type of specification**	**Type of analysis**
	Changes in housing prices	Regulation stringency index, Disequilibrium measure, Interaction between regulation index and disequilibrium term		(Contradicting results)		
Capozza et al. (2004)	Real housing prices, Changes in real housing prices	Population, 5-year change in population, real personal income, Changes in real personal income, real construction cost index, user cost, Land supply index, Use fees, Approval time, Payable fees by developers, Lagged real price changes, Disequilibrium measure, Interaction between changes in population and Lagged real price changes, Interaction between changes in real income and lagged real price changes, Interaction between real construction cost index and lagged real prices changes, Interaction between land supply index and lagged real price changes, Interaction between changes in population and disequilibrium term , Interaction between changes in	Housing price	Land supply index, use fees, approval time, other payable fees by developers (Contradicting results)	Error-correction	Empirical

Table 3-1: Summary of theoretical housing market dynamic models

Author (Date)	**Endogenous variables/ dependent variables**	**Exogenous variables**	**Variables with adjustment**	**Type of regulations**	**Type of specification**	**Type of analysis**
		real income and disequilibrium term , Interaction between real construction cost index and disequilibrium term , Interaction between land supply index and disequilibrium term				
Hwang and Quigley (2006)	Changes in log of housing prices, changes in log of housing stock, Changes in log of vacancies	Changes in log of number of households, Changes in log of user cost, Changes in log of rent, Expected rate of change in housing price, Variance of rate of change in housing price, Changes in log of material cost, Changes in log of labor cost, Changes in prime interest rate, Regulation index, Changes in log of personal income, Changes in log of employment, Changes in log of unemployment compensation, Log of price-to-rent ratio	Housing price	Restrictiveness index (Proving the theoretical expectations)	Vector Auto Regressive (VAR)	Empirical and Numerical

3-6- SD as a Method for Dynamic Modeling

In previous sections, I explained the theoretical origin of dynamic economic modeling. I then traced its application and diverse manifestation in the theoretical and empirical dynamic modeling of property markets. In the following sub-sections, I situate the dynamic economic modeling within a broader theoretical and methodological context of dynamic systems and dynamic modeling. I then elaborate on the SD method as the modeling method of this thesis and its capabilities in addressing the complexities of modeling planning regulations' effect.

3-6-1- The Feedback Structure of Adjustment Process

As discussed at the beginning of this chapter, the adjustment process is the intrinsic mechanism of dynamic economic modeling. At the heart of the adjustment mechanism, there is a repetitive process of checking the output of the process with the desired output creating the course of the output over time. A well-known example is the Walrasian adjustment process. The concept of excess demand implies that the right-hand side of the equation is more than zero. The excess demand function converts the discrepancy between the demand and supply to the adjustment amount. Assuming that it is not an instant adjustment process (equation (3-6)), the adjustment amount will be added to the price level in the previous period. The result will be the actual price at the end of the current period. Since both demand and supply are a function of prices, this information will be fed back to the right-hand side of the equation in the next step of adjustment. Again, the discrepancy between the new level of demand and supply will be compared to define the adjustment level. Hence there is a feedback loop inside the Walrasian price adjustment process.

Feedback loops are often found in the partial adjustment model. Considering equation (3-3) and (3-4), the former defines the desired level of output. The right-hand side of equation (3-4) compares the output level at the end of the previous period with the desired level. If there is a discrepancy between the two, a part of it will be added to or subtracted from the output level at the beginning of the current period. At the end of the current period, the level of output is fed back as an information signal to the right-hand side of the adjustment mechanism at the beginning of the next period to control the error between the actual level and the desired level. Since the adjustment mechanism is the basic building block of dynamic economic models in general and the dynamic models of the property market in particular, all those models contain the information feedback loop(s).

3-6-2- SD and Its Theoretical Roots for Modeling Feedback Loop Systems

The information feedback loop inside different markets, including property markets, categorizes them as a type of systems known as Feedback Control Systems in Control Systems Theory. A feedback control system or a Closed-loop Control System is a type of system in which there is a "prescribed relationship between the output and the reference input" (Ogata, 2002: 6). The system works based on a continuous comparison of the reference input and output of the system and using the difference between the two to control the whole system performance by bringing the output to the desired level (Ogata, 2002). The closed-loop control action causes the constant reduction (correction) of the error inside the system. Control System Theory is the specific field of analyzing and designing these systems. For analysis, it relies heavily on sophisticated mathematical methods, specifically differential equations (Mohapatra, 1980).

SD is the other methodology specifically devised for modeling, analyzing, and studying feedback control systems or Information Feedback Systems as it is known in this methodology. Despite its broad applicability, SD was developed based on control systems theory, in order to analyze human systems such as the economy, business, and industry. The specific decision-making problems in these fields require the simulation of non-linear behavior. They were the starting point for the development of SD by Jay W. Forrester (Vennix, 2001). Due to the non-linearity and complexity of such systems, analytical methods on which control system theory is based are not appropriate for SD. Instead of using differential equations, SD uses integration equations and simulation for analyzing the behavior of the systems under study. Mohapatra (1980) showed that the mathematical structure of control system theory and SD are equivalent. The mathematical equivalence can be explained by using equation (3-55) as an example. For convenience, equations (3-55) is repeated below with prime index. That equation defines the change in the housing stock. In order to limit the number of symbols, $C_t(X_{2t}, P_t)$ and δS_{t-1} (which are rates of the change in the stock), new notations - c_t and d_t can replace them. Here, capital letters denote stocks and small letters stand for rates. Equation (3-55') changes to equation (3-136) below:

$$\Delta S = S_t - S_{t-1} = C_t(X_{2t}, P_t) - \delta S_{t-1} \quad (3\text{-}55')$$

$$S_t - S_{t-1} = c_t - d_t \quad (3\text{-}136)$$

The units of c_t and d_t are Dwelling Units/Time Interval. This implies that c_t and d_t are the number of dwelling units constructed and depreciated during the time interval, which lasts from the end of period $t-1$ to the beginning of period t. Hence, there is an implicit Δt which is equal to the unit time interval and multiplied to the right-hand side of the equation. Equation (136) can be rewritten as below in which $\Delta t = 1$:

$$S_t - S_{t-\Delta t} = \Delta t.(c_t - d_t) \tag{3-137}$$

$$S_t = S_{t-\Delta t} + \Delta t.(c_t - d_t) \tag{3-138}$$

Considering $S_{t-\Delta t}$ as initial state S_0 and over an infinitely small Δt, equation (3-138) can be rewritten in the form of an integral equation as below. Equation (3-139) shows that the housing stock is the integration of newly constructed and depreciated housing units in each period of time.

$$S_t = S_0 + \int_0^t (c_t - d_t).dt \tag{3-139}$$

On the other hand, differentiating equation (3-139) with respect to time results in equation (3-140). The latter is a differential equation which is the main format used in the control systems theory.

$$\frac{d}{dt} S_t = c_t - d_t \tag{3-140}$$

Equations (3-136), (3-139), and (3-140) are equivalent but written in different forms as difference equation, integral equation, and differential equation, respectively. Equation (3-139) is used in SD if time is treated as continuous. If time is considered as a discrete quantity, equation (3-136) is the applicable format. However, there is a subtle difference between the two approaches of dynamic modeling, and between equations (3-136) and (3-139) on one hand and equation (3-140), on the other hand. The causal direction depicted in equation (3-139) conforms to the exact direction of causality, which can be found in the real world, whereas the direction of causation in equation (3-140) is reversed. Indeed, the sum of newly constructed housing units and depreciated housing units alters the stock of housing and not the reverse (Mohapatra, 1980; Forrester, 1985).

3-6-3- Approaches in Applying SD

Identifying the causal relationships in a feedback loop system is the major modeling task in this approach. Radzicki (2020) identifies three approaches for identifying causal relationships and developing a SD model: modeling from scratch, translating existing economic theories and models, and the hybrid approach. The dominant approach of modeling in SD has been Modeling from Scratch. It is an inductive process of developing a dynamic model based on the specific case under study (Radzicki, 2020). Adopting such an approach to model economic systems has given rise to confrontations between economists, specifically in neoclassical economics, and system dynamicists (Nordhaus, 1973; Rothenberg, 1974). The neoclassical approach in modeling is a deductive process that works based on existing theories and a set of developed theoretical notions. Although the modeling-from-scratch approach may challenge neoclassical theories, it may also result in ignoring the most sophisticated existing theories developed through decades. A well-known example has been William Nordhaus's (1973) article criticizing Forrester's book World Dynamics (1971) in which Forrester tried to model the world consumption of the natural resources in the long future. Nordhaus's critique targeted three areas, namely population subsystem, production function, and resource allocation. Despite the fact that his critique about the way Forrester modeled the population subsystem is not relevant (see Forrester's response to Nordhaus's paper: Forrester et al., 1974), all the other major flaws that Nordhaus correctly pointed in his article are attributable to the apparent ignorance of the model builder about the economic concepts behind some of its key variables and mathematical relationships (Nordhaus, 1973). However, none of them is related to the SD as a method: "The basic notions of SD – usually called simultaneous difference or differential equations – have been used extensively in economics and elsewhere for decades." (1182).

This common methodological root makes it possible to translate the existing economic theoretical models into SD models. However, as a simulation method, SD offers more mathematical modeling tools that can complement pure mathematical modeling through difference equations as used in property economics. For example, the modeler can apply the IF function to incorporate conditions in modeling decision-making processes. These tools are specifically helpful in encompassing more complexities that are simplified in most mathematical models. Therefore, one can adopt the third approach to combine the two other approaches into a hybrid one (Radzicki, 2020). Based on this approach, the modeler applies the existing economic theories with some modifications to reflect the real-world situation. In this thesis, the latter approach is adopted in the modeling process described in Chapter 4.

3-6-4- SD's Tools for Modeling Feedback Structures and causal relationships

After identifying causal relationships and feedback structures in a system, connecting variables based on the identified causal relationships is the major task. The model can become more complex depending on the number of variables and feedback structures. Therefore, there are representation tools to define the direction of causal relationships between variables, and the nature of variables (whether they are stock or flow). These tools are causal relationship loops and stock-flow diagrams. They facilitate abstracting the structure of real-world systems based on their three structural elements known as stocks, flows, and feedback loops (Radzicki, 2020; Sterman, 2000). Linking all the variables in the model to one another based on their causal relationships yields the causal loop diagram. Understanding the type of causal loops in the diagram and the mathematical formulations that underpin them helps identify the stock and flow variables.

The fundamental constituent of a causal loop diagram is a causal link between the two variables. An arrow with a plus or minus sign shows the causal relationship between two variables. It starts from the cause and ends with the effect variable. The plus and minus signs on them demonstrate whether the cause and the effect change in the same (positive) or opposite (negative) directions. A positive relationship means, all else equal, the cause increases (decreases) the effect above (below) what it would have been. A negative relationship means, all else equal, an increase (decrease) in the cause decreases (increases) the effect below (above) what it would have been. For conciseness, from this point onward, whenever I discuss the direction of change in the cause and the effect in a causal relationship, I omit the expression 'above/below what they would have been.' For more information about the necessity of mentioning this expression, see (Sterman, 2000: 139-140).

A causal loop is a cycle that starts from a variable and ends at the same variable. Accordingly, any change in the start variable propagates across the loop and comes back to the starting point with a different magnitude depending on the type of the loop. There are two types of causal loops, namely balancing and reinforcing loops. In reinforcing loops, the direction of change in variables in the loop is in a way that the loop reinforces the initial change in the start variable when it comes back to its point of origin after one cycle of the loop. Hence, the loop reinforces the initial change passing through a cycle in the loop. Reinforcing loops are also called positive loops since the multiplication of the signs of the constitutive relationships is positive. Consider a loop with four variables and four causal relationships. We break the loop in $x_1$to show the time elapse through one cycle of the loop. Thus, instead of x_1, we will have x_1^I and x_1^O, which are the input x_1 and the output x_1, respectively. In a reinforcing or positive loop, the derivative of effect variables with respect to their immediate cause is positive. Mathematically, the change in x_1 due to the small change in itself passing one cycle of the loop results from the partial derivative of x_1^O to x_1^I. Hence, the sign (SGN) of the change in the output x_1^O with respect to the input x_1^I is the multiplication of the sign of all derivatives of effects with respect to their immediate causes as shown below. For a more complete discussion about the polarity of loops see (Sterman, 2000: 143-146).

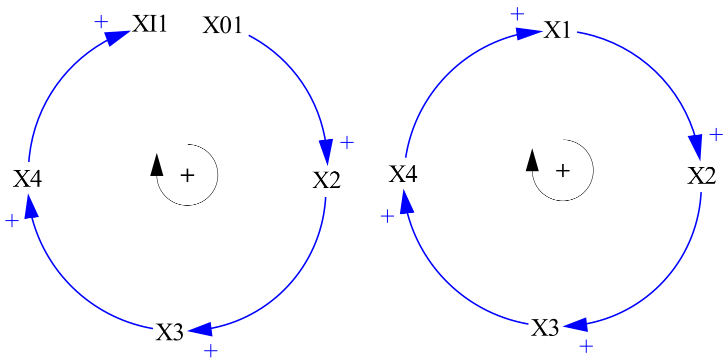

Figure 3-1: Defining the polarity of a positive loop

$$\frac{\partial x_2}{\partial x_1^I} > 0\,, \frac{\partial x_3}{\partial x_2} > 0\,, \frac{\partial x_4}{\partial x_3} > 0\,, \frac{\partial x_1^O}{\partial x_4} > 0 \tag{3-141}$$

$$SGN\left(\frac{\partial x_1^O}{\partial x_1^I}\right) = SGN\left(\frac{\partial x_2}{\partial x_1^I}\right).SGN\left(\frac{\partial x_3}{\partial x_2}\right).SGN\left(\frac{\partial x_4}{\partial x_3}\right).SGN\left(\frac{\partial x_1^O}{\partial x_4}\right) > 0 \tag{3-142}$$

On the other hand, in balancing or so-called goal seeking loops, some variables in the loop change in the opposite direction with respect to others. Hence, the loop opposes the initial change in the start variable when it comes back to its point of origin after one cycle of the loop. As a result, the net outcome is convergence towards a specific value over time. They are also called negative loops since the multiplication of the signs of the constitutive relationships is negative. Given the same loop in the footnote 6 with one negative derivative, the sign of the loop will be negative.

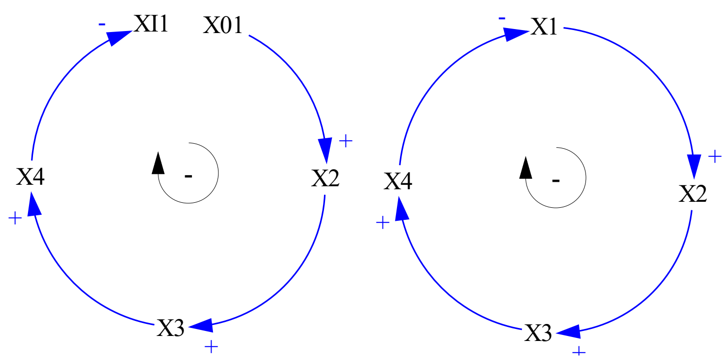

Figure 3-2: Defining the polarity of a negative loop

$$\frac{\partial x_2}{\partial x_1^I} > 0\,, \frac{\partial x_3}{\partial x_2} > 0\,, \frac{\partial x_4}{\partial x_3} > 0\,, \frac{\partial x_1^O}{\partial x_4} < 0 \quad (3\text{-}143)$$

$$SGN\left(\frac{\partial x_1^O}{\partial x_1^I}\right) = SGN\left(\frac{\partial x_2}{\partial x_1^I}\right).SGN\left(\frac{\partial x_3}{\partial x_2}\right).SGN\left(\frac{\partial x_4}{\partial x_3}\right).SGN\left(\frac{\partial x_1^O}{\partial x_4}\right) < 0 \quad (3\text{-}144)$$

A causal loop in a system implicitly means all the variables in the loop are defined endogenously, because all variables in the loop are both the cause and the effect of each other. Since SD modeling works based on the endogeneity of variables, it is an ideal method for modeling systems prone to the endogeneity problem.

After defining the causal loop diagram, we can translate the model to the stock-flow model needed for simulation purposes. Stocks are the containers for the accumulation of materials and information. They provide information about the current state of the system. This information transmits through a feedback loop to the other principal elements of the system, i.e. flows. Flows control the rate of entrance and exit of material and information to and from the stocks. Stocks and flows define the start and end of a feedback loop. An essential function of a causal loop diagram is that it helps identify the minimum number of stock variables and their place in the model. Each loop should have at least one stock variable. All the variables used as information signals are potential stocks or stem from a stock variable. The third flag for identifying the stock variables is potential delays. Such delays are defined by an arrow with two parallel lines crossing its middle point. Moreover, the durability of some things measured by variables can determine whether it is stock or not. Last but not least, mathematical formulations of a theory are another critical way to define the stock variables. This way is appropriate when the approach is hybrid or translates an existing theory. For instance, in the partial adjustment process defined in difference equation format, a variable whose values enter the equation in at least two different periods is a stock variable. Defining the stock variables helps to define the flow variables responsible for changing stocks. The result of defining all the stock and flow variables is the stock-flow diagram of the model. It helps to complete the rest of the mathematical relationships, complete the model, and use it for simulations. The stock-flow diagram represents the direction of causality and the type of variables.

In order to clarify the application of SD tools in translating the mathematical model, the typical partial adjustment model defined by equations (3-3) and (3-4) is represented in causal-loop and stock-flow diagrams below. For convenience, equations (3-3) and (3-4) are repeated below with prime indices:

$$y_t^* = \alpha^0 + \sum_{i=1}^{n} \alpha^i . x_t^i \tag{3-3'}$$

$$\Delta y_t = y_t - y_{t-1} = \delta.(y_t^* - y_{t-1}) \qquad 0 < \delta < 1 \tag{3-4'}$$

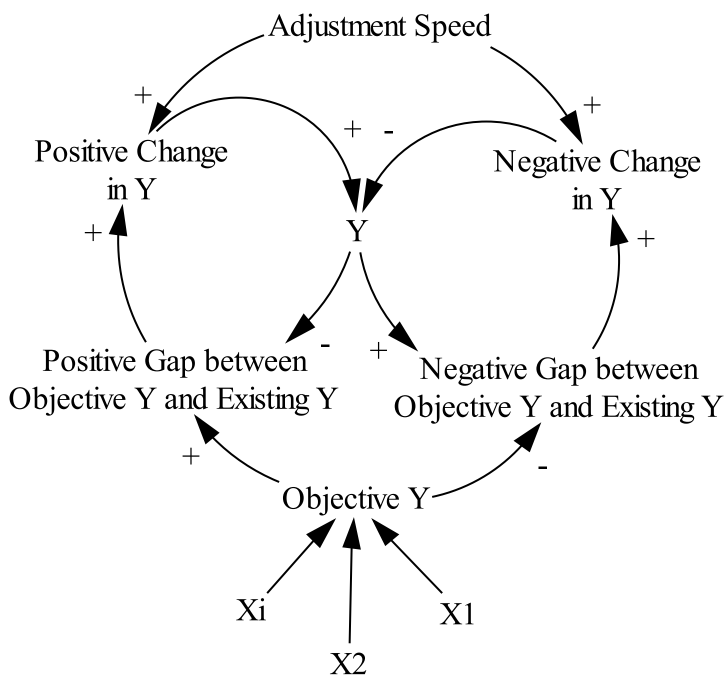

Figure 3-3: The causal diagram of the typical partial adjustment model

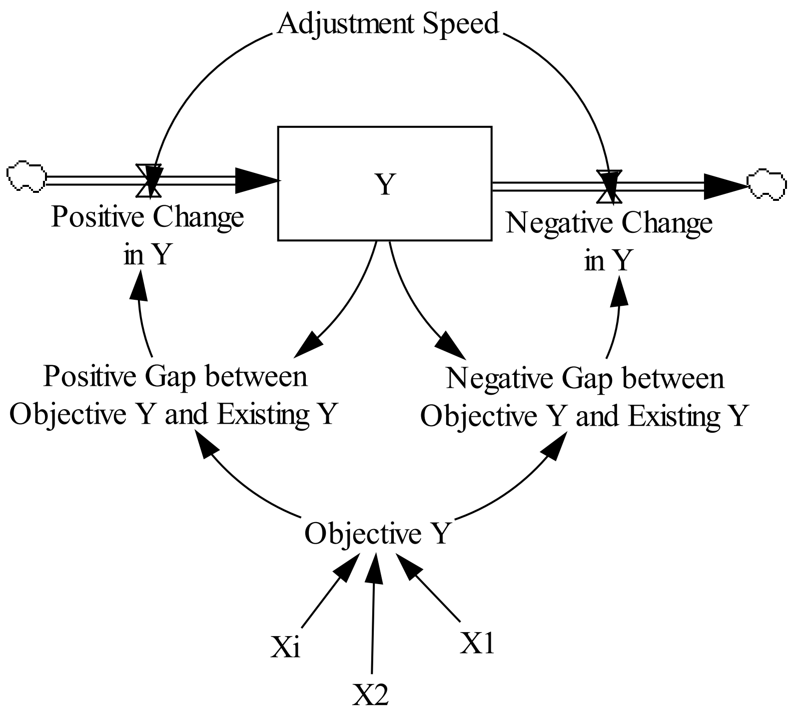

Figure 3-4: The stock-flow representation of the typical partial adjustment model

δ in equations represents the adjustment speed. In the causal diagram, the direction of arrows shows the direction of causality, and the positive and negative signs indicate the direction of the relationship between two variables. In a positive relationship, holding other variables constant, the effect will increase/decrease if the cause increases/decreases. In a negative relationship, holding other variables constant, the effect will increase/decrease if the cause decreases/increases. Since the relationships between Xi and Y* are not defined, there is no sign on the corresponding arrows. However, in a real modeling case, the direction of all relationships should be identified. To avoid ambiguity about the direction of relationships, two variables have been defined in each diagram to show the discrepancy between the stock variable Y and its desired or objective level Y*. One is for the case that the objective level of Y is larger than the existing level of Y, (Y*-Y)>0, and one for the case that the objective level of Y is smaller than its existing level, (Y*-Y)<0. Hence, there are two modes for Δy, which are shown in diagrams by the positive change in Y and the negative change in Y. The positive Δy means inflow and the negative Δy means outflow.

The above example shows how one can translate the dynamic core of mainstream economic modeling into an SD model. However, the SD methodology gives more flexibility in incorporating variables than the mainstream method. The mainstream dynamic economic modeling uses a limited number of equations to keep the model tractable and capable of being estimated empirically. The contributing factors enter the long-term equilibrium relationship (the first equation in partial adjustment models and equation (3-3') in this sub-section). In the few dynamic models of property markets enumerated in Section (3-5), which incorporated planning regulations, regulations are added to both short-term and long-term equations either directly or indirectly as restrictiveness indices. Their effect takes a linear additive form, similar to other hypothetically influential variables added to the model. These aggregate statistical models aim to find a linear correlation between regulations and housing prices.

In the real world, however, regulations act as constraints that dynamically affect developers' decisions, and most likely, they have non-linear effects on housing and land prices. Thus, a more practical way to capture their individual effects over a period is to incorporate regulations in a causal model of residential land development—the modeler searches for the direct causal relationship between the variables in SD. Thus, in a partial adjustment model, the first equation is formulated as a series of causal rather than correlational relationships. This process may break down and change the equilibrium relationship to several other non-linear relationships (incorporating constraints) or adjustment processes. On this basis, SD models are categorized as white-box or grey-box models compared to pure statistical models categorized as black-box models (Kleijnen, 1995). This characteristic of the method lets the modeler incorporate more regulations as constraints on different stages of the development process and measure both the individual and the combined effects of planning regulations. In other words, we can capture a level of heterogeneity without losing planning regulations' individual effects.

3-7- Conclusion

This chapter is devoted to the dynamic method of modeling in housing economics. The economic literature on dynamic modeling is broad. Most of this volume is related to the empirical issues of dynamic modeling and estimating the specifications. The current chapter’s focus is on the method of extracting dynamic specifications and specifically its theoretical bases. It is demonstrated that the adjustment process, which is the gradual inclination of the variables towards their desired values, is the driving force of the movement in the markets. The partial adjustment models are the first ones developed based on the adjustment process. Different transformations of partial adjustment models can lead to different specifications, such as auto-distributed lag models and error-correction models, each with its estimation and interpretative merits.

Addressing the adjustment mechanism and the corresponding models revealed the existence of a feedback loop. The dynamic of the adjustment process depends on this feedback loop. The information about the system's situation at the end of the previous period is fed back to the other side of the adjustment equation through this loop to push the market towards the equilibrium condition. Based on control systems theory, any system with such a loop inside its structure is a closed-loop control or feedback control system. On this basis, all markets, including the housing market, can be regarded as a feedback control system. Furthermore, it has been shown that SD is a preferred method for modeling such systems, specifically because it can deal with human factors. Mathematically, SD relies on difference equations or integral equations. It works based on identifying causal loops in a system and its constituent variables. As a simulation method, SD helps combine the existing theory with more realistic details. These characteristics, plus the ability to capture the dynamic behavior of variables, make this method ideal to deal with the three difficulties of analyzing planning regulations' effect. Based on these merits, this study uses SD to develop a dynamic model of the housing market.

The next chapter applies the theoretical foundation of dynamicity in the housing market to develop an integrated model of housing and land markets. The partial adjustment mechanism is the building block of formulating the theoretical relationships between the market variables in a dynamic way. The process of formulating the relationships will be facilitated and implemented by using SD methodologically complementary tools known as causal loop diagram and stock-flow diagram.

4. Conceptual Framework and The Model

4-1- Introduction

This chapter is devoted to the development of the model and its structural validation. By adopting the system dynamics approach, an integrated model of housing and land markets is developed to answer the main questions of this thesis and bridge the gap identified in both the static and dynamic modeling of housing and land market (elaborated in Chapter 2 and 3). The process of modeling commences by defining three important concepts in housing economics, and explains how this thesis deals with them in the modeling process. It continues with modeling the land market, the housing market, and integrating them. Writing the equations of the model follows the conventional difference-equations format used in all the theoretical dynamic models of the property market investigated in Chapter 3. It is followed by a subsection assigned to the structural validation of the model. Three broad types of validity tests, namely the extreme condition tests, phase-relationship tests, and sensitivity analysis tests have been performed. The chapter ends by concluding the major findings.

The model consists of three sub-models: the housing market, the construction sector, and the land market. The construction sub-model plays the role of an intermediary connecting the two other sub-models. Based on the hybrid approach of system dynamics modeling, I use the existing microeconomic theories of the property market to derive mathematical formulations defining the relationships between the variables. They have been combined with the partial adjustment mechanism explained in the previous section to convert the theoretical relationships to a dynamic model. In addition, three types of planning regulation are incorporated into the model. In this section, I explain the key elements and structure of the three sub-models.

4-2- Conceptual Definitions

Before introducing the model, it is necessary to explain two concepts and the way they have been dealt with in the model.

4-2-1- Heterogeneity of Housing

There are three characteristics making housing as a unique commodity among the others. These are durability, heterogeneity, and spatial fixity (Fallis, 1985; O'Sullivan, 2012). Among them, the heterogeneity of housing stock has been the most challenging in modeling the housing market. Housing as a commodity consists of a bundle of characteristics, including its area, age, number of bedrooms, number of bathrooms, accessibility to public transportation, and closeness to green space. Differences in housing units in one or more than one of these characteristics make it almost impossible to find two identical housing units. In this situation, defining a standardized unit for measuring the housing supply, housing demand, and housing production output is difficult (Fallis, 1985).

Heterogeneity has been addressed in three ways in the literature. In microeconomic theoretical models, all the heterogeneous housing units provide the quantity of an unobservable homogenous service called 'housing services,' which is implicitly supplied and demanded in the housing market (Olsen, 1969). In stock-flow models of the housing market, often, the measure of output is the dwelling unit, and all the dwelling units supply the same number of units of housing services. Indeed, these models treat housing as a homogeneous commodity that is identical across the entire market (Smith et al., 1988). The third group of studies has treated the housing floor area (housing space) as the unit demanded and supplied in the housing market (DiPasquale and Wheaton, 1996). In this view, each square meter of the housing floor area provides an identical level of housing service throughout the housing market. The first approach has been applied successfully in both theoretical and empirical models of the housing market. However, as Fallis (1985: 6) explained, it is inappropriate. One of these cases is the incorporation of planning regulations in housing market models since regulations such as maximum building density deal with the area of the housing units not the theoretical abstract concept of housing services. To incorporate the concept of building density (i.e. floor area ratio) in the model, the third interpretation of the concept of housing is the most relevant one here.

4-2-2- Non-land Production factors

The second important concept to clarify is the non-land production factors in housing development (e.g., construction materials, labor, and equipment). Combes et al. (2017) equated non-land production factors with capital, which "get frozen into the housing through the construction process" (pp. 5). As a corollary, the total cost of capital will be the cost for each unit of capital included in the profit function. The problem with this method is that changes in the price of each non-land factor are not reflected in the amount of capital used. For example, one cannot determine definitively how much the total amount of capital will increase if wages double. Another method of accounting for non-land factors is to define an arbitrary unit of the combination of these factors based on their monetary value (Harvey, 2000: 91). The second method addresses this limitation, but the amount of capital should be defined meaningfully rather than arbitrarily. One way to do this is to define the unit of capital (C) based on the amount of monetary value of non-land factors needed to construct one square meter of housing space. However, there is a non-linear relationship between FAR and the construction cost per square meter of housing space: changing FAR will change the construction cost per square meter

(DiPasquale and Wheaton, 1996: 73-75; Brueckner et al., 2017). Hence, the price of non-land factors (or capital factor) should consider the effect of FAR. One can avoid this problem by defining the price of capital factor as the cost expended on the construction of one square meter of housing with a FAR of one (can be referred to as 'a standardized square meter of housing').

4-3- Assumptions

In all modeling efforts, we need to define the assumptions on which a model is based. The assumptions behind the model are: First, construction is undertaken by commercial developers only, not self-builders. Second, the municipality has consistent and predictable goals when setting levels of MBD restrictiveness. This means the housing price level does not affect the municipality's decision on the MBD level. Third, the owner-occupied and rental housing markets are in equilibrium. Fourth, regulations do not differ within the city, and there is no zoning. Fifth, there is no speculative demand for land and no land banking. Therefore, all the sold lands are immediately used for development purposes. Also, there is no housing speculation, and under-construction dwelling units will not affect the housing market until they are available on the market. Based on the sixth assumption, this model treats informal settlements as the last resort for the marginalized lowest-income households rather than a choice. Finally, other cities are not substitute housing markets for the modeled city.

4-4- Housing market sub-model

The supply of housing (a durable good) is equal to the existing stock of housing. The existing housing stock increases with the completion of under-construction housing and decreases through the demolition of depreciated space[7]. On the demand side, the total housing demand is the aggregation of individual levels of housing demand. The individual demand for housing depends on the housing rent and household income level and the demand elasticity for those two variables. The model is a closed-city model, but inward migration may provide a demand shock.

The model is a disequilibrium model: there is no presumption that demand for and supply of housing are equal. To dynamically model housing rent, I use the partial adjustment formulation. The first equation in the partial adjustment model is the equilibrium relationship. However, I do not use the natural vacancy and the partial adjustment mechanism for vacancy rates. Because the measurement unit of output is the floor area of housing space, it is challenging to define the

[7] It is assumed that housing spaces in the under-construction stock will not affect the housing market until they are available on the market.

vacancy rate. Instead, I used the Walrasian adjustment process in which the objective housing rent depends on the current housing rent and the gap between housing supply and demand. The excess demand function in the Walrasian adjustment process can serve as the equilibrium relationship. Instead of the subtraction form (supply is subtracted from demand), I use the fractional form to show the imbalance between the housing demand and supply, and the Walrasian adjustment process is translated into difference equations format (Samuelson, 1971; Arrow and Hurwicz, 1958).

$$RH_t^* = RH_{t-1}.(THD_{t-1}/HS_{t-1})^{\sigma h} \quad (4\text{-}1)$$

$$RH_t = \left((RH_t^* - RH_{t-1})/T_{adjr}\right) + RH_{t-1} \quad (4\text{-}2)$$

In which, RH_t is the housing rent at the end of time t, RH_t^* is the objective housing rent targeted to be reached till the end of time t, $THD_{t-1}$and HS_{t-1} are the total demand for and supply of housing at the end of time t-1, σh is the parameter measuring the sensitivity of housing rent adjustment to the housing demand-and-supply imbalance, and T_{adjl} denotes the time needed to cover the gap between the actual housing rent and the objective housing rent.

The mathematical theory of partial adjustment explained above can be translated into causal loop diagrams. Figure (4-1) shows the causal loop diagram of the housing market sub-model. The blue arrows show the causal effect between the variables. The plus and minus signs on them demonstrate whether the cause and the effect change in the same (positive) or reverse (negative) directions. The partial adjustment mechanism explained above consists of two causal loops. They are B1 and R1 in Figure (4-1). B and R stand for balancing and reinforcing, respectively. Balancing or goal seeking loops are causal structures that lead the system towards a specific value. They are also called negative loops since the multiplication of the signs of the constitutive relationships is negative. Reinforcing loops perpetuate positive or negative change for variables in the loop. They are also called positive loops since the multiplication of the signs of the constitutive relationships is positive. For instance, in the housing market sub-model, the red R1 loop denotes that if the objective (desired) housing rent increases or decreases, the difference between objective housing rent and housing rent (given their positive subtraction) increases or decreases the amount of positive change which the housing rent will have. Hence, all the variables change in the same direction.

On the other hand, the red B1 loop implies that the increase of housing rent reduces the difference between objective (desired) housing rent and housing rent (if their subtraction result is positive). This change, in turn, causes the positive amount added to the housing rent to decrease gradually. This loop continues until the amount of change in housing rent equates to zero. At that point, the housing rent inclines towards a specific value. We have two versions of each loop. Depending on whether the objective housing rent is more than the actual rent or less than it, the model switches from one to the other in each period. They have been shown in red and yellow colors.

Apart from the partial adjustment loops, there are two other loops that are inherent to all markets - the supply loop and the demand loop. Considering Figure (4-1) at the end of this sub-section, any increase/decrease in numbers of households affects the total demand for housing. This increase/decrease changes the balance between the demand and supply. The imbalance between demand and supply signals real estate agents (as intermediaries between sellers and buyers) to increase or decrease asking rents. Consequently, the imbalance defines a new objective housing rent to which the housing rent inclines through the same causal link defined in the partial adjustment mechanism. Then, the new rent has the reverse effect on the objective (desired) individual housing demand. However, it usually takes time for the households to actualize their desired demand level. Hence, there is a lag between the objective and the actual individual housing demand. The aggregation of the actual individual housing demand yields the total housing demand and closes the demand loop in the next step. The demand loop denoted by B2 is a balancing loop.

To describe the supply loop, we can start from a change in the housing rent for any reason, such as a change in demand. Housing supply and developers' decisions on new construction depend on the asset price of housing, whereas housing demand depends on the rental price of housing (Mills and Hamilton, 1994). Hence, to be used as a signal by developers, the housing rent should be converted to the housing price. Assuming that the owner-occupied and the rental housing markets are in equilibrium, one can use the cost of capital for yielding the housing price. Based on this, the asset price of housing is equal to the discounted future value of returns (rental payments) (Shiller, 2006; Shi et al., 2021).

$$PH_t = RH_t/\rho \tag{4-3}$$

The causal link between the housing price and housing supply is not straightforward; there are other intervening variables. These intermediary variables are contained in the construction sector sub-model, explained in the following subsection. Hence, I show the causal link between the housing price and the housing supply by a dashed arrow. Any change in the housing supply changes the housing demand-to-supply balance in the reverse direction. The remaining part of the loop is the same as the demand loop. The supply loop denoted by B3 is a balancing loop similar to the demand loop.

The demand-side of the housing market sub-model needs elaboration since it is the point in the cycle where marginalization occurs. This thesis adopts the concept of informal settlement as a last resort for the marginalized lowest-income households who cannot afford to rent a minimum liveable space in the formal housing market without sacrificing their other needs to the basic amount of other non-housing goods (Heikkila and Lin, 2014; Heikkila and Harten, 2019). Theoretically, this approach can be justified by referring to the same theoretical base behind the Linear Expenditure System (LES), which has been used extensively in the specification and estimation of demand functions (Pollak and Wales, 1995). The essence of this theory states that people need a certain amount of each good in their bundle to guarantee their survival. Hence, they first meet these amounts by devoting their budget to purchase them. Secondly, they maximize their utility by assigning the remaining part of their purchase power to obtain more of the choice bundle (Pollak and Wales, 1995). Heikkila and Lin (2014) were the first to model the formation of informal settlements based on the LES theoretical framework. Referring to LES, it has nothing to say about the demanders' behavior when their purchase power is low as they are not able to meet the minimum amount for subsistence. What Heikkila and Lin (2014) did is explaining this unexplained domain of behavior by adding the informal settlement and marginalization process. On this basis, similar to any other goods, people need a minimum amount of space to survive. If they cannot obtain this minimum liveable space inside the formal housing market, they will leave the formal market to guarantee their subsistence. All those who leave the formal market become marginalized in the informal settlements.

In order to model the marginalization process, it is essential to differentiate people based on their income. Depending on their income level, people with higher income can afford the rising prices and stay in the market; however, those with lower income levels might not afford even the minimum liveable space and resort to informal settlements. To capture the income differentiation effect, at least, two income groups are needed (Brueckner and Selod, 2009; Heikkila and Lin, 2014). However, one can compartmentalize the society to more than two income groups. More income categories will provide a more realistic income distribution of a society. In this model, the city's hypothetical income distribution is modeled by ten income categories. These categories can further shape three groups in combination with each other. The three higher-end categories form the high-income group. The four income-categories after that shape the middle-income group. Finally, the lower-end categories unite as the low-income group. This rearrangement is useful for incorporating income growth rates for the analysis purpose in that instead of adding ten growth rates only three rates will be used.

For all income categories, a similar housing demand adjustment and household number adjustment mechanisms are used. Like all previously explained adjustment mechanisms, there is an objective level of housing demand for the individual housing demand adjustment mechanism. This objective demand is the ideal demand level based on the housing rent and income level. For all three income groups, the individual demand can be written as equation (4-4).

$$IHD^*_{t,j} = B_h + \frac{d.\left(I_j - RH_t.B_h - B_o\right)}{RH_t} \qquad \forall\, j \in \{1,2,3,\dots,10\}\,, \qquad (4\text{-}4)$$

In which, $IHD^*_{t,j}$, RH_t, and I_j stand for the object individual housing demand of a household in income group j at time t, the rent per square meter of housing at time t, and the income level of households in group j, respectively. The expression inside the parentheses is the supernumerary income. d is the share of supernumerary income devoted to rent housing space. B_h and B_o represent the necessary amount of housing space and the monetary value of the necessary amount of all other goods.

However, due to inertia in the market, households cannot instantly change their actual demand to comply with their objective demand. One of the main impediments is transaction costs (Hanushek and Quigley, 1979). For instance, in the rental sector, households have to wait (when they can afford a larger housing unit) or have the chance to wait (when they cannot afford the rent of their current housing unit) until the end of the lease term. Therefore, households in each income category gradually shift their actual demand towards their objective demand. The adjustment of actual demand can be formulated as below.

$$IHD_{t,j} = \left(\left(IHD^*_{t,j} - IHD_{t-1,j}\right)/T_{adjd,j}\right) + IHD_{t-1,j} \qquad (4\text{-}5)$$

In which, $T_{adjd,j}$ is the time needed to fill the gap between the actual individual housing demand and the objective individual housing demand. In parallel with the demand adjustment mechanism, another adjustment mechanism exists. Instead of directly altering the actual individual demand, the marginalization mechanism changes the population in an income group when their purchase power drops down the supernumerary income level. As a result of the decrease in the purchasing power, the objective individual demand will stand at a level lower than the minimum subsistence amount. From this point, the marginalization process starts functioning along with the demand adjustment mechanism.

The marginalization process is a unidirectional mechanism leading to the loss of resident households in the affected income groups. In the causal loop diagram of the housing market sub-model, the B4 and B5 loops explain the marginalization process. Considering the B4 loop, given a decrease in the objective individual demand for housing, if it is less than the minimum required housing space for the survival of a household, the marginalization mechanism becomes activated. Based on this, households who cannot afford the minimum livable space start leaving the formal market. As long as the individual housing demand is less than the minimum survival space, the rate of leaving the formal market, known as marginalization rate, changes in the reverse direction that the individual housing demand changes. The increase in the number of marginalized households decreases the number of households in the formal market. This consequently slows the rate of growth of marginalized households. In the B5 loop, due to the decrease in the number of households in the formal market, the total demand diminishes. This change decreases the housing rent resulting in more affordable space in the formal market, a revived individual housing demand, and a decline in marginalization. The marginalization process can be formulated mathematically as below.

$$mhn_{t,j} = \left(Min\left(sgn\left(IHD^*_{t,j} - B_h\right).\left(HN_{t-1,j}.\left(\frac{\left|IHD^*_{t,j} - B_h\right|}{B_h}\right)^{ed}\right), 0\right) \Big/ Texit \right) \tag{4-6}$$

$$IHN_t = IHN_{t-1} + \sum_{j=1}^{10} mhn_{t,j} \tag{4-7}$$

Equation (4-6) yields the number of households in each income category who are marginalized and thus who move to informal settlements in each unit of time ($mhn_{t,j}$=the marginalization rate of households in j income category at time t). The combination of Min and Sign function guarantees the negative marginalization rate. The number of households marginalized in each income group depends on the amount the objective individual housing demand drops below the minimum liveable space. To make variables dimensionless, one can divide it to the minimum liveable space. The parameter ed is the elasticity of number of marginalized households to the relative discrepancy between the objective individual housing demand and the minimum liveable space. For brevity, such a discrepancy can be called the affordability gap. All the outflows from affected income groups function as inflows feeding the informal settlement. Thus, the total number of households residing in informal settlements is simply the sum of all marginalized households from affected income groups through the time. Equation (4-7) yields the total number of households at end of time t.

The total demand for housing is the sum of the total demand of each income group, which is the product of the number of households in each income group and their actual demand. Equation (4-8) yields the total demand for housing.

$$THD_t = \sum_{j=1}^{10} HN_{t,j}.IHD_{t,j} \tag{4-8}$$

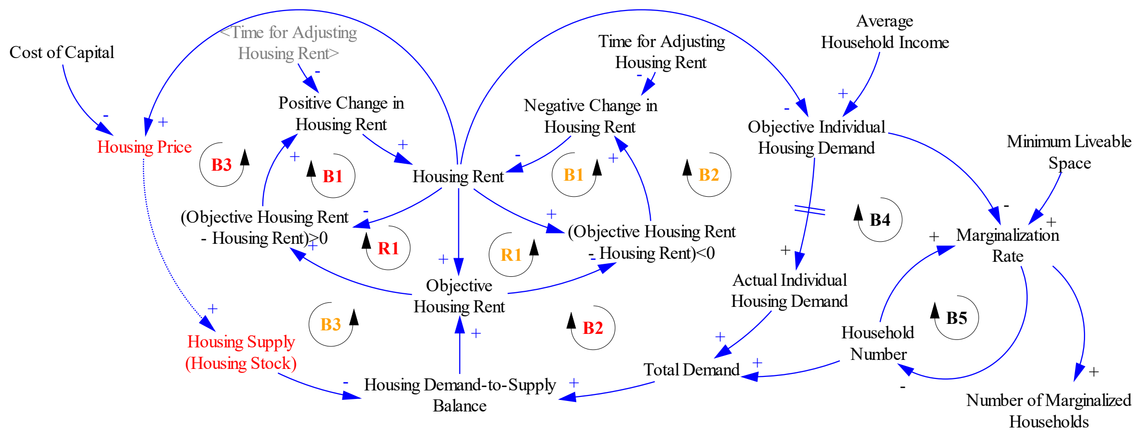

Figure 4-1: The housing market sub-model causal loop diagram

4-5- Construction sector sub-model

As discussed above, the housing price is on the boundary of the housing market sub-model and the construction sector sub-model. In the construction sector, developers use the signals of other markets, including the housing market, the land market, and the capital market, to take two consequent decisions. First, should they enter the market and embark on construction? If yes, how much should they build to maximize their profit? The critical quantity used in taking both decisions is the optimum building density or FAR (floor area ratio).

The optimum FAR is the combination of production factors that maximizes the profit (minimizing the loss). The incorporation of this concept is necessary for two reasons. First, it makes it possible to incorporate the MBD into the model. Second, the calculation of the profit depends on having the optimum building density. This concept is important, but to our knowledge has not been incorporated in other dynamic housing market models. Zhang et al. (2018)

incorporated FAR but treated it as an exogenous constant. However, optimum building density is part of the static analytically-solved general equilibrium models of the housing market. In those models, the supply side of the housing market reflects developers' decisions aimed at maximizing their profit functions by choosing the optimum FAR (Bertaud and Brueckner, 2005; Ding, 2013; Brueckner et al., 2017). There are two types of profit functions representing construction costs. One considers the total capital spend on the construction, and its unit cost is the cost of capital. The less familiar form considers construction cost as a function of construction density (Brueckner et al., 2017). Here, the latter approach has been adopted, and modified to incorporate the effect of cost of material and labor (the price of non-land factor/capital factor) into the model. I define the unit price of capital factor as the cost expended on the construction of one square meter of housing with a FAR of one (which can be referred to as 'a standardized square meter of housing' or 'a unit of capital factor').

Determining how to find the optimum FAR and incorporating this mechanism is very important for our model. To do this, the housing production function of a typical developer is rewritten based on FAR; from this I derive the optimum FAR through the profit maximization process, as discussed below. For this purpose, a Cobb-Douglas type of production function with constant returns to scale is used, as follows:

$$S = A.C^{\alpha}.L^{1-\alpha}, 0 < \alpha < 1 \ , \ A > 0 \tag{4-9}$$

In which S is the floor area of housing space, L is the amount of land, C represents all non-land factor (or capital factor), α is the sensitivity of outputs to the amount of each input. The profit function of a developer (π) can then be formulated as follows:

$$\pi = P_h.A.C^{\alpha}.L^{1-\alpha} - P_c.C - P_l.L \tag{4-10}$$

Here, Pc represents the minimum cost of non-land factors for one square meter of housing in a single-storey building with a Floor Area Ratio of 1. It is the price of capital factor. P_l is the price per square meter of land. It is assumed that the construction market is competitive and all developers are price-takers. Profit can be maximized with respect to land and capital factors if the following conditions are satisfied:

$$\frac{\partial \pi}{\partial L} = 0 \tag{4-11}$$

$$\frac{\partial \pi}{\partial C} = 0 \tag{4-12}$$

The above conditions correspond to the following derivatives:

$$A.(1-\alpha).P_h.C^{\alpha}.L^{-\alpha} - P_l = 0 \tag{4-13}$$

$$A.\alpha.P_h.L^{1-\alpha}.C^{\alpha-1} - P_c = 0 \tag{4-14}$$

Hence, the optimal land and capital amounts are formulated as:

$$L = \left(\frac{A.(1-\alpha).P_h}{P_l}\right)^{\left(\frac{1}{\alpha}\right)}.C \tag{4-15}$$

$$C = \left(\frac{P_c}{A.\alpha.P_h}\right)^{\left(\frac{1}{\alpha-1}\right)}.L \tag{4-16}$$

Equations (4-7) and (4-8) can be entered into the production function separately. The result of these substitutions will be:

$$S = A^{\left(\frac{1}{\alpha}\right)}.\left(\frac{(1-\alpha).P_h}{P_l}\right)^{\left(\frac{1-\alpha}{\alpha}\right)}.C \tag{4-17}$$

$$S = A^{\left(\frac{1}{1-\alpha}\right)}.\left(\frac{P_c}{\alpha.P_h}\right)^{\left(\frac{\alpha}{\alpha-1}\right)}.L \tag{4-18}$$

And, the production function can be rewritten as follows:

$$S = A.C^{\alpha}.L^{1-\alpha} \tag{4-19}$$

$$S^{\alpha}.S^{1-\alpha} = A.C^{\alpha}.L^{1-\alpha} \tag{4-20}$$

$$S^{\alpha} = A.C^{\alpha}.\frac{L^{1-\alpha}}{S^{1-\alpha}} \tag{4-21}$$

Given that $\frac{S}{L}$ is in fact the Floor Area Ratio (FAR), denoted by F, the result will be:

$$S = A^{\left(\frac{1}{\alpha}\right)}.C.\left(\frac{1}{F}\right)^{\left(\frac{1-\alpha}{\alpha}\right)} \tag{4-22}$$

By using (4-14), (4-9) can be rewritten as:

$$P_h = \frac{P_l}{F.(1-\alpha)} \tag{4-23}$$

In addition, (4-10) can be rewritten as:

$$F = A^{\left(\frac{1}{1-\alpha}\right)}.\left(\frac{P_c}{\alpha.P_h}\right)^{\left(\frac{\alpha}{\alpha-1}\right)} \tag{4-24}$$

By putting (4-23) into (4-24), the final result will be:

$$F = A.\left(\frac{P_l}{P_c}.\frac{\alpha}{1-\alpha}\right)^{\alpha} \tag{4-25}$$

Equation (4-26) will give the optimum building density, F, with a direct relationship with the price of land and an inverse relationship with the price of capital factor. Adding the time indices to the above relationship yields the difference-equation format of it as below.

$$F_t^* = A.\left((PL_{t-1}/PC_{t-1}).(\alpha/1-\alpha)\right)^{\alpha} \tag{4-26}$$

In which F^{*t} is the optimum building density at the end of period t. In system dynamics modeling, to make the variables dimensionless and reduce the number of parameters in the equations, one can add the reference level of variables to equations. As Sterman (2000) explains, these reference levels of current variables "can be constants or variables representing equilibrium levels, the desired state of the system, or the values of the variables at some time in the past." (pp. 525). They make it possible to measure the effect of deviations from the reference (normal) values of key variables on the system. For equation (4-27), the reference values (which start with a capital R) are incorporated into the equation through dividing the main equation by the equation with reference values.

$$F_t^* = RF^*.\left((PL_{t-1}/RPL).(RPC/PC_{t-1})\right)^{\alpha} \tag{4-27}$$

Based on bounded rationality, developers are not completely optimizing economic agents. They cannot instantly discover the optimum building density because they cannot access all the information needed for a complicated calculation and use their own rule of thumb instead of complex mathematical optimization. Also, their estimation knowledge is based on their previous experiences. Their estimation will coincide with the optimum level if they have enough time to have more experience. Therefore, it is plausible to assume that developers may discover this optimum building density after a delay. Thus, development decisions may be based on developers' perception of optimum building density (i.e., perceived optimum building density) rather than the true optimum building density. If the market remains stable, the two will converge over time. On this basis, one can assume a partial adjustment mechanism through which developers' perception about optimum building density gradually adjusts towards the true optimum building density.

$$\tilde{F}_t^* = \left(\left(F_t^* - \tilde{F}_{t-1}^*\right)/T_{perceive}\right) + \tilde{F}_{t-1}^* \qquad (4\text{-}28)$$

In Equation (4-28), $\tilde{F}_t^*$ is the perceived optimum building at the end of period, and $T_{perceive}$ represents the time needed to close the gap between the perceived optimum building density at the end of the previous period (t-1) and the optimum building density.

Using the perceived optimum building density, developers calculate the optimum amount of land by knowing the amount of construction they intend to complete or calculate the optimum volume of construction based on the area of land they already have. However, they do that in the context of the MBD. When the MBD imposed by the municipality is lower than developers' estimate, it may modify developers' available optimum building density choices. If the perceived optimum building density is higher than the MBD, the municipality may offer the option of paying a development charge in return for a higher allowed density. This procedure is very common in Iran's municipalities (Karampour, 2021). The development charge changes the cost of production of a standard unit of housing, defined previously as the price of the capital factor.

Figure (4-2) shows the causal loop diagram of the construction sector sub-model. The two balancing loops B1 and B2 are attributable to the relationships discussed above. Both of these loops become activated if the perceived optimum building density exceeds the MBD. Considering loop B1, by an increase in the land price, the optimum building density increases. Following that but with a delay, the perceived optimum building density changes in the same direction. If the increase in the perceived optimum building density exceeds the MBD, the price of the capital factor increases since the development charge will be added to the initial price of the capital factor. The more expensive capital factor rationalizes the lower optimum building density. In loop B2, the more the perceived optimum building density exceeds the MBD, the higher is the development charge making the higher-density construction expensive. Equations (4-29) and (4-30) are the mathematical formulation of relationships mentioned above. Equation (4-29) yields the optimum amount of capital factor. It is derived from the calculations of optimum building density through equations (4-9) to (4-25). In this equation, PC_0 is the initial price of capital factor without accounting for the development charge. Equation (4-30) calculates the extra development charge normalized for each unit of capital factor. The Max function guarantees the positive values of development charge. Equation (4-31) captures the MBD restriction. If a developer intends to build above the building density restriction, s/he must pay the extra development charge. In that event, the price of capital factor will increase by the extra development charge payable by the developer (Equation (4-32)).

$$C_t = AUL_t.\left(PC_0/(A.\alpha.Ph)\right)^{(1/(\alpha-1))} \tag{4-29}$$

$$DC_t = Max\left(\left(\left(\left(\tilde{F}_t^*.AUL_t\right) - \left(MBD_t.AUL_t\right)\right).MUC_t\right)/C_t, 0\right) \tag{4-30}$$

$$EDC_t = \begin{cases} DC_t, & \tilde{F}_t^* > MBD \\ 0, & \tilde{F}_t^* \leq MBD \end{cases} \tag{4-31}$$

$$PC_t = PC_0 + EDC_t \tag{4-32}$$

Most dynamic models have not incorporated the construction profit (for examples which did not consider the profit see: Wheaton, 1999; Malpezzi and Maclennan, 2001, and for works which considered it see de Leeuw and Ekanem, 1973; Barras and Fergusen, 1987 [8]). Having the perceived optimum building density helps the inclusion of profit as the main factor informing developers' decisions about their entrance into the market and production levels. Besides the housing price, the land cost per square meter of building and the construction cost per square meter of the building are the two cost elements of the profit for which we need the optimum building density in order to calculate them. Equations (4-33) and (4-34) yield the construction cost per square meter of building, CUC_t, and the land cost per square meter of building, LUC_t, respectively. These equations are derived from the calculations of optimum building density through equations (4-9) to (4-25). Equation (4-35) defines the construction profit per square meter of building. Instead of using the common minus-form of profit per square meter of building (unit profit), the fractional form where profit consists of the housing price per square meter as the numerator and the sum of construction cost and land cost per square meter of building as denominator is used (Ball et al., 2004: 227). This form has the advantage of being

[8] Wheaton (1999) took the price of space as the underlying factor on which developers base decisions about future projects. His rationale was to simplify the mathematical explanation (Wheaton, 1999: 214). According to de Leeuw and Ekanem's (1973) theoretical model, housing stock adjustment (whether by new development or demolition) depends on the discrepancy between the actual rent and the marginal cost of construction (or the long-run equilibrium rent). Barras and Ferguson (1987) related the supply of new buildings to the profitability of construction in their theoretical model developed for all property types. In their model, the profitability of construction is related to the asset price of the property and is inversely related to construction cost and land prices.

dimensionless, which helps quantify the effect of profit on construction by using a relative figure. A typical developer will embark on further development as long as the profit is more than zero. Here, the profit means the economic profit. Zero profit or less means zero construction. Based on this, the effect of profit can be shown by an If function (Equation (4-36)). In which, EP_t stands for the effect of profit and β_c denotes the elasticity parameter which can accept different values depending on the variable on which it has effect. In the fractional form, one means zero profit.

$$CUC_t = \left((1/A)^{(1/\alpha)}\right). PC_t . \tilde{F}_t^{*(1-\alpha/\alpha)} \tag{4-33}$$

$$LUC_t = PL_t / \tilde{F}_t^{*} \tag{4-34}$$

$$CP_t = PH_t / (CUC_t + LUC_t) \tag{4-35}$$

$$EP_t = \begin{cases} CP_t^{\beta}, & CP_t > 1 \\ 0, & CP_t \leq 1 \end{cases} \tag{4-36}$$

As mentioned, the effect of profit is twofold, each of which creates causal linkages. Firstly, it determines developers' decisions on the volume of construction they will initiate. In this model, I assume developers have an optimum construction level. It is the product of perceived optimum building density and the average size of land parcels available for development. It is called "normal individual construction." This optimum level yields the maximum profit or minimum loss given the market prices. In profitable markets, new-entrant developers aim to capture all available profits in the market. This works through incorporating a multiplier (normal construction multiplier); changes in its volume in each period depends on its size and the amount of profit in the previous period. As a result, the amount of construction that an individual developer intends to embark on in each period is the product of the normal individual construction and the multiplier. Equation (4-37) and (4-38) represent the adjustment process explained above. In which, NCM and NCM^* denote the normal construction multiplier and the objective normal construction multiplier. T_{adjc} stands for the time needed for adjusting the construction multiplier. Equation (4-39) and (4-40) yield the initial optimum construction, and the individual intended construction explained above, respectively. In which, NIC, AUL and IIC represent normal individual construction, average under construction lot size, and individual intended construction.

$$NCM_t^* = EP_{t-1}.(NCM_{t-1} + 1)$$ (4-37)[9]

[9] In Equation (4-37), since the effect of profit can equate zero in some instances, the normal construction multiplier can approach to zero. This can lead to the production of small amounts for individual intended

$$NCM_t = \left((NCM_t^* - NCM_{t-1})/T_{adjc}\right) + NCM_{t-1} \quad (4\text{-}38)$$

$$NIC_t = AUL_t.\tilde{F}_t^* \quad (4\text{-}39)$$

$$IIC_t = NCM_t.NIC_t \quad (4\text{-}40)$$

Second, the profit signals developers to enter or exit the market, which restructures the industry in the long term. The size of the market, and the profit available, determine the number of developers the market can support. Thus, the profit effect influences the aggregate level of construction by determining the number of developer-entrants. On this basis, the aggregate intended construction is the product of the individual intended construction and the number of entering developers in each period (Figure (4-2)). Equations (4-41) and (4-42) yield the number of entering developers ($\overrightarrow{ED}$) and the aggregate intended construction (TIC). PND is the potential number of developers who can enter the market in each time period.

$$\overrightarrow{ED}_t = EP_t.PND \quad (4\text{-}41)$$

$$TIC_t = \overrightarrow{ED}_t.IIC_t \quad (4\text{-}42)$$

The aggregate intended construction and the perceived optimum building density give the total land demand for new construction. The land supply cannot necessarily meet all this demand. Therefore, the land sale for new construction is less than or equal to the land demand for new construction. The land demand for new construction, the land price, and the land sales are three variables connecting the construction sector sub-model and the land market sub-model, addressed in the following sub-section. Those causal relationships are shown succinctly by dashed arrows in Figure (4-2).

Based on our assumptions in Section (4-3), there is no speculative demand for land and that all land sold will be used immediately for development. Thus, there is no land banking in the market, and the optional value of holding a piece of land is zero. On this basis, developers start constructing on the purchased land based on the perceived optimum building density. Since construction takes time, this actual housing construction will ultimately increase the supply of housing space after a lag. Therefore, the housing supply (housing stock) and the housing price

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construction even when the profit is positive. Adding one to the normal construction multiplier in the parenthesis sets the objective normal construction multiplier more than one as soon as the profit gets positive and eradicates this mathematical problem.

are the other two common variables (in red font) linking the construction sector sub-model with the housing market sub-model (Figure (4-2)).

Equations (4-43) and (4-44) capture the lag between the start of housing construction and its completion. Equation (4-43) yields the under-construction housing stock at the end of period t (UH_t) which is the result of the addition of actual housing construction starts (ac_t) during the period t to the under-construction at the end of period t-1 (UH_{t-1}) and the subtraction of completed housing stock during the period t (cc_t). The built housing stock (BH_t) as the housing supply results from the addition of completed housing stock and the subtraction of demolished housing spaces during the period t, represented by cc_t and dm_t, respectively, from the built housing stock at the end of period t-1 (BH_{t-1}). Equations (4-45) to (4-47) give the rate variables. The multiplication of perceived optimum building density to the amount of purchased land by developers (land sales) at the beginning of the current period yields the amount of housing construction during the period t (Equation (4-45)). The housing construction completion rate depends on the under-construction stock and the time needed for the completion. The critical parameter is the time needed for completion, defining the speed of housing construction. The time frictions imposed by legal processes for example to get building permissions are incorporated here into the model (Equation (4-46)). The amount of housing space demolished in each time period depends on the fractional demolition rate (δ)(Equation (4-47)).

$$UH_t = ac_t - cc_t + UH_{t-1} \tag{4-43}$$

$$HS_t = BH_t = cc_t - dm_t + BH_{t-1} \tag{4-44}$$

$$ac_t = \left(SA_{t-1}.\tilde{F}_t^*\right)/T_{start} \tag{4-45}$$

$$cc_t = UH_{t-1}/T_{comp} \tag{4-46}$$

$$dm_t = (\delta.BH_{t-1})/T_{dem} \tag{4-47}$$

The relationships mentioned above, added by incorporating the construction profit, create many loops (20) to the construction sector sub-model. In contrast with B1 and B2 loops, these new loops have variables in common with the other two sub-models. Due to the space limitation, explaining all of these loops is impossible. Here, I suffice to explain the two main balancing loops: B3 and B4. The former incorporates variables from the land market sub-model, and the latter has variables from the housing market sub-model.

Considering the B3 loop, an increase in the construction profit increases the number of developers entering the market. This positive change in the number of developers raises the aggregate intended construction, which increases the land demand for new construction and, subsequently, the total land demand. The increase in total land demand changes the land price in the same direction but with a delay. The increase in the land price increases the land cost per square meter of building, making the construction less profitable compared to the previous period. In the B4 loop, the initial relationships from construction profit to land price are the same as B3. If land price increases, then land supply increases. It changes the land sales in the same direction. The increase in land sales increases the under-construction housing stock resulting in the increase of housing supply, with a delay. The increase in housing supply changes the housing price in the reverse direction. Finally, the decrease in housing price decreases the profitability of the construction.

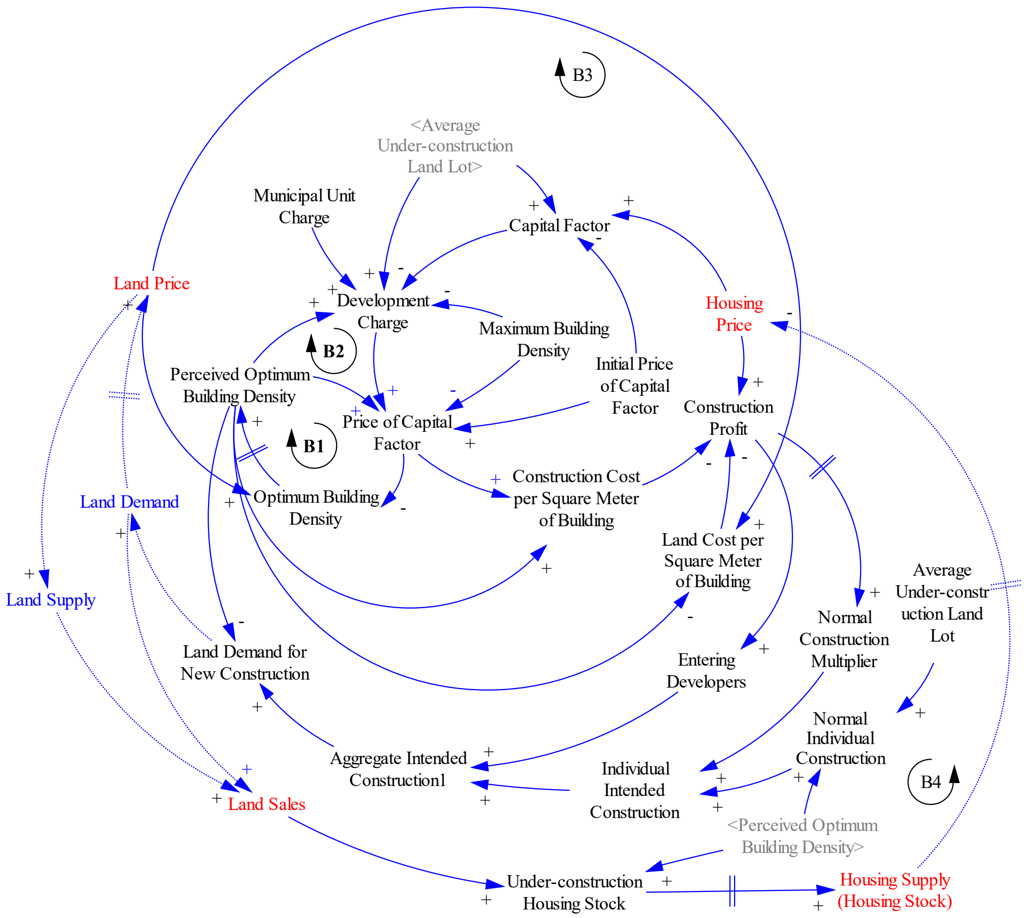


Figure 4-2: The construction sector sub-model causal loop diagram

4-6- Land market sub-model

In their discussion of dynamic models of commercial property markets, Ball et al. (2004) pointed out that none of them considered land costs. This raises a theoretical concern - without the land cost, the construction will appear more profitable than it is (Ball et al., 2004: 226). When it comes to modeling a local property market, the land cost is of significant importance. In contrast to the cost of other production factors which are mobile and have higher supply elasticity, land is immobile and its supply is relatively inelastic; its cost can significantly affect profitability. Moreover, it is essential to understand land markets, as the object of the planning regulations I study. All three regulations affect land consumption. Setting the MBD can increase the demand for land by each developer. The MLS affects the amount of undeveloped land supply. Imposing the UGB sets a limit for the suppliable land if there is no close substitute for the city's housing and land markets. Based on the final assumption behind the model, the UGB can set such a limit in this model.

Like the housing market, the land market follows the partial adjustment process yielding the equilibrium land price. Hence, the same number of balancing and reinforcing causal loops are at work in the partial adjustment section of the land market. In Figure (4-3), B1 and R1 loops in both red and yellow colors correspond with the below partial adjustment mathematical formulation similar to the housing market's one.

$$PL_t^* = PL_{t-1}.(LD_{t-1}/LS_{t-1})^{\sigma l} \tag{4-48}$$

$$PL_t = \left((PL_t^* - PL_{t-1})/T_{adjl}\right) + PL_{t-1} \tag{4-49}$$

In which, PL_t is the land price at the end of time t, PL_t^* is the objective land price targeted to be reached till the end of time t, LD_{t-1} and LS_{t-1} are the total demand for and supply of land at the end of time t-1, σl is the parameter measuring the sensitivity of land price adjustment to the demand-and-supply imbalance, and T_{adjl} denotes the time needed to cover the gap between the actual land price and the objective land price. The land price gradually adjusts towards the desired price. The price adjustment mechanism in the land sub-model follows the same rules described for the housing market sub-model.

Here, I focus on the demand and supply loops that complete the land price adjustment process. The demand side variables are those in common with the construction sector sub-model. In loop B2, a change in the land price leads to a change in the optimum building density in the same direction and consequently in the perceived optimum building density. Any change in the perceived optimum building density has a reverse effect on the land demand for new construction (LDN) (Equation (4-50)) and the total land demand (LD). Since land is a durable good, the land demand for new construction is only one element of the total land demand, including the existing stocks of land, namely developed (built) land (BL) and land under construction (UL) (Equation (4-51)).

$$LDN_t = IC_t / \tilde{F}_t^* \tag{4-50}$$

$$LD_t = BL_t + UL_t + LDN_t \tag{4-51}$$

The supply-side loop B3 is derived from the mathematical formulation of the theory of land supply modeling. Modeling land supply in static disaggregate models (traditional monocentric city models) is different from dynamic aggregate models. In the former, the equilibrium supply of land defines the city's boundary, where the urban land price equates to the agricultural land price. In dynamic aggregate models, it is not possible to use such an equation as a condition for defining the equilibrium land supply. Land supply is defined as a function of the average land price and other independent variables such as restrictions (geographical or legal) (Potepan, 1996). This study adopts the latter approach since the model deals with land at the aggregate level. Based on this, the total land supply is a function of the average land price and legal restrictions - planning regulations directly affecting the land supply. However, regulations are incorporated in different stages, each of which corresponds with the causal relationships in Figure (4-3). The initial total land supply without imposing the regulations follows the below functional form:

$$LS_t = RLS.(PL_t/RPL)^{el} \quad , \qquad 0 < \; el \tag{4-52}$$

In which, LS_t represents the total supply of land at time t, RPL is reference price of land RLS is reference supply of land, and el defines the price elasticity of land supply.

The reference supply of land is the developed land area in the city at the beginning of the analysis. If the total land supply equates to the city's developed area in advance, the land price is the reference price. The city's developed area includes three types of land, namely, the under-construction lands, built lands, and post-demolition lands. The UGB is the first regulation that affects the supply of land. Imposing the UGB acts as a constraint on the land supply. The supply of land cannot be more than the amount that the UGB delineates for the developers. This relationship is reflected in Equation (4-53) below. Thus, the causal relationship between the total suppliable land inside the UGB and the adjusted supply of land by UGB shown in Figure (3) takes the negative sign. However, it should be mentioned that if the land supply meets the UGB constraint, the negative sign does not matter anymore. After being adjusted by the UGB, the MLS restriction may affect the land supply. If the size of land lots is more than the MLS, it will not affect their supply. However, land lots smaller than MLS will be excluded from the amount of suppliable land lots. A necessary simplifying but reasonable assumption is that lot size categories' share follows a semi-normal distribution form. This assumption makes it possible to calculate the amount of suppliable undeveloped land when the MLS is binding. Based on the durability of land, the total land supply consists of the undeveloped land supply and the city's developed area. The MLS restriction is binding for the undeveloped areas. The more restrictive MLS leads to the reduction of the fraction of undeveloped land that can be supplied (expression $(1-\theta)$ in Equation (4-54)). Hence, as Figure (4-3) shows, the more the share of developed area (which includes vacant sites from demolished buildings), the less the undeveloped land supply and the less the effect of MLS. On the other hand, the change in the city's developed area changes the land supply adjusted by MLS and UGB (the total land supply) in the same direction. The change in the adjusted land supply by regulations affects the balance between the land demand and the land supply in the reverse direction. This balance variable closes the land supply loop (B3). Equations (4-53) and (4-54) embody the process of land supply adjustment by UGB and MLS constraints that is explained above. In which, $SLinUGB$, DAC, and θ denote the total suppliable land inside UGB, the developed area of the city, and the fractional decrease in land supply due to the MLS restriction, respectively.

$$LSaugUGB_t = \begin{cases} SLinUGB, & LS_t > SLinUGB \\ LS_t, & LS_t \leq SLinUGB \end{cases} \tag{4-53}$$

$$LSaugUGB\&MLS_t = \begin{cases} \left((1-\theta).(LSaugUGB_t - DAC_t) \right) + DAC_t, & LSaugUGB_t > DAC_t \\ LSaugUGB_t, & LSaugUGB_t \leq DAC_t \end{cases} \tag{4-54}$$

The result of the encounter between demand and supply in the land market is land sales. The amount of land sales in each period is the minimum of the land supply and land demand. The total amount of land sales can be assigned to two sources of suppliable land stock for construction based on land availability in each of them, namely, the post-demolition land stock (DL) and the undeveloped land inside the UGB. It is assumed that the land demand will be met first by the land stock from demolished buildings, and then by the undeveloped land stock inside the UGB. Equations (4-55) yields the amount of land sale as the minimum of land demand for new construction (LDN) and the supply of land for new construction (the second expression inside the parenthesis). In which, SA stands for the land sales. Equations (4-56) and (4-57) show the assignment of the land sale to the two land stocks mentioned above. In these equations, DLS and $UDLS$ denote post-demolition land sales and undeveloped land sales.

$$SA_t = Min(LDN_t, (LSaugUGB\&MLS_t - BL_t - UL_t)) \tag{4-55}$$

$$DLS_t = \begin{cases} SA_t, & SA_t \leq DL_t \\ DL_t, & SA_t > DL_t \end{cases} \tag{4-56}$$

$$UDLS_t = SA_t - DLS_t \tag{4-57}$$

The purchase of land lots from the undeveloped land stock inside the UGB changes the total developed area in the city (DAC). The city's developed area consists of three stocks: the under-construction land stock (UL), the built land stock (BL), and the post-demolition land stock (DL). Equation (4-58) depicts the relationship between these elements. These are sequentially connected and formed a big reinforcing loop R2 balanced by three balancing loops, including B4, B5, and B6. Considering R2, an increase in the post-demolition land sales rate (dls) increases the under-construction land stock, which increases the land development rate. The increase in the development rate (dv) subsequently leads to an increase in the built land stock, the built land clearing rate (dm), post-demolition land stock, and finally, post-demolition land sales rate. However, any increase in each of the mentioned three stocks which increases the outflow rates is balanced by those increasing outflows. Therefore, these outflow rates form balancing loops. Equations (4-58) to (4-61) are the mathematical representation of causal relationships containing loops R2, B4, B5, and B6. Variables represented by capital letters are stocks and those with small letter are rates or flows.

$$DAC_t = BL_t + UL_t + DL_t \tag{4-58}$$

$$BL_t = dv_t - (dm_t.(BL_{t-1}/BH_{t-1})) + BL_{t-1} \tag{4-59}$$

$$UL_t = dls_t + udls_t - dv_t + UL_{t-1} \tag{4-60}$$

$$DL_t = (dm_t.(BL_{t-1}/BH_{t-1})) - dls_t + DL_{t-1} \tag{4-61}$$

Connecting the city's developed area to the supply loop creates two reinforcing (R3 and R4) loops. Their starting point is land sales. First, they branch out from land sales and are then joined to affect the city's developed area by changing the built land stock and the under-construction land stock. It is impossible to show all the loops which are added to the whole land market sub-model. Hence, only some of the primary instances are highlighted in bold.

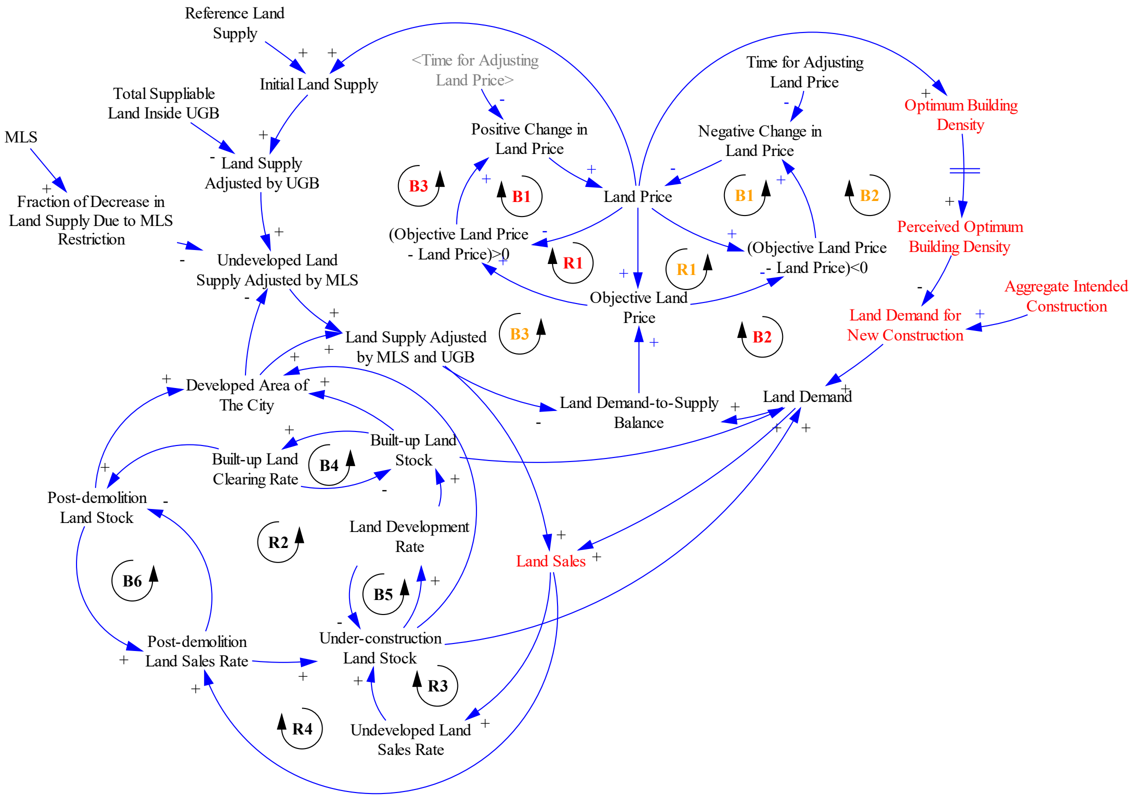


Figure 4-3: The land market sub-model causal loop diagram

4-7- Integrated model

Figure (4-4) illustrates the integrated model consisting of all three sub-models. An essential function of a causal loop diagram is that it helps identify the place of stock and the minimum number of stock variables in the model. Each loop should have at least one stock variable. All the variables used as information signals are potential stocks or stem from a stock variable. Good examples for the former in our model are housing rent and the land price, and examples of the latter case are housing price and the construction profit. The third flag for identifying the stock variables is potential delays. When there is a delay between the cause and effect, a stock might hold the information and material. In the housing market and construction sector sub-models, such delays are defined by an arrow with two parallel lines crossing its middle point. For example, in the construction sector sub-model, there is an information delay between the optimum building density and perceived optimum building density. Here, the perceived optimum building density is a stock variable whose amount inclines towards the true optimum building density. There is a similar delay between the actual individual housing demand and the objective individual housing demand. The third case of delay can be found again in the construction sector sub-model. It occurs between under-construction housing stock and the housing stock. Such a delay is due to the construction time.

Moreover, the durability of things measured by variables can determine whether it is stock or not. Since land and housing are durable goods, all the variables measuring them are regarded as stock variables in our model. Last but not least, mathematical formulations of a theory are another critical way to define the stock variables. This way is appropriate when the approach is hybrid or translating an existing theory. For instance, in the partial adjustment process defined in difference equation format, a variable whose values enter the equation in at least two different periods is a stock variable. Defining the stock variables helps to define the flow variables responsible for changing stocks. The result of defining all the stock and flow variables is the stock-flow diagram of the model. It helps to complete the rest of the mathematical relationships, complete the model, and use it for simulations. Figure (4-5) depicts the stock-flow representation of the model. This diagram contains all the variables and relationships. However, due to limited space, only the critical relationships are explained in the previous subsections. The mathematical formulations of the relationships are represented in Appendix B.

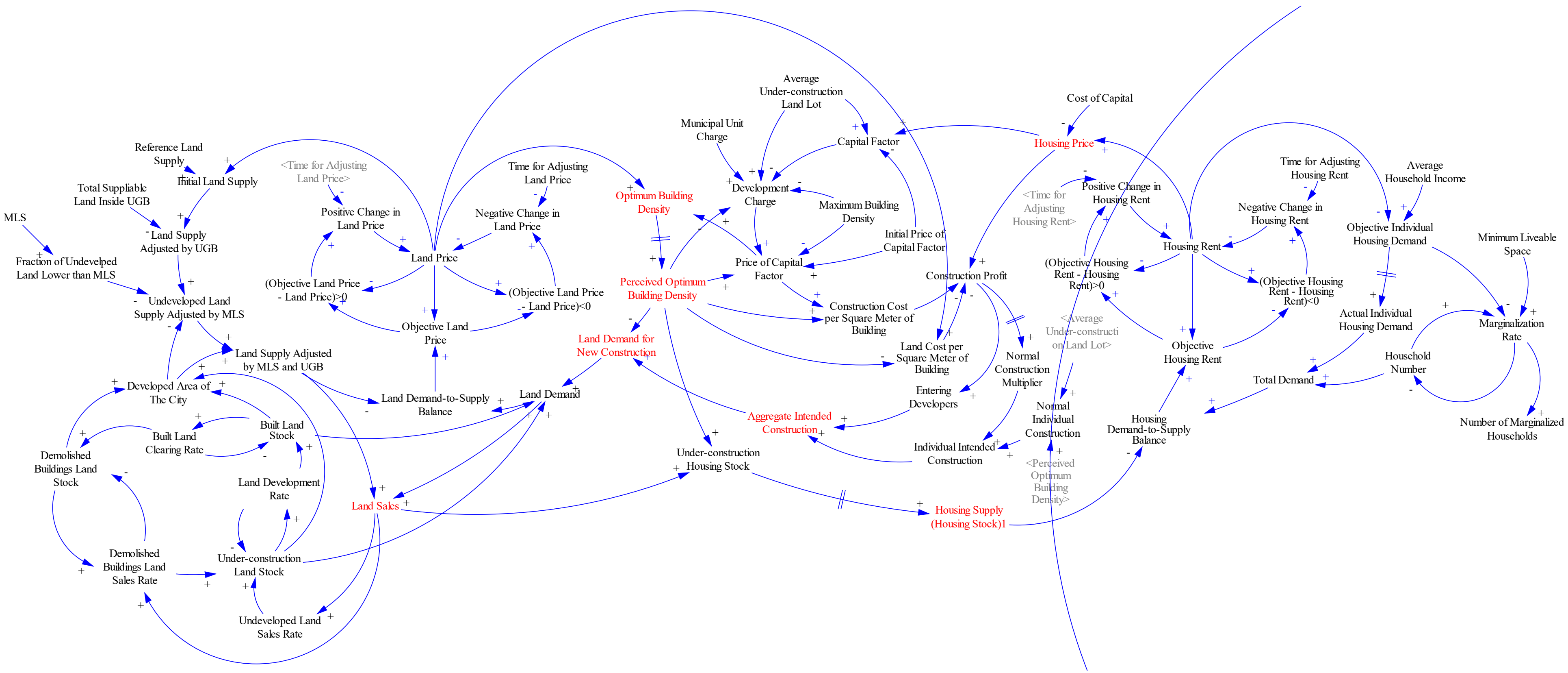


Figure 4-4: The causal diagram of the integrated model of housing market, construction sector, and land market

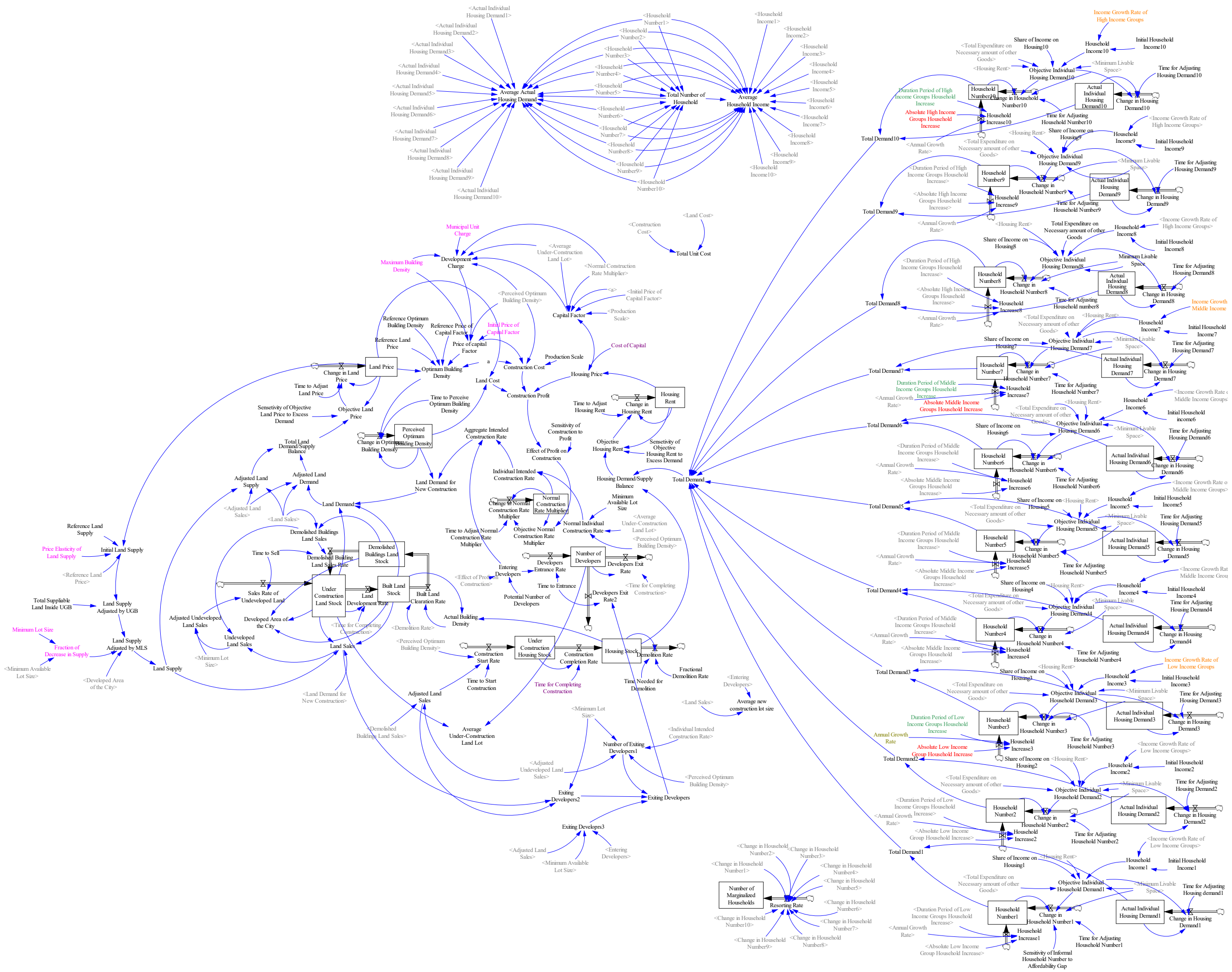


Figure 4-5: The stock-flow diagram of the integrated model (Zoomable)

4-8- Model Validation

Model validation, as Sargent defines it, is “the substantiation that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model.” (Sargent, 2013: 12). The accuracy of the model is defined with respect to the representation of the real system behavior (Kleijnen, 1995). The more a model accurately represents the system under study, the more confidence can be built. Building such confidence in the accuracy of the model is a process that involves different types of tests (Senge and Forrester, 1980). There are several tests devised and proposed to build the confidence in system dynamics models (Senge and Forrester, 1980; Barlas, 1989; Barlas, 1996; Sterman, 2000). These tests have been structured in the form of a procedure to validate system dynamics models. Following the simulation literature on validation, this process divided into two stages, namely structural validation and behavioral validation, each of which consists of different tests and checking procedures (Senge and Forrester, 1980; Barlas, 1989; Barlas, 1996).

Based on Barlas’s (1996) description of this validation procedure, the structural validation is comprised of two sub-groups of tests: direct-structure tests and structure-oriented behavioral tests. Direct structure tests assess the validity of the model structure by directly comparing the equation and all types of relationships with the existing theories or empirical knowledge about the real system structure. The latter sub-group of tests assess the validity of the structure indirectly by checking the appearance of certain types of behavior or exposing the model to the situations in which there are always certain types of reactions that emerge in the system’s behavior. Once there is confidence about the validity of the model’s structure, one can start testing the model’s accuracy in reproducing the major behavior patterns exhibited by the real system.

The behavioral validation measures the accuracy of the model in reproducing the real-world data. To this end, scholars in the system dynamics field have proposed several types of statistics and their related tests such as mean-square error and root-mean-square percent error (Sterman, 1984; Barlas, 1989). Others propose statistical procedures to test the elements of behavioral patterns including trends, periods of oscillations, phase of oscillations, average values, and amplitudes (Barlas, 1989). Some have followed the procedure of statistical modeling and used calibration as a way of validation (Oliva, 2003). However, since there is the risk of fitting the wrong model structure to the historical data through calibration, structural validity comes first with respect to priority in the validation procedure. This is the structure that produces a specific behavior.

As Barlas (1996: 200) argues, for those models to evaluate/testing an existing theory, the structural level of validation is sufficient, and insightful. The behavioral level of validation is necessary for the models intending to analyze a real system to improve undesirable performance patterns. Thus, there is a congruency between the approach of developing a system dynamics model and the type of validation. For those stylized models translating existing theories or adopting the hybrid approach to model a generic case, the structural validation tests are sufficient. For those models developed based on a specific case using the modeling-from-scratch approach, both the structural and the behavioral tests are needed (Barlas, 1996).

Following Oliva (2003), the model structure is the combination of equations and parameters. Theoretical structure refers to equations and the way they are related to each other. In terms of the observability of causal relationships between the variables, system dynamics models can be categorized under the title of white-box models, which is in the opposite corner to black-box models like econometrics time-series model (Barlas, 1996; Kleijnen, 1995). In system dynamics models, all the equations are based on either theoretical causal relationships or empirically observable relationships between the variables. This makes it possible, specifically in the latter case, for one to be able to directly observe and extract the logical range of change for most of the parameters in the model. Thus, one can run the simulations before the automated calibration of the model to produce the simulated behavior, perform the sensitivity analysis, and check the model's capability to produce theoretically well-known behaviors. Due to this observability of theoretical relationships, any counterintuitive behavior can be attributable to syntax errors (through the programming phase) or modeling error. If neither of the above reasons apply, counter-intuitive behaviour can indicate a new insight (Kleijnen, 1995: 158).

The model in this thesis is a stylized one developed by adopting the hybrid approach of system dynamics modeling. It is the result of translating the existing theories of housing and land economics modified by incorporating planning regulations based on real world causalities. Hence, as far as the range of parameters is known, validating the theoretical structure is sufficient for the analytical purpose of this research.

This thesis follows the procedure proposed by Barlas (1996) for the structural validation. Since the model's equations have been derived from microeconomic theories, and there is no inconsistency between the measurement units of variables based on the units check performed by Vensim Pro. Software, the model has indeed passed the direct structure tests mentioned in the description of the process. Hence, only structure-oriented behavioral tests are needed to validate the model. There is a long list of tests for validating SD models. Even a selection of tests in that list may be too demanding to perform (Senge and Forrester, 1980; Barlas, 1989; Barlas, 1996; Sterman, 2000). However, as Barlas (1996) truly mentions, not all these tests are equally important and relevant. Therefore, Barlas (1996) defines the minimum most crucial number of tests. This thesis adopts this minimal approach to validate the developed SD model.

In this sub-group, Barlas (1996: 202) enumerates three tests: extreme condition, phase relationship, and sensitivity tests. There are extreme conditions in which the system's reaction is known or can be easily anticipated, whether it has been observed or not. These extreme conditions can be produced by "assigning extreme values to selected parameters" (Barlas, 1996: 191). The extreme values that model inputs can take on are "zero or infinity." By infinity, it means higher than the observed maximum amount of that specific input (Sterman, 2000: 869). The phase-relationship test compares the behavior phase of pairs of variables with their phase relationships in the real world. The lags and leads in the model should comply with the lags and leads in the observed data (Barlas, 1996; Sterman, 2000). Sensitivity analysis is the exploration of the model's behavior by changing the plausible range of parameters. Its aim is to see that the model output has the same sensitivity to the changes in its parameters as the system the model reflects demonstrates in the real world (Barlas, 1996). The comparison of model sensitivity can be qualitative and quantitative. In qualitative comparisons, the direction of the change in the output variable matters. Moreover, if it is possible, the reasonableness of the magnitude of its change should be addressed. In quantitative comparisons, both the direction and the precise magnitude of change are examined (Sargent, 2013: 19). The next sub-sections report the results of the structural validation tests based on the procedure explained above. The duration of 200 quarters (50 years) is sufficient for the emergence of the test effects until the new equilibrium appears.

4-8-1- Extreme Condition Tests

In this section, two extreme conditions are imposed on the model. The first condition happens when the demolition rate becomes zero. In the other extreme situation, the income levels of three income groups equate to zero one after the other. Theoretically, these variables can accept the value of zero and offer the possibility of checking the behavior of the model in that condition.

4-8-1-1- Zero Demolition Rate

In the steady-state, the demand level of different income groups is constant. However, the presence of the demolition rate results in a constant change in the housing stock. A hypothetical extreme condition could be the time that the demolition rate equates to zero. For clarity, the demolition rate is set to zero by the start of the 20th quarter. The result of the test for three variables is shown in Figure (4-6). After the 20th quarter, both housing and land prices first drop down and then stand in a steady state.

On the other hand, the housing stock increases from the 20th quarter for a while and follows a plateaued trend afterward. However, the relative decrease in the housing price is more significant than the land price. The reason is that developers first purchase the amount of land they need. Hence, under-construction land and built land stocks represent both total supply and total demand for land. The only part that can change total demand is the land demand for new constructions. After setting the demolition rate to zero, the intention for new construction and the demand for new land diminish shortly after that. The situation is different for the housing price since only the built housing stock is considered in the total supply. The under-construction stock affects the housing supply with a lag being equal to the construction time. The lagged addition of under-construction stock to the total supply leads to the gradual increase and decrease in the housing stock and housing price, respectively. The durability of housing and land implies that in the extreme hypothetical condition of zero change in supply and demand, their price levels follow the steady-state.

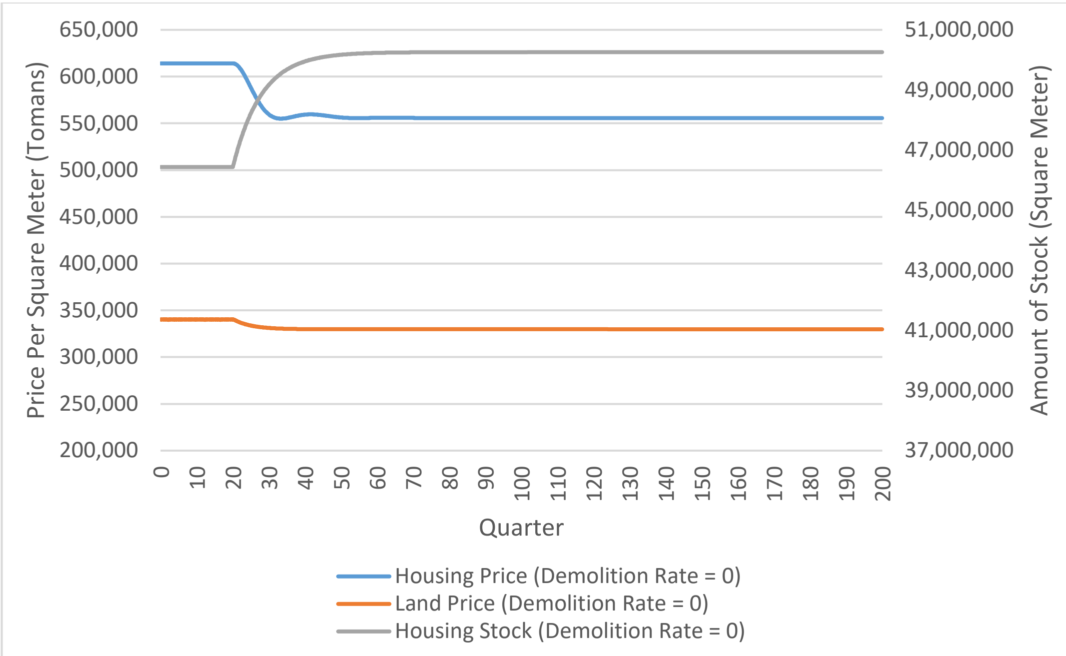


Figure 4-6: The results of zero demolition rate

4-8-1-2- Zero Income Levels

Setting the income levels of three income-groups almost equal to zero, the total demand for housing diminishes to near zero. In order to show the gradual change in the related variables, income levels have been set equal to a figure close to zero. It was a gradual process in which the income level of low-income households changed to zero. Secondly, the income-level of lower and middle-income groups was set to zero. Finally, all groups' income levels became zero. Due to applying the linear expenditure system, almost zero income does not mean that the individual demand for a good will also be zero. However, due to the marginalization process, people cannot obtain the necessary amount of goods from the formal market and start leaving it. Hence, each income group's total demand, as it is the product of individual demand and the number of households in that group, would be zero.

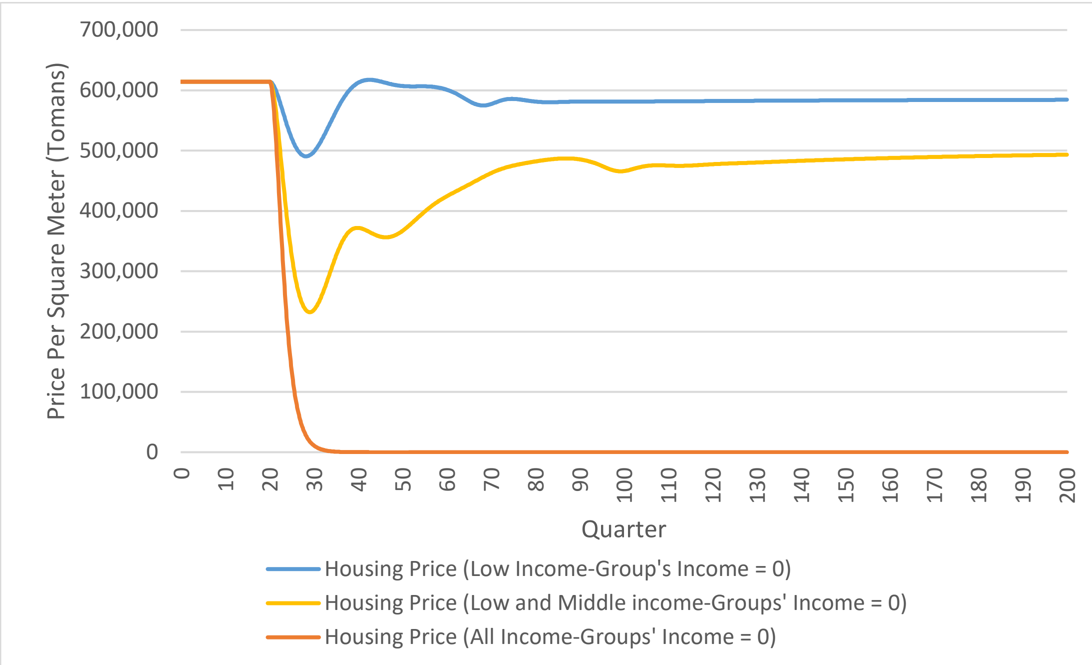


Figure 4-7: The effect of step-wise reduction of income levels on the housing price

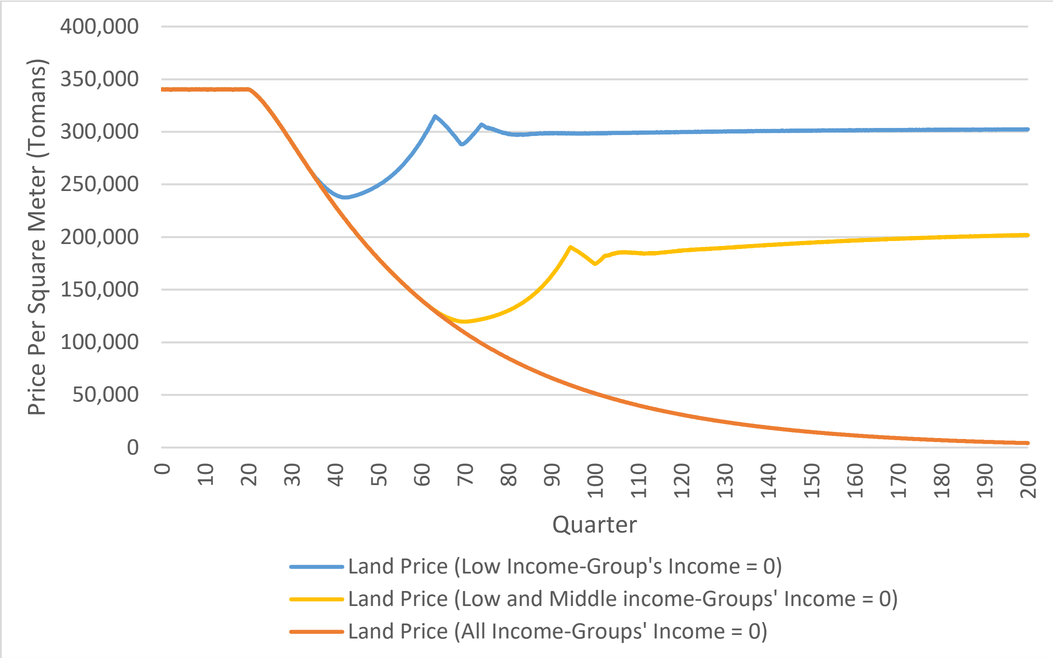


Figure 4-8: The effect of step-wise reduction of income levels on the land price

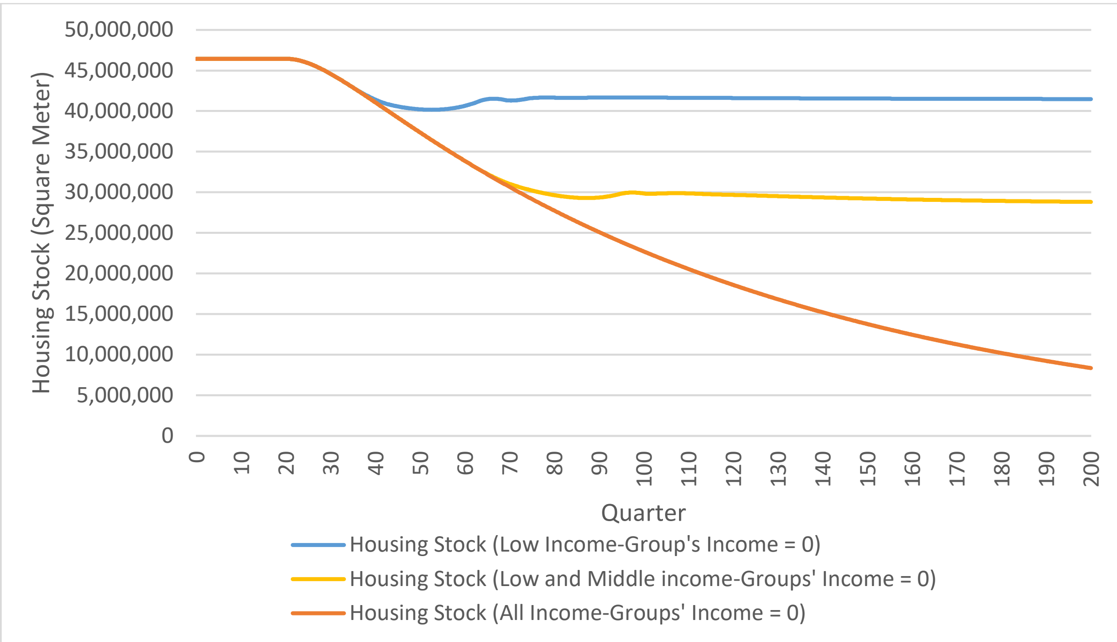


Figure 4-9: The effect of step-wise reduction of income levels on the housing stock

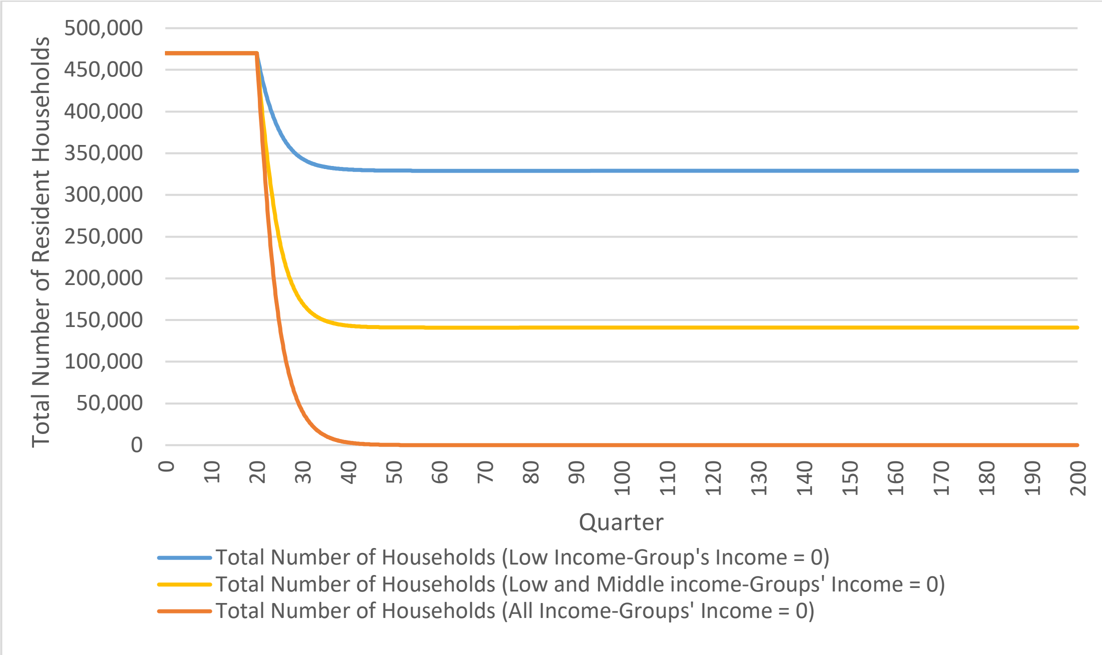


Figure 4-10: The effect of step-wise reduction of income levels on the total number of households

4-8-2- Phase Relationship Tests

Phase relationship tests intend to identify the lead-and-lag relationship among the variables. Among all the variables in the model, the housing and land price are the most major variables of the two interrelated markets. Hence, their phase relationship is tested.

4-8-2-1- Determining Lag and Lead among Housing and Land Prices

The relationship between housing and land prices has been both theoretically and empirically controversial. Due to the scarcity of data on land transactions, the empirical works have been rare in this field compared to the works on the housing price and its determinants. In classical economics, affected by Ricardo's theory of agricultural land rent, the land is considered a specific good that is not produced, that has a fixed amount and thus, its supply is inelastic. Hence, its rent is determined by demand-side factors and, above all, the demand for other goods for which land is considered a production factor (Evans, 2004). On this basis, land demand is a derived demand. Neoclassical economics considers the land as a production factor following the general rules of supply and demand. Also, its supply can be affected by different factors, including planning regulations (Evans, 2004; Ball et al., 2004).

Along with this theoretical basis, Wen and Goodman (2013) identify three opinions about the relationship between housing and land prices: the cost-driven perspective, the derived demand perspective, and the mutual causation perspective (pp. 9-10). The first group considers land acquisition cost as a component of housing construction cost, which can affect its price. The second group insists on the unidirectional relationship between housing and land since land demand is a derived demand. The third group points out that there is a mutually causal relationship between housing and land prices due to these markets' interaction.

Perhaps, the first work that examined the dynamic relationship between these two variables belongs to Ooi and Lee (2006). They performed the Granger causality test on quarterly data on housing and land prices in Singapore to define the lag-and-lead relationship. Results showed that the housing price is the Granger-cause of the land price. However, they admitted that theoretically there should be a feedback relationship from the land market to the housing market. Since then, other studies have tested the Granger causality in different contexts, and the results have been inconsistent. As an example, Wen and Goodman (2013) enumerate the studies that have been done on the relationship between the housing and land prices in the Chinese urban context and find ambiguous results, all of which are derived from the Granger causality test and vector autoregressive models. On this basis, while some studies have found the housing price is the Granger cause of the land price, others who check different lags have found that in the shorter period, both housing and land price are the Granger cause of each other, but in the longer period, the housing price is the Granger cause of the land price. Wen and Goodman (2013) estimate a simultaneous-equations model that takes housing and land prices as endogenous variables with other external factors that affect them. By performing the Hausman test, they show that the endogeneity hypothesis cannot be rejected, and there is an interaction between land and housing prices. Moreover, estimating the coefficients proves that both housing and land prices affect each other. However, the magnitude of the housing price effect is larger than the land price influence.

In this thesis, the land is considered as a production factor whose market is integrated with the housing market. It is expected that owing to the mutual causal interrelationship between the two markets, both of them appear as the Granger-cause of each other. In order to perform the test, a demand shock is imposed on the model in the 20th quarter under two modes of regulations restrictiveness: A moderately restrictive condition (the UGB size of 125% of the initially developed area of the city and the MBD is set equal to 240%) and a highly restrictive condition (the UGB size of 102.5% of the initially developed area of the city and the MBD is set equal to 120%). The simulated housing and land prices are used for the test. However, before performing the Granger causality test, we should be confident about the stationarity of the time-series data. Table (4-1) shows the result of the Augmented Dickey-Fuller (ADF) test for housing and land prices under both restrictive conditions. The result of the ADF test shows that the housing price data in all cases is not stationary. Therefore, I use the first difference of both the housing and land prices to perform the Granger causality test since their first difference is stationary. For performing the Granger causality test, we should determine the number of lags of the independent variable in the model. Since I use quarterly data, the number of lags to do the Granger Causality is four or eight quarters (Wooldridge, 2015: 590). The result of doing the Granger causality test for different lags shows different patterns. For the 4-quarter lag, the results of the test under both restrictive conditions show that both changes in land and housing prices are the Granger-cause of each other, indicating the mutual relationship between them in the shorter term. However, in the case of an eight-quarter lag, only the change in land price is the Granger cause of the change in the housing price, which implies that in the longer term, the land price can be used for the prediction of the housing price. The results of the four-quarter lag are consistent with the results of part of the studies, but the results on the eight-quarter lag introduce the land price as the lead. Table (4-2) represents the result of tests for the four-quarter and the eight-quarter lags under two modes of restrictiveness in planning regulations.

Table 4-1: The result of Augmented Dickey-Fuller Test for the stationarity of time series

Regulations Restrictive ness	Null Hypothesis	Level			1st Difference		
		t-Statistic	Prob.*	Lag Length	t-Statistic	Prob.*	Lag Length
Moderately Restrictive	HOUSING_PRICE has a unit root	-2.3646	0.3955	5	-3.4248	0.0540	3
	LAND_PRICE has a unit root	-3.1638	0.0978	1	-3.2594	0.0792	1
Highly Restrictive	HOUSING_PRICE has a unit root	-2.2849	0.4377	5	-3.4451	0.0515	3
	LAND_PRICE has a unit root	-3.2011	0.0902	1	-3.2430	0.0823	1

Table 4-2: The result of Granger causality test for the four-quarter and eight-quarter lags

The price elasticity of land supply	Lags	Null Hypothesis	Number of Observations	F-Statistic	Prob.
Moderately Restrictive	4	D1(LAND_PRICE) does not Granger Cause D1(HOUSING_PRICE)	97	4.19452	0.0037
		D1(HOUSING_PRICE) does not Granger Cause D1(LAND_PRICE)	97	2.75487	0.0328
	8	D1(LAND_PRICE) does not Granger Cause D1(HOUSING_PRICE)	93	2.06894	0.0493
		D1(HOUSING_PRICE) does not Granger Cause D1(LAND_PRICE)	93	1.16089	0.3339
Highly Restrictive	4	D1(LAND_PRICE) does not Granger Cause D1(HOUSING_PRICE)	96	4.03532	0.0048
		D1(HOUSING_PRICE) does not Granger Cause D1(LAND_PRICE)	96	2.75645	0.0328
	8	D1(LAND_PRICE) does not Granger Cause D1(HOUSING_PRICE)	92	1.99882	0.0580

		D1(HOUSING_PRICE) does not Granger Cause D1(LAND_PRICE)	92	1.16490	0.3316

4-8-3- Behavior Sensitivity Tests

In this section, the behavioral sensitivity tests have been performed to compare the model's behavior with the known behavior of the system obtained from the existing theories or other models that have been developed in this ambit. The type of comparison is both qualitative and quantitative. In qualitative comparison, the direction of the change in the model's major variables and their pattern of behavior are examined. The quantitative comparison is more related to the examination of elasticities.

4-8-3-1- Change in Income Level

The change in the income level affects the housing demand. The relationship between the income level and the housing price is direct. Raising households' income increases their demand and leads to the increase in the long-term equilibrium housing prices. Figure (4-11) shows the effect of increasing the income level by 12.5%, 25%, and 50% on the housing price. Alm and Follain (1994) derived the same results from their dynamic model of housing market.

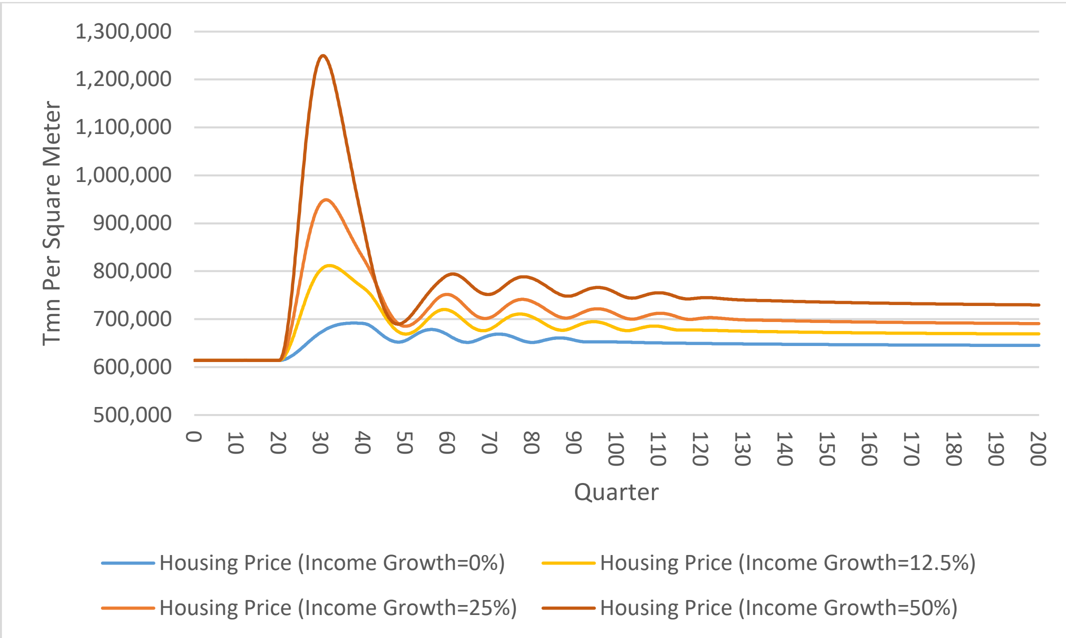


Figure 4-11: The effect of raising households' income on the housing price

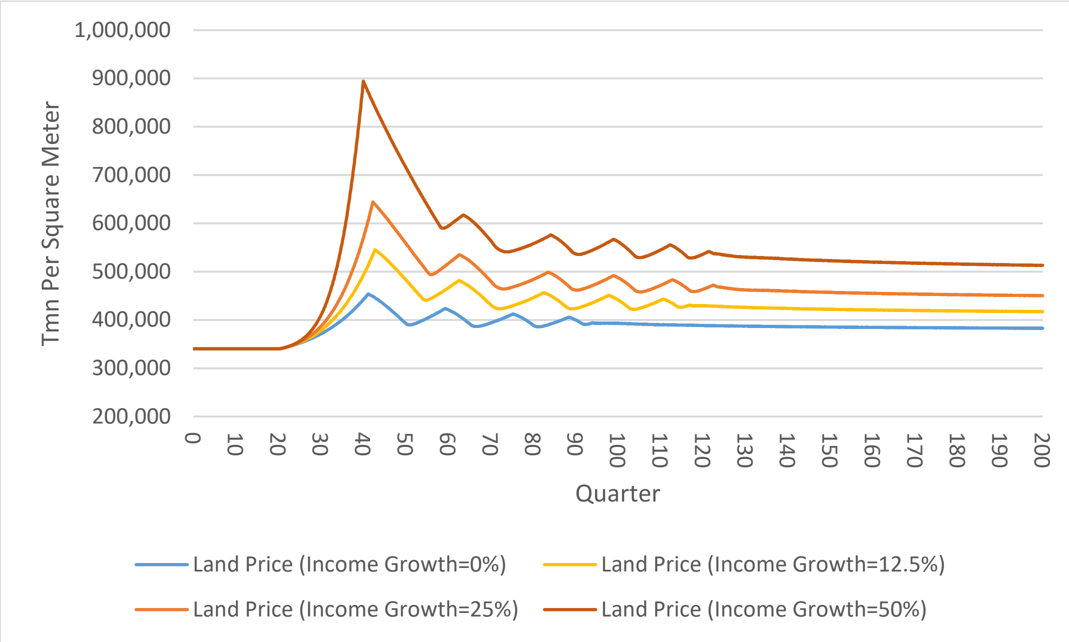


Figure 4-12: The effect of raising households' income on the land price

4-8-3-2- Change in Demolition Rate

In the steady state of the system, the city develops as much as needed to replace the demolished buildings. The demolition of the housing stock is the source of new demand and the dynamic equilibrium. Increasing the demolition rate means giving a demand shock to the city. Figure (4-13) depicts the effect of increasing the demolition rate on the housing price and its behavior. It lifts up the price level. Moreover, higher demolition rates increase both the amplitude and frequencies of fluctuations. The reason for this behavior is that developers lack perfect foresight about the future of prices, causing them to react to the market signals excessively or insufficiently. A jump in the demolition rate means a jump in the housing demand and price, which causes the developers to develop more than what is required to meet the demand. Later, the resulting excess supply leads to a drop in housing prices and development. After decreasing to a certain level, the housing price rises since the excess supply is completely absorbed, and the demand accumulates. The next phase of rise in the price and the excess supply is similar to the first one, but the peak in the housing price is lower than the previous peak since the excess supply is less than the first phase. These fluctuations continue until the housing price converges to its new equilibrium level. If the first shock in the form of an increase in the demolition rate occurs to a higher level, it will take more time for the market to converge to the new steady state, which means more fluctuations with higher amplitudes. These results are consistent with the findings of Wheaton's (1999) dynamic model. The land price follows the same changes in its pattern and long-term equilibrium levels.

Figure 4-13: The effect of increasing demolition rate on the housing price

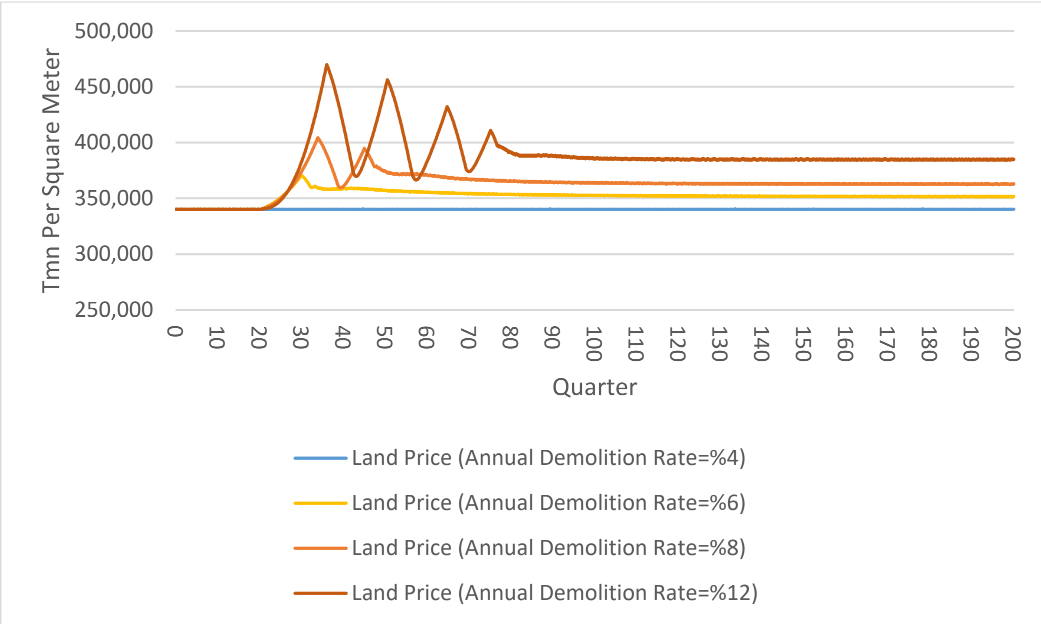


Figure 4-14: The effect of increasing demolition rate on the land price

4-8-3-3- Change in Construction Time

There is an inevitable lag between the start and completion of new construction. This lag is the average time required for the completion of construction by an individual developer. As an initial value, the construction time is set to eight quarters (two years). This is the construction time for maintaining a steady-state housing and land markets. By increasing the construction time in two stages, (first twice the original value and then four times the initial value), both price series rise and then converge to their new steady states (See figures (4-15) and (4-16)). This result is consistent with the microeconomics theory on the housing supply elasticity since the construction delay reduces the elasticity of supply, which results in the uplift of prices.

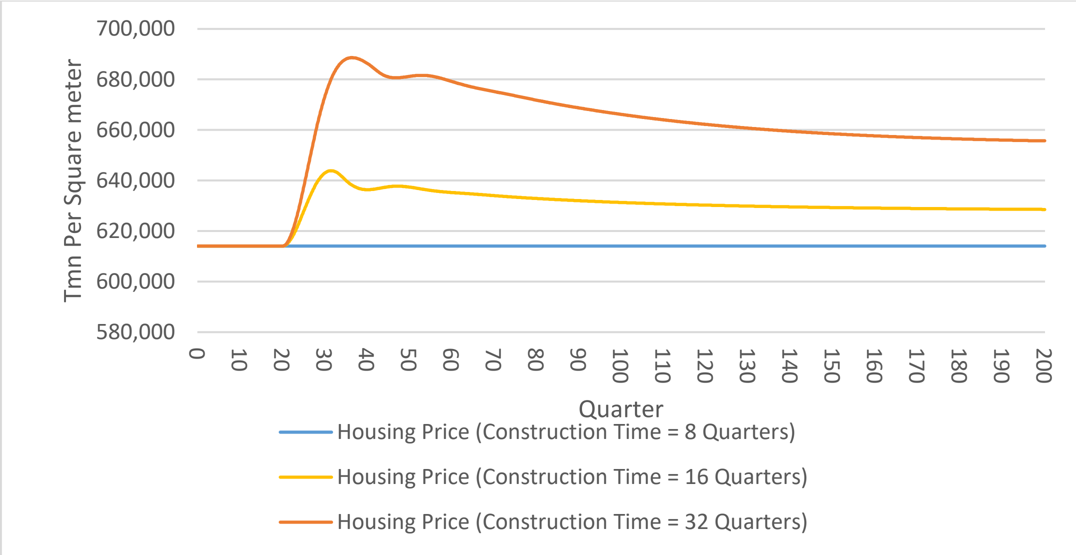


Figure 4-15: The effect of increasing construction time on the housing price

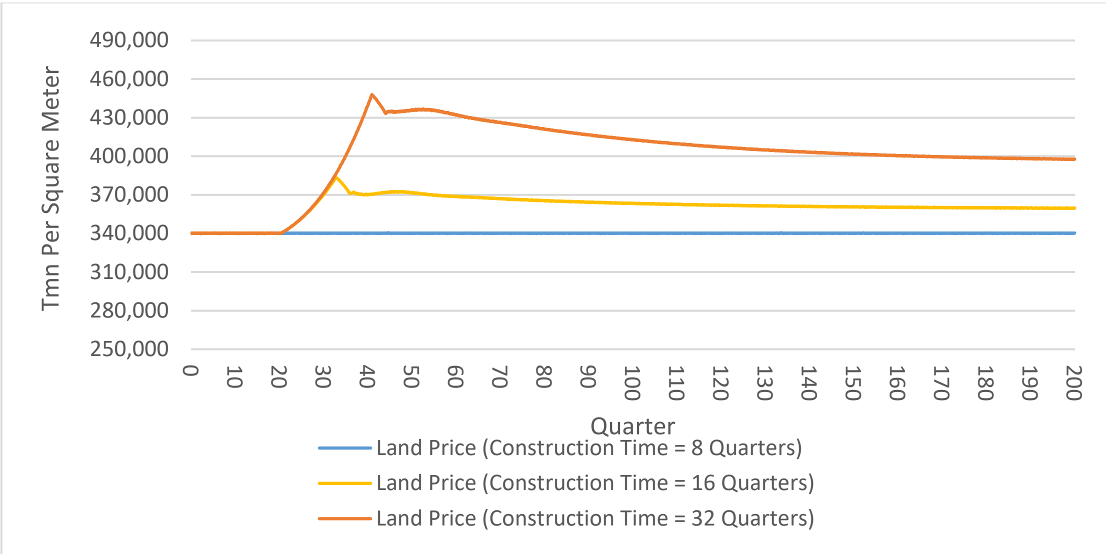


Figure 4-16: The effect of increasing construction time on the land price

To examine the effect of construction lag on the model's behavior, one can combine the demand shock and change in the construction time. This combination helps address the effect of construction lag on the stability of the model behavior and compare it with the existing model's findings. A 3% demand shock lasting for 20 quarters (five years) from quarters 20 to 40 is imposed on the model. Concomitantly, the construction time has been increased to 8, 16, and 32 quarters.

Increasing the steady-state construction time increases the amplitude of fluctuations especially in the first jump due to the demand shock, but decreases the frequency of fluctuations and prices converge to their new long-term equilibrium more smoothly. Hence, the length of cycles increases, and it takes more time for the housing price to settle down. These results are consistent with the results that Wheaton's (1999) simulation model yielded about the office market.

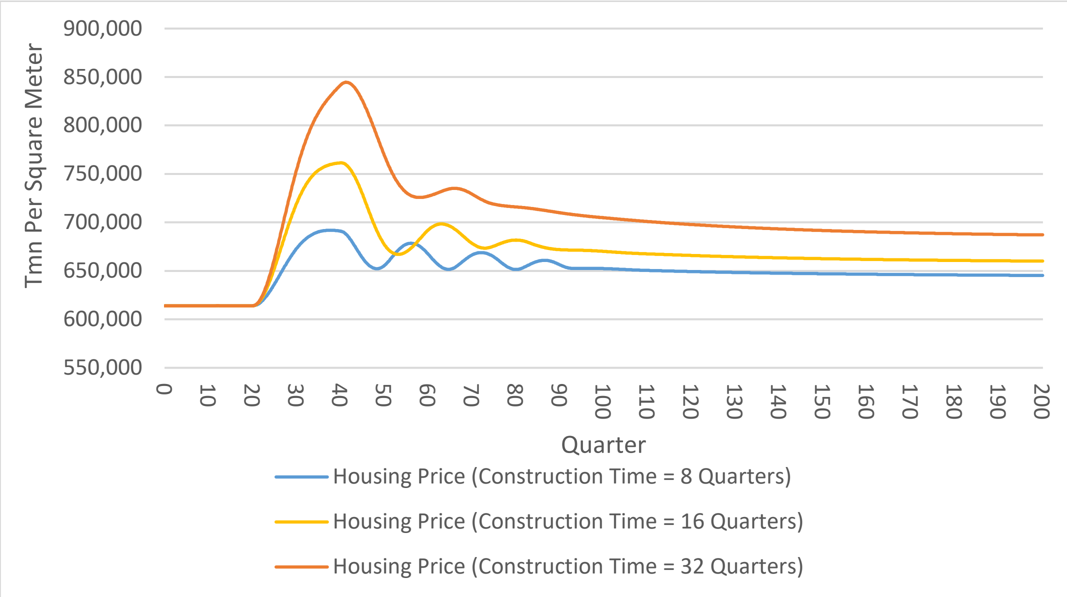


Figure 4-17: The combined effect of change in the constriction time and positive demand shock

4-8-3-4- Change in the Price of Capital Factor

Change in the price of capital factor has the same effect that is expected from the alteration of all other production factors prices. The steady-state price of capital factor has been increased by 50 percent and 100 percent in two stages in the 20th quarter. By increasing it, the housing price rises and then converges to its new equilibrium level. Moreover, the increase in the price of one factor, whose price changes are more related to the national economy, affects the price of land as a strictly local production factor. It is the substitution effect based on which, by the increase in the price of one production factor, developers economize on that expensive factor by relying more on the cheaper factor. However, the dynamic relationship implies that by developers demanding more land, its price will increase. Decreasing the price of capital factor brings about similar results in different directions.

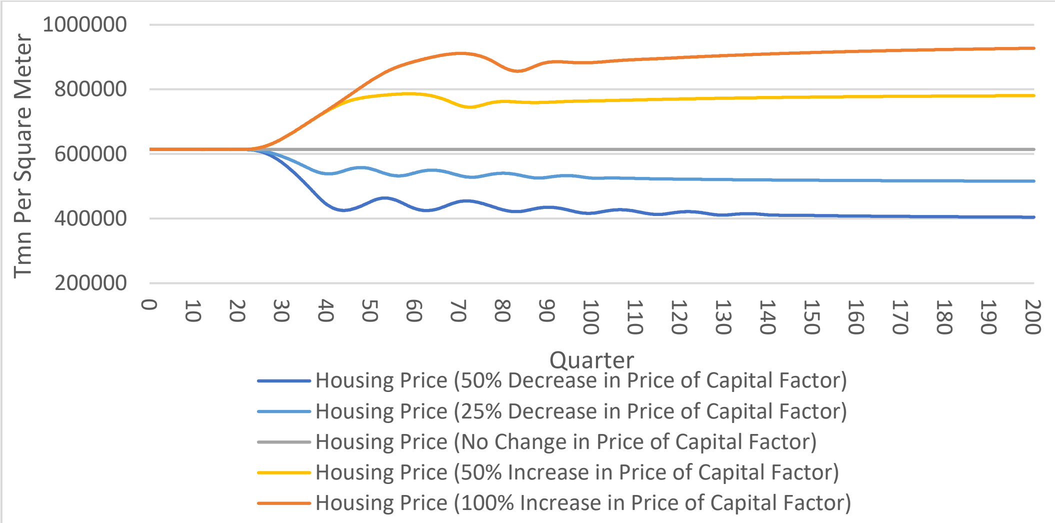


Figure 4-18: The effect of changing the price of capital factor on the housing price

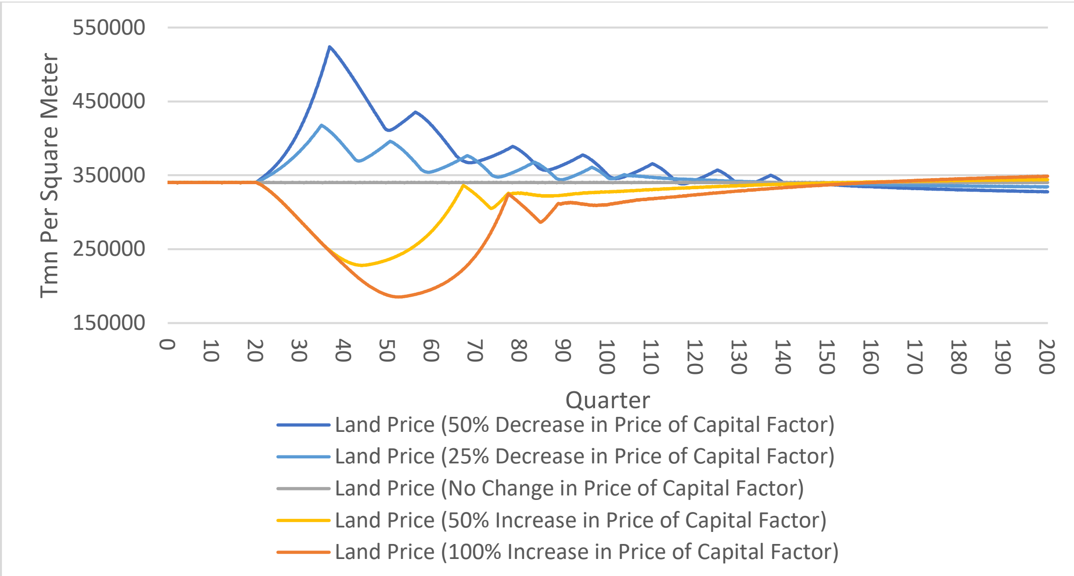


Figure 4-19: The effect of changing the price of capital factor on the land price

4-8-3-5- Change in the Cost of Capital

The cost of capital refers to the profitability of housing construction in comparison to other industries. The model behavior has been tested in two situations: when a sharp increase and a sharp decrease in the cost of capital is imposed in quarter 20. The rise in the cost of capital means that the housing construction market loses its relative attractiveness. Hence, the housing price decreases, which in turn reduces the housing market profitability and leads to the reduction of new construction. The ultimate result of the increase in the cost of capital is the contraction of the housing construction industry and the growth of housing rents. On the other hand, the decrease in the cost of capital increases the housing price and absorbs more capital from the rival industries. The oversupply of housing ultimately reduces the rent level. These results are consistent with the results derived by Alm and Follain (1994) from their dynamic model of housing market.

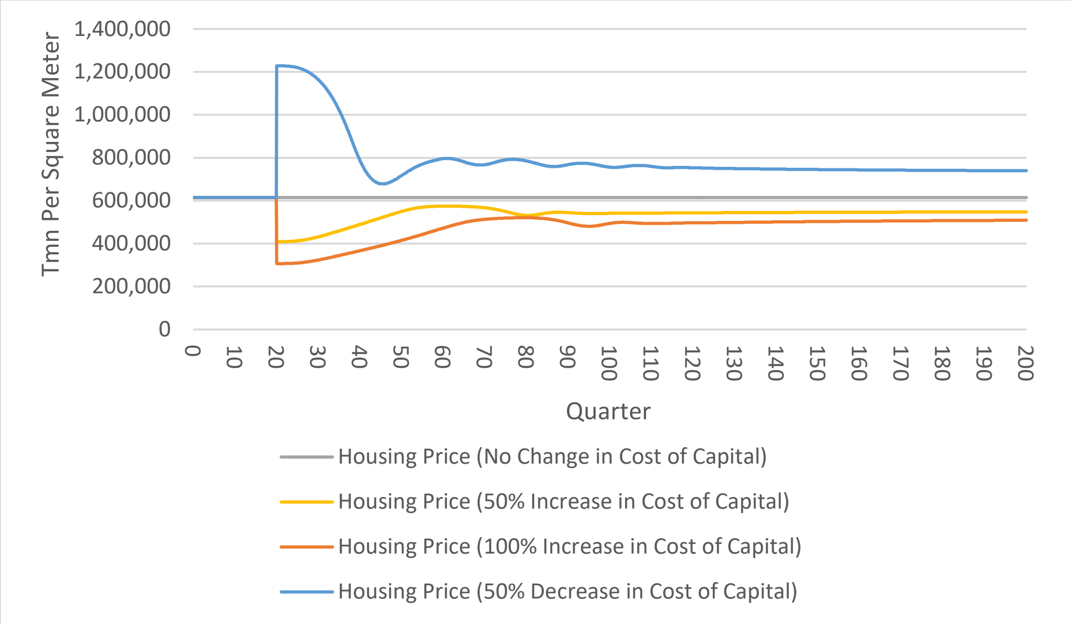


Figure 4-20: The effect of changing the cost of capital on the housing price

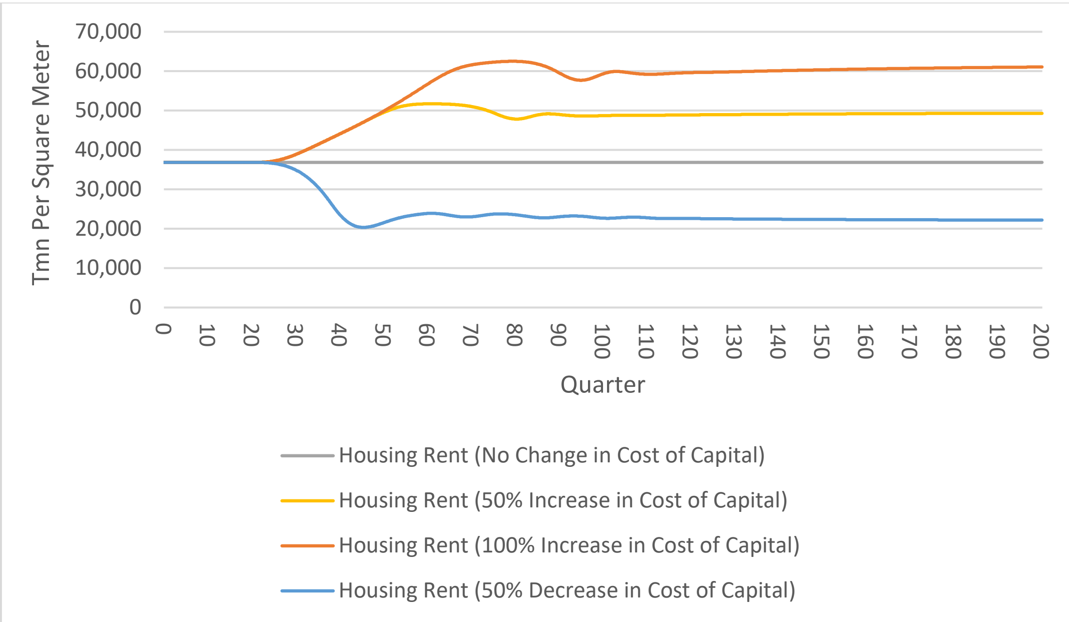


Figure 4-21: The effect of changing the cost of capital on the housing rent

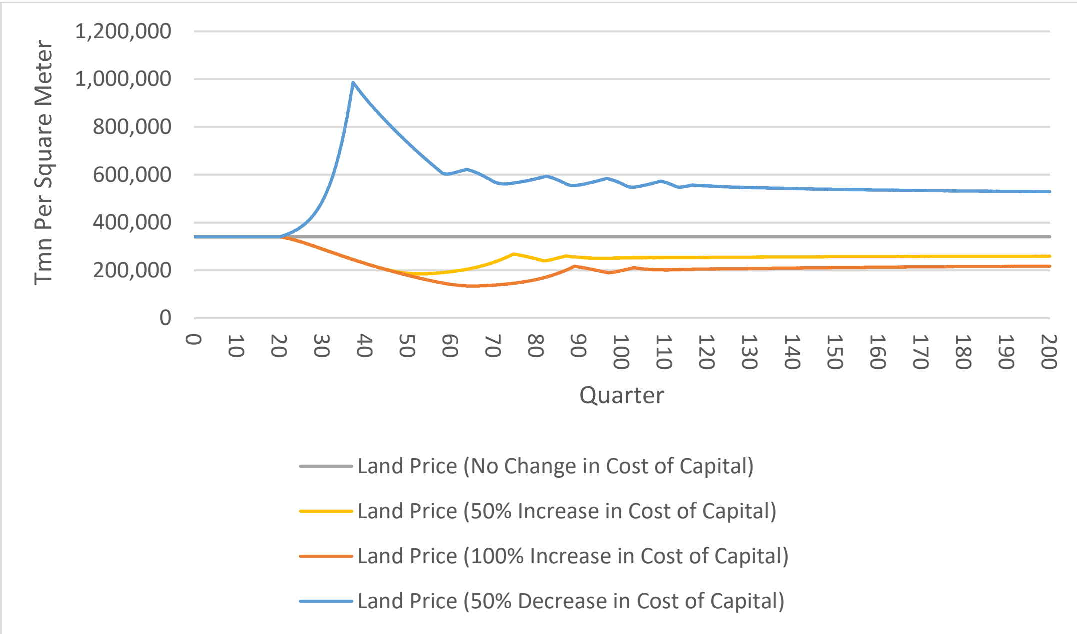


Figure 4-22: The effect of changing the cost of capital on the land price

4-8-3-6- Change in the Price Elasticity of Land Supply

The price elasticity of land supply is initially set to 0.4. However, the supply elasticity of land can be lower than this. It can be even zero, which means the city has no place to expand, and all it has is the existing stock of developed land. Figures (4-23) and (4-24) show the effect of decreasing the price elasticity of land supply on housing and land prices while there is a demand shock in the 20th quarter. It is decreased in two stages. First, it drops down to 0.2 and then it falls to zero. Changing the land supply elasticity affects the housing supply elasticity in the same direction (Yan et al., 2014). Calculating the long-term price elasticity of housing supply by using simulation data shows that by decreasing land supply elasticity from 0.4 to 0.2 and eventually to zero, the long-term elasticity of housing supply[10] decreases from about 2.41 to 1.98 and ultimately to 1.52, respectively. As the reduction in land price elasticity decreases the housing supply elasticity, both housing and land prices increase. The less the land supply elasticity and consequently the housing supply elasticity, the higher will be the housing price appreciation in the produced bubble after the demand shock. This result is consistent with the empirical results provided by Ihlanfeldt and Mayock (2014) and Glaeser et al. (2008). Although both of these studies considered the elasticity of new home supply or housing starts, the elasticity of new housing is the essential part of the elasticity of the housing stock. Therefore, their results are applicable for checking the result of the model. In both housing and land prices, initially, prices increase rapidly, and after reaching their maximum point, they diminish more smoothly and

[10] The mentioned elasticities are yielded without imposing restrictive planning regulations.

converge towards an equilibrium value. The other point is that decreasing the land supply elasticity will reduce the number of oscillations in housing and land markets and increase their amplitude. These results are similar to the results of Malpezzi and Wachter (2005) simulation model about the effect of change in the housing supply elasticity on the housing price fluctuations.

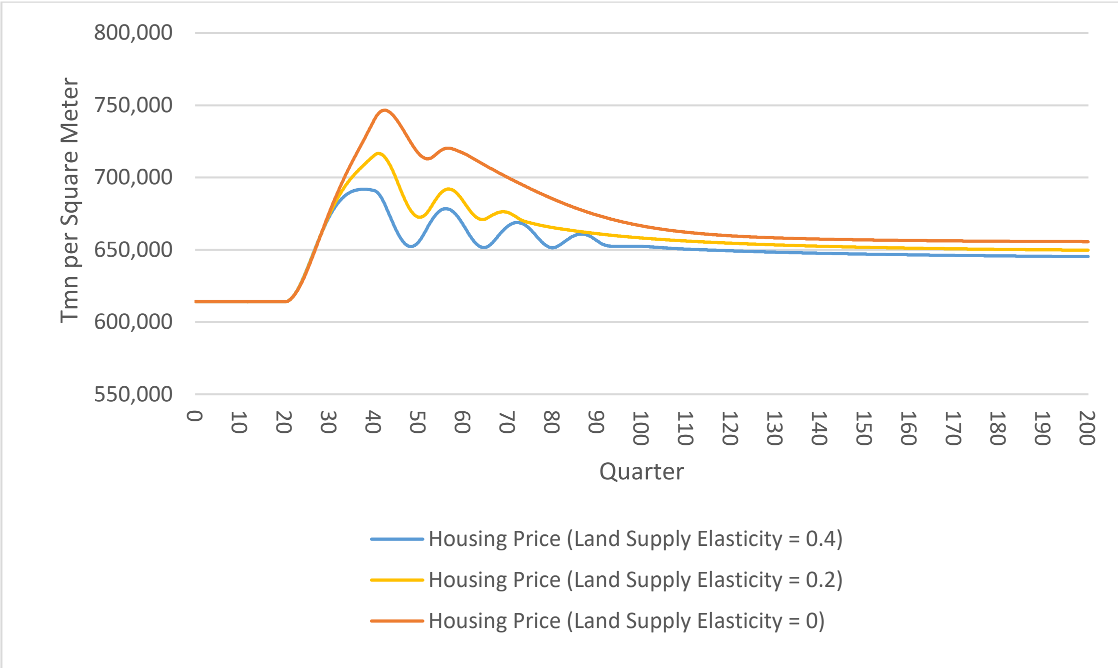


Figure 4-23: The effect of decreasing the land supply elasticity on the housing price after a positive demand shock

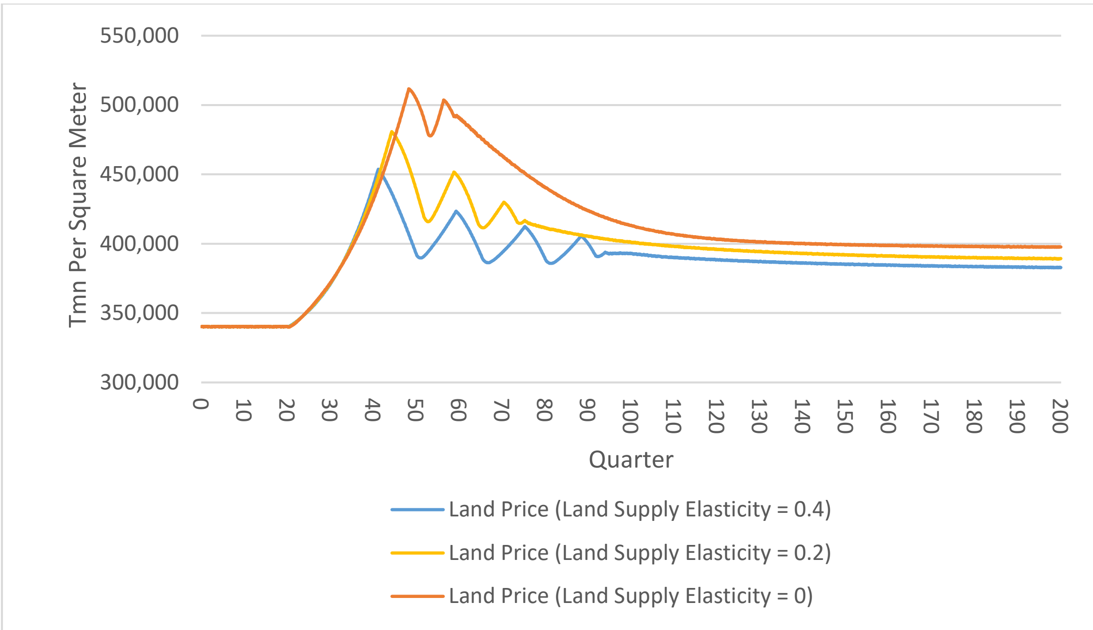


Figure 4-24: The effect of decreasing the land supply elasticity on the land price after a positive demand shock

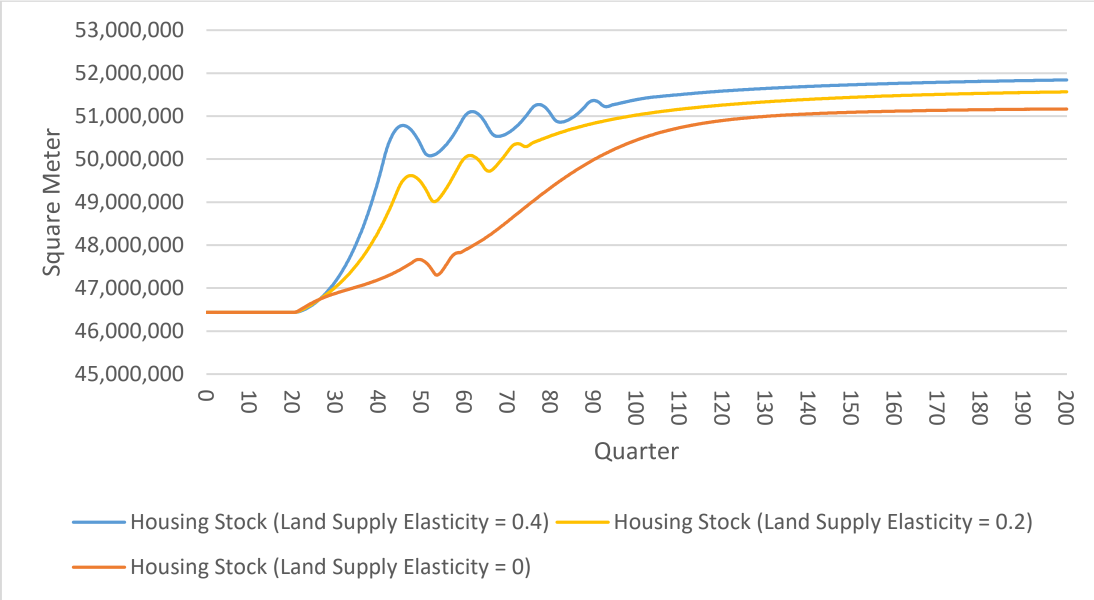


Figure 4-25: The effect of decreasing the land supply elasticity on the housing stock after a positive demand shock

The effect of an increase in the land price on the building density in the event of inelastic land supply is the other behavior that further validates the model. Considering the extreme condition of inelastic land supply, the price of land increases, and developers economize on the land factor by increasing the construction density. Through the reconstruction of the entire existing housing stock and reacting to the initial demand shock, the city's actual building density gradually increases and converges towards the optimum building density that developers choose for construction (Figure (4-26)). At this new equilibrium point, the building density of the entire city increases.

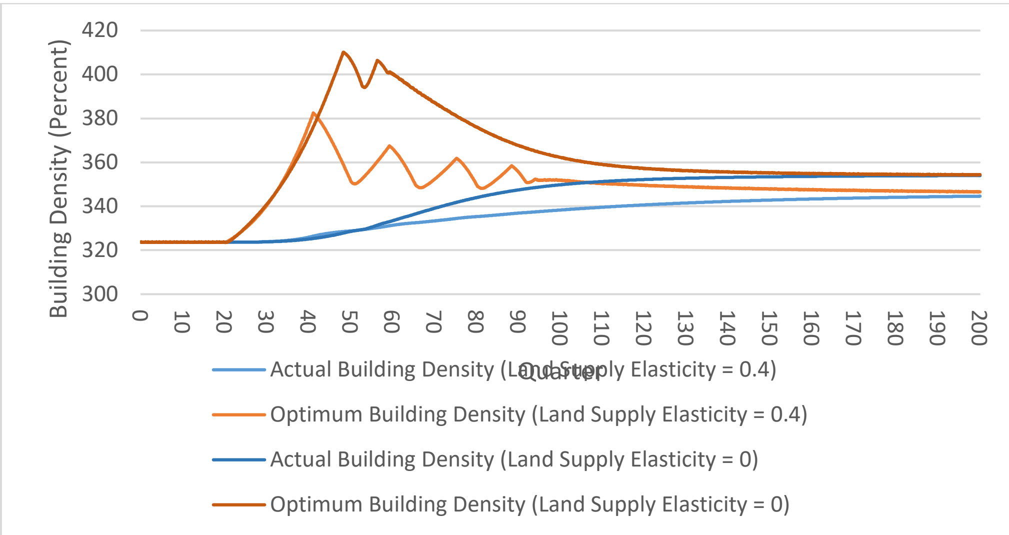


Figure 4-26: The gradual inclination of the actual building density towards the optimum building density after a positive demand shock and under the different land supply elasticity conditions

4-8-3-7- Rent Elasticity of Housing Demand

Applying the LES form for the demand function instead of other conventional forms makes the rent elasticity of housing demand implicit and variable. As Mayo (1981) shows, the demand elasticity derived from such a function depends on both price and income levels. This form enables one to calculate the rent elasticity of housing demand, compare it to theoretical and empirical results, and build more confidence in the model structure. Describing the process of calculation geometrically, one should hold the demand function fixed and change the supply function. The locus of equilibrium points provides the scheme of the long-term housing demand function. The long-term elasticity can be derived for each price point. Instead of this tedious process, the long-term elasticities have been estimated using the percentage of changes between the initial steady point and new ones. The housing supply has been changed by changing the price of the capital factor. The change rates are $\pm 10\%, \pm 20\%$, and $\pm 30\%$. The demand elasticity has been estimated for the total demand and the individual demand of each income-group. The results are presented in table (4-3). Comparing it with Mayo's (1981) table confirms the consistency of results with the housing demand theory. Because of the increase in the housing price and housing rent, the absolute value of demand elasticity decreases. The absolute value of demand elasticity increases through the income-groups by an increase in the income level. The only exception for these rules is the demand elasticity for the first decile when the price of capital factor increases by 30%. In this case, the absolute value of elasticity has increased. This happened because the housing price has increased to the extent that the first decile' households have resorted to the informal sector. The resulting fall in the number of people in this decile exacerbates the demand reaction to the change in housing prices compared to other income groups.

Table 4-3 The estimation of rental elasticity of housing demand under the different conditions of change in the price of capital factor

Change in the Price of Capital Factor	Decile 1	Decile 2	Decile 3	Decile 4	Decile 5	Decile 6	Decile 7	Decile 8	Decile 9	Decile 10	Total Demand
-30%	-0.44	-0.72	-0.81	-0.87	-0.91	-0.95	-0.98	-1.03	-1.07	-1.13	-0.98
-20%	-0.41	-0.66	-0.74	-0.80	-0.84	-0.88	-0.91	-0.94	-0.98	-1.04	-0.90
-10%	-0.38	-0.62	-0.69	-0.74	-0.78	-0.82	-0.84	-0.88	-0.92	-0.97	-0.84
10%	-0.34	-0.54	-0.61	-0.66	-0.69	-0.72	-0.74	-0.78	-0.81	-0.85	-0.74
20%	-0.32	-0.51	-0.58	-0.62	-0.65	-0.68	-0.71	-0.73	-0.77	-0.81	-0.70
30%	-0.83	-0.49	-0.55	-0.59	-0.62	-0.65	-0.67	-0.70	-0.73	-0.77	-0.68

4-8-3-8- Price Elasticity of Housing Supply

In this model, the supply process has been decomposed in different objectively tangible stages that happen over time. Due to the durability of housing and land, housing supply is the total housing stock. Indeed, the new construction is the new supply, which, along with the depreciation rate, defines the total supply (total housing stock). The new construction is the function of profit in the housing construction market, which is, in turn, determined by both housing price and construction cost. In the long-run, when the market runs out of profit due to the equality of marginal revenue and marginal cost, the new construction would offset the depreciation, and the total supply remains at a constant level. At this long-term equilibrium point, total supply depends merely on the housing price (i.e. marginal revenue, which is equal to marginal cost). The long-term price elasticity of housing supply has been calculated using the equilibrium values of housing prices and total housing stock. The process of estimation is similar to that explained for the estimation of demand elasticities. To provide the locus of equilibrium points, one can impose different levels of demand shock. To this end, the number of households in all income groups has increased by 3%, 5%, 8%, and 10% for 20 quarters (five years). Table (4-4) shows the estimated price elasticities of housing supply in two conditions: with and without imposing regulations. When regulations are not imposed, all the figures are more than one, which complies with the general theory of supply stating that in the long term, supply is completely elastic. However, the empirical works on the price elasticity of housing supply have provided different estimations. The literature on this subject is twofold. The majority of works have estimated what is known as the elasticity of new supply or starts (Yan et al., 2014). Few studies have estimated the elasticity of the stock (Malpezzi and Maclennan, 2001; Ball et al., 2010). Here, the latter concept of housing supply elasticity matters. Based on these estimations, the long-term housing supply elasticity is inelastic or elastic. For example, Mayer and Somerville (2000) estimated it as 0.08, and Dipasquale and Wheaton's (1994) estimation fell between 1.2 and 1.4 which is elastic. A critical factor in determining the housing supply elasticity is the regulatory environment, and the difference between countries in this respect can justify the difference between estimations (Malpezzi and Maclennan, 2001, Ball et al., 2010). Hence, to achieve more realistic estimations, it is necessary to account for the effect of planning regulations. The imposition of planning regulations on the model provides estimations which are close to the range of estimations provided in the literature (third column). Increasing the restrictiveness of regulations provides figures closer to the empirical estimations.

Table 4-4: The estimation of price elasticity of housing supply under the different conditions of change in the income levels

Household Growth	Housing Supply Elasticity	
	Without Regulation	With Regulation
3%	2.41	0.32
5%	2.46	0.65
8%	2.54	0.94
10%	2.59	1.01

4-9- Conclusions

In this chapter, the thesis model has been developed to answer the major questions of the research. The model has several features that make it different from the other dynamic models of property markets discussed in Chapter 3. These are as follows:

- The land market has been explicitly modeled and integrated into the housing market. The reason behind this explicit modeling of the land market is that most of the planning regulations target the consumption of land for development purposes. The land market model will enable the study to test the effect that regulatory changes have on the housing market and marginalization of low-income households to the informal housing sector.
- The integration of the housing and land markets has been achieved by incorporating the construction sector and the concept of optimum building density at the core. This notion captures the economic concept of the optimum combination of production factors, namely, land and capital factor.
- The formula for the optimum building density is derived from the Cobb-Douglas form of the production function with the constant return to scale. Hence, instead of developing an aggregated behavioral equation for the new supply of housing, which should be statistically estimated, it has been disaggregated based on the production theory and the concept of profit maximization.
- The disaggregated production is converted to aggregated production through the incorporation of the market adjustment process. The adjustment mechanism changes the number of developers active in the housing construction industry and the amount of individual construction they complete. This disaggregation process helps to incorporate an understanding of how the planning regulations affect the behavior of each individual developer.
- Also, a form of rationality boundedness in the production process has been incorporated by incorporating delay in developers' perception of the optimum building density.

- On the demand side of the housing market, the linear expenditure system has been used as a form of demand function for different income groups. This incorporates the necessary level of each good and service including housing, in the demand function. It helps embed the marginalization process in the model developed here, based on viewing informal settlements as a last resort for the marginalized lowest-income households. This form of demand function has been used before by Heikkila and Lin (2014), although in a static way. Here, it is applied dynamically.
- Ten levels of income-groups have been assigned to represent income differentiation throughout the city.

After developing the model, the structural validity of the model has been tested by performing three subgroups of structure-oriented behavioral tests, namely, extreme condition tests, phase-relationship tests, and sensitivity tests.

In extreme condition tests, one tests the situation in which a parameter takes on the extreme value, which can be zero or infinity (larger than the normal amounts it usually takes). This test has been performed regarding two parameters: the demolition rate and income levels. By setting the former to zero, the housing and land prices moved from their initial steady-state. After a fall, which was infinitesimal for the land price, housing and land prices reached the new steady-state situation. Setting the income levels of all income groups to zero led to the evacuation of the city and zero housing and land prices.

In the phase relationship test, the lag-and-lead relationship between the main variables is the subject of investigation. The relationship between housing and land prices has grabbed the interest of scholars for decades. The neoclassical theory considers the land to be like other production factors whose prices comply with the general rules of supply and demand. Although its demand is a derived demand, there is a mutual interaction between the land and housing price. By performing the Granger causality test under the different land supply elasticity conditions, it has been shown that both the land and housing price are the Granger-cause of each other. Due to the feedback relationship between the housing and land market, this result was expected.

In sensitivity tests, the model's behavior is explored by changing the parameters' values through a reasonable range and comparing the changes in the model output with the real-world system data. The pattern of model behavior and the numerical change of the model output can be compared qualitatively or quantitatively. Since the information on the magnitude and behavioral change in the system is more qualitative, the direction of change and the overall behavior of the model output have been examined with the available theories. However, the comparison was performed quantitatively for the rent elasticity of demand and price elasticity of supply. The sensitivity of model output (housing prices) was examined with respect to changes in six main parameters: income levels, demolition rate, construction time, price of capital factor, cost of capital, and price elasticity of land supply. The model's behavior was consistent with behavior predicted and shown by other theoretical or empirical works. Raising the income level of all households increases housing and land prices due to boosting the housing demand. Increasing the demolition rate functions as a demand shock and increases the long-term equilibrium prices levels. Also, higher demolition rates make the housing market more volatile. The longer construction time increases the housing price. Prolonging the construction lag, in the case of a demand shock, prolongs the period of the housing price appreciation. Although it reduces the number of fluctuations, the market requires more time to smoothly converge to the new higher long-term equilibrium price.

There is a direct relationship between the price of capital factor and the housing price. Also, increasing/decreasing the price of capital factor increases/decreases the land price. This direct relationship is the manifestation of the substitution of production factors. By increasing the price of one factor, producers economize on the expensive factor by substituting it with more of the cheaper factor. However, more reliance on land increases its price.

Considering the steady state, by increasing/decreasing the cost of capital, as a result of contraction or expansion of the housing construction industry, the housing rent increases/decreases. Reducing the price elasticity of the land supply increases housing and land prices. Estimating the price elasticity of housing supply for different amounts of land supply elasticity shows that the reduction of the latter will reduce the former leading to higher housing prices.

The estimated rent elasticities of different income groups' housing demand show that the absolute value of the elasticities increases with income and decreases with the price and rent levels. The only exception is the elasticity of the lowest income households' demand when the housing price is high enough to marginalize them. Apart from that, for most of the income groups and at most of the rent levels, the housing demand is inelastic. On the other hand, the estimations of long-term elasticity of housing supply with and without imposing planning regulations proves the critical role of regulations in converting the completely elastic housing supply to an inelastic one in the long term.

5. Analysis and Results

5-1- Introduction

This chapter analyzes the effect of three planning regulations, namely, Maximum Building Density (MBD), Minimum Lot Size (MLS), and Urban Growth Boundary (UGB), on the target variables: housing price, land price, and the number of informal dwellers (the number of households resorting to informal settlements). The analyses have been done through running simulations.

To this end, first, the model is externally calibrated by using data on major Iranian cities. The model calibration produces the profile of a hypothetical city, consisting of seven critical endogenous variables, within the range of the values of the seven Iranian metropolises' profiles. The next section discusses the calibration process. The further sections explain the data and its sources.

The result of the calibration is the hypothetical city in its steady state. This steady-state of the model is the base case on which a series of contributing factors and planning regulations is imposed to test their effect on housing and land prices and the number of informal dwellers by running simulations. First, the chapter analyzes the effect of five non-regulatory contributing factors. After that, it analyzes the effect of planning regulations on the target variables in two parts: the first investigates the individual effect of each regulation and, the second analyzes the combined effect of each three possible pair of regulations. The last section concludes by summarizing the results of the chapter.

5-2- Solving and calibration method

The model described in Chapter 5 is non-linear, so analytically solving it is challenging. The type of analysis is the impulse response analysis that De Leeuw and Ekanem (1973), Wheaton (1999), and Hwang and Quigley (2006) used for the dynamic analysis of property markets. The process of analysis consists of two stages: first, numerically solving the model to achieve a steady-state situation, and second, changing the parameters mentioned in the introduction of the chapter to analyze their effect on housing and land prices and the number of informal dwellers. The model developed for this research is a stylized one. The objective is to study the system's behavior (a hypothetical city), which it is representing, in response to changes in the restrictiveness of planning regulations rather than to provide a point-by-point prediction of a variable in a specific case. Thus, internal calibration is not meaningful and yields unreasonable estimations for some of the model's parameters. In this case, the external calibration is sufficient. It has two stages.

First, many of the parameters are determined by using external sources. The available data makes it possible to estimate a part of this first group of parameters. There is another part that one cannot directly estimate by the existing data. For the latter group, reasonable values are defined. For estimating the first group, this study uses existing data series predominantly produced by the Central Bank of Iran (CBI) or Statistical Center of Iran (SCI). The results of the Investigation of the Private Sector's Construction Activities in the Urban Areas of Iran's Provinces from 2007 to 2016 is the only data series produced by CBI that has been used for the model calibration. The SCI-produced Data series used for the calibration are as follows:

- The 2011 National Population and Housing Census Data,
- The 2016 National Population and Housing Census Data,
- Urban Household, Expenditure and Income in 2011,
- The Information of Building Permits Issued by Municipalities in 2011,
- The Information of Housing Prices and Rents in Cities from 2005 to 2017,
- The Demographic, Social, and Economic Characteristics of Metropolises based on the 2011 and 2016 National Population and Housing Census Data.

However, the remaining data is not available at the city scale. In those cases, the research uses provincial data, which is mostly based on sampling from major provincial urban centers. In estimating the parameters of the housing production function, additional data from other major cities ensures there are sufficient data records for robust estimation.

After that, the process continues to estimate the remaining few parameters and all the endogenous variables, including the stock variables, by using an iterative tuning process similar to the tuning process followed by Wheaton (1999). The tuning process aims to estimate the values of the model's seven major variables representing the profile of the typical city between the maximum and the minimum values (the range) of the same variables reported for the seven second-tier metropolises in Iran. The seven variables making up the profile of the typical city are the housing price, the land price, the optimum building density, the actual individual housing space demand (average size of a housing unit), the average size of an under-construction land lot, the number of households, and the average annual household income. The tuning process estimates these seven endogenous variables by testing different values for three undefined parameters: the reference optimum building density, reference land price, and the potential number of developers, given the values of other parameters determined by external sources. The results of the external calibration are not necessarily the median or mean values of the variables. Therefore, the iteration continues until it produces the values for the seven variables standing between the maximum and minimum values (the range) of each variable in the profile of seven metropolises. The following subsections address the estimation process of the first group and discuss the reason behind the determined values of the second group of parameters defined externally.

5-2-2- Parameters Estimated by Using Existing Data

This section addresses parameters estimated by using the existing data. In total, I estimate 16 parameters by using the existing data. I explain the process of estimating each of them in a separate sub-section.

5-2-2-1- Capital Factor Price

The capital factor price is a concept defined for this research to connect maximum building density with the housing production function. Based on the definition provided in Chapter 5, the price of capital factor is the cost expended on the construction of one square meter of housing with a floor area ratio (FAR) of one. The only way to extract it from the existing data is to find the construction cost per square meter of cases where the FAR equates one. Searching all data records for ten years in the major cities of 29 provinces leads to only 15 records. Hence, it is impossible to estimate a sophisticated time series model to define the mean capital factor price. The data limitation forces this study to estimate a simple linear regression to produce the data on the mean price of the capital factor as the dependent variable by the year as the independent variable. The model gives the mean value of capital factor price for 2011, which is the year for which the profile of the typical city is produced. Figure (5-1) is the scatter plot of the existing data on the price of the capital factor. Table (5-1) to Table (5-3) show the statistics and coefficients of the linear curve fitted on the data.

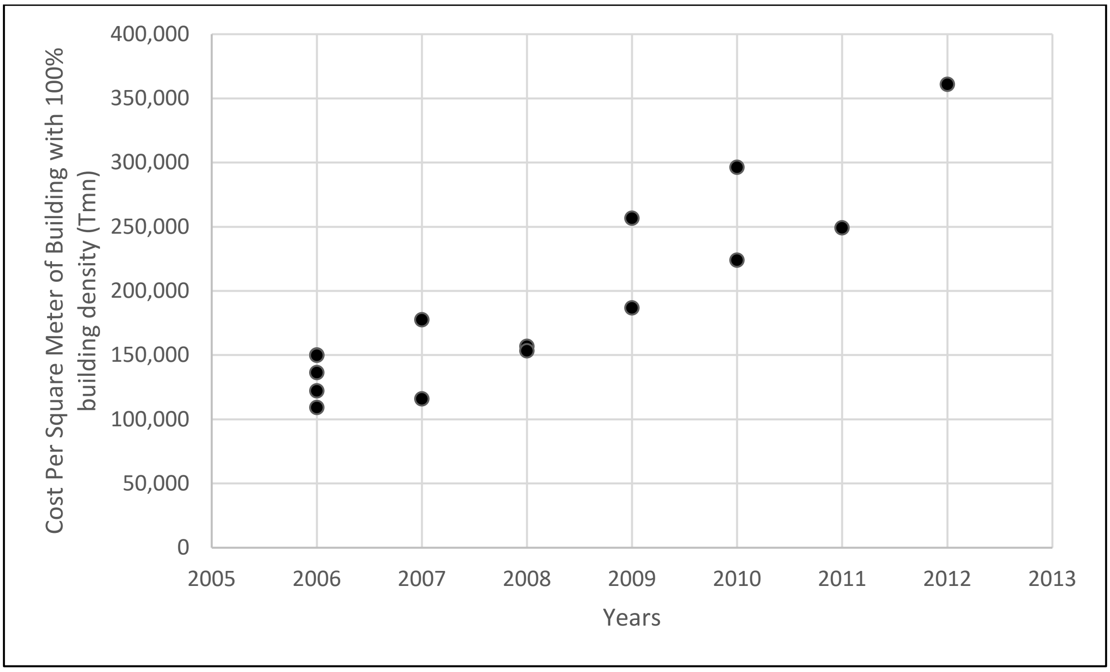


Figure 5-1: The scatter-plot of data points on the cost per square meter of building with 100% building density

Table 5-1: The statistics of the linear regression model for estimating the capital factor price

Regression Statistics	
Multiple R	0.899140736
R Square	0.808454064
Adjusted R Square	0.793719761
Standard Error	33207.18759
Observations	15

Table 5-2: The result of F-test for the linear regression model for estimating the capital factor price

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	6.05E+10	6.05E+10	54.86884	5.13962E-06
Residual	13	1.43E+10	1.1E+09		
Total	14	7.48E+10			

Table 5-3: The estimated coefficients and statistics of the linear regression model for estimating capital factor price

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-45028045.49	6104450	-7.37627	0.0000
Year	32599.55475	4400.974	7.40735	0.0000
Equation	Capital Factor Price=32599.55475*Year-45028045.49			

The model is fit to the existing data. Since the objective of the regression model is to yield the mean values of the capital factor price for the same period, the negative sign of the intercept would not be problematic. The regression model estimates the mean price of the capital factor in the period 2006 to 2012. Among these years, the value for 2011 is of interest. The equation yields the mean capital factor price in 2011 by putting 2011 in the estimated equation in Table (5-3). Table (5-4) shows the estimated mean capital factor price for the targeted period.

Table 5-4: The estimation of mean capital factor price

Year	2006	2007	2008	2009	2010	2011	2012
Mean Price of capital factor (Tmn per square meter)	122,331	154,931	187,530	220,130	252,729	**285,329**	317,929

5-2-2-2- Parameters Related to Housing Production Function

These parameters are production scale, housing production sensitivity to the capital factor and housing production sensitivity to the land factor in the Cobb-Douglas production function. The formula developed for calculating the optimum building density in Chapter 4 uses these parameters. The data used for the estimation has been derived from the data on the construction activity of the private sector in Iran's urban areas, which predominantly includes the major cities. The initial data has included the average area of land and the average total construction cost of a building on residential buildings from 2006 to 2016 in the urban areas of the 29 provinces.

Based on the discussion about using the capital factor instead of investment in the housing production function, it is needed to convert the total construction cost of a building figures to the amount of capital factor. Dividing the total construction cost figures into the estimation of capital factor prices for each year yields the amount of capital factor. Since data is on different urban areas, fixed effect dummies are incorporated to deal with place-based differences. Because we do not expect to witness a noticeable change in construction technology during ten years, I ignore the time-fixed effects. Using the natural logarithm of the data helps linearize the Cobb-Douglas production function.

Table (5-5) summarizes the estimated coefficients of the model and their significance levels. The second and the third rows of the second column display the estimated values for the production to land factor sensitivity and the production to capital factor sensitivity, respectively. Both of them are significant at the 99 percent level. The constant and most of the estimated coefficients for fixed effects dummies are highly significant. For estimating the production scale of the hypothetical city, I add the constant to each of the estimated coefficients for dummies, take the average of them, and raise it to the power of Euler's number.

Table (5-6) summarizes the estimated three parameters of the model. The estimated parameters demonstrate that housing production in Iranian major cities is more sensitive to the capital factor than the land factor. Most importantly, the sum of the sensitivity parameters is

0.9968, which is very close to the unit. Thus, the estimation confirms that the housing production function has the constant return to scale as it is for most industries.

Table 5-5: The estimations of the coefficients of natural logarithm model of housing production function

Variables and Dummies	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	0.316	0.166		1.903	0.058
LN_Land	0.413	0.040	0.247	10.345	0.000
LN_Capital_Factor	0.584	0.017	0.732	33.600	0.000
West_Azar	-0.109	0.044	-0.048	-2.462	0.014
Ardebil	-0.043	0.044	-0.019	-0.968	0.334
Isfahan	-0.153	0.044	-0.067	-3.490	0.001
Ilam	-0.243	0.045	-0.107	-5.404	0.000
Booshehr	-0.260	0.045	-0.115	-5.784	0.000
Chaharmahal	-0.074	0.045	-0.032	-1.635	0.103
South_Khor	-0.168	0.046	-0.074	-3.685	0.000
Razavi_Khor	-0.158	0.044	-0.070	-3.604	0.000
North_Khor	-0.083	0.045	-0.037	-1.841	0.067
Khozestan	-0.225	0.044	-0.099	-5.091	0.000
Zanjan	-0.160	0.044	-0.070	-3.610	0.000
Semnan	0.043	0.047	0.019	0.917	0.360
Sistan	-0.413	0.048	-0.182	-8.530	0.000
Fars	-0.259	0.046	-0.114	-5.594	0.000
Ghazvin	-0.205	0.044	-0.090	-4.659	0.000
Ghom	-0.215	0.044	-0.095	-4.905	0.000
Kordestan	-0.072	0.045	-0.032	-1.587	0.114
Kerman	-0.415	0.048	-0.183	-8.709	0.000
Kermanshah	-0.083	0.044	-0.036	-1.867	0.063
Kohgilooyeh	-0.317	0.047	-0.139	-6.778	0.000
Golestan	-0.038	0.044	-0.017	-0.859	0.391
Gilan	-0.159	0.044	-0.070	-3.606	0.000
Lorestan	-0.118	0.044	-0.052	-2.679	0.008
Mazandaran	-0.076	0.044	-0.034	-1.738	0.083
Markazi	-0.067	0.044	-0.030	-1.541	0.124
Hormozgan	-0.188	0.046	-0.083	-4.050	0.000
Hamadan	-0.059	0.044	-0.026	-1.345	0.180
Yazd	-0.228	0.047	-0.100	-4.805	0.000

Table 5-6: The estimated parameters of the housing production function

Average Production Scale	Sensitivity of housing production to land	Sensitivity of housing production to capital factor	Sum of Factors' Sensitivities	Adjusted R-square
1.17	0.4130	0.5838	0.9968	0.939

5-2-2-3- Total Expenditure on Necessary Amount of Goods other than Housing

One can estimate this parameter by subtracting the amount of money expended by the lowest income group on housing and some goods that are unnecessary for survival. The necessary categories of expenditures are Shoes and Clothes, Sewer, Water, Electricity, Housing Furniture, Transportation and Communication, Health and Hygiene, and Foods and Drinks. These items are similar to categorizing non-housing budget necessities determined by responsible institutions to define housing affordability standards based on the residual income approach (Stone, 2006). The only difference is related to two items that are not included in this thesis. I do not include Child Care which is also excluded by some of those categorizations. The reason is that spending on child care is not a norm among the poor in Iran. I exclude the Other Goods and Services category to be more conservative about the expenditures necessary for survival. Table (5-7) contains the annual expenditure on necessities other than housing for Iran's lowest-income urban households.

Table 5-7: The annual expenditure on the necessities other than housing for the lowest income Iranian urban households in 2011

Categories	**Annual expenditure (1000 Tmn)**
Shoe and cloths	48
Sewer, water, electricity	224
Housing furniture and utensil	76
Health and hygiene	191
Transportation and communication	207
Foods and drinks	1,114
Total	1,859

5-2-2-4- Share of Household Income in each Decile Expended on Housing

The share of income that households in each decile expend on housing can only be calculated using the national-level data. The data on household income is usually prone to underestimation since households usually report their total income as less than the actual amount. Thus, I use the total expenditure and the share of housing expenditure from the total expenditure as proper substitutes for total household income and the share of housing expenditure from total household income. The share of household income on housing in each decile is as follows in Table (5-8).

Table 5-8: Share of housing from household income in each decile in 2011

	Decile 1	Decile 2	Decile 3	Decile 4	Decile5	Decile6	Decile7	Decile 8	Decile9	Decile10
Housing Expenditure (1000 Tmn)	1,293	1,882	2,217	2,622	2,920	3,440	3,933	4,667	5,622	9,578
Household Income (1000 Tmn)	4,018	6,192	7,524	8,958	10,253	12,042	14,103	16,687	20,568	34,411
Share of Housing from Household Income (%)	32.2	30.4	29.5	29.3	28.5	28.6	27.9	28.0	27.3	27.8

5-2-2-5- Average Annual Household Income in each Decile

I calculate the average annual household income in each decile as each decile's weighted average household income in seven metropolises. As mentioned in the previous sub-section, in order to be more accurate, I use the total expenditure of households in each decile in the seven metropolises as a closest proxy for the household income. The weights were the population number of the seven metropolises in 2011. Table (5-9) shows the data on the total expenditure of each decile in seven metropolises and their weighted average using their population numbers as weights.

Table 5-9: The total expenditure of decile in seven metropolises and their weighted average in 2011 (figures in 1000 Tmn)

City	Tabriz	Esfahan	Karaj	Mashhad	Ahvaz	Shiraz	Qom	Weighted Average
Decile1	2,622	3,283	3,746	2,599	3,707	3,376	3,396	3,152
Decile2	4,141	6,049	5,847	4,468	6,181	6,140	5,084	5,303
Decile3	5,425	7,662	7,102	5,764	7,397	8,074	6,131	6,694
Decile4	6,648	9,099	8,147	6,906	8,555	9,914	7,163	7,960
Decile5	7,880	10,650	9,129	8,188	9,619	11,829	8,376	9,289
Decile6	9,093	12,396	10,246	9,614	10,940	14,035	9,906	10,790
Decile7	10,945	14,393	11,408	11,226	12,819	16,561	11,822	12,598
Decile8	13,642	16,941	13,076	13,454	15,587	20,189	14,078	15,086
Decile9	17,827	23,429	16,086	16,785	21,495	26,200	17,353	19,560
Decile10	30,109	34,996	23,766	25,768	31,852	33,552	29,545	29,433

5-2-2-6- User Cost of Capital

Due to the lack of accurate data on some elements of the user cost of capital, it is impossible to calculate it precisely based on the values of its elements. The assumption of equilibrium between the rental and owner-occupied markets lets us take the rent-to-price ratio as a proxy for the user cost of capital. The average of this ratio for seven metropolises fluctuates around

0.06 during the intended period. Hence, I set the user cost of capital equal to 0.06. Figure (5-2) depicts the time trend of the average rent-to-price ratio based on the weighted average of the housing rent and price in seven metropolises.

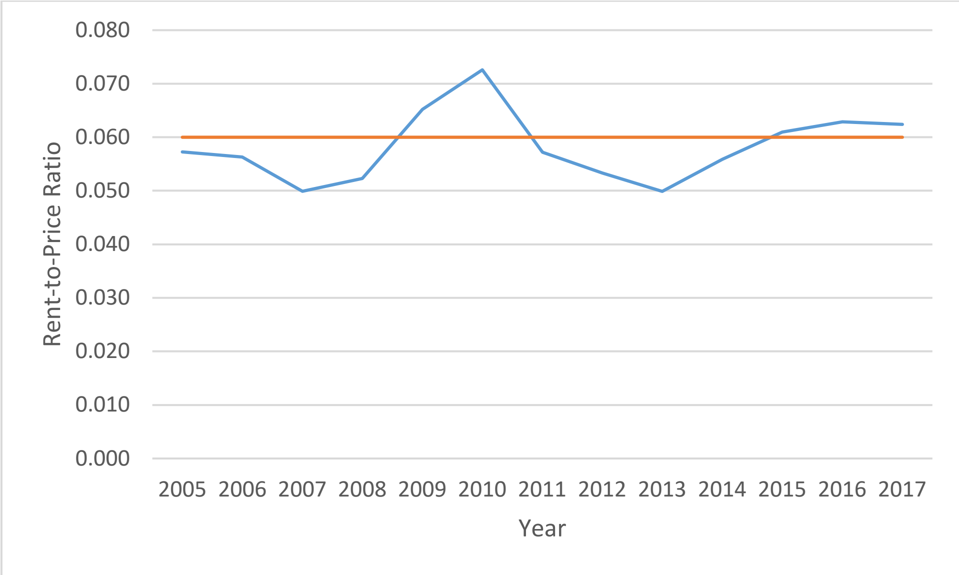


Figure 5-2: Average rent-to-price ratio in seven metropolises as a proxy for the user cost of capital (2005-2017)

5-2-2-7- Demolition Rate

I define fractional demolition rate based on the average age of the residential buildings. Statistical Center of Iran (SCI) provides this information in terms of two broad categories: apartments and houses. Table (5-10) and Figure (5-3) illustrate the share of age categories from the total stock of each type of residential buildings and in total based on the information of the 2011 census.

Figure (5-3) shows that apartments less than five years old have the highest share among the others. The highest share in houses belongs to two age categories of 15-24 and 25-34 years. Apartments are relatively new residential buildings for Iran's metropolises compared to houses. Hence, in the future, the shape of apartment buildings distribution based on their age will be closer to a normal distribution as for houses is. The median age of houses for all the seven metropolises is 21 years. Thus, considering that the age of apartments can be slightly more than houses due to using higher quality construction technologies, the median age of all types of residential buildings is more than 21. Here, I take the round figure of 25 as the average age of a residential building. The demolition rate is the reverse of the average building age. Based on this, the fractional demolition rate is 4% a year or 1% in a quarter. Zhang et al. (2018) used 20 years as the average building age for their hypothetical city in China, and on that basis, estimated the demolition rate equal to 5%, which seems relatively high.

Table 5-10: The share of age categories from the total stock of each type of residential buildings based on the information of 2011 census

	Less than 5 Years	5-14 Years	15-24 Years	25-34 Years	35-44 Years	More than 45 Years	Median age (Years)
Apartments	73	14	9	3	1	1	3
Houses	11	25	26	26	9	4	21
All Types	22	34	20	17	6	2	13

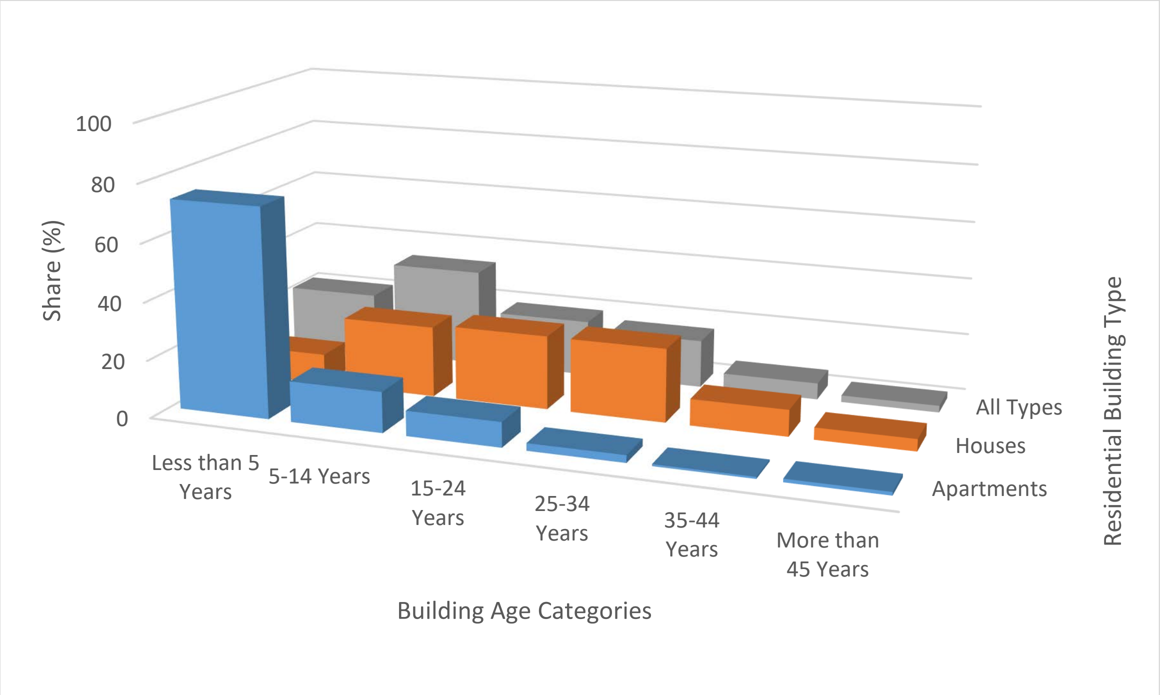


Figure 5-3: The share of age categories from the total stock of each type of residential buildings based on the information of 2011 census

5-2-2-8- Average Area of Under-Construction Land Lots

I estimate the average size of the under-construction land lots by using the data on building permits in the seven metropolises in 2011 (Table (5-11)). The data are categorical with an open-ended last category. Thus, the median is the best representative for this variable in each of the seven metropolises. Then, I calculate the weighted average of medians in which the number of building permits acted as weights as the average area of under-construction land lots in the hypothetical city.

Table 5-11: The number of lots by size categories in seven metropolises and their median in 2011

Land Lot Size (Residential Buildings)	100>=	101-150	151-200	201-250	251-300	301-500	501=<	Total	Median Size (Square Meter)
Esfahan	707	2910	7,363	4118	1769	1405	633	18905	189
Ahvaz	518	2305	3,934	2556	1213	1015	286	11827	188
Tabriz	697	939	3,330	1793	930	801	260	8750	190

Land Lot Size (Residential Buildings)	100>=	101-150	151-200	201-250	251-300	301-500	501=<	Total	Median Size (Square Meter)
Shiraz	173	591	3,177	4076	2788	2659	731	14195	238
Qom	194	1516	702	137	189	99	58	2895	141
Karaj	278	417	728	736	372	979	884	4394	255
Mashhad	519	1870	3051	2599	1328	1068	555	10990	201
Total	3086	10548	22285	16015	8589	8026	3407	71956	200

5-2-2-9- Fraction of Decrease in Undeveloped Land Supply Due to MLS

For defining the fraction of decrease in the supply of land due to MLS restriction, I use the same categorical data of Table (5-11). Although it contains all types of land, whether undeveloped or not, it is the only proxy data available to estimate the distribution of land lots based on their size. Table (5-12) shows the cumulative distribution of under-construction land lots in each of the seven metropolises. I use the total distribution resulted from summing up the number of land lots in each category for all the seven metropolises, to calculate the cumulative distribution of land lot sizes. The lowest two rows in Table (5-12) show the figures for the distribution and the cumulative distribution for the whole seven metropolises. These figures are rounded for few categories. Also, I expand the last category and divide it into three categories to provide a smooth continuation for the right-hand tail of the distribution. By imposing the minimum lot size on undeveloped land, the share of suppliable land which cannot be supplied, is equal to the left-hand side of the cumulative distribution.

Table 5-12: The cumulative distribution of under-construction land lots in the seven metropolises in 2011

Land Lot Size (Residential Buildings)	100>=	101-150	151-200	201-250	251-300	301-500	501=<
Esfahan	3.7	15.4	38.9	21.8	9.4	7.4	3.3
Ahvaz	4.4	19.5	33.3	21.6	10.3	8.6	2.4
Tabriz	8.0	10.7	38.1	20.5	10.6	9.2	3.0
Shiraz	1.2	4.2	22.4	28.7	19.6	18.7	5.1
Qom	6.7	52.4	24.2	4.7	6.5	3.4	2.0
Karaj	6.3	9.5	16.6	16.8	8.5	22.3	20.1
Mashhad	4.7	17.0	27.8	23.6	12.1	9.7	5.1
Total	4.3	14.7	31.0	22.3	11.9	11.2	4.7
Cumulative Distribution	4.3	18.9	49.9	72.2	84.1	95.3	100.0
Reconstructed distribution	5	15	30	22	12	11	5
Reconstructed Cumulative Distribution	5	20	50	72	84	95	100

5-2-2-10- Minimum Lot Size and Maximum Building Density

The model is developed and works based on the average values of stock variables. The hypothetical city constructed in this model does not have any zone. Incorporating zoning in the model can make it more complex and intractable. Therefore, all the variables are treated as the average of the whole city. Apart from the average price of land and housing, regulations should be treated based on average restrictions. Among the three types of regulations, only MBD and MLS can be treated in this way.

The calculation of the average level of restriction for each type of regulation in a city requires the share of each zone with different levels of restriction to estimate the weighted average of the restriction level. In the formal documents of the seven metropolises, except for the restriction levels, the area of each regulatory zone is not mentioned. Here, I follow an alternative way in which the average size of the under-construction land lots and the average building density of residential construction in the seven metropolises are the proxy data for the average level of restrictions. This average can serve as a good proxy for MLS, but since developers can pay to build more than the imposed level of MBD, the average building density of new construction is higher than the average restriction level. Hence, the restriction level should be lower than the estimated average. Also, the average building density without any restriction should be higher than this level.

Table (5-13) shows the median size of under-construction land lots and the average building density of new residential constructions in each metropolis. The building density expresses the ratio of the construction area to the land area in percentage. Therefore, I first estimate the weighted average of new residential construction building densities in seven metropolises. Based on the point mentioned about defining the average MBD and the weighted average of building density in seven metropolises (207%), I expect the average level of restriction on building density for the hypothetical city to be 180%. Development plans in Iran usually take the occupation ratio equal to 60%. Based on that, they define MBD levels to implicitly determine the number of floors. Hence, figures mainly used as MBD levels in these plans include 120%, 180%, 240%, and 300%, which are the multiplications of 60% and refer to buildings with two, three, four, and five storeys, respectively.

Table 5-13: The median size of under-construction land lots and the average building density in the seven metropolises in 2011

City	Median size of under-construction land lots (Square Meter)	Average building density of new residential construction (%)
Esfahan	189	227
Ahvaz	188	159
Tabriz	190	270
Shiraz	238	153
Qom	141	201
Karaj	255	339

City	Median size of under-construction land lots (Square Meter)	Average building density of new residential construction (%)
Mashhad	201	189
Weighted Average	203	207

5-2-2-11- Urban Growth Boundary Sizes

The developed model in this thesis uses the total suppliable residential area of the defined UGB as its size[11]. These figures are not available for the seven Iranian metropolises. However, Iran's metropolises have a serious lack of suppliable land forced them to impose restrictive UGBs and establish new towns around them from the end of the 1980s. On this basis, I choose a restrictive UGB, which is 102.5% of the initially developed area of the hypothetical city.

5-2-2-12- Municipal Unit Charge

The municipal unit charge is a fee that developers should pay per square meter of development beyond the MBD to the municipality if they intend to construct more than the level determined by MBD. It is the extra-development charge. There is no formal data on the municipal unit charge that municipalities set on the extra development over the imposed building density. However, discussing with the experts in the housing field reveals a rule of thumb applied to estimate the average municipal unit charge. Based on this, the average municipal unit charge ranges from 10 to 15 percent of the average price of one square meter of housing in the market (Bahrami, October 2011). Given the weighted average housing price in all seven metropolises, the average municipal unit charge places between 77,000 to 115,000 Toman per square meter. I choose 100,000 Toman per square meter as the municipal unit charge for the hypothetical city.

5-2-2-13- Construction Time

The construction time can vary from one type of building to another depending on their materials, floor area, and the number of storeys. Like other works incorporating construction time as a parameter, I use an average amount for all cases. There is no record in the formal sources of statistics for the construction time. Hence, based on experts' knowledge, the average construction time of a typical apartment in seven metropolises is almost two years (eight quarters). This is the average time that starts from obtaining the building permits to completing construction and receiving the completion permit. Zhang et al. (2018) use the exact figure as construction time for their hypothetical city in China.

[11] In the analysis sub-sections, we represent the UGB size in the percentage of the hypothetical city's initially developed residential area.

5-2-2-14- Minimum Livable Space

This minimum livable space does not mean the minimum healthy habitable space, but the minimum residential space lower than which it is not possible to live. Hence, it is the minimum basic need of everyone. Different studies provided different suggestions. Here, the suggestions provided in Iran's urban areas context are presented. Habibi and Ahari (1996) defined the minimum habitable space between 40 and 56 square meters. The Detailed Plan of Tehran (2011) defined a 35-square-meter pattern for young couples' housing units (Vice-Presidency of Housing and Urban Development, 2011). This pattern is based on the per capita space of 17.5 square meters. The Comprehensive Housing Plan (CHP) used 13 square meters as a minimum per capita livable space (Iran's Ministry of Roads and Urban Development, 2014). Multiplying this number with the average household dimension yields the average minimum livable space. Considering the average household dimension in Iran's urban areas is 3.1 people, CHP suggests 40 square meters as the minimum livable space for a family.

However, based on the SCI data on the number of families residing in different housing areas, the actual per capita space is smaller than 13 square meters. There are housing units in seven metropolises with less than 50 square meters of area accommodating more than four families. Even if we consider that each family consists of one person, the per capita space would be 12.5 square meters. However, we know that the household dimension is larger than one specifically for low-income households. On this basis, this research adopts a conservative number of 30 square meters as the minimum livable space for a household with four members. This leads to 7.5 square meters per person, which is in the range of figures estimated from the SCI data.

5-2-2-15- Time for Adjusting Housing Rent and Land Price

Regarding the housing and the land price, the estimations of the error-correction term coefficient in error correction models of housing markets give us proper estimations for the time for adjusting the housing rent. As Tu (2004) mentions, estimations differ from study to study based on the context and data. His review on European studies ranges from 0.47 to 0.84 in absolute value. His estimation for Singapore is 0.1075 in absolute value. Stevenson and Young's (2014) estimation based on the Irish housing market data is 0.0997 in absolute value. Riddle's (2004) estimation based on the US data is 0.63. DiPasquale and Wheaton (1994) estimated the price adjustment parameter in their partial adjustment model of the US housing market equal to 0.29. There are also a few studies on Iran's housing market that estimated error-correction models. Sabbagh et al.'s (2010) estimation for error-correction coefficient in the Tehran housing market between 1994 and 2006 is 0.37. Khalili Araghi et al.'s (2012) estimation based on the whole country's housing market data shows the figure of 0.788. Kafaei and Yavari (2021) report 0.60 for their coefficient estimation.

Considering the estimates in studies on the Iranian context, I choose 0.50 as a round figure among the three. The error-correction term coefficient shows the fraction of the gap between the equilibrium price and the current price, which the current price will cover during the selected period. In the case of our chosen figure, 50 percent of the gap will be covered during the period. In other words, it tells us how fast the housing price adjusts to the equilibrium price. Hence, the equivalence of the above interpretation is that twice the mentioned period should elapse until the current price fully adjusts to the equilibrium price. Since our model works based on quarterly data, the time needed for adjusting the housing rent is two quarters. I consider the same figure for the time needed for adjusting the land price because I could not find any similar estimation about the land price even in the global context.

5-2-2-16- Price Elasticity of Land Supply

Regarding the land supply elasticity, there is a serious lack of studies on the urban land supply and the price elasticity of urban land supply. The reason is the same as Ball et al. (2004) give for the absence of land prices in the dynamic models of the property market: the lack of reliable time series data on land prices. However, there are estimations for the elasticity of agricultural land supply, which can help choose a more reasonable value for the urban land supply elasticity.

Tabeau et al. (2017) provide a collection of estimates of the price elasticity of agricultural land at the country level from different studies. These estimates range from close-to-zero elasticities (0.001) to more than one in very occasional cases. They also provide estimates of agricultural land supply elasticity using two methods: deriving from the land supply formula and calculating the ratio of percentage change in the acreage of agricultural land to the percentage change in the total return from the unit of agricultural land. Both estimates show a less than elastic agricultural land supply[12]. However, the latter group generally includes estimates that are too low, to the extent that they barely exceed 0.1. The average of the second group of estimates with and without the two cases being elastic are 0.25 and 0.33. Tabeau et al. (2017) relate the low elasticities to the slow rate of growth in the area of agricultural land or even the fixity of the agricultural land stock.

The land economics theory states that urban land supply is mostly price-inelastic (Potepan, 1996). On this basis, it must be less than one. However, we expect the price elasticity of land

[12] Two cases in the first group of estimates demonstrate an elastic agricultural land supply.

supply for urban use (without considering the effect of planning regulations) to be generally higher than the elasticity of agricultural land supply. Hence, the elasticity of urban land supply cannot be zero or close to zero without planning regulations or a type of geographical limitation. To have a starting point and an average for the distribution of urban land supply elasticity, I set it 0.4, which does not represent an elastic land supply, and it is slightly higher than the average of estimates for the elasticity of agricultural land supply.

5-2-3- Parameters Determined based on Reasonable Values

This section addresses parameters determined based on reasonable values. In total, I define 11 parameters based on reasonable values. I divide these parameters based on their similarity into two groups and devote a sub-section to each group.

5-2-3-1- Adjustment Time Parameters

Some parameters are related to the time required for performing a specific action, such as selling land lots, utilizing resources and starting the construction operation, entering the market, and demolishing buildings. These parameters are for adjusting the dimension of the rate variables. Hence, they should be equal to the time unit, which is a quarter here. These parameters include time unit for construction, time unit for demolition, and time unit for the entrance of developers. Other time-related parameters refer to the time that agents (demanders, developers, and suppliers) need to adjust the corresponding variables, including land price, housing rent, individual housing demand, household number, normal construction multiplier, and optimum building density. These are similar to adjustment time parameters for the housing rent and the land price defined in sub-section (5-2-2-15). However, since there is no formal data source to define these parameters, it has been tried to determine a reasonable value for them.

For adjusting the normal construction multiplier, developers look to the experience in the market. They look to the finished works that are entering the market, or the other works will be completed. Hence, the most reasonable time for adjusting the normal construction multiplier is the construction time, which is eight quarters (two years). As mentioned in Chapter 4, it takes time for the households to adjust their actual demand towards their desired demand. The most reasonable reference period is the lease term. The minimum and the ubiquitous leasing term in rental contracts in Iran’s cities is one year. Hence, the time for adjusting individual housing demand is set as four quarters.

For the same reason, the time for adjusting the household number is set as four quarters. It means the time delay between the moment the households realize they cannot afford the rental prices in the formal market and the moment they ultimately move to the informal sector is at least four quarters. As one of the core decision variables in the construction process, developers decide on the optimum building density with relatively high precision. Therefore, the assumption for this analysis stage is that the time needed to perceive the optimum building density is only one quarter.

Table 5-14: The determined values of the parameters related to the adjustment time of stock variables

Parameter	Determined Value (quarter)
Time for Adjusting Normal Construction Multiplier	8
Time for Adjusting Individual Housing Demand	4
Time for Adjusting Household Number	4
Time for Perceiving Optimum Building Density	1

5-2-3-2- Elasticity Parameters

There are four abstract parameters that are similar to the price or rent elasticity of land and housing demand or supply. When one variable affects the other, we can capture the relative change in one variable due to the change in the other by defining a sensitivity parameter. It states how much the effect variable changes are sensitive to the changes in the cause variable. The other way in System Dynamics modeling is to use the table function in Vensim software, which depicts a hypothetical relationship between the two variables. The former relationship is preferable since it allows changing the sensitivity parameter and performing a sensitivity analysis when there is uncertainty about the quantity of the parameters. The four sensitivity parameters include:

- the sensitivity of construction to profit,
- the sensitivity of objective land price to the land demand-supply imbalance (excess land demand),
- the sensitivity of objective housing rent to the housing demand-supply imbalance (excess housing demand),

- the sensitivity of the percent of change in household number in each income decile due to the marginalization to the relative difference between the objective individual housing demand of each income decile and the minimum liveable space, and

Since there is no estimation for these parameters, the reasonable assumption in advance is to consider that there is a unit elasticity. Any deviation from the unit elasticity means that we are biased towards an elastic relationship or inelastic one that there is no evidence in favor of neither of them. Therefore, it is reasonable to take the middle quantity for the analysis. I perform the analysis by setting these elasticity parameters equal to one. However, since the true value of these parameters is uncertain, I also do a sensitivity analysis to see how much the changes in the major output variables in the model are sensitive to those parameters' values. The result of sensitivity analysis comes at the end of this chapter.

Table 5-15: The determined values for elasticity parameters

Parameter	Determined Value
Sensitivity of Construction to Profit	1
Sensitivity of Objective Land Price to Excess Land Demand	1
Sensitivity of Objective Housing Rent to Excess Housing Demand	1
Sensitivity of the Percent of Change in Household Number (in each income decile) to Relative Affordability Gap	1

5-2-4- Profile of the typical city

After defining all the parameters, the tuning process described at the beginning of the chapter follows, to produce a profile for the typical city in the range of the seven metropolises in Iran. The last two rows of Table (5-16) show the values of the profile variables of the typical city with and without imposing regulations. I use the latter as the base case for simulating the effect of different levels of planning regulations. It is the steady-state or the dynamic equilibrium situation of the system.

Table 5-16: The six major endogenous variables defining the profile of the typical city and Iran's seven metropolises

City		Median Size of a Housing Unit (Actual Individual Demand) (Square Meter)	Housing Price (Toman per Square Meter)	Land Price (Toman Per Square Meter)	Floor Area Ratio of New Developments (%)	Average Size of an Under-construction Land Lot for Residential Buildings (Square Meter)	Average Total Annual Household Income (Toman)	Number of Households
Mashhad		82	737,450	213,400	189	201	10,477,184	802,720
Karaj		85	796,350	342,000	339	255	10,855,273	487,991
Esfahan		102	954,950	497,850	227	189	13,889,839	532,884
Tabriz		89	776,650	360,150	270	190	10,833,147	453,866
Shiraz		109	711,550	335,950	153	238	14,986,876	414,717
Ahvaz		97	551,100	221,800	159	188	12,815,178	287,638
Qom		86	734,500	409,200	201	141	11,285,298	299,281
Hypothetical City	Without Binding Regulations and A Demand Shock (Base Case)	99	614,075	340,222	323	202	11,986,504	470,000
	With Binding Regulations and A Demand Shock	89	706,914	393,425	325	209	12,075,600	539,993

5-3- Simulation

The main objective of running simulations is to derive the individual and combined effects of planning regulations. The individual effect means the effect of each planning regulation without changing other factors or imposing other regulations. However, among three regulations, it is only MBD whose effect emerges even without any demand shock. Restricting MBD can affect the dynamic equilibrium or the steady-state. It directly affects the amount of floor area. The other two regulations do not. Hence, the effects of UGB and MLS will appear when there is a demand shock in the market.

The combined effect means the effect of one regulation when we impose it on the system in combination with each of the two others. This part is of the highest importance since it can demonstrate whether the combined effect of regulations is simply additive or nonlinear. Apart from planning regulations, which is the main focus of this research, other factors can have a significant effect on housing and land prices and, consequently, on the number of informal dwellers. Some of them can affect housing and land markets individually, and others can impact these markets in combination with a demand shock. In the following sub-sections, I address the other factors' effect first. After that, I analyze the individual and combined effects of planning regulations.

5-3-1- Effect of non-regulatory factors

In this part, I address the effects of five non-regulatory factors: population, household income, capital factor price, cost of capital, and construction time. To detect the pure effect of non-regulatory factors, I set the planning regulations on non-restrictive levels. The only type of regulations in action is building codes represented by the estimated parameters of the housing production function. They should be effective since, without any imposed regulations, there would not be any difference between the formal and informal housing sectors.

Among all non-regulatory factors, the population effect or the demand shock effect is the most fundamental one. However, to demonstrate its noticeable impact on the functioning of other factors in a comparative manner, the effect of other factors is presented in two parts: one with adding the effect of the population (joint-mode analysis) and the other without it. However, there are eight modes of population change, and analyzing the effect of factors combined with all of these eight modes occupies too much space. Hence, I need to choose a population mode and investigate the effect of non-regulatory factors in combination with that mode. I take the 3% annual growth over the 20 quarters (5 years), which does not cause marginalization individually. I increase the non-regulatory factor step by step to see the first value of the non-regulatory factor causes the marginalization of lowest-income households. The comparison of this value with the pure effect of non-regulatory factors (in the absence of any demand shock) lets us see the criticality of the population effect and the first appearance of the nonlinearity of the factors' effects in combined modes.

5-3-1-1- Population effect

Before investigating the population effect, it should be clarified that I use the population effect and the demand shock interchangeably in this text. For example, when I say a 3% demand shock, it means a 3%-household-number growth. In addition, I define the size of the demand shock (the population effect) by the growth rate of household numbers. Here, the objective is to analyze the effect of underlying demand[13].

Along with the size of the demand shock, the duration of the shock is an essential factor. Based on this, here, by combining different modes of household number growth rate and the duration, I differentiate levels of the demand shock. To this end, I consider four growth rates and two duration periods. The four annual household growth rates are 3%, 5%, 8%, and 10%. These growth rates result from the household formation rate plus the inward migration rate net of outward migration rate. I choose these growth rates similar to the historical annual growth rates in the household number that the seven metropolises experienced on average from 2006 to 2016. For example, the average annual growth rate during the period 2006-2016 is 3.6%. Here, a rounded growth rate of 3% is used as the starting point raised to 10% as the maximum growth rate. In addition, I consider two periods for the duration of the growth in household numbers: ten quarters (2.5 years), and 20 quarters (5 years). More than five years is a fundamental change rather than a shock—half of the maximum duration can be the lower bond. The combination of these modes creates eight categories of the demand shock.

The result of imposing the different modes of demand shock is almost straightforward. Firstly, I discuss the effect of the demand shock on housing and land prices (see Figure (5-4) and (5-5)). Different shades of blue and red represent the graphs. The former represents the demand shocks lasting for ten quarters, and the latter implies 20 quarters. Prolonging the duration of the shock given a specific growth rate increases housing and land prices. Also, increasing the growth rate given a length of duration for shocks increases housing and land prices. An increase in the duration of a mild demand shock can boost its effect to the extent that it exceeds the effect of

[13] We can address the effect of change in the investment demand when we analyze the effect of the cost of capital.

a higher demand shock lasting for a shorter time. For example, the 5% demand shock lasting for 20 quarters can increase the equilibrium housing and land prices as much as the 10% demand shock enduring ten quarters. Regarding the number of informal dwellers, the critical factor is the course of the housing price rather than the level of long-term equilibrium prices.

Comparing Figures (5-4) and (5-6) reveals that the shape of the graphs in the latter is affected by the number of peaks in the former above a specific price. This price is the highest housing price beyond which lowest-income households cannot afford to rent a minimum liveable space without sacrificing their other essential needs. If we rank the peaks in the housing price, it will match the rank of the number of households marginalized to informal settlements in each demand shock mode. The two lowest peaks belong to the demand shock with 3% growth rates enduring 10 and 20 quarters. These demand shocks do not marginalize lowest-income households to informal settlements.

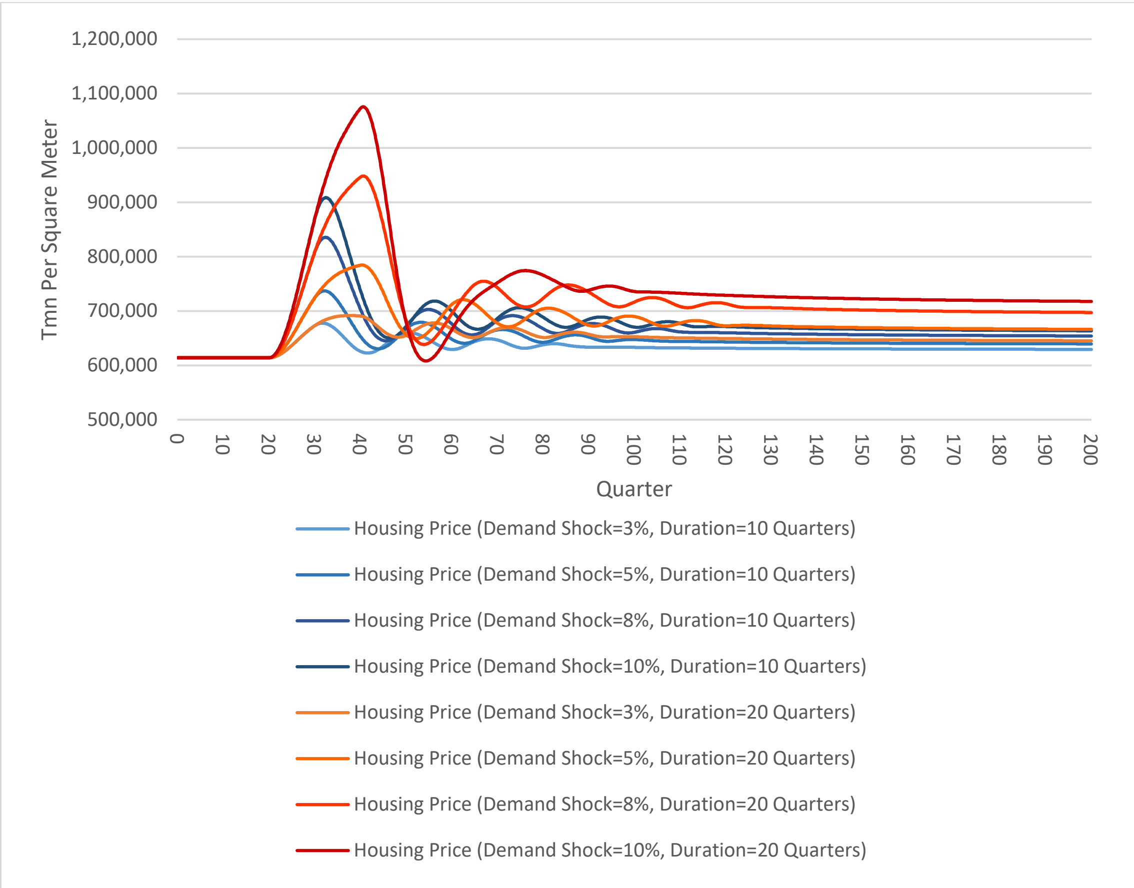


Figure 5-4: The effect of different modes of demand shock on the housing price

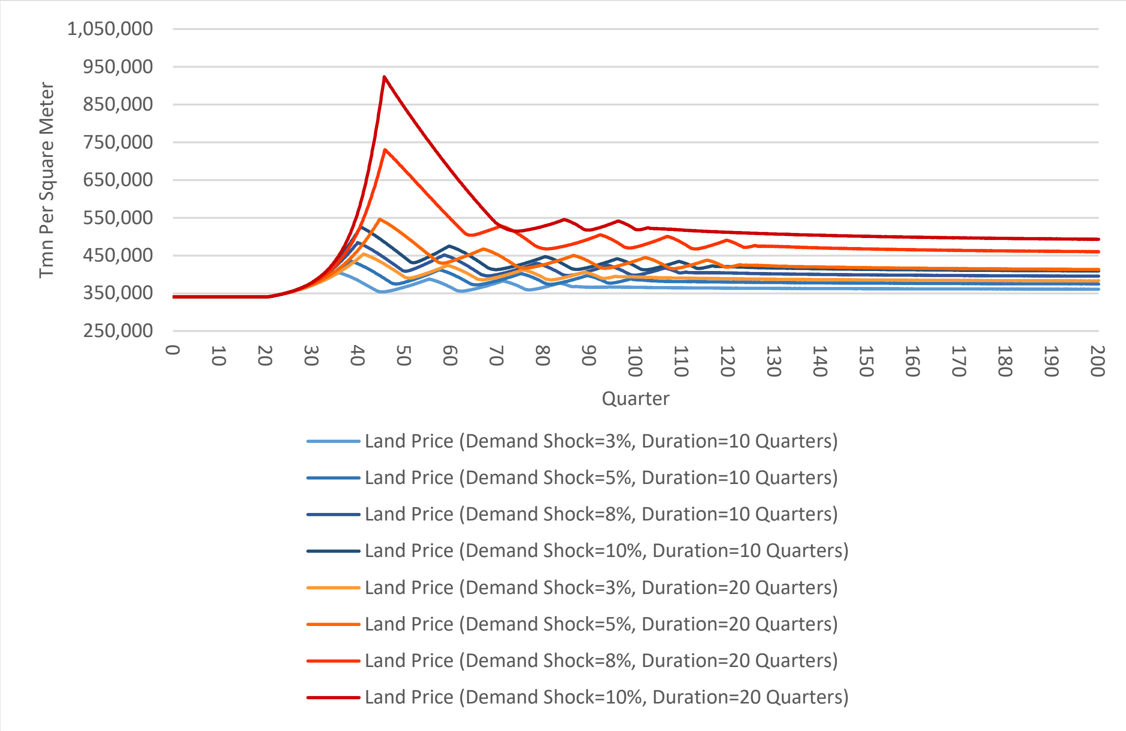


Figure 5-5: The effect of different modes of demand shock on the land price

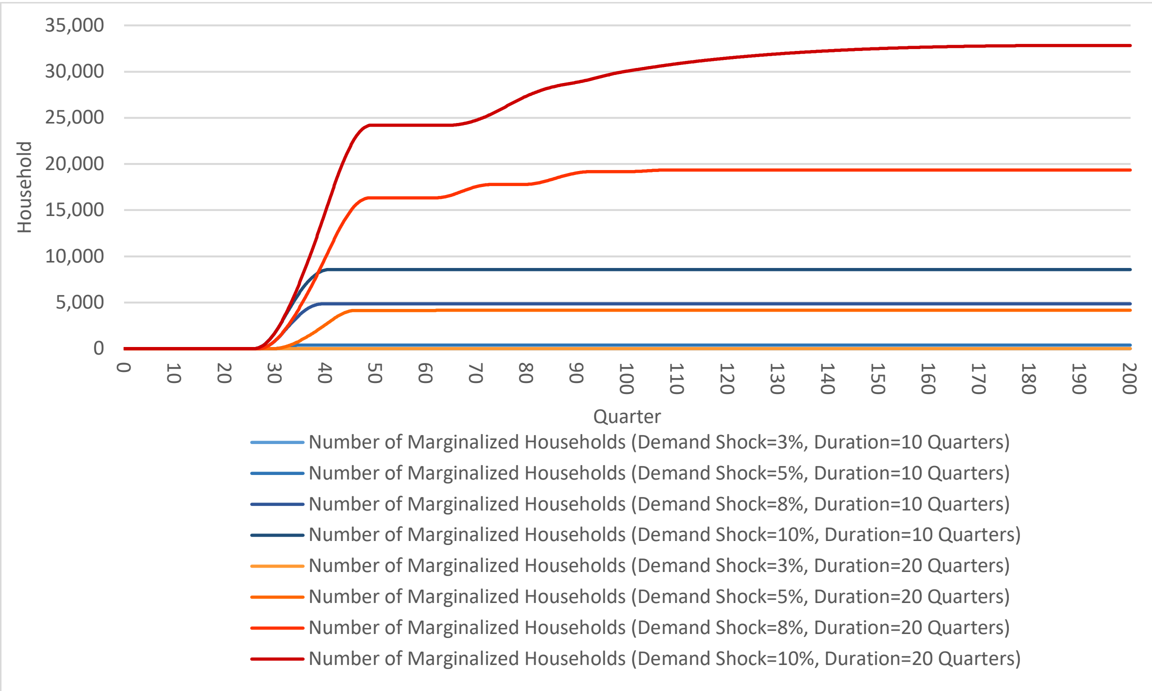


Figure 5-6: The effect of different modes of demand shock on the number of marginalized households

5-3-1-2- Income effect

The hypothetical city accommodates ten income groups. Changing each income level can bring about an unnecessary complexity for analyzing the income effect. Instead, I categorize the ten income groups into three qualitative income categories: high, medium, and low-income. The high and low-income categories consist of the three highest and lowest income groups, respectively. The medium income category consists of the remaining four middle-income groups. To test the income effect, I change all the income levels of all the income groups inside a category with the same rate.

To detect the income effect, first, I increase the income level of the high-income category step by step to the point that the model results in some households leaving the formal market for the informal market. In figures (5-7), (5-8) and (5-9), the three income growth rates from left to right belong to the high-, medium-, and low-income categories. As can be seen in Figure (5-9), the first informal dwellers emerge after increasing the income level of people in the high-income category by 30%. Then, by increasing the middle-income group category by 10%, the number of informal dwellers, all of whom belong to the lowest income group, increases (Figure (5-9)). With a 30% increase in the income level of people in both high and middle-income categories, the number of informal dwellers rises to nearly 5000 households. The increase in the former categories' income increases their demand for housing and consequently increases the housing price, which, in turn, pushes the low-income groups out of the formal market to resort in the informal housing sector.

On the other hand, we can increase the income level of people in the low-income category to see its effect on the marginalization process. As can be seen, by increasing their income by 10%, households in the lowest income group can afford the housing rent in the formal market. None of low-income households requires to resort to the informal housing sector in the case of increase in the income level of high- and middle-income households.

On the other hand, decreasing the income level of the low-income households can lead to significant marginalization of these households to informal settlements. Based on this, we can see that by reducing the income level of the low-income households by 10% and 20%, the number of informal dwellers dramatically increases relative to the case that I increased the income level of high-and medium-income categories. The reduction in the income and in the number of low-income households decrease the housing and land prices due to the reduction in housing demand. However, the reduction in income is not enough to stop the flow of people towards informal settlements. In both modes mentioned above, the depth of income gap between the lowest income category and the other two pushes low-income households to leave the formal housing market and resort to informal settlements. The income gap differs based on the relative decrease or increase in the income level of different income groups. However, among all income groups, the lowest group's income level changes are more critical than the others in exacerbating or alleviating the marginalization process. Changes in their income level directly affect their ability to compete with others in the formal housing market.

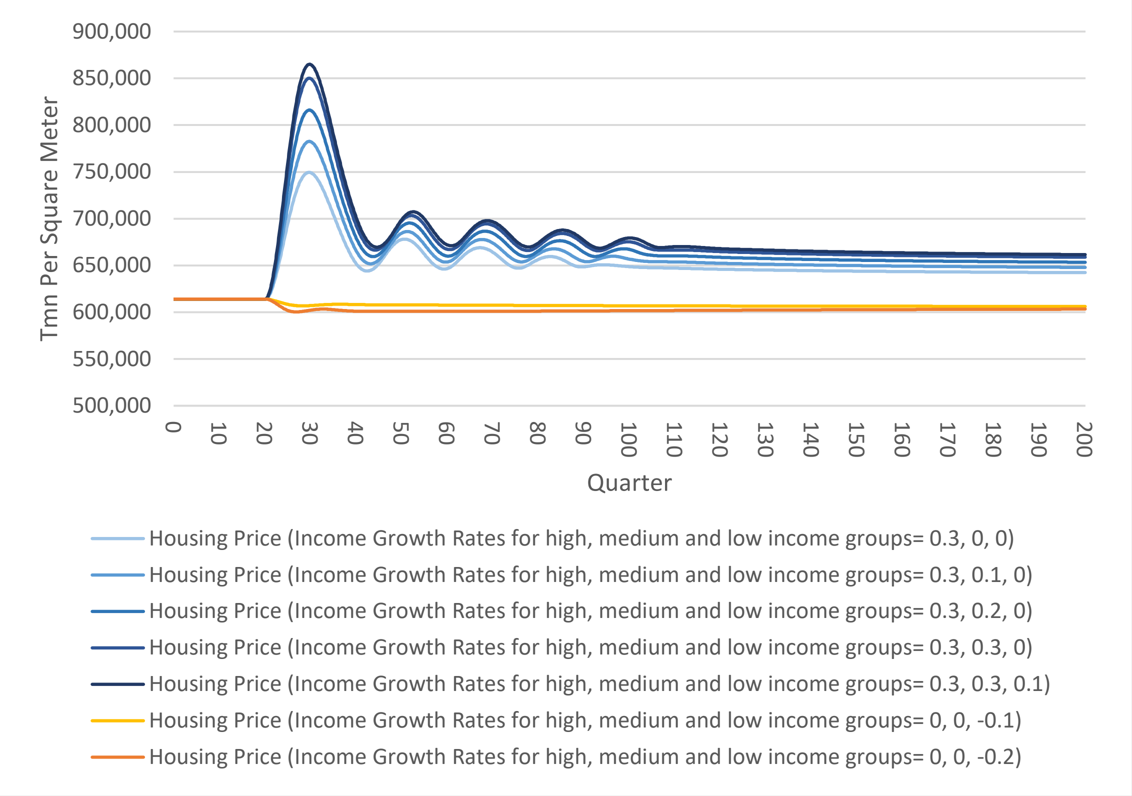


Figure 5-7: The effect of changes in household income on the housing price

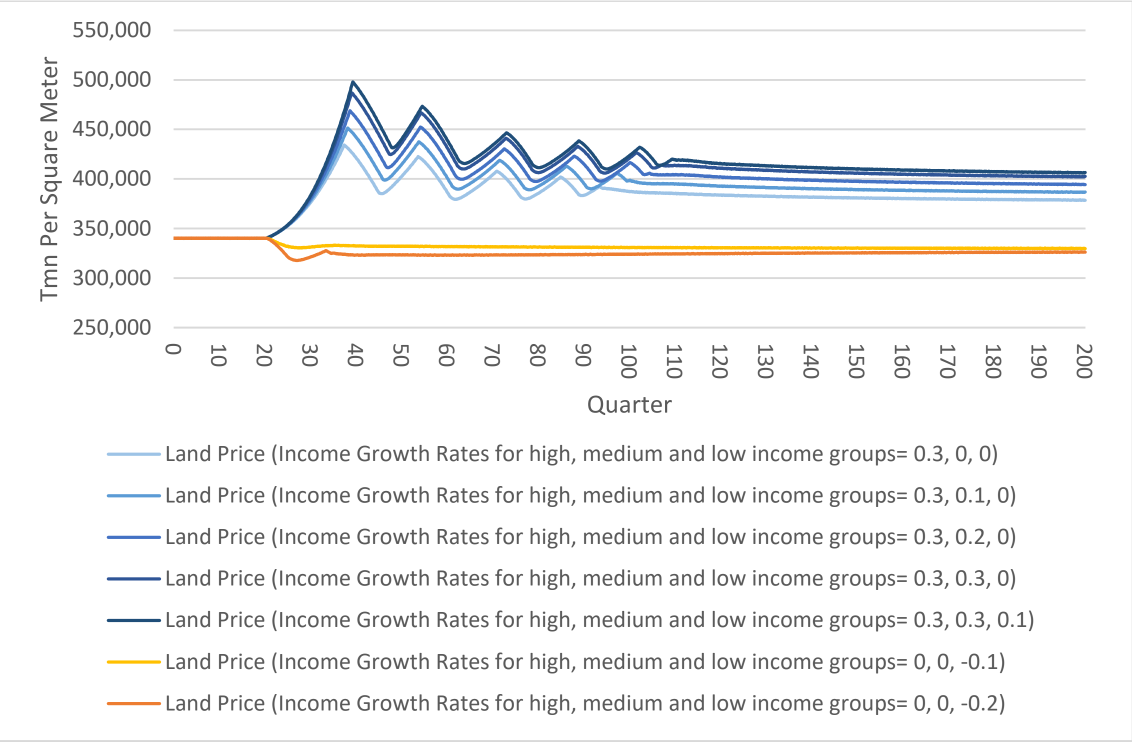


Figure 5-8: The effect of changes in household income on the land price

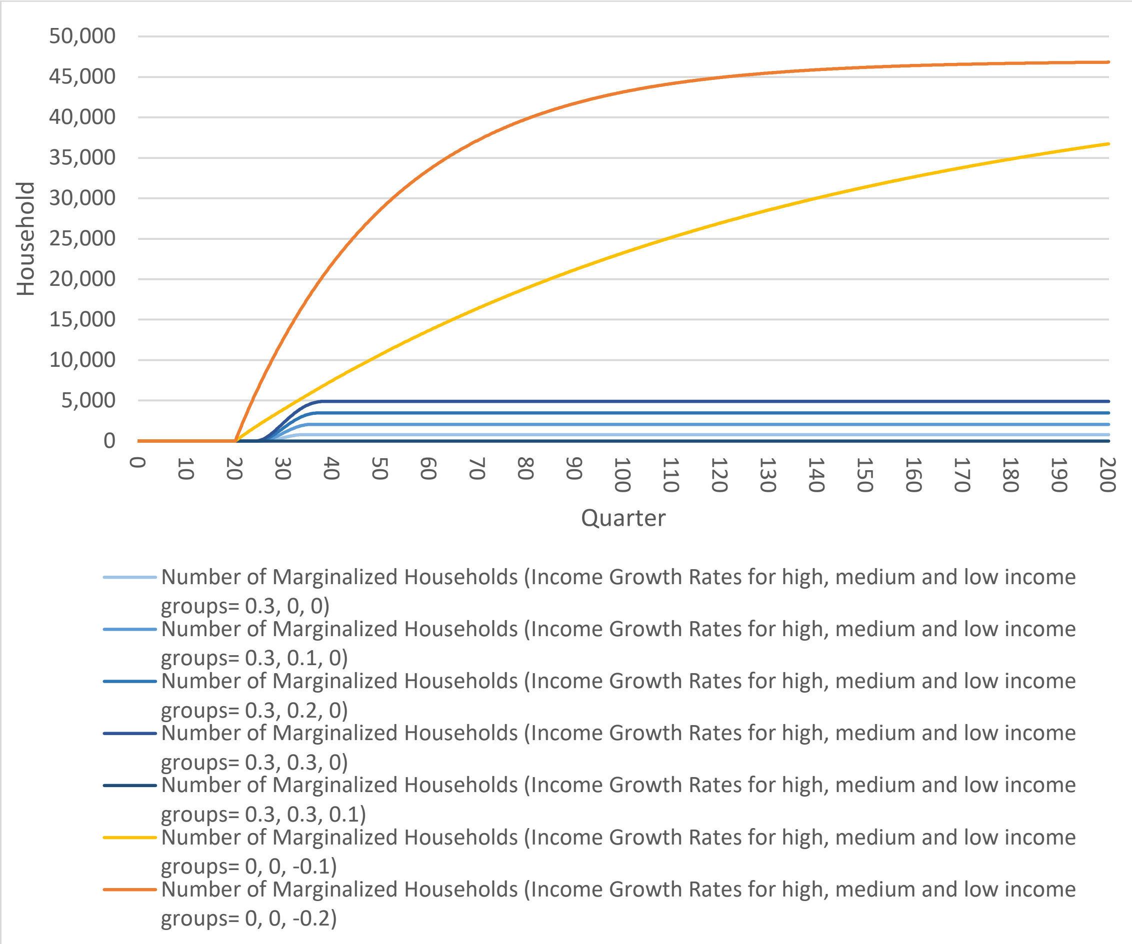


Figure 5-9: The effect of changes in household income on the number of marginalized households

Moreover, it is possible to detect the combined effect of population and income. To this end, I choose a mode of a demand shock, which does not cause low-income households to resort to informal settlements. I choose the mode of 3% annual growth in household number during 20 quarters (5 years). Then, the income level of households in each income category is increased step by step until the first jump in the number of marginalized households appears. Figure (5-10) shows that the first jump emerges when the income level of the highest income category increases by only 10%. From the previous analysis, we know that for pushing the lowest income group out of the market by increasing the income level of the highest income category, their income growth should be at least 30%. This is an example of the combined effect in which none of the factors can individually cause an increase in the number of informal dwellers, but their combination can.

In addition, although increasing the income level of the lowest income households again has a decreasing effect on the marginalization, it cannot stop the marginalization process. On this basis, increasing their income by 10% in the event of only 30% and 10% income growth in high and middle-income households' income levels respectively, results in an infinitesimal rise in the marginalized households. Increasing the income level of middle-income households leads to a considerable rise in the number of marginalized households. Such an effect is not detectable in the case of no demand shock. These findings imply that giving a demand shock to the hypothetical city can lead to the marginalization of low-income households even if the income gap is less deep than in the case that there is no demand.

Figure 5-10: The effect of changes in household income in three income groups on the housing price in the presence of regular demand shock

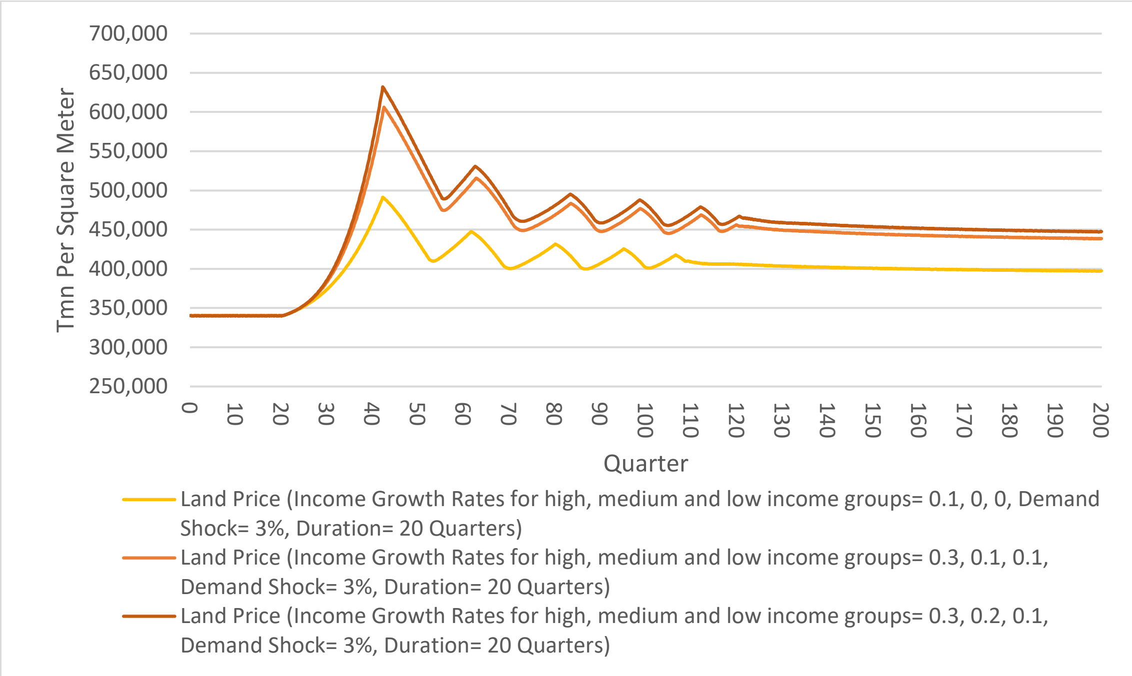


Figure 5-11: The effect of changes in household income in three income groups on the land price in the presence of regular demand shock

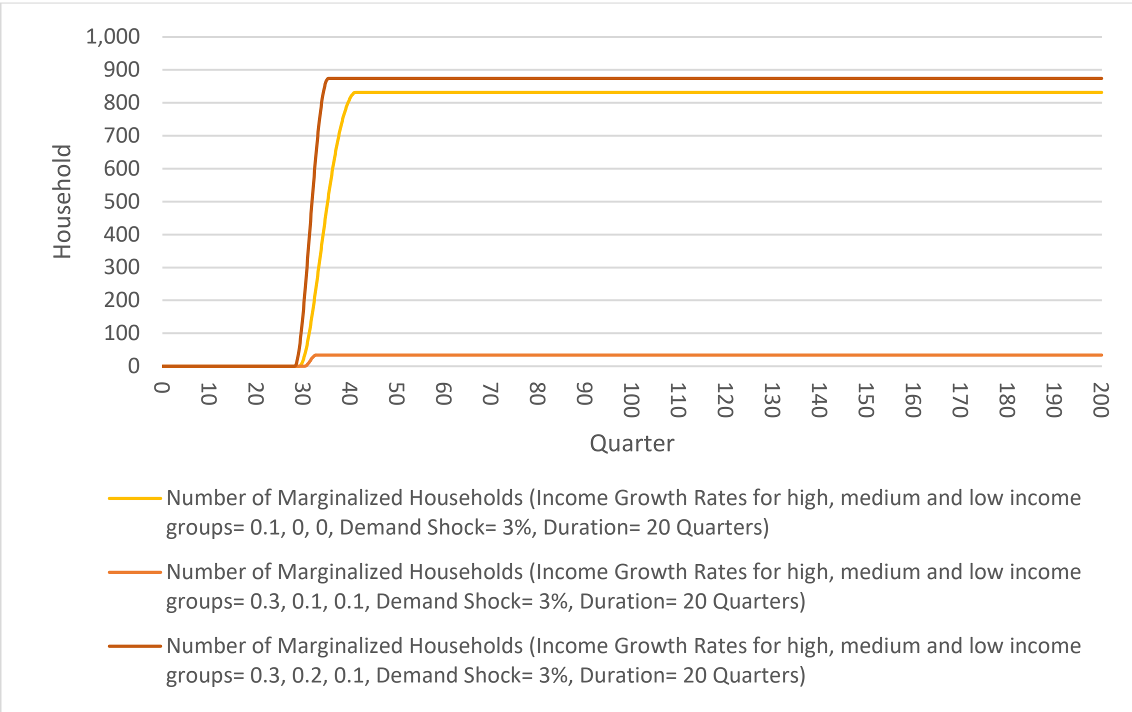


Figure 5-12: The effect of changes in household income in three income groups on the number of marginalized households in the presence of regular demand shock

5-3-1-3- Capital factor price effect

In order to detect the effect of capital factor price, I increase it by 25%, 30%, 50%, and 100%. By increasing the price of capital factor, the construction cost per square meter of the building increases, making the housing construction unprofitable. When the housing market is out of profit, developers do not embark on further construction, which lowers the housing supply and increases the housing prices. However, due to the less profitability of construction, the demand for land decreases, reducing the land price. After the housing price sufficiently increases to make the construction profitable again, demand for land returns and surges again. Due to the increase in the price of capital factor, developers economize on it and rely more on land as the cheaper production factor. However, if the capital factor price increases too much, too much reliance on the land factor can raise the land price too.

Figure (5-15) shows the effect of increasing the capital factor price on the number of marginalized households. A 25% increase does not affect the housing price to cause the marginalization. The 30% increase raises the housing price to the level that reduces the amount of housing space that the lowest income group can afford to the lower level than the minimum liveable space. This results in low-income households resorting to informal settlements. The effect of 50% and 100% increase in the capital factor price is noticeably intense. The increase in the number of informal dwellers shows an inclination towards a particular limit: the total number of households in the lowest income group. More increase in the capital factor price leads to faster inclination towards the limit and curves the graph of the number of informal dwellers. If we categorize the city population into more income groups, the number of marginalized households can increase even more with more bending points. This means that marginalization will not be limited to the lowest income group.

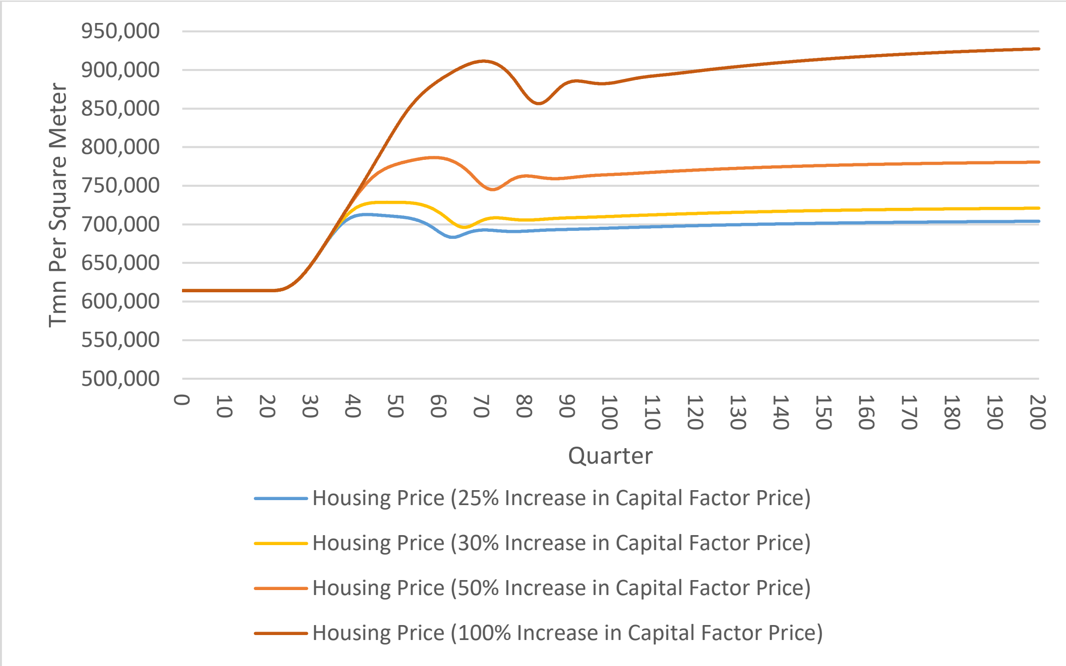


Figure 5-13: The effect of changes in capital factor price on the housing price

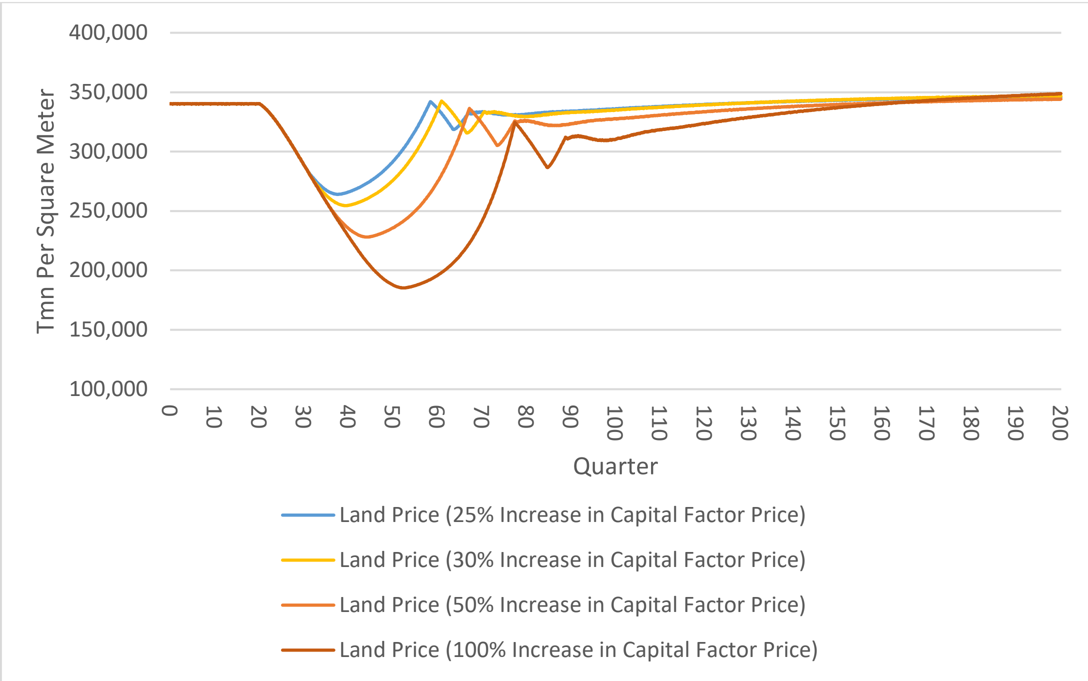


Figure 5-14: The effect of changes in capital factor price on the land price

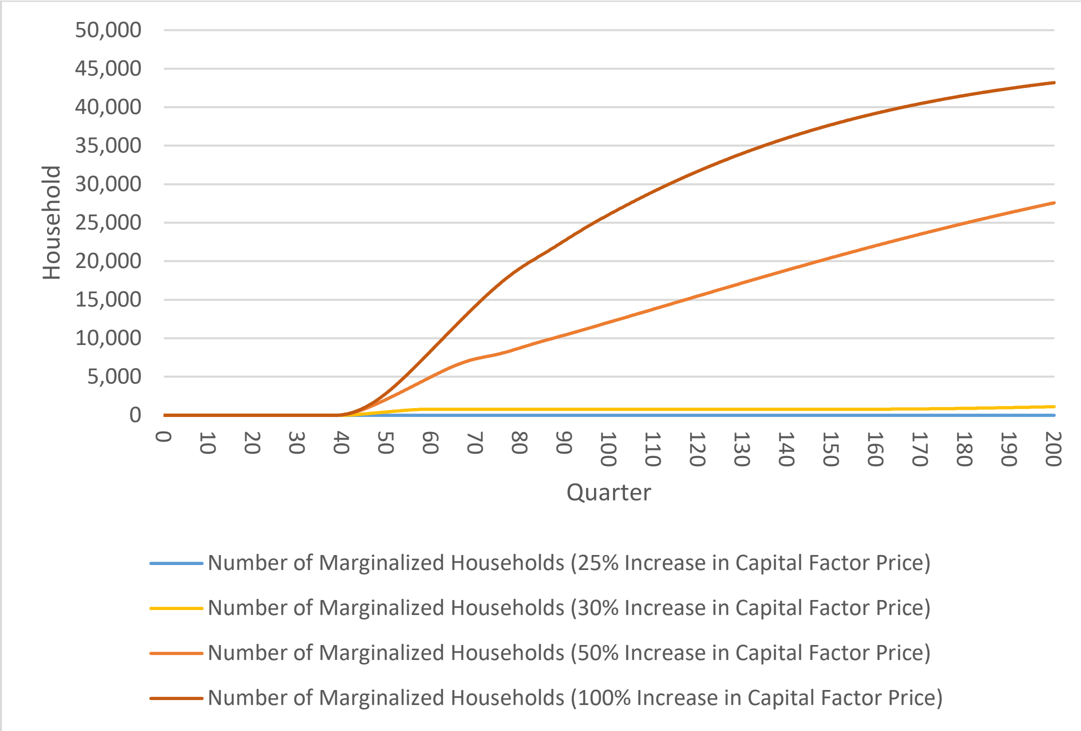


Figure 5-15: The effect of changes in capital factor price on the number of marginalized households

To discover the combined effect of capital factor price and population, I choose the mode of 3% growth in households during 20 quarters (5 years), which does not cause marginalization. Then, the capital factor price increases step-by-step to find the first emergence of the marginalization of low-income households to informal settlements. With moderate household growth, a slight increase in the capital factor price can force the lowest income households to resort to informal settlements. Increasing the capital factor price by 2.5%, 5%, and 10% leads to the marginalization of around 150, 1000, and 2850 households, respectively. However, since the long-term equilibrium housing price does not remain above the critical price, which is not affordable by the lowest income group, the number of marginalized households stays fixed in the mentioned quantities. It should be mentioned that none of these increase modes for the capital price results in the marginalization of low-income households when there is no demand shock. However, the combined effect of population and capital factor price change causes low-income households to resort to informal settlements.

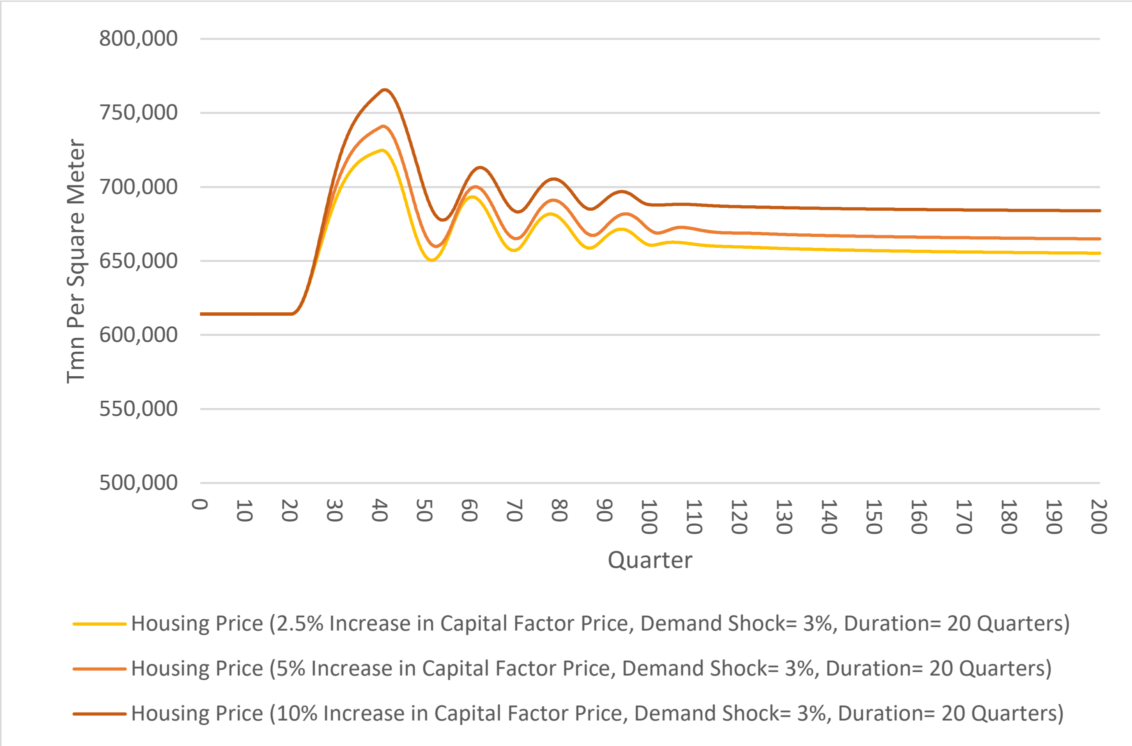


Figure 5-16: The effect of changes in capital factor price on the housing price in the presence of regular demand shock

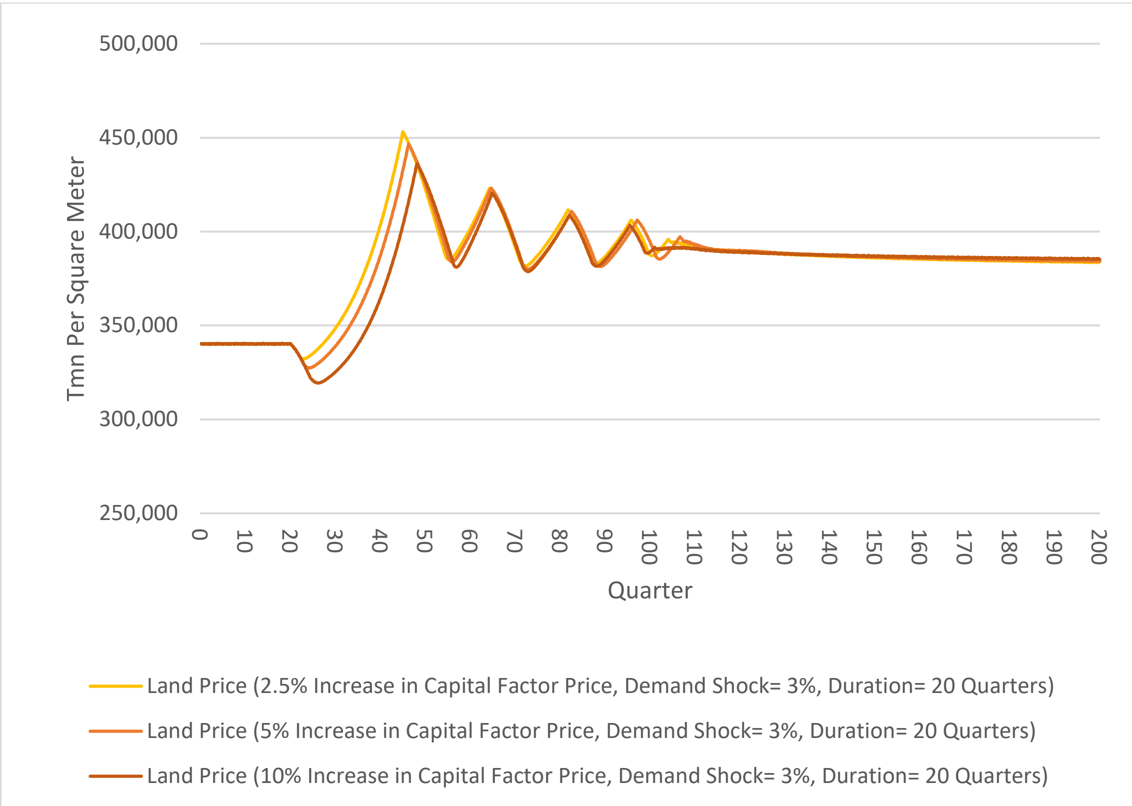


Figure 5-17: The effect of changes in capital factor price on the land price in the presence of regular demand shock

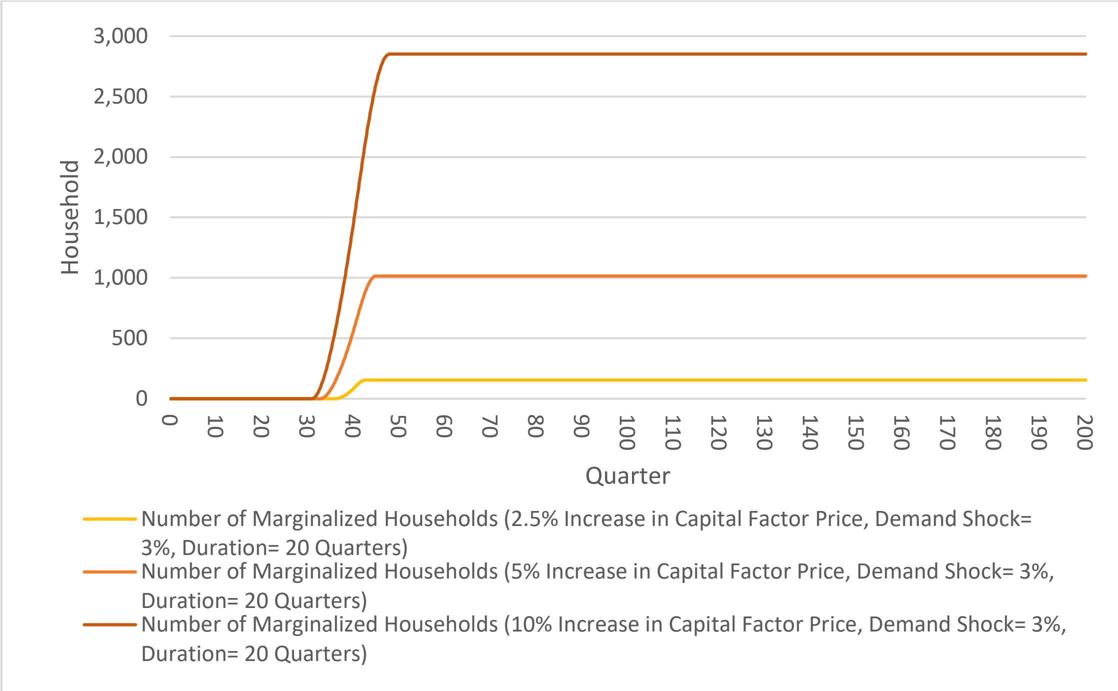


Figure 5-18: The effect of changes in capital factor price on the number of marginalized households in the presence of regular demand shock

5-3-1-4- Cost of capital effect

The cost of capital is the opportunity cost of using the capital in the housing construction industry instead of other markets. It shows the connection of the housing construction sector with the other industries outside the model boundaries. Changing the cost of capital affects the relationship between the housing rent and the housing price. In previous subsections, since the cost of capital was fixed, I could use the housing price and housing rent interchangeably. Thus, In order to avoid redundancy, I reported the housing price results. Here, in contrast, the housing rent results are important since the housing rent affects the housing demand and the expansion of informal settlements. The increase in the cost of capital means that the housing construction industry is less profitable than before in relation to the other industries. Therefore, the developers will be reluctant to embark on new development unless other variables in the housing and land markets adjust to cause the construction sector regains its relative profitability.

To analyze the cost of capital effect, I increase it in four stages: from 0.06 in the initial steady-state to 0.10 (0.07, 0.08, 0.09, and 0.10) in the 20th quarter. Increasing the cost of capital leads to a decrease in the housing price since developers regard housing as a less profitable investment than other investments. In this situation, they stop constructing more housing in response to the ongoing demand, which should be met due to the constant demolition rate. This, in turn, decreases developers' demand for land and causes the land price to drop. More reduction in the cost of capital decreases the housing and land prices more. Hence, it takes more time for the housing market to regain its profitability. The prolonging of the unprofitability period leads to an increase in the housing rent since the demand is unsatisfied. This period is longer in the case of the higher cost of capital. In all cases, after the jump in the cost of capital, after a downward adjustment, both housing and land prices start rising and follow the housing rent. Hence, higher levels of the cost of capital lead to lower equilibrium housing and land prices.

Moreover, the cost of capital has a greater impact on the marginalization of households in informal settlements than the other factors addressed. A slight increase in it can considerably change the number of informal dwellers. This effect is infinitesimal when the cost of capital increases from 0.06 to 0.07. Nevertheless, it is significant when the cost of capital increases to 0.08, 0.09, or 0.1.

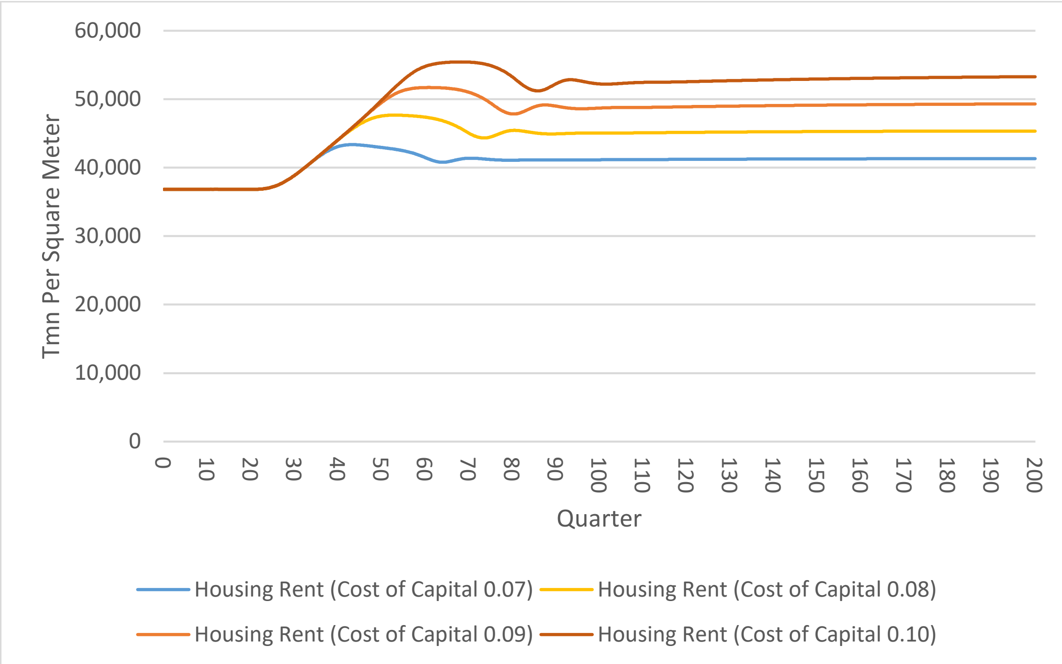


Figure 5-19: The effect of changes in the cost of capital on the housing rent

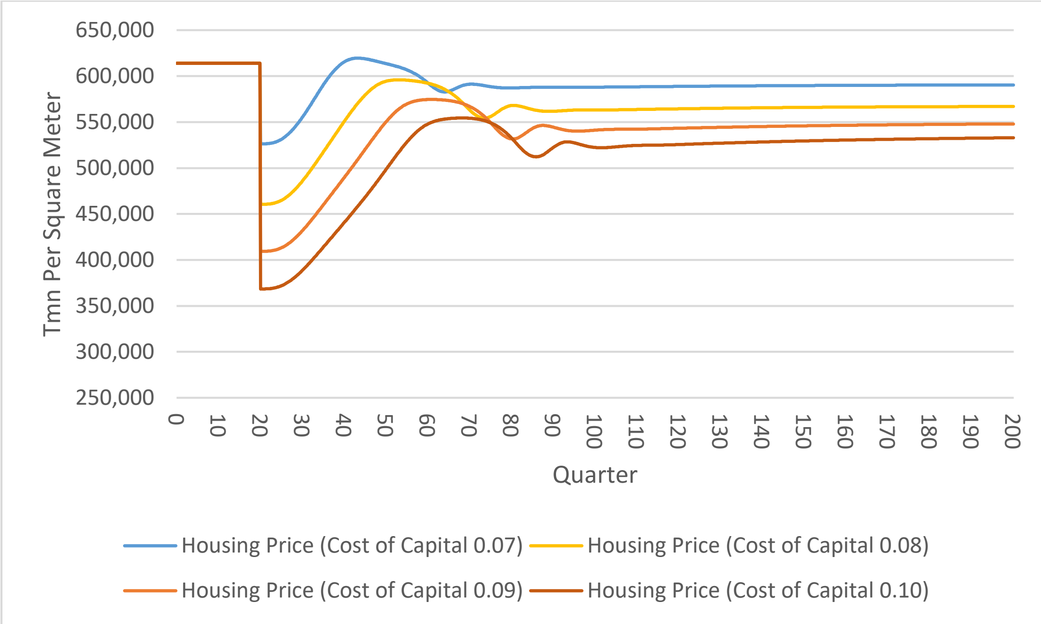


Figure 5-20: The effect of changes in the cost of capital on the housing price

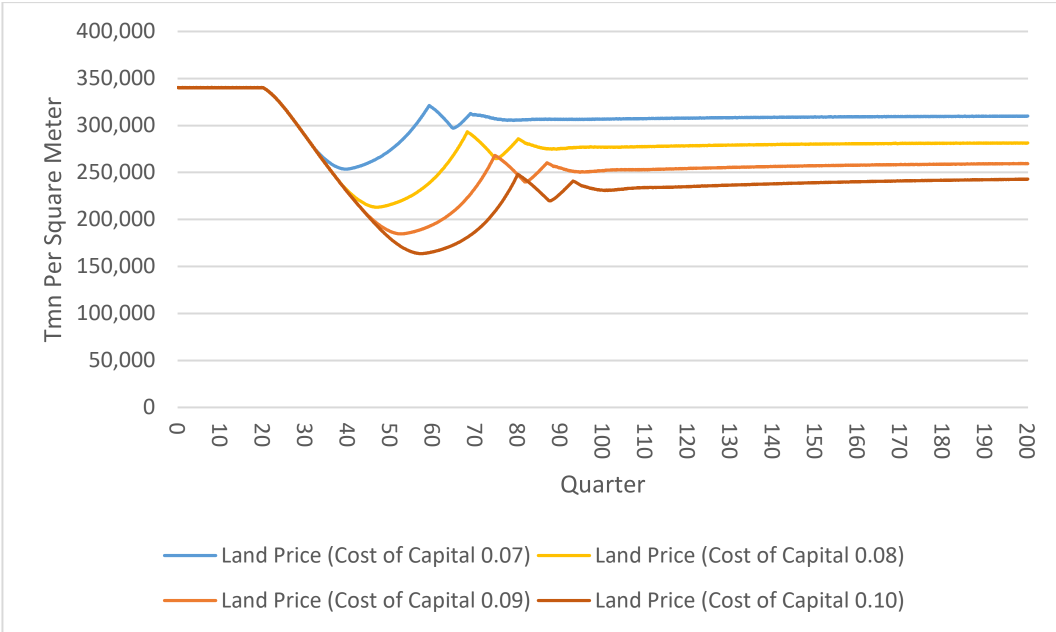


Figure 5-21: The effect of changes in the cost of capital on the land price

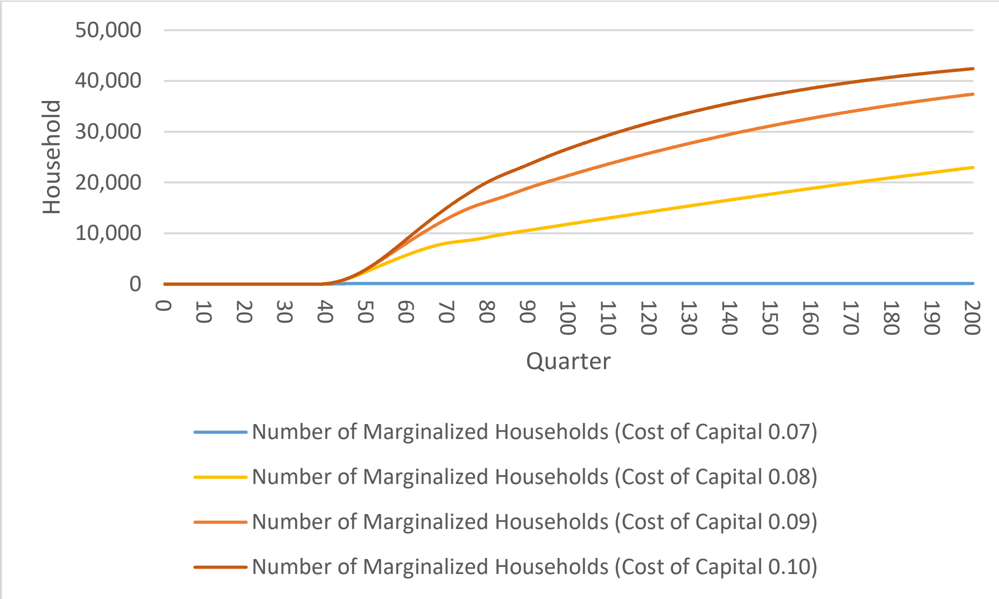


Figure 5-22: The effect of changes in the cost of capital on the number of marginalized households

The powerful individual effect of the cost of capital is more noticeable when it is combined with the population effect. Again, I combine the 3% growth in the number of households for 20 quarters with the lower levels of cost of capital. As can be seen in Figure (5-26), even a slight increase in the cost of capital to 0.0625 and 0.065 can push low- income households to resort in informal settlements in the event of a demand shock. In none of these two cases, the cost of capital can result in marginalization without a demand shock. The comparison of the two modes of increasing the cost of capital to 0.07, one with demand shock (the red line in Figure (5-26)) and the other without it (the blue line in Figure (5-22)), noticeably demonstrates the combined effect of the demand shock and the cost of capital. The number of informal dwellers grows from almost 120 persons in the former to 16,000 (and more if the graph continues) in the latter.

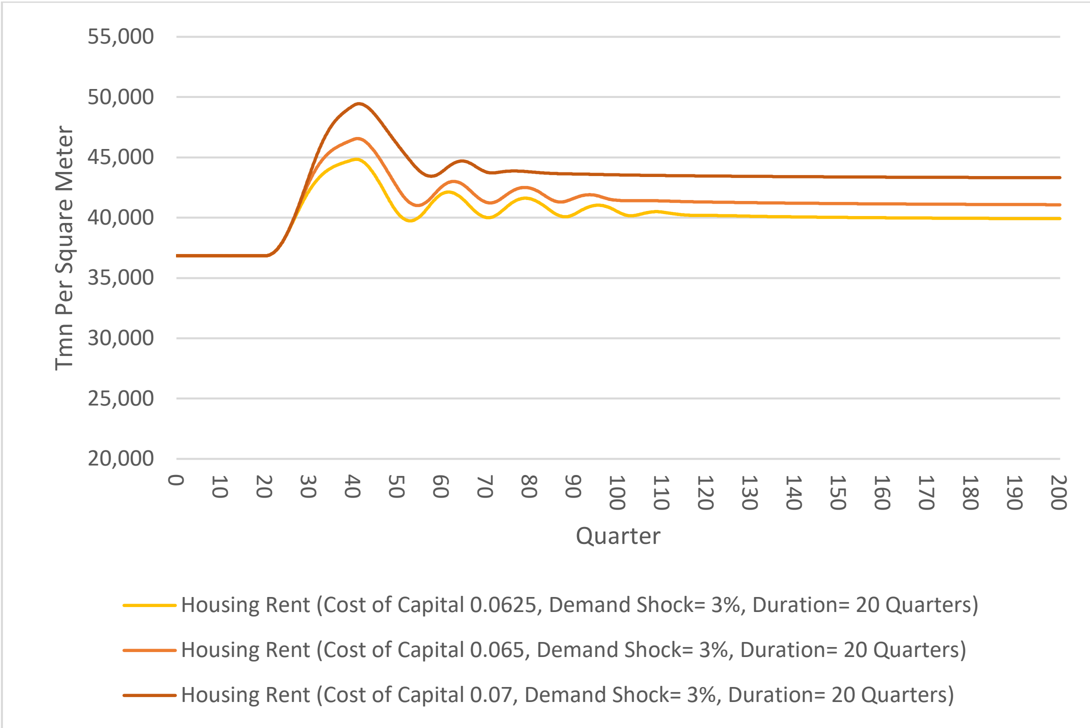


Figure 5-23: The effect of changes in the cost of capital on the housing rent in the presence of a regular demand shock

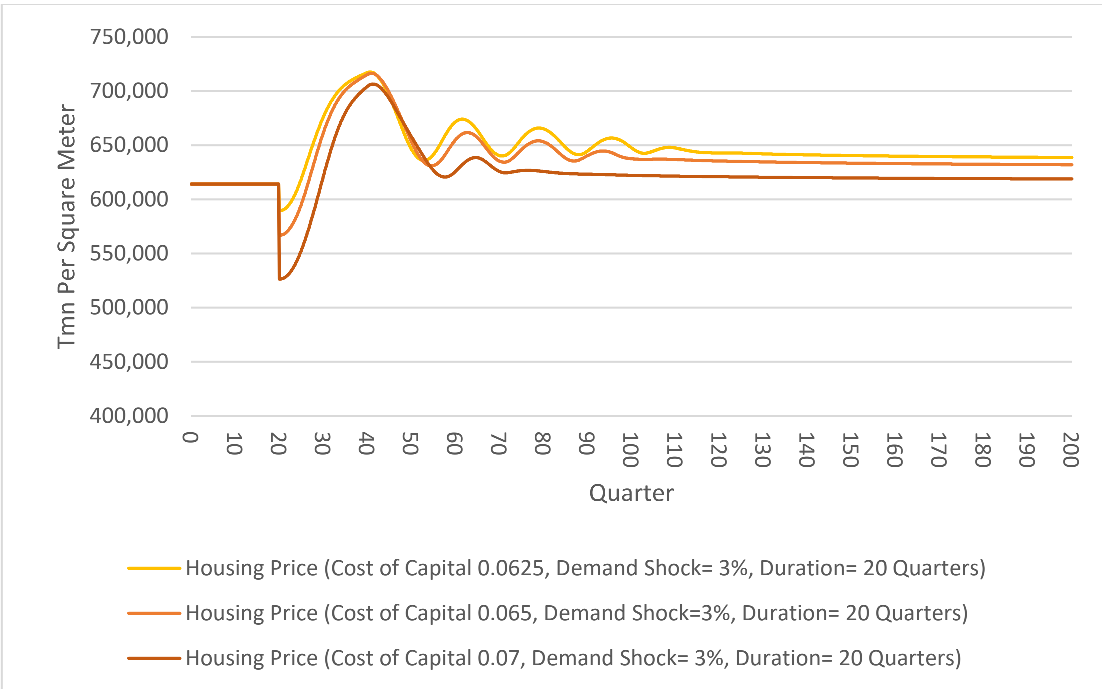


Figure 5-24: The effect of changes in the cost of capital on the housing price in the presence of a regular demand shock

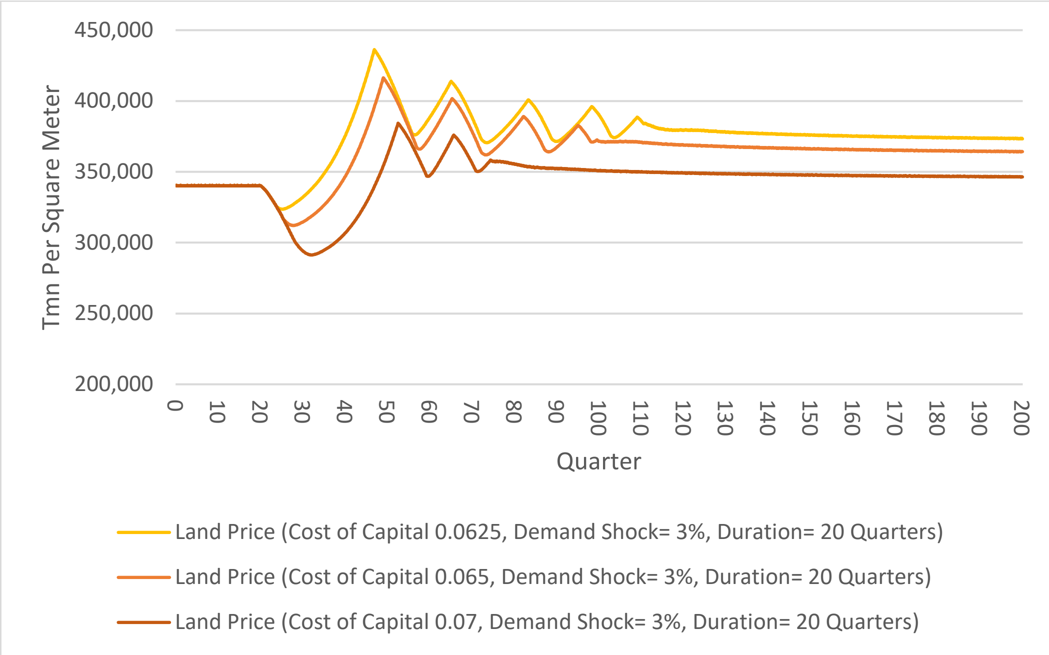


Figure 5-25: The effect of changes in the cost of capital on the land price in the presence of a regular demand shock

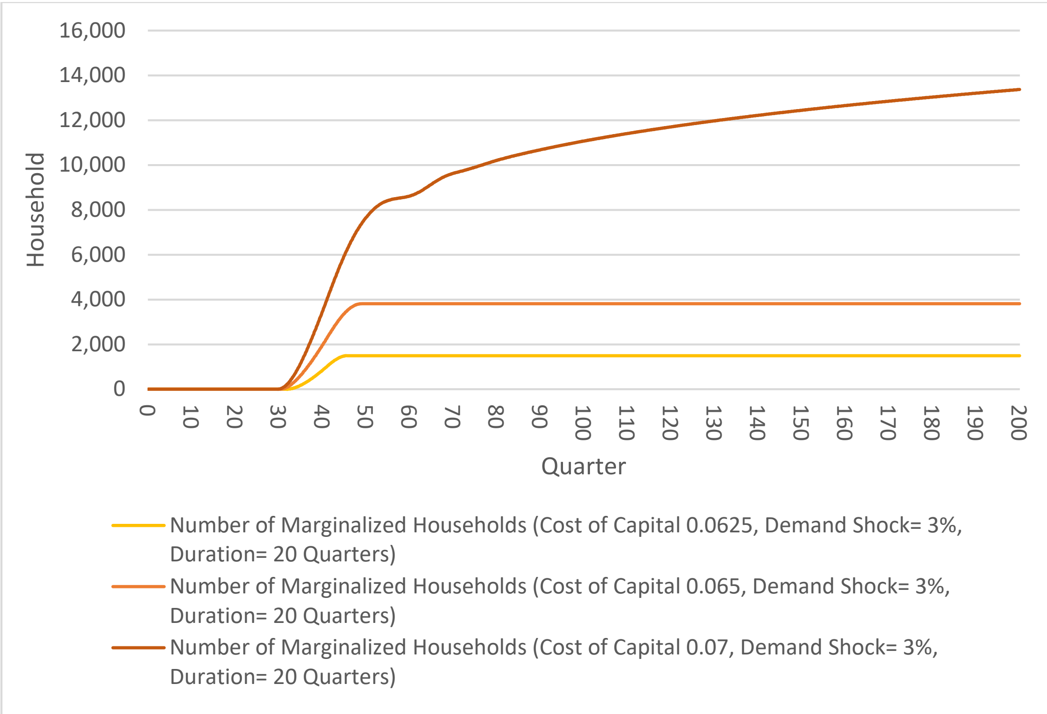


Figure 5-26: The effect of changes in the cost of capital on the number of marginalized households in the presence of a regular demand shock

5-3-1-5- Construction time effect

In Chapter 4, I showed that prolonging the construction period increases both housing and land prices. However, this increase is not enough to marginalize lower-income households from the formal housing market. Here, to detect the effect of construction time on the number of informal dwellers, I gradually increase the construction time until low-income households start resorting to informal settlements. In figures (5-27), (5-28), and (5-29), when the construction time increases by ten years, the housing price rises to the level causing marginalization. However, its marginalizing effect is infinitesimal. A 10-year increase in construction time is an unrealistic scenario, even if one has a pessimistic viewpoint.

Although the individual effect of construction time is negligible, it does not mean that there is no effect in reality. In order to have more realistic results, I give a demand shock as when analyzing the other non-regulatory factors. Following the previous subsections, while the 3% household growth lasting for 20 quarters is imposed on the city, I increase the construction time gradually until the first effect on marginalization appears. As shown in Figure (5-32), in the event of a demand shock, only one year of prolonging the construction time can have a price effect marginalizing the lowest-income households. Although the number of marginalized households is not high, it is noticeably higher than when the construction time was extended by ten years. Prolonging the construction time by 1.5 and 2 years has a more evident marginalization effect. The marginalization in these cases is due to the combined effect of the demand shock and construction time, none of which can individually force low-income households to leave the city and resort to informal settlements.

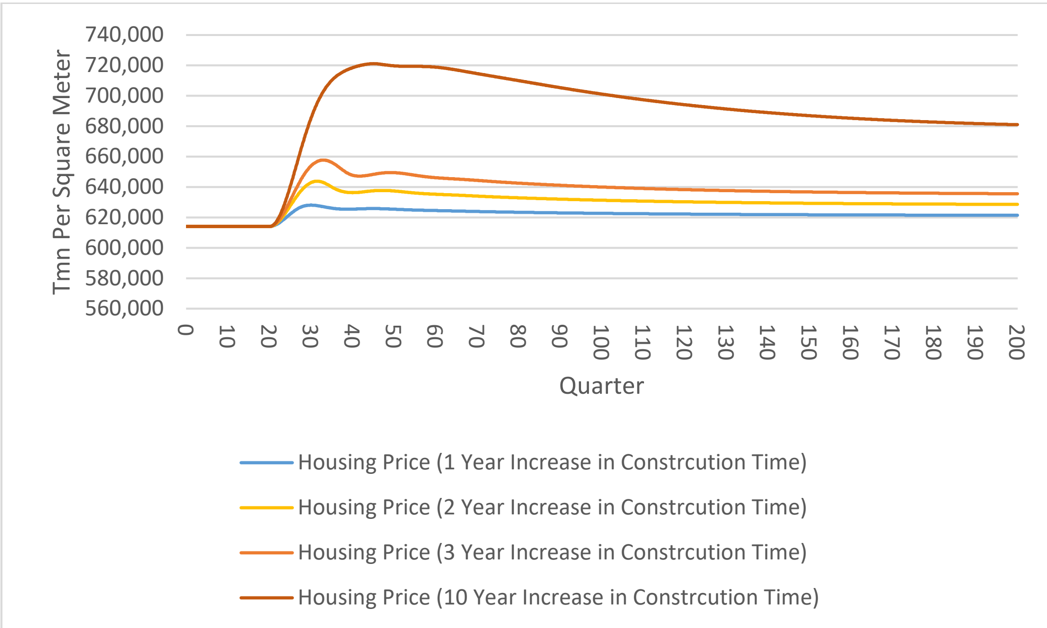


Figure 5-27: The effect of changes in construction time on the housing price

Figure 5-28: The effect of changes in construction time on the land price

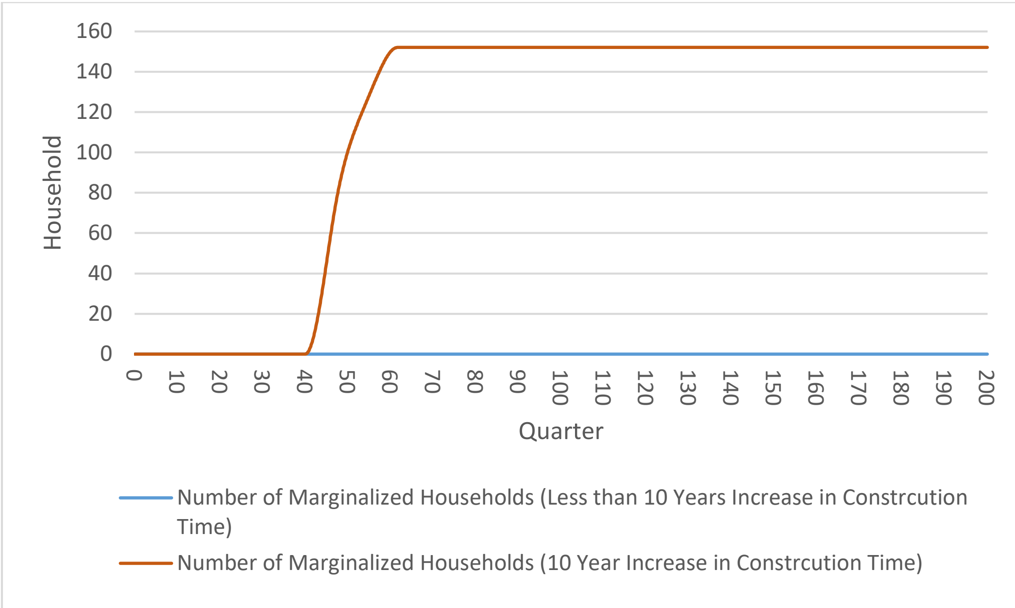


Figure 5-29: The effect of changes in construction time on the number of marginalized households

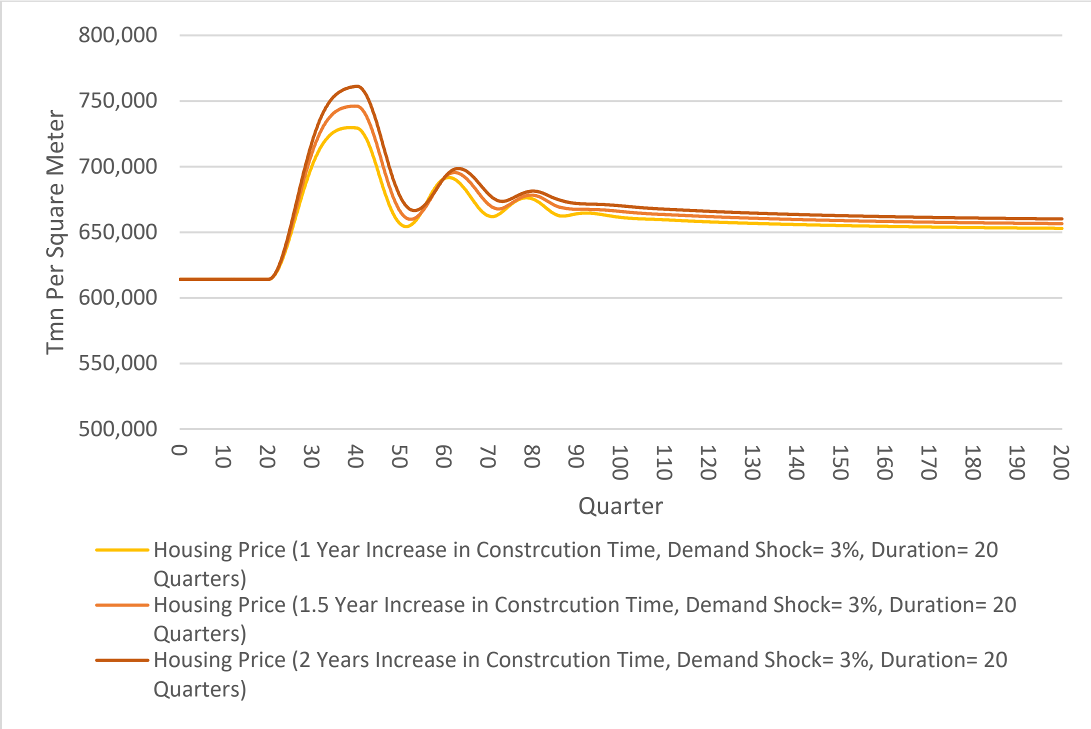


Figure 5-30: The effect of changes in construction time on the housing price in the presence of a regular demand shock

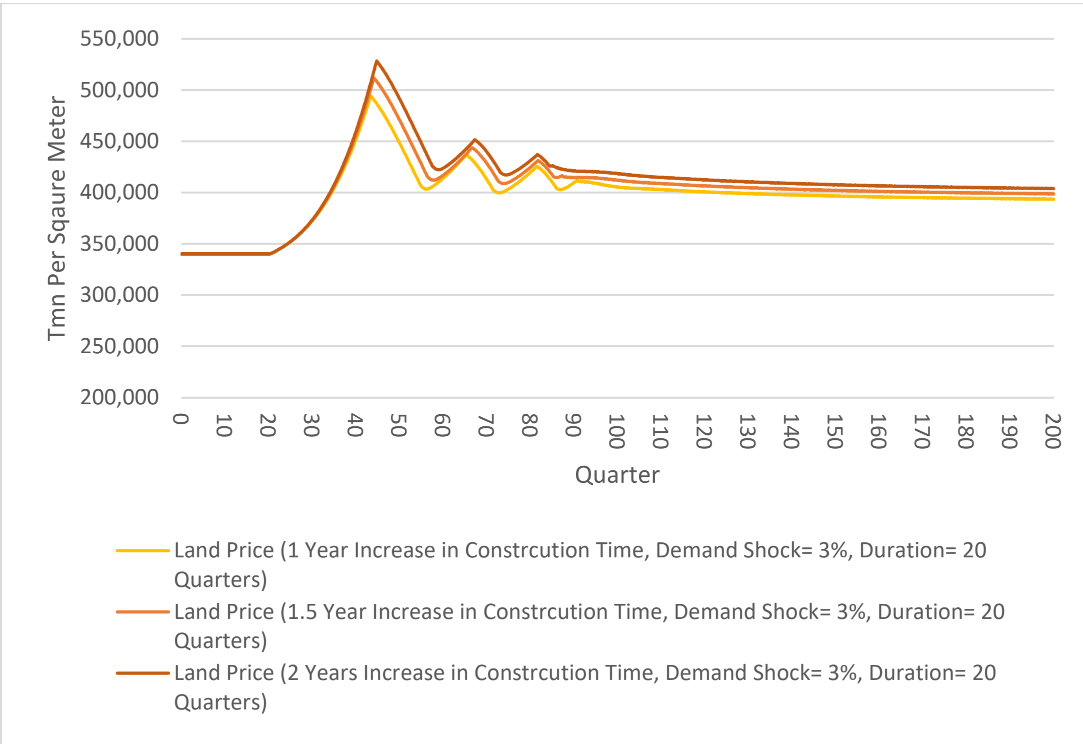


Figure 5-31: The effect of changes in construction time on the land price in the presence of a regular demand shock

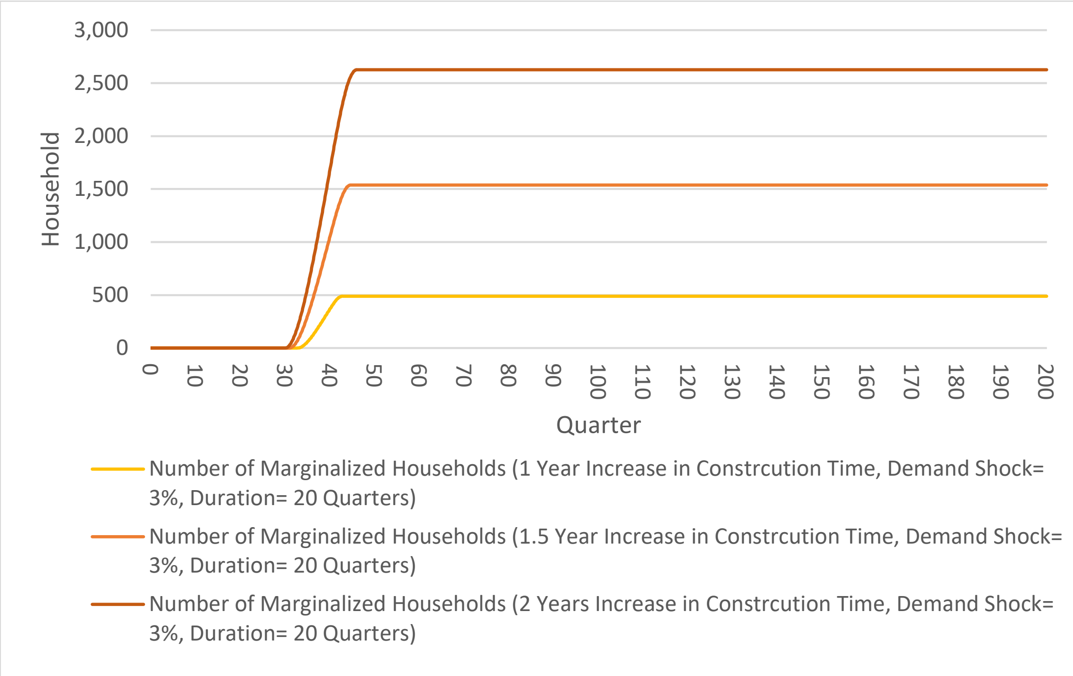


Figure 5-32: The effect of changes in construction time on the number of marginalized households in the presence of a regular demand shock

5-3-1-6- Comparative effectiveness of non-regulatory factors

Apart from the individual analysis of the effect of each non-regulatory factor on the expansion of informal settlements, a comparative analysis shows us which non-regulatory factor is more important than the others. I analyze four non-regulatory factors: the cost of capital, price of capital factor, income gap, and construction time. I do not enter the population effect in the comparison. The effect of typical changes in two of these four non-regulatory factors (name them) on the number of informal dwellers appears after a demand shock. I do the analysis assuming a demand shock of 3% annual growth over 20 quarters. To perform such an analysis, I account for two considerations. First, the results should be comparable. Thus, instead of sheer numbers, I increase all the factors by the same percentile increase (here, 10 percent). Second, since the model is dynamic and demonstrates the results over time, I need to select a time period where all the output variables settle down after the first shock. To this end, I compare the results in the 50th quarter.

The second fundamental factor modelled is the effect of changes in the income distribution. As mentioned in Section (5-3-1-2), what I mean by the income effect is the effect of the income gap between the low-income households and households in upper-income groups. Since the income gap can be increased either by increasing the income level of high-income households or decreasing the income level of low-income households, I have to compare the results by each of these modes.

Figure (5-33) shows the change in the number of informal dwellers after the 10-percent increase in each of the factors using the two modes for increasing the income gap by 10 percent. As can be seen, the effect of the income gap is asymmetric. A 10-percent income gap increase created by decreasing the income level of low-income households has larger effects than the same increase in the income gap stemming from the increase in the income level of upper-income groups. In the latter mode, the most influential factor is the cost of capital, and the income gap has weaker effects than the price of the capital factor. In the former mode, the income gap becomes the most influential factor with a considerable difference in the number of informal dwellers marginalized compared to the case of the increase in the cost of capital. The least influential factor is the construction time.

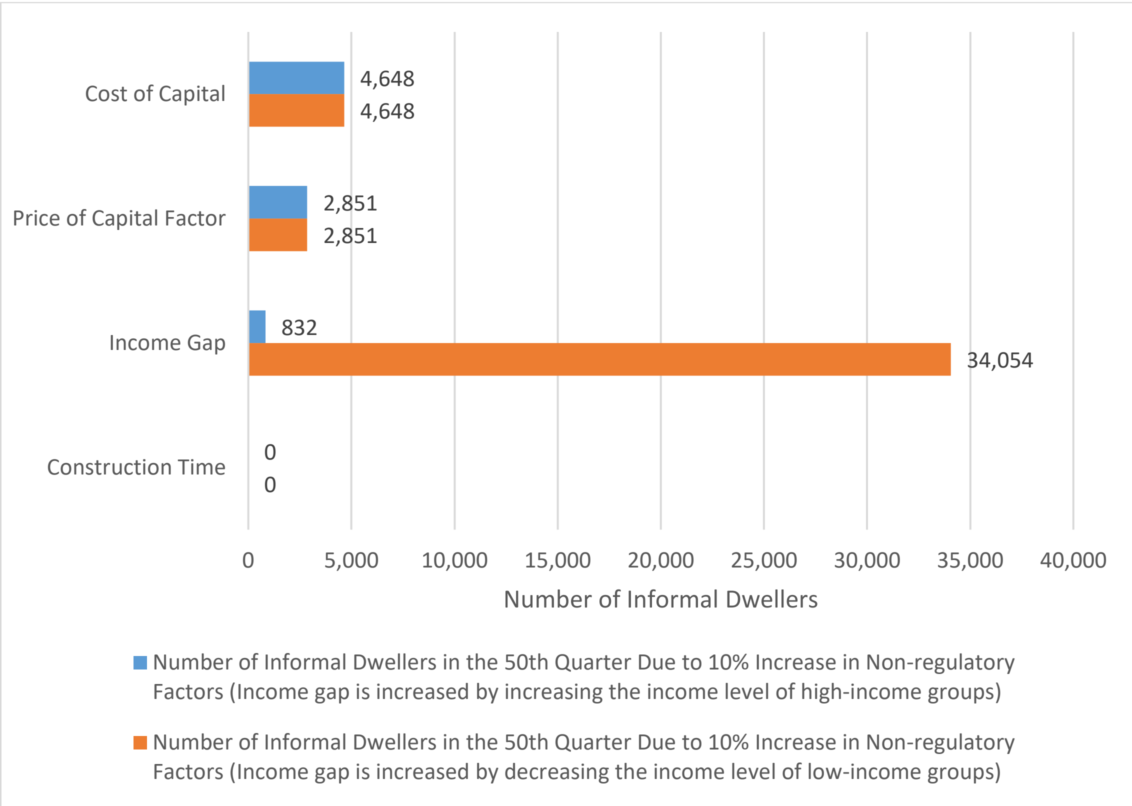


Figure 5-33: The comparison of non-regulatory factors on the number of informal dwellers under two modes of the increase in income gap

5-3-2- Individual effect of planning regulations

This section analyses the individual effect of three planning regulations. As mentioned earlier in this chapter, the individual effect means the effect of each planning regulation without changing other factors or imposing other regulations.

5-3-2-1- UGB effect

In order to discover the individual effect of imposing a UGB, I consider the different modes of demand shock and, then, impose different restricting UGBs on the city in each mode. There are eight modes of demand shocks and four levels of UGB restrictions. Thus, the total combined modes are 32, and entering the three graphs for each of them occupies considerable space. Hence, due to the space limitation, I only address the demand shock modes that last for 20 quarters, and the graphs of modes with a ten-quarters duration are shown in the Appendix. The four UGB restrictions define four UGB sizes based on the initially developed area of the city. These four UGB sizes are 150%, 125%, 110%, and 102.5% of the size of the city's initial developed area.

Juxtaposing and investigating all the housing and land price figures demonstrates that more restrictive UGBs in all modes of demand shock reduce the volatility of both housing and land markets by producing milder fluctuations after the first jump. The most restrictive UGB (102.5% of the initially developed area) not only changes the trend of housing and land prices but inclines toward higher long-run equilibrium prices. For the other UGBs, the incremental effect on the long-run equilibrium prices is infinitesimal. The more intense the demand shock, the more differentiated the effect of different UGBs is.

As can be seen in the first two modes of the demand shock (see figures (5-33) to (5-38)), there is no difference between the housing and the land courses of larger UGBs (i.e., 150% and 125% of the initially developed area). The reason for these behavior patterns is that the UGB is a constraint that sets a limit for the total supply of land and limits the fluctuations in the land supply. When the fluctuating land supply does not exceed the capacity set by the UGB, it does not touch the limit. In this case, the UGB is not restrictive. However, when the UGB is more restricted, or the supply is higher due to higher prices stemming from higher demand shocks, the fluctuating supply may exceed the constraint more and more or even always pass the limit set by the UGB constraint. The latter case happens in the most restrictive UGB and the highest level of demand shocks (household growth rates). In this case, the choices for the land demand are limited. In mathematical terms, the solution space is limited by the UGB constraint to find the long-run equilibrium price. Hence, the frequency of the fluctuations diminishes and, in the event of the most restrictive UGB, disappears. In economic terms, restrictive UGBs diminish the land supply elasticity.

Regarding the number of marginalized households, in the case of 3% household growth, only the most restrictive UGB leads to the marginalization of low-income groups to informal settlements. However, the number of informal dwellers is negligible. Following the pattern of housing price trend, increasing the demand shock to a 5% household growth rate leads to the emergence of marginalization in the case of less restrictive UGBs. The number of informal dwellers in the case of the most restrictive UGB rises dramatically.

Juxtaposing the trend of numbers of informal dwellers and the trend of housing prices demonstrates that the price trend is the prime factor in defining the growth pattern of numbers of informal dwellers. The longevity of the growth in informal sector households depends on the period for which housing prices are unaffordable. In the case of the tightest UGB (102.5%), the number of households marginalized to informal settlements grows over a more extended period since it takes longer for the price to decline to affordable levels. The difference between the long-term equilibrium housing prices does not matter for the size of informal settlements if these prices are all within the affordable range. Based on this, every price peak, which is more than the affordable level for the low-income households, leads to their marginalization from the formal housing market until the housing price drops to the affordable level. When the long-term equilibrium price level exceeds the affordable level, the number of informal dwellers increases steadily (see figure (5-42) and (5-44)).

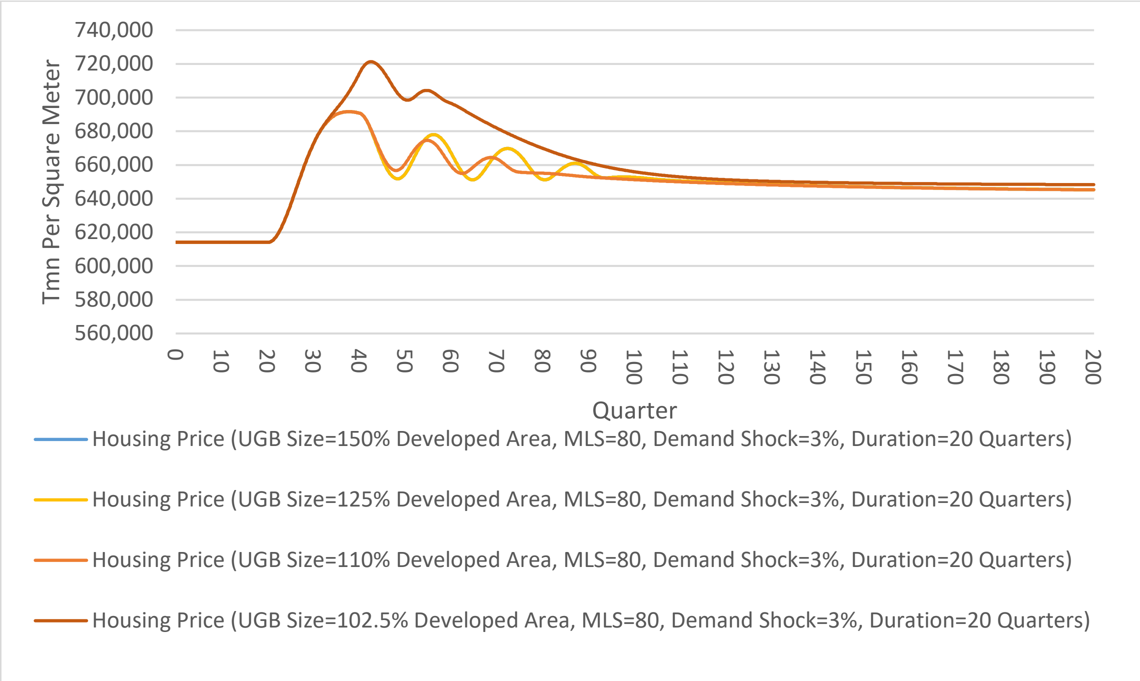


Figure 5-34: The effect of changes in UGB on the housing price under 3% demand shock lasting for 20 quarters

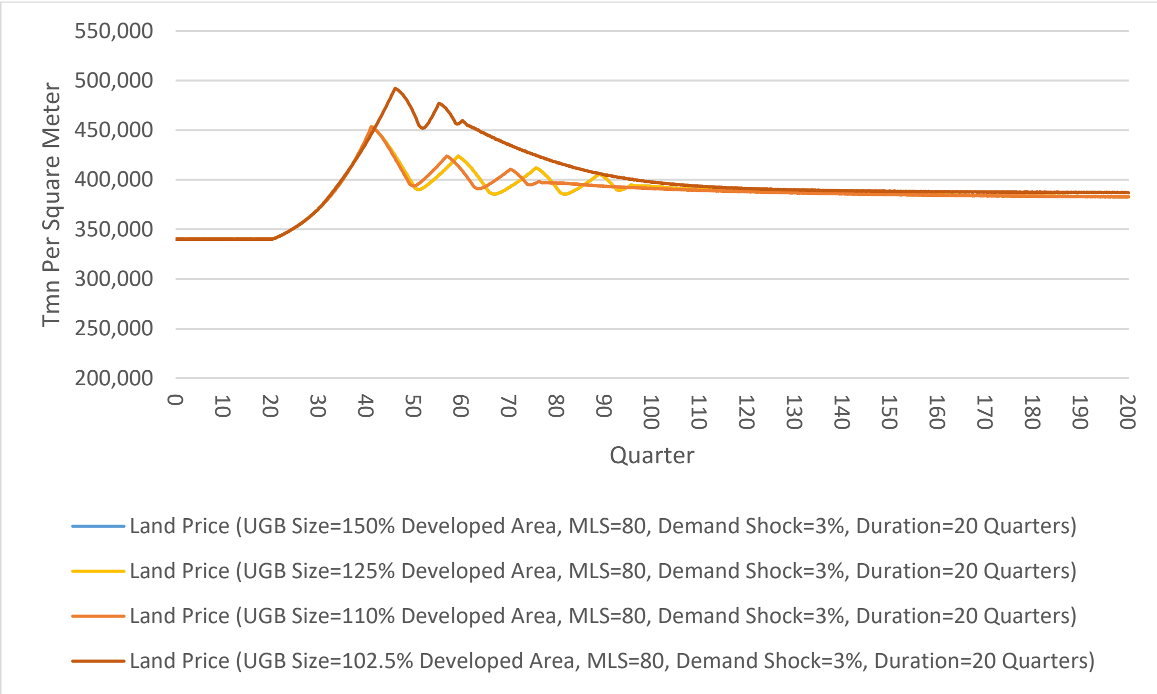


Figure 5-35: The effect of changes in UGB on the land price under 3% demand shock lasting for 20 quarters

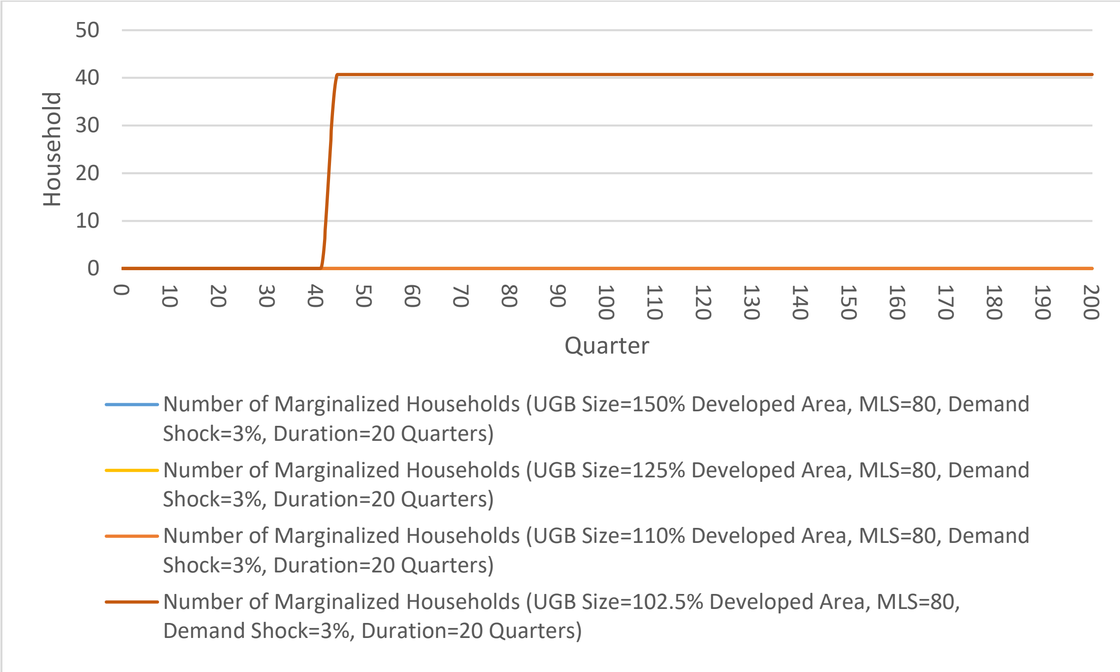


Figure 5-36: The effect of changes in UGB on the number of marginalized households under 3% demand shock lasting for 20 quarters

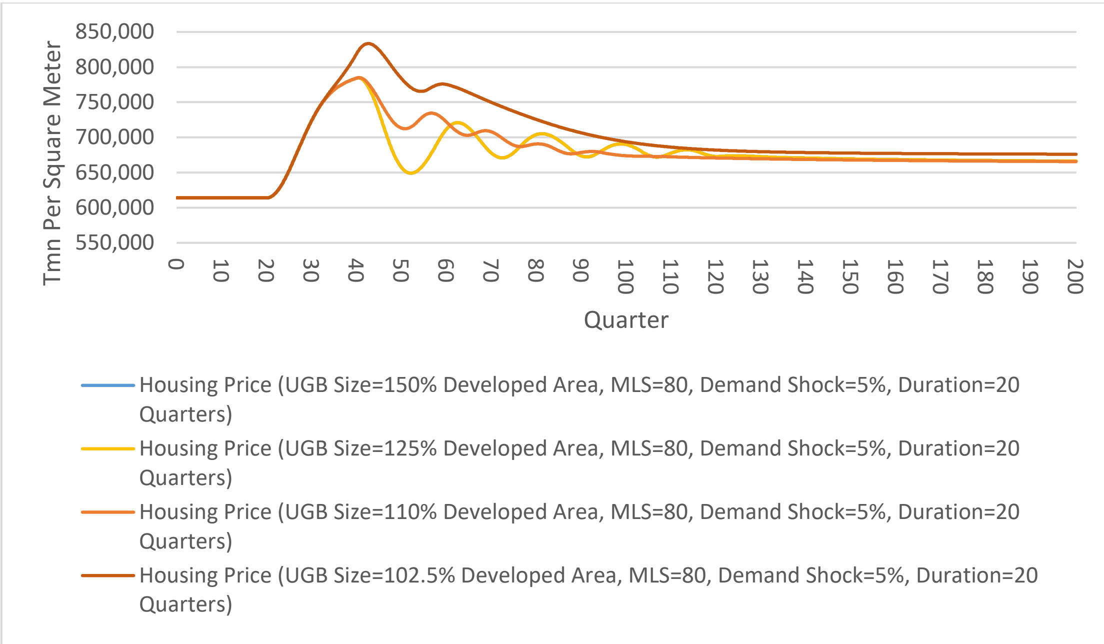


Figure 5-37: The effect of changes in UGB on the housing price under 5% demand shock lasting for 20 quarters

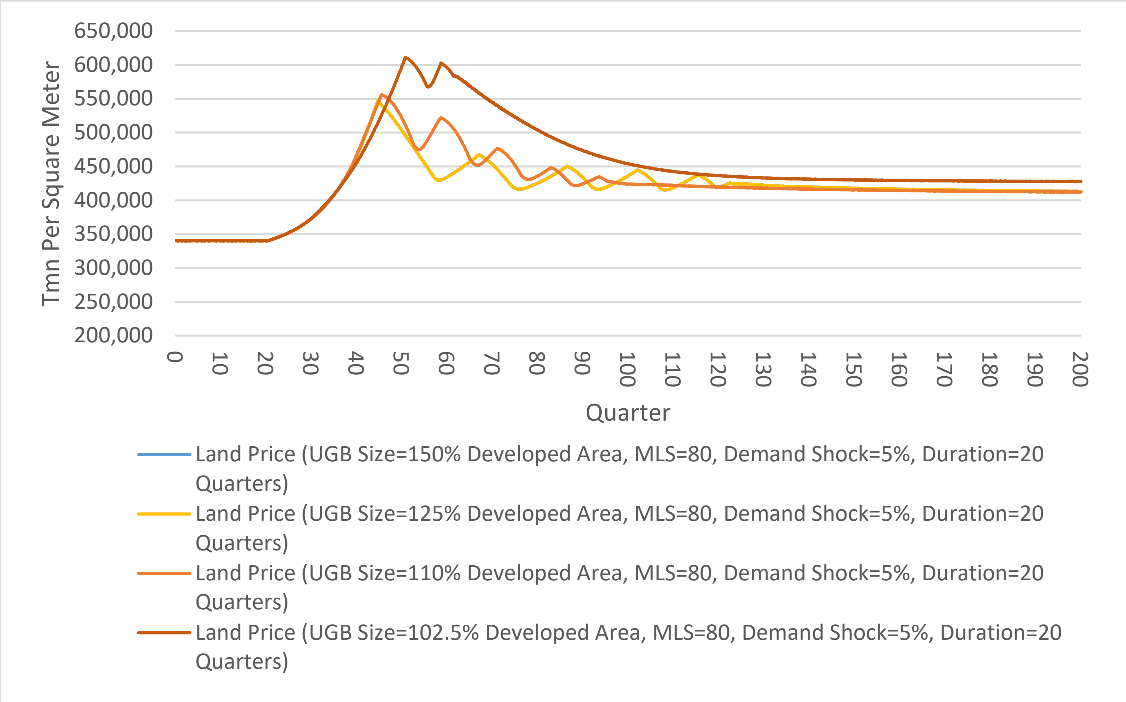


Figure 5-38: The effect of changes in UGB on the land price under 5% demand shock lasting for 20 quarters

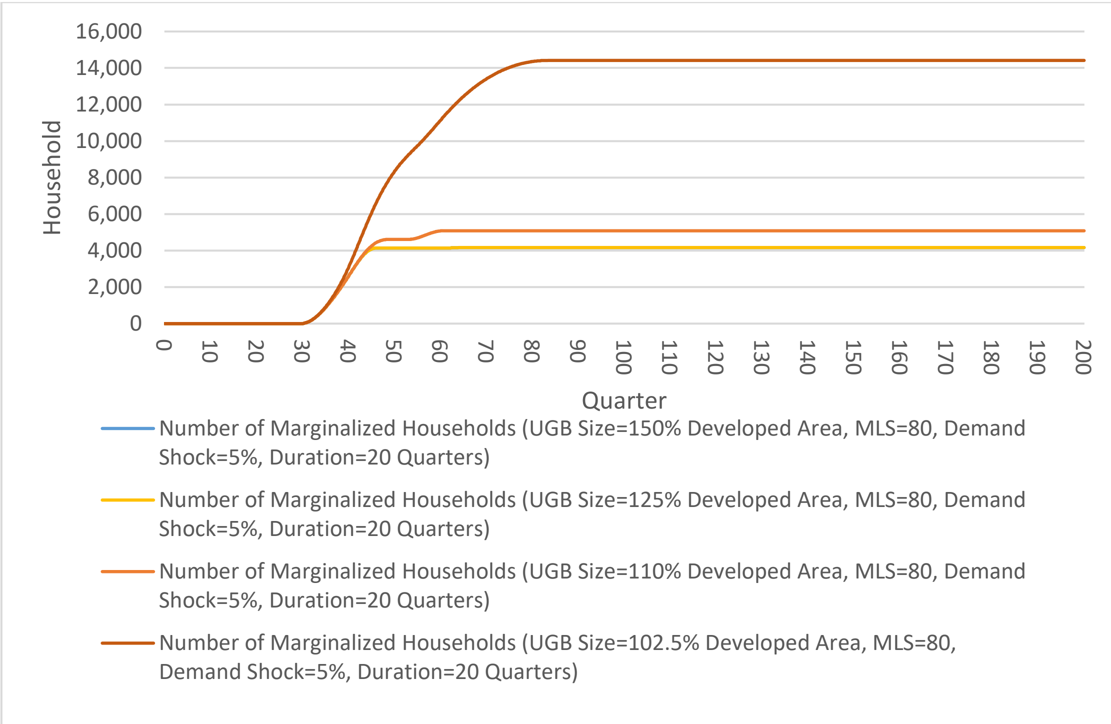


Figure 5-39: The effect of changes in UGB on the number of marginalized households under 5% demand shock lasting for 20 quarters

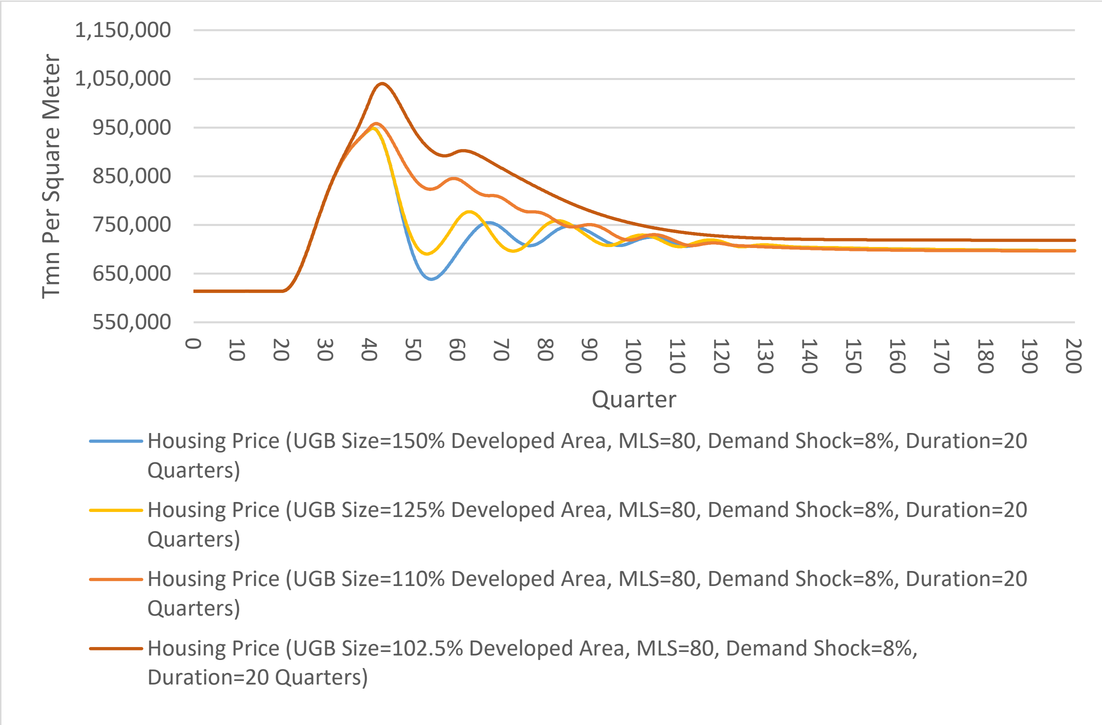


Figure 5-40: The effect of changes in UGB on the housing price under 8% demand shock lasting for 20 quarters

Figure 5-41: The effect of changes in UGB on the land price under 8% demand shock lasting for 20 quarters

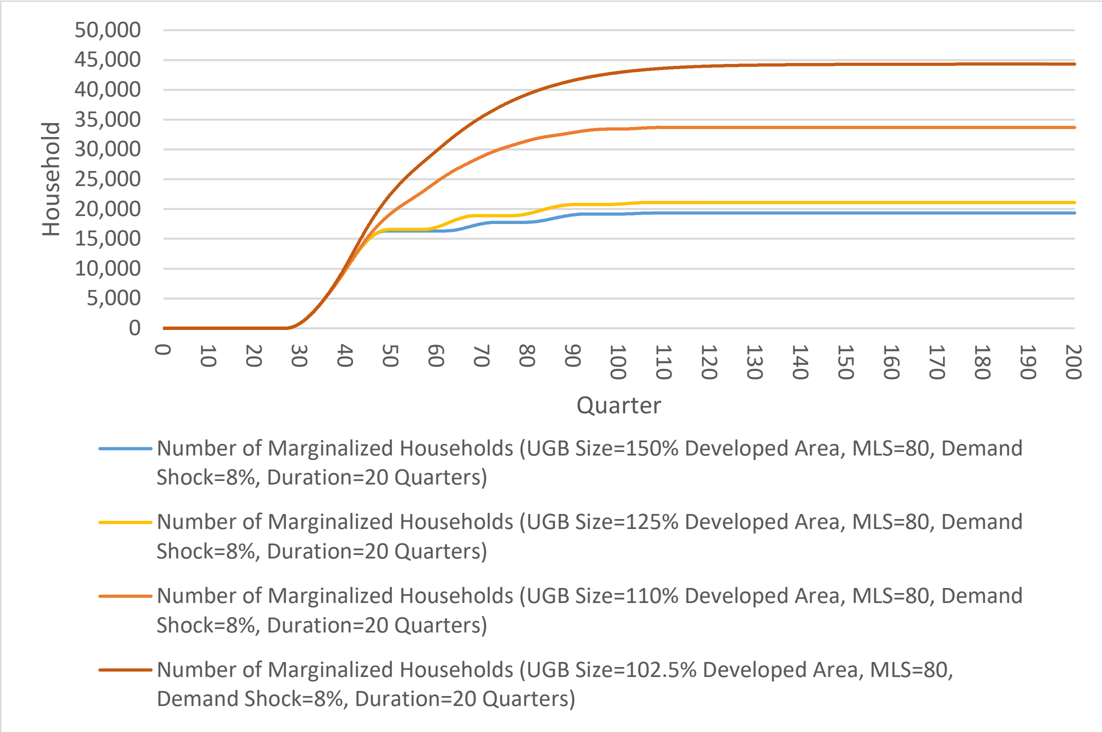


Figure 5-42: The effect of changes in UGB on the number of marginalized households under 8% demand shock lasting for 20 quarters

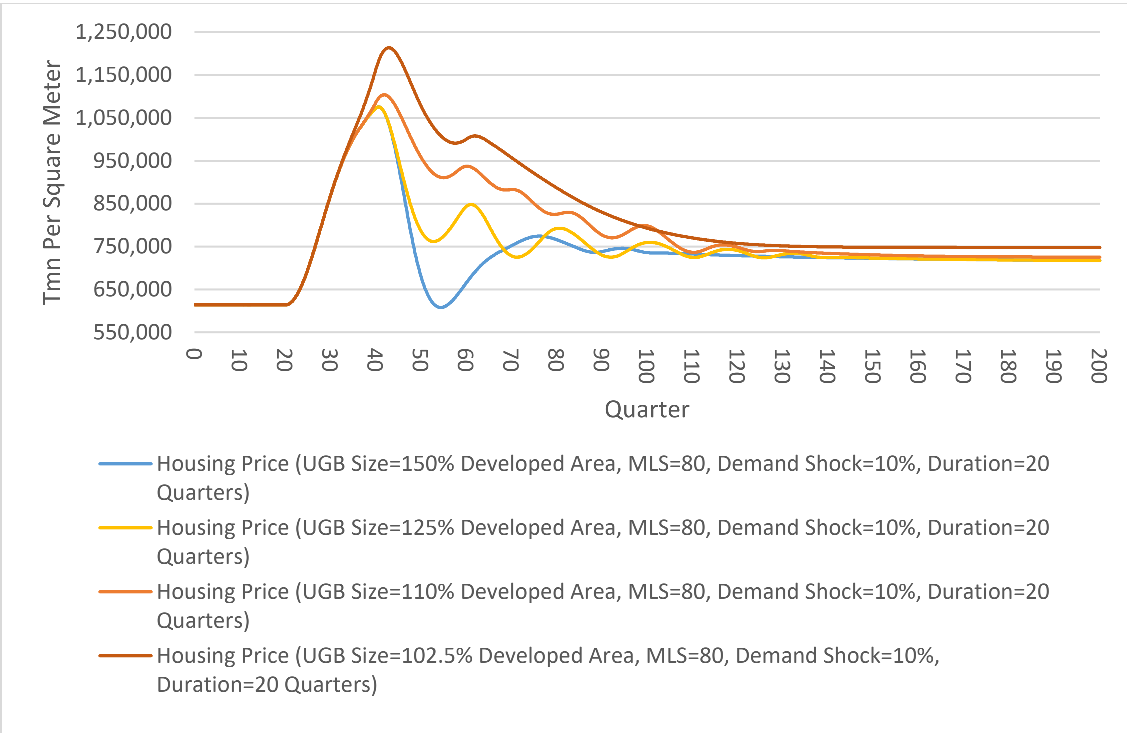


Figure 5-43: The effect of changes in UGB on the housing price under 10% demand shock lasting for 20 quarters

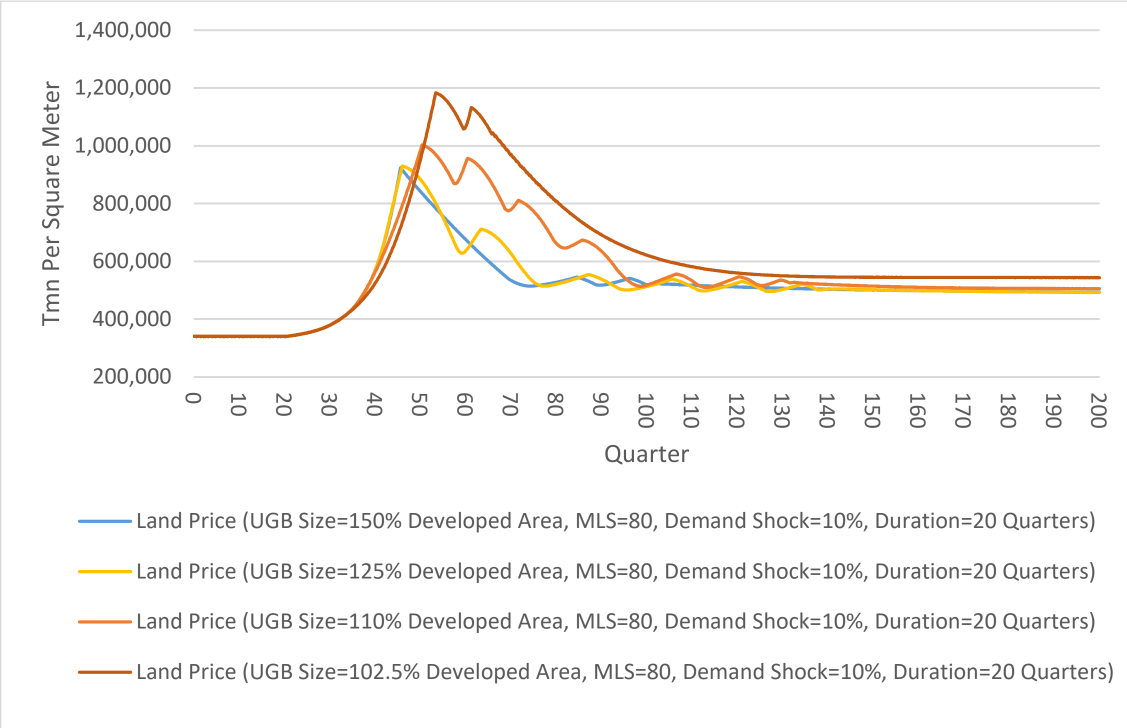


Figure 5-44: The effect of changes in UGB on the land price under 10% demand shock lasting for 20 quarters

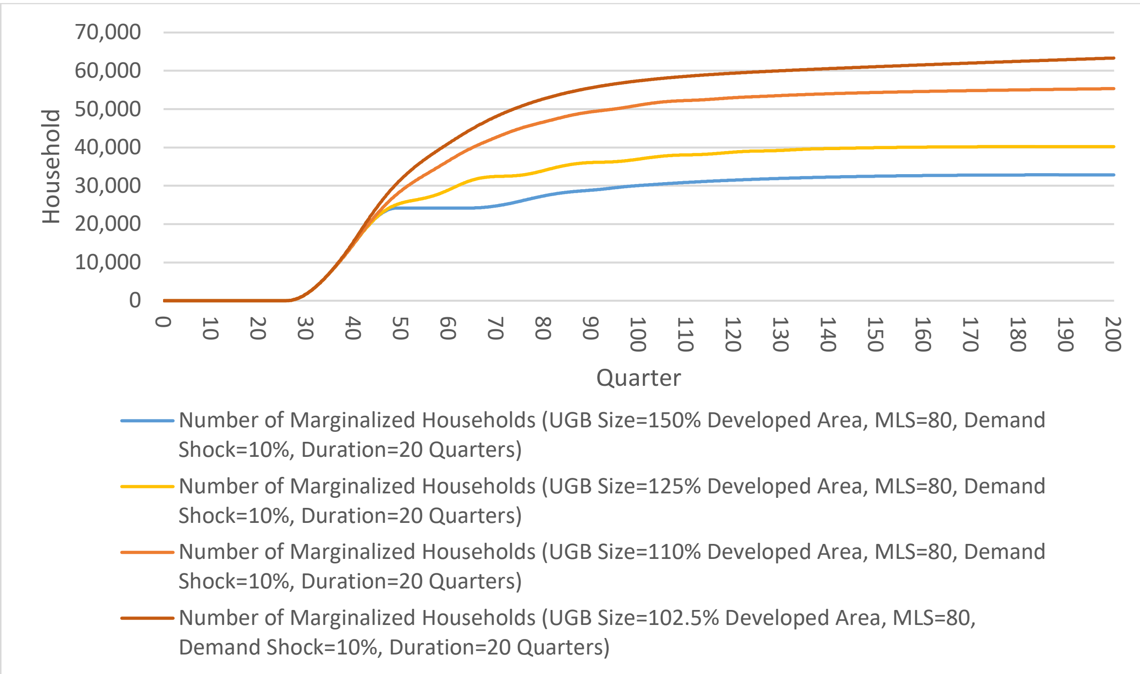


Figure 5-45: The effect of changes in UGB on the number of marginalized households under 10% demand shock lasting for 20 quarters

5-3-2-2- MBD effect

As mentioned at the beginning of this chapter, MBD is the only regulation among the three that can affect the housing and land prices in the initial steady state in which the household growth is zero and the only source of new construction is the demolition rate. As far as the demolition rate is constant, UGB and MLS do not affect the market since the demand for undeveloped land is zero. On the contrary, imposing a restrictive MBD sets a capacity for construction, affecting the housing supply. Based on this, in the following subsections, I first investigate the effect of MBD without the demand shock. Since the municipal unit charge can affect developers' decisions in the event of a restrictive MBD, I then address the effect of increasing the municipal unit charge when there is a restrictive MBD without any demand shock. In the end, I analyze the MBD effect in the presence of different levels of the demand shock.

5-3-2-2-1- MBD effect (without demand shock)

In order to discover the MBD effect, I choose four limits of restriction, including 300%, 240%, 180%, and 120%. Given the occupation rate of 60% for the ground level which is pervasively used in Iran's cities development plans, the mentioned MBD restrictions correspond with four limits on the number of building storeys being five, four, three, and two storeys. The MBD is imposed in the 20th quarter to depict the effect on the steady-state of the main variables more evidently. Despite changing housing and land prices, the imposed MBDs do not trigger the marginalization process, even the most restrictive one (120%).

The critical point here is the effect of the MBD on the trend of movement in housing and land prices. Higher restrictions on the building density increase both housing and land prices in the long-term equilibrium. However, they follow different patterns. A more restrictive MBD increases the cost of construction per square meter of building. The resulting increase in the capital factor price makes housing construction unprofitable for a while. Due to the unsatisfied housing demand during this period, housing prices rise, and land prices fall since there is no demand for new construction. This downward movement of the land price, which is evident after the 20th quarter in Figure (5-46), is in accordance with the theoretical prediction of Brueckner et al.'s (2017) static model. Based on their model, imposing the MBD restriction on a land lot decreases its price since the restriction reduces the profitability of development on the land lot and developers' willingness to pay for the lot.

However, their static model is at the parcel level rather than the city and takes the housing price constant, implying the MBD restriction does not affect the housing price. Here, our dynamic model allows us to investigate the effect of MBD restriction on the whole market and changes the housing price. On this basis, we can see in Figure (5-46) that the land price starts rising after the following increase in housing prices makes construction profitable once again. A more restrictive MBD makes construction expensive due to increasing the price of capital factor and leads developers to economize on the expensive factor by relying more on a relatively cheaper factor (land). However, the dynamic relationship implies that when demand for land rises, its price will ultimately increase. Brueckner et al. (2017) predict that this market effect only emerges in a closed city model; however, the semi-open city model of this research shows such an effect too. The reason is that by merely imposing more restrictive MBDs, the marginalization process, which is a kind of outward migration, is not activated. Therefore, the hypothetical city can still be regarded as a closed city.

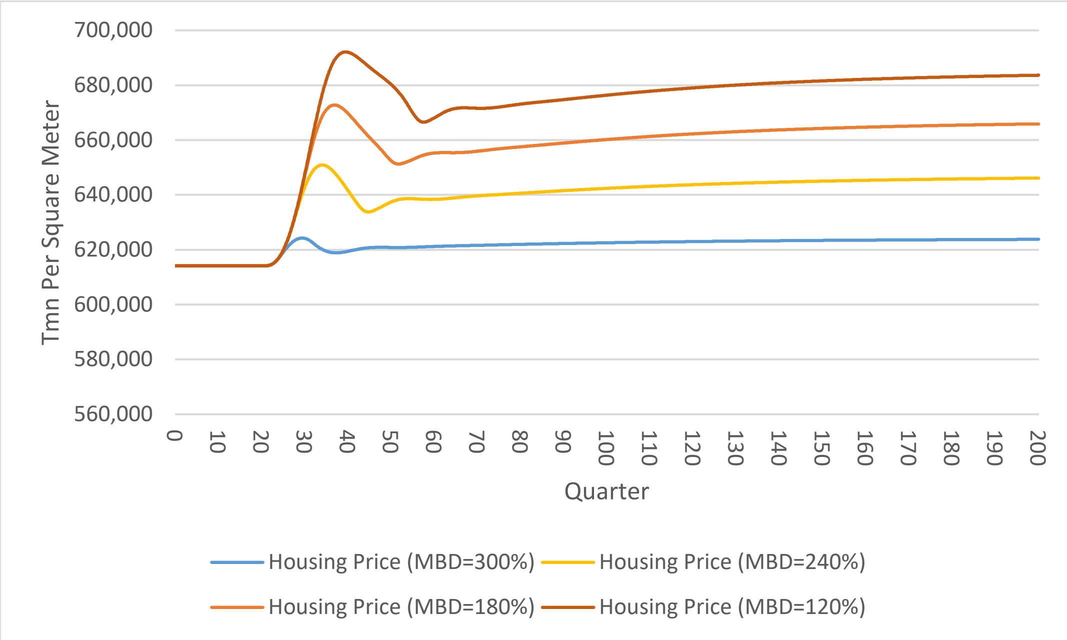


Figure 5-46: The effect of changes in MBD on the housing price

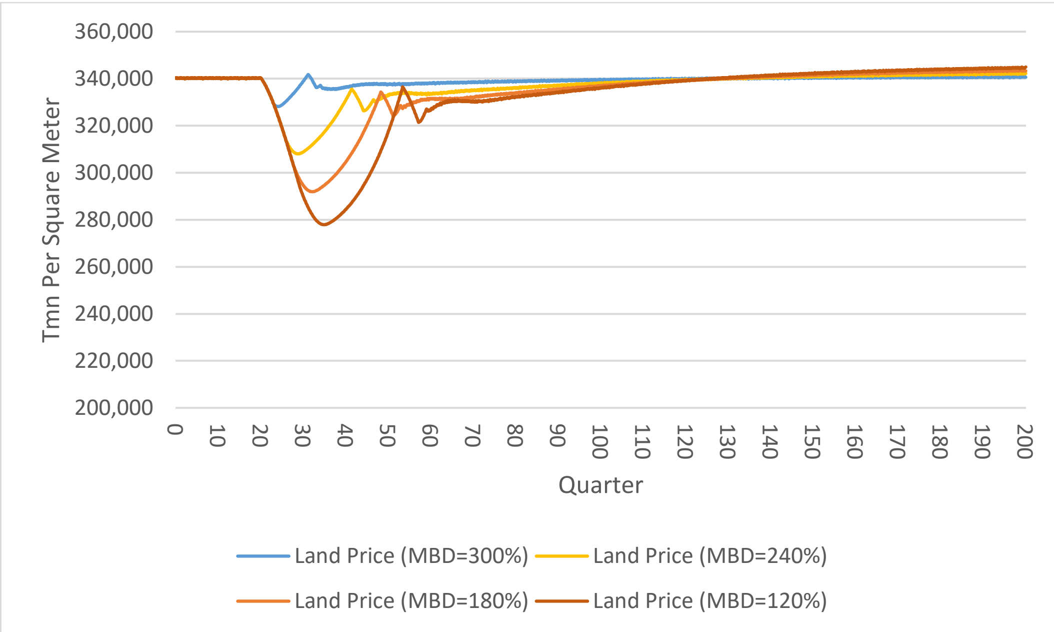


Figure 5-47: The effect of changes in MBD on the land price

5-3-2-2-2- MBD effect (without demand shock) combined with the effect of changing development charge

In order to explore the effect of the extra development charge (municipal unit charge), I increase it by 50% and by 100%. Figures (5-48) and (5-49) compare the effect of such increases with the base case of imposing a 120% MBD. Both housing and land prices increase in the long term, and their pattern of increase explained in the previous subsection are more evident. Figure (5-50) shows the effect of increasing the extra development charge on the number of informal dwellers. Low-income households start leaving the formal market the extra development charge increases by 100%. The pattern of growth in the number of informal dwellers follows the housing price trend. Between the 20th and 60th quarters, the housing price rises, hits a maximum, and decreases. Indeed, the housing price exceeds the affordable housing price for the lowest income households. The housing price hits this critical value twice, and during the period between them, the number of informal dwellers increases from zero to nearly 500. After the second point, the price drops below the critical point, and the process of marginalization stops. However, it is evident that the price slowly surges to a level in the long term, which is higher than the critical affordable level for the lowest-income households. The transition to the unaffordable region happens around the 150th quarter. Such a mild increase leads to a gradual rise in the number of marginalized households which is evident in the trend of orange line in Figure (5-50).

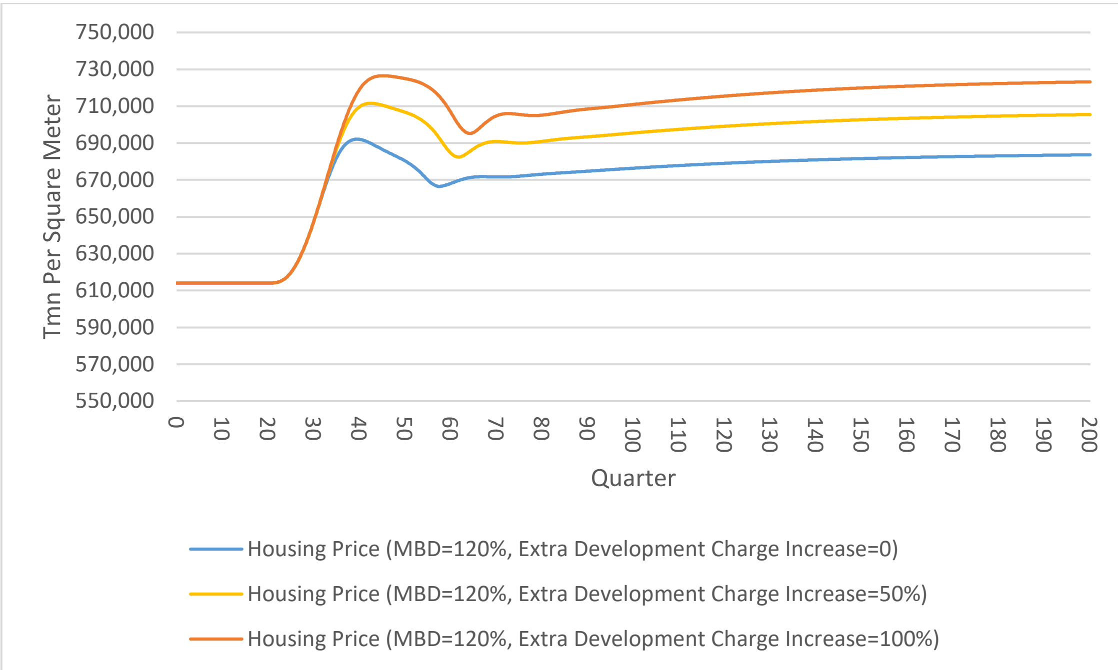


Figure 5-48: The effect of increasing the extra development charge on the housing price under the imposition of 120% MBD

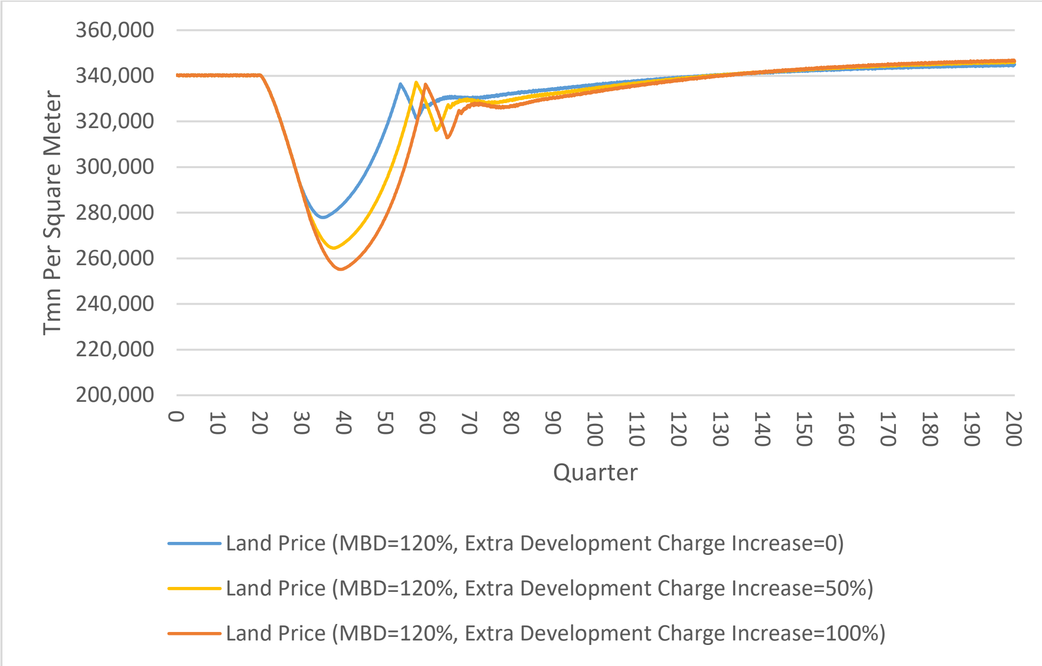


Figure 5-49: The effect of increasing the extra development charge on the land price under the imposition of 120% MBD

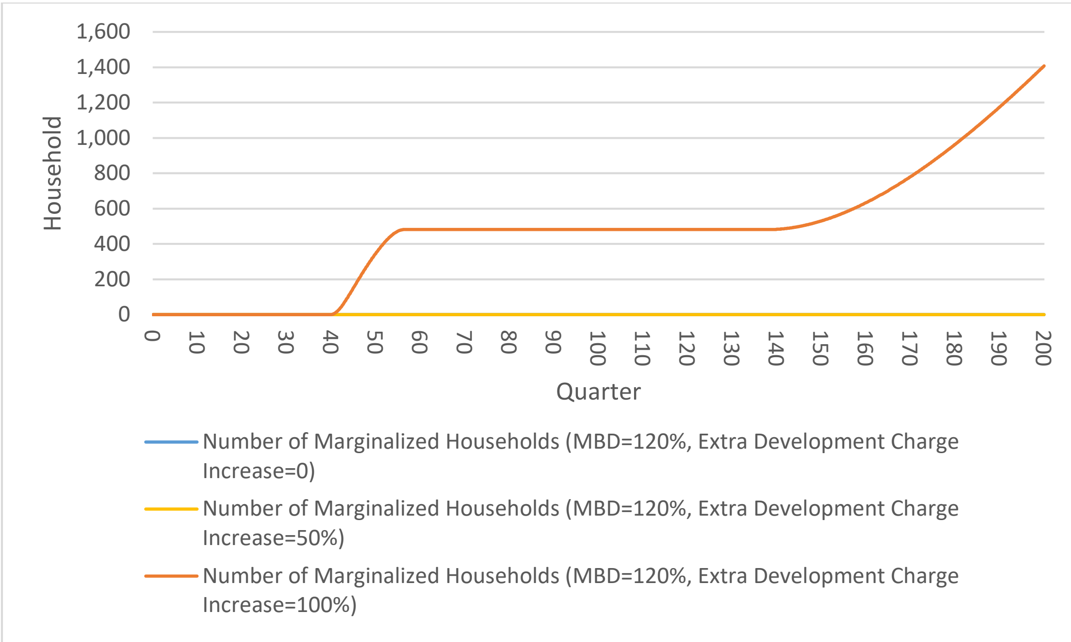


Figure 5-50: The effect of increasing the extra development charge on the number of marginalized households under the imposition of 120% MBD

5-3-2-2-3- MBD effect (with demand shock)

I impose the mentioned four limits of MBD on the hypothetical city while it is facing different levels of demand shock lasting for 20 quarters. The figures at the end of this subsection show the results. In all modes of demand shock, further restricting the MBD has an incremental effect on housing and land prices. However, this incremental effect is more evident for the housing price than the land price. Also, we can see that housing price trends are closer to one another under the intensified demand shocks.

Regarding the land price, the trends are almost inseparable when the demand shock is more intense. These patterns stem from the activation of the marginalization process and the length of its activation period. The length of a period over which the marginalization mechanism is active depends on the length of the period through which the housing price is above the critical level unaffordable for the lowest income households. During this period, lowest income households resort to informal housing sector, and consequently, the city functions as an open city.

In the lower demand shock, like all the MBD restrictions in the case of 3% household growth rate and the first two MBD restrictions in the case of 5% household growth rate, the marginalization process is transitional. The growth pattern of informal dwellers in these cases consists of a period of increase whose length depends on the length of the period over which the housing price is not affordable for the lowest income households and then a straight line implying the drop of the housing price to the affordable zone and the end of marginalization. Hence, the city does not ultimately act as an open city model, which makes it unable to expel the pressure of the extra demand into the outside regions. In other words, the pressure of the restrictions intensified by the demand shock is not enough to increase prices to the level, making the city expel the extra pressure into the outer region. Therefore, housing and land prices emerge in more differentiated trends when the extra pressure cannot be completely relieved.

When the effect of more severe demand shock and restrictive MBDs combine with each other, the long-term housing price level stands above the critical level affordable for the lowest-income households. This means the marginalization process is active in the long run, and the city is converted to an open city. Thus, the extra pressure cannot show its full power in housing and land prices, and their trends are getting closer and even superimposed in the long-run equilibrium in the case of the land price. The reason for this difference between the long-term behavior of the housing price and the land price is that reducing MBD increases housing prices but initially results in reduced land prices that increase subsequently. Therefore, in contrast to the housing price, the long-run equilibrium land price (in the case of a more restrictive MBD) cannot be higher than the price in the less restrictive case. The informal sector absorbs the added pressure of the more restrictive MBD. Figures (5-52), (5-55), (5-58), and (5-61)-supports the critical prediction provided by Breueckner et al. (2017) with respect to the open city. This point states that restricting MBD in the open city model does not lead to an increase in the land price.

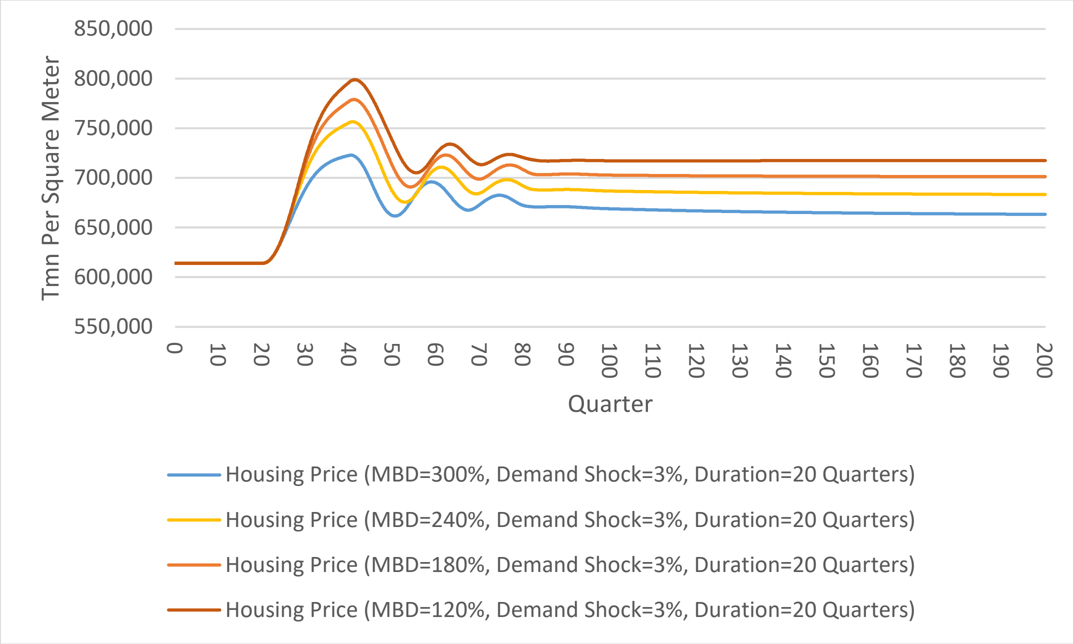


Figure 5-51: The effect of changes in MBD on the housing price under 3% demand shock lasting for 20 quarters

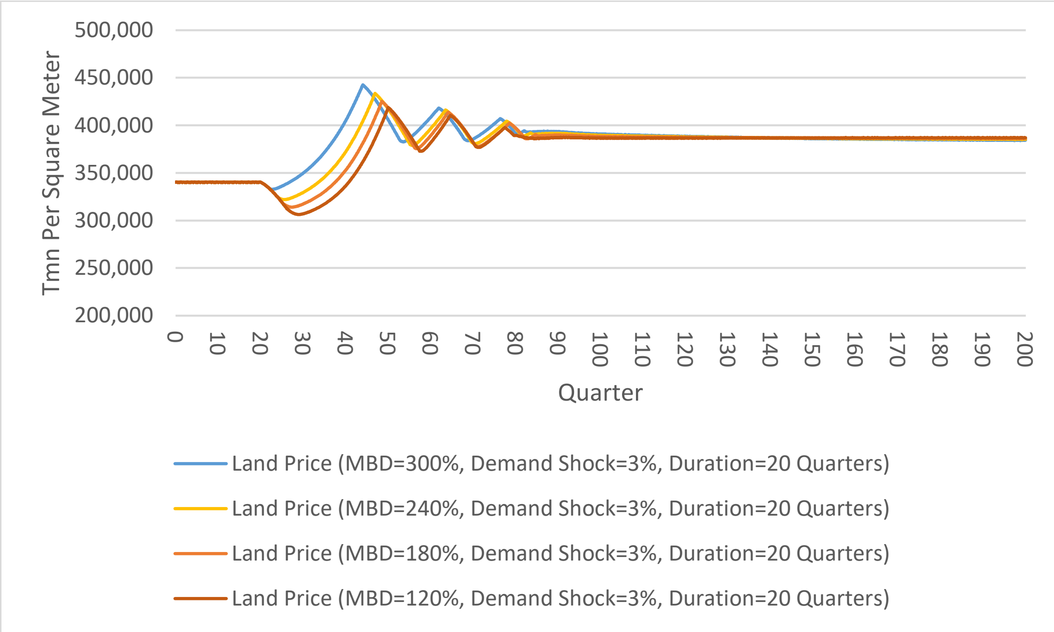


Figure 5-52: The effect of changes in MBD on the land price under 3% demand shock lasting for 20 quarters

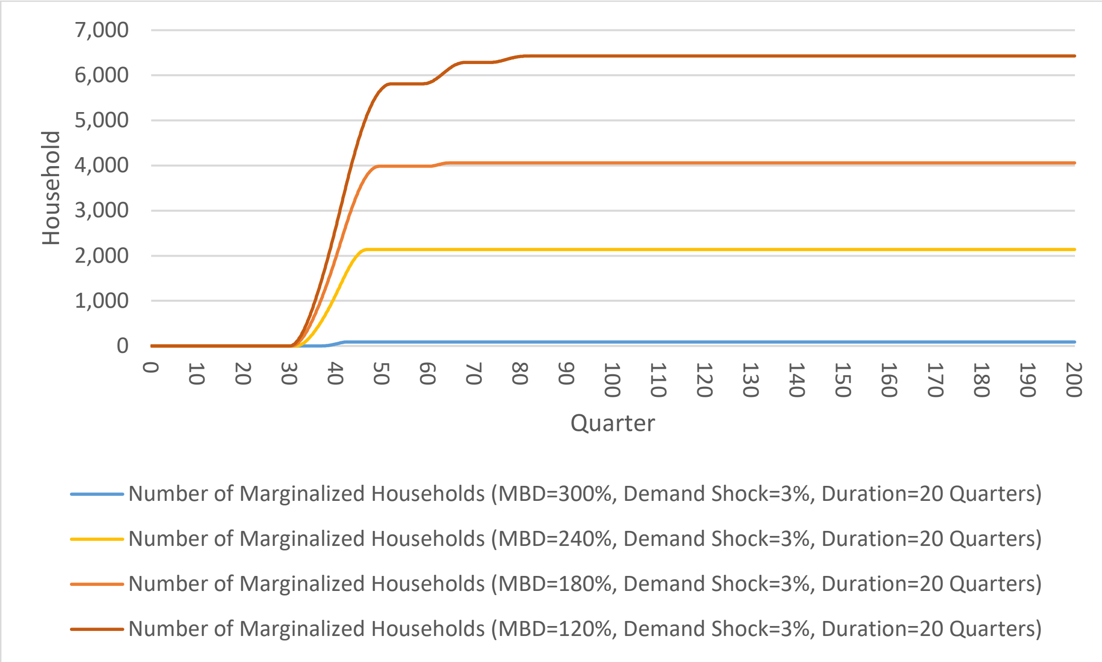


Figure 5-53: The effect of changes in MBD on the number of marginalized household under 3% demand shock lasting for 20 quarters

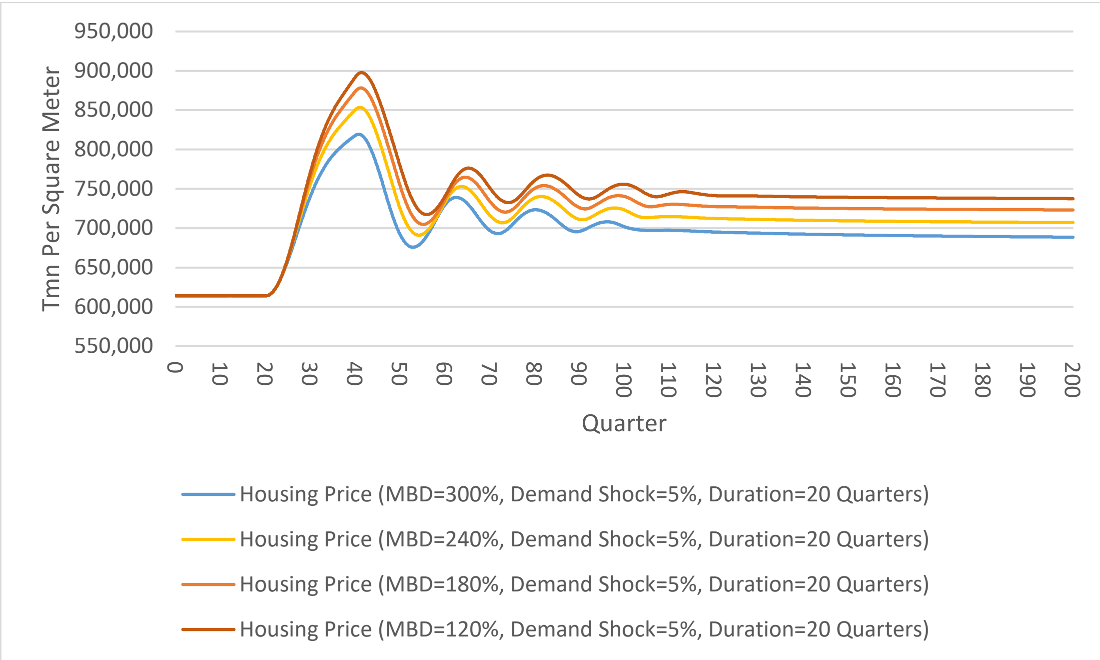


Figure 5-54: The effect of changes in MBD on the housing price under 5% demand shock lasting for 20 quarters

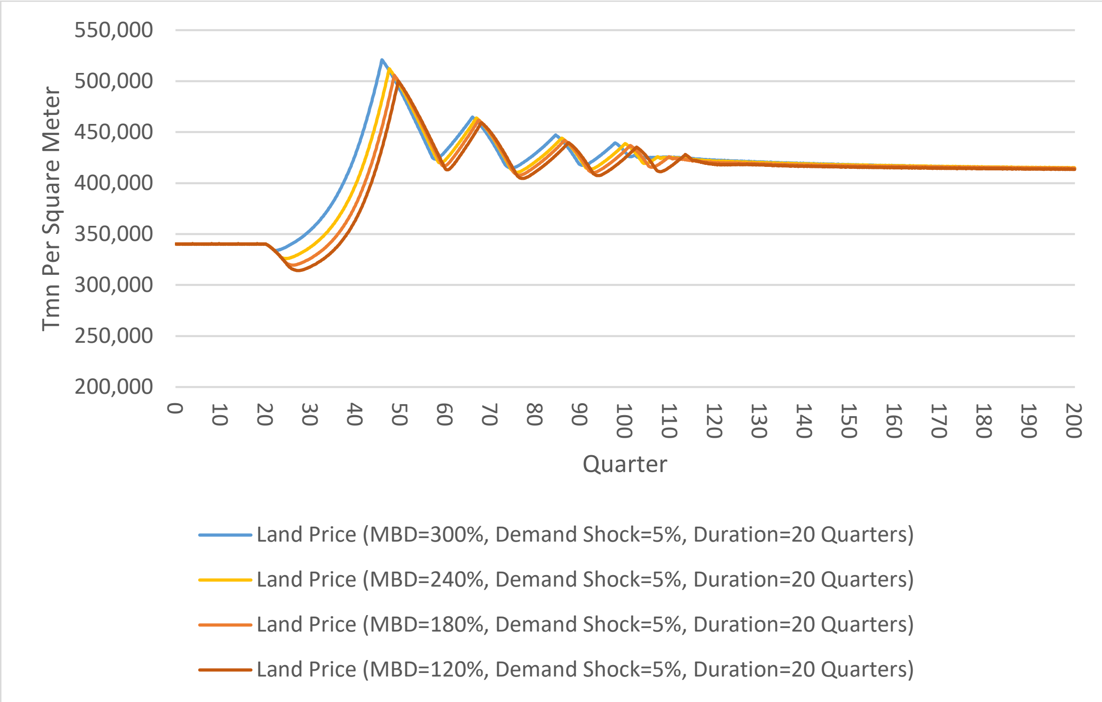


Figure 5-55: The effect of changes in MBD on the land price under 5% demand shock lasting for 20 quarters

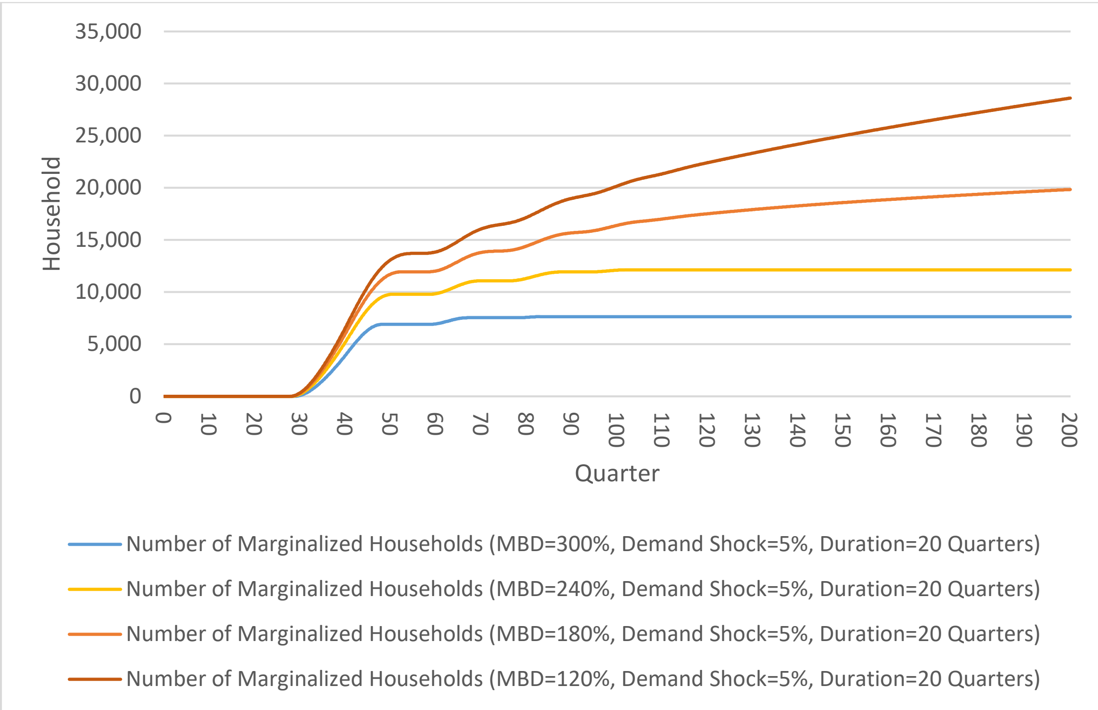


Figure 5-56: The effect of changes in MBD on the number of marginalized household under 5% demand shock lasting for 20 quarters

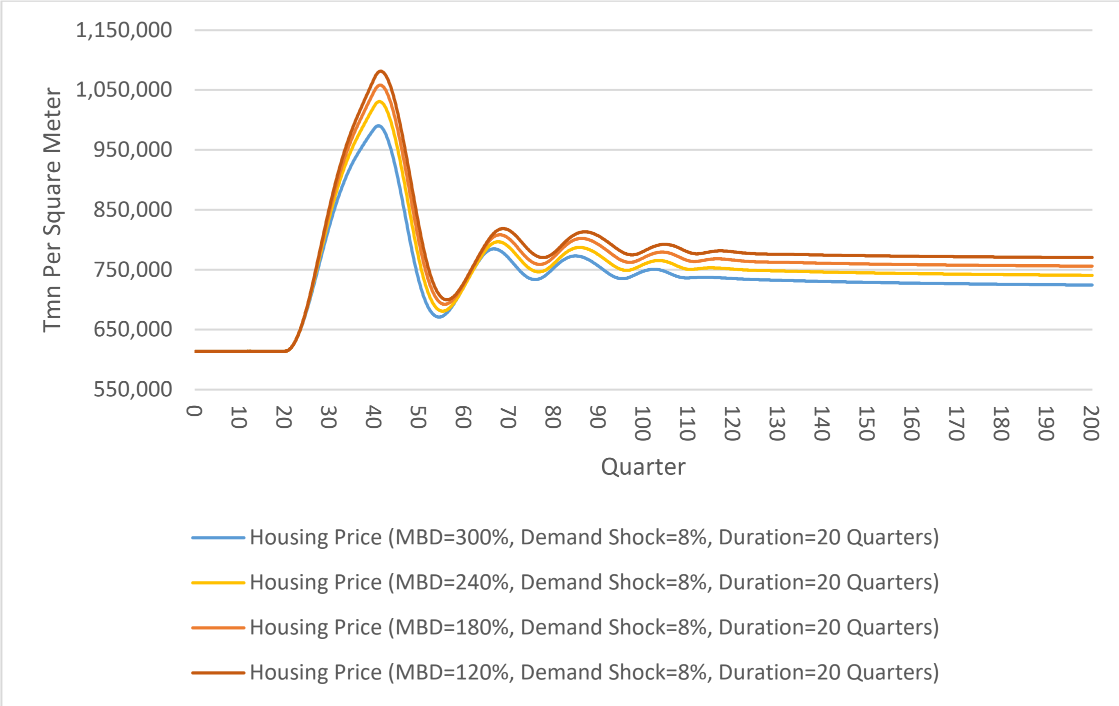


Figure 5-57: The effect of changes in MBD on the housing price under 8% demand shock lasting for 20 quarters

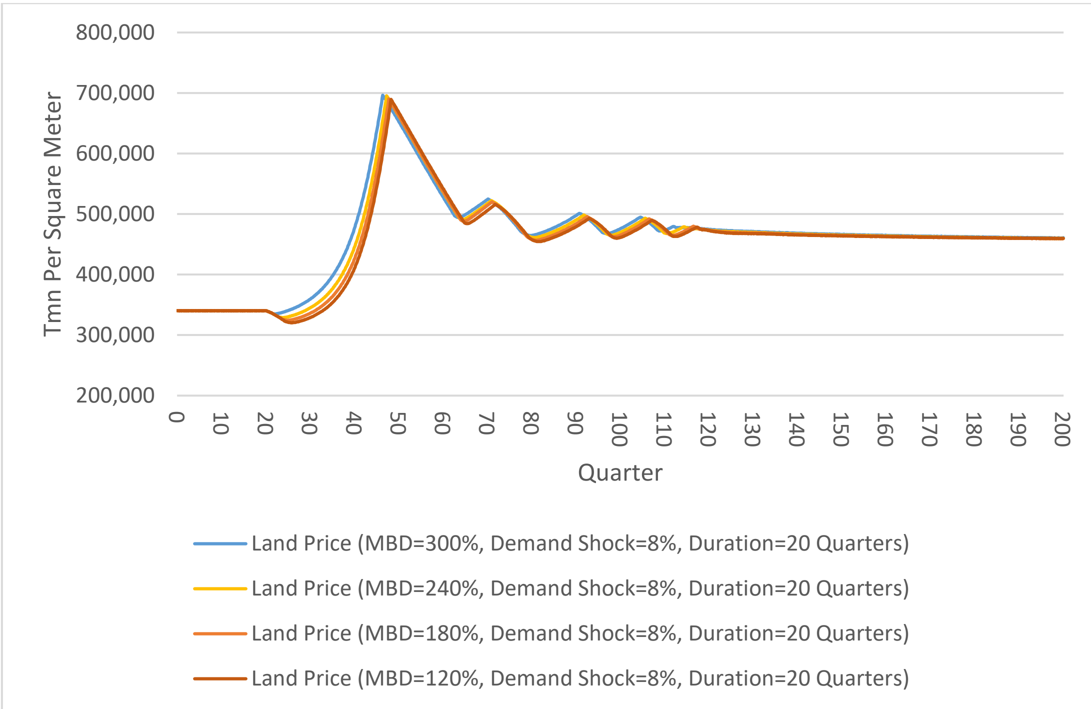


Figure 5-58: The effect of changes in MBD on the land price under 8% demand shock lasting for 20 quarters

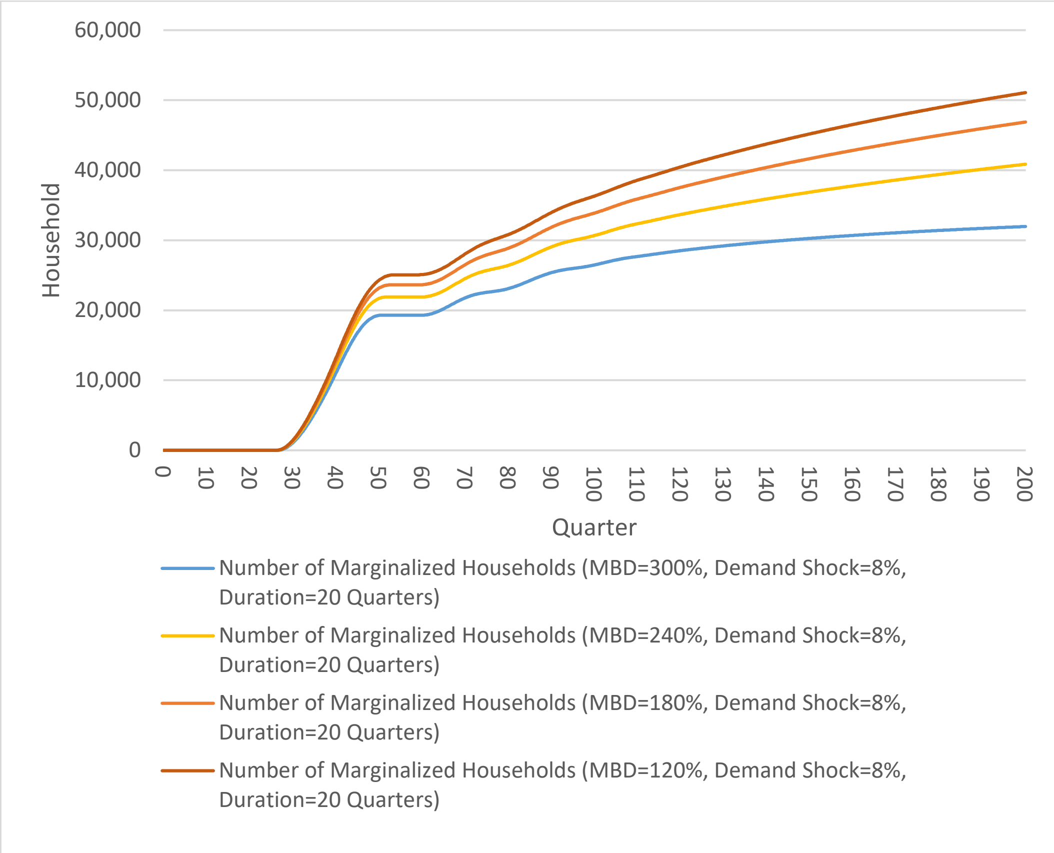


Figure 5-59: The effect of changes in MBD on the number of marginalized households under 8% demand shock lasting for 20 quarters

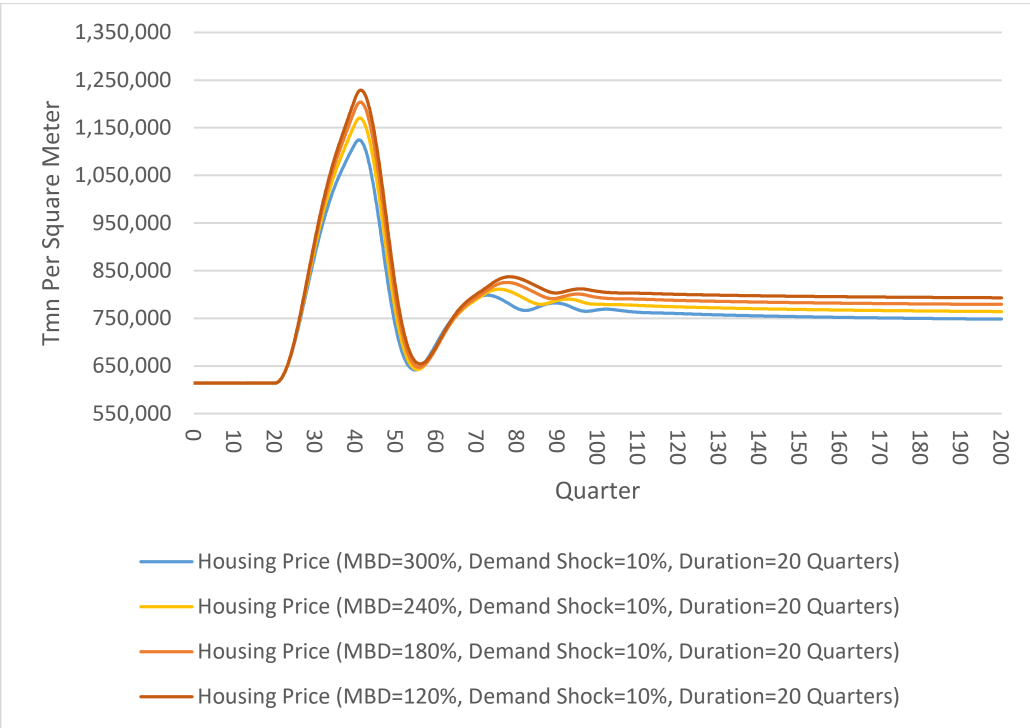


Figure 5-60: The effect of changes in MBD on the housing price under 10% demand shock lasting for 20 quarters

Figure 5-61: The effect of changes in MBD on the land price under 10% demand shock lasting for 20 quarters

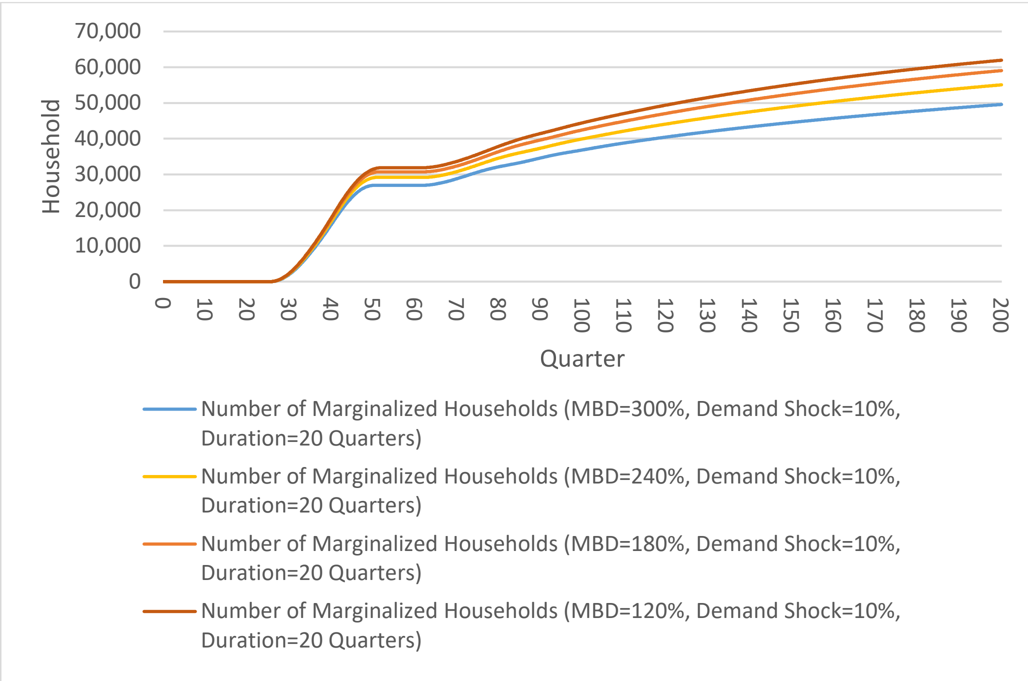


Figure 5-62: The effect of changes in MBD on the number of marginalized households under 10% demand shock lasting for 20 quarters

5-3-2-3- MLS effect

In order to test the effect of MLS, I impose four levels of lot size restriction on the undeveloped land lots. These levels are defined based on the size distribution of the under-construction land lots explained at the beginning of this chapter. The 80-square-meter MLS is not restrictive. All the undeveloped land lots inside the UGB are larger than 80 square meters. By increasing the MLS, the share of the undeveloped land area meeting the restriction level decreases. These restrictions are imposed on the city under demand shock modes similar to UGB and MBD.

Under all modes of the demand shock, increasing MLS does not change long-run equilibrium housing and land prices. The main effect of changing MLS is on the pattern of fluctuations in both of the markets. Increasing MLS leads to an increase in the first jump in housing and land prices. It happens because more restrictive MLS slows down the reaction of the land supply to land price changes. Indeed, more restrictive MLSs diminish the short-term land supply elasticity.

The main difference of MLS with the other two regulations is that it is only binding for the undeveloped land lots. On this basis, after the demand shock necessitating the consumption of undeveloped land lots for new construction, the MLS reduces the price elasticity of land supply and, subsequently, diminishes the land supply increase in reaction to the price increase. This process is a self-reinforcing loop that leads to a higher jump in the price in more restrictive MLSs. However, after the absorption of the demand shock, the demand for the land stems merely from the reconstruction process, which is met from the demolished buildings' land lots to which the lot size restriction is not applicable. Therefore, approaching the long-run equilibrium, the land supply can regain its reaction power by relying on the demolished buildings' land stock, and the equilibrium price will be the same.

The results of imposing the MLS are the best examples of how the price trend matters in the growth of informal dwellers regardless of the long-term equilibrium housing price. Considering the result of changing the MLS restrictiveness in each demand shock mode, we can see that long-term equilibrium housing and land prices do not change. Also, none of the long-run equilibrium housing prices are above the affordable level for the lowest-income households. However, the number of marginalized households differs by changing the MLS restrictiveness. The reason for this difference is the change in housing price trends stemming from imposing different MLSs. More restrictive MLS results in a higher number of marginalized households. Except for the 3% demand shock, all the other modes of demand shock cause the marginalization of low-income households in informal settlements.

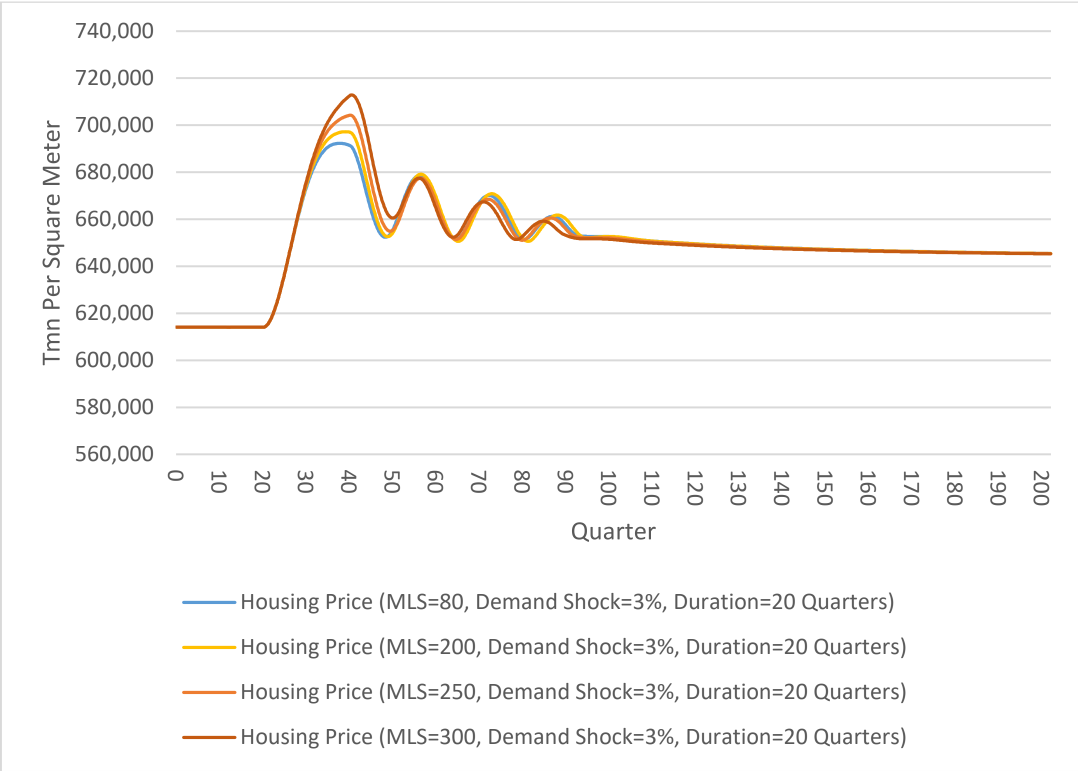


Figure 5-63: The effect of changes in MLS on the housing price under 3% demand shock lasting for 20 quarters

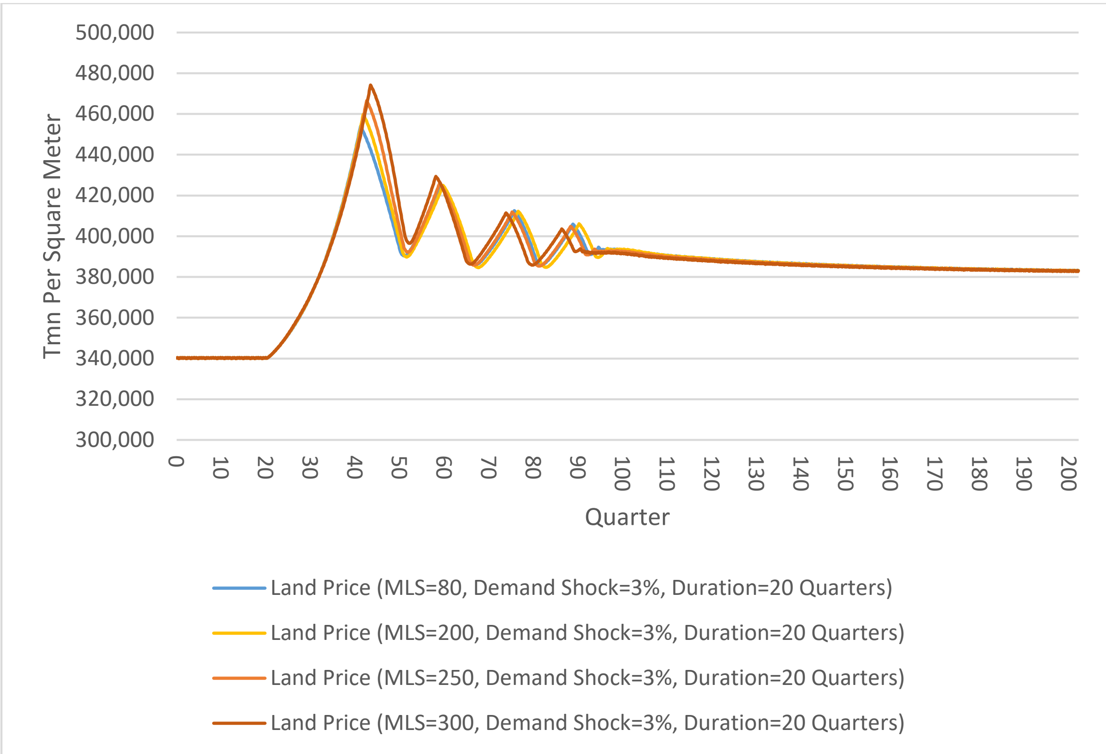


Figure 5-64: The effect of changes in MLS on the land price under 3% demand shock lasting for 20 quarters

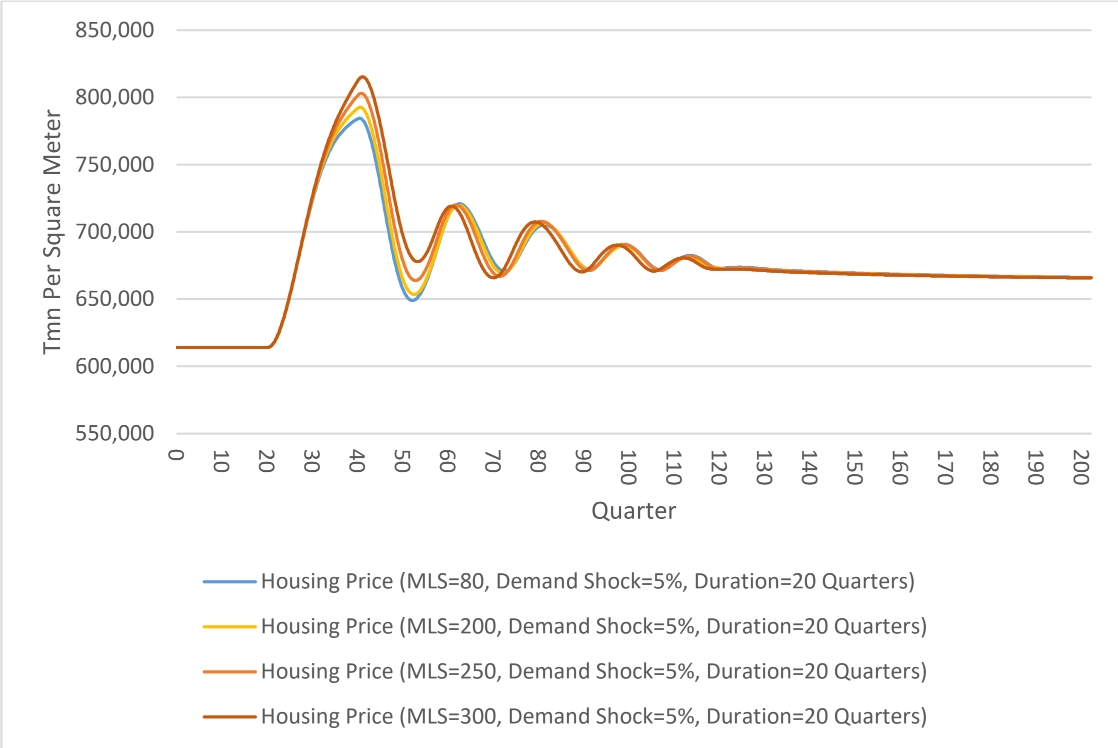


Figure 5-65: The effect of changes in MLS on the housing price under 5% demand shock lasting for 20 quarters

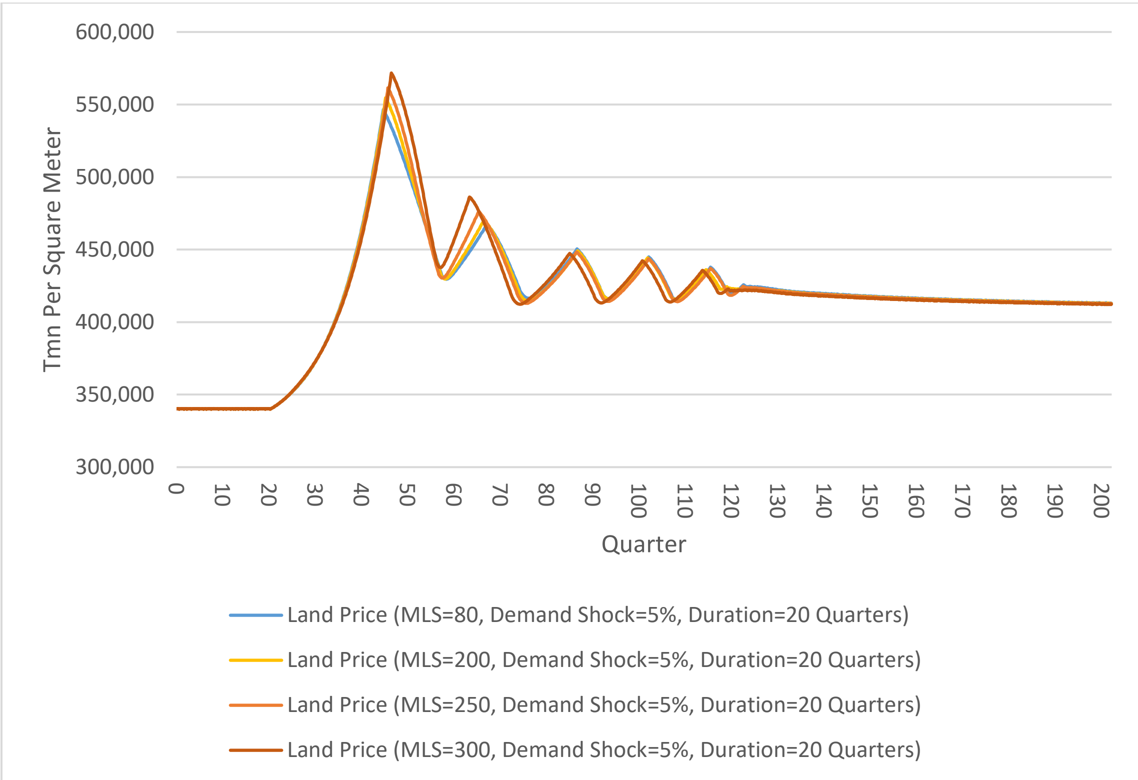


Figure 5-66: The effect of changes in MLS on the land price under 5% demand shock lasting for 20 quarters

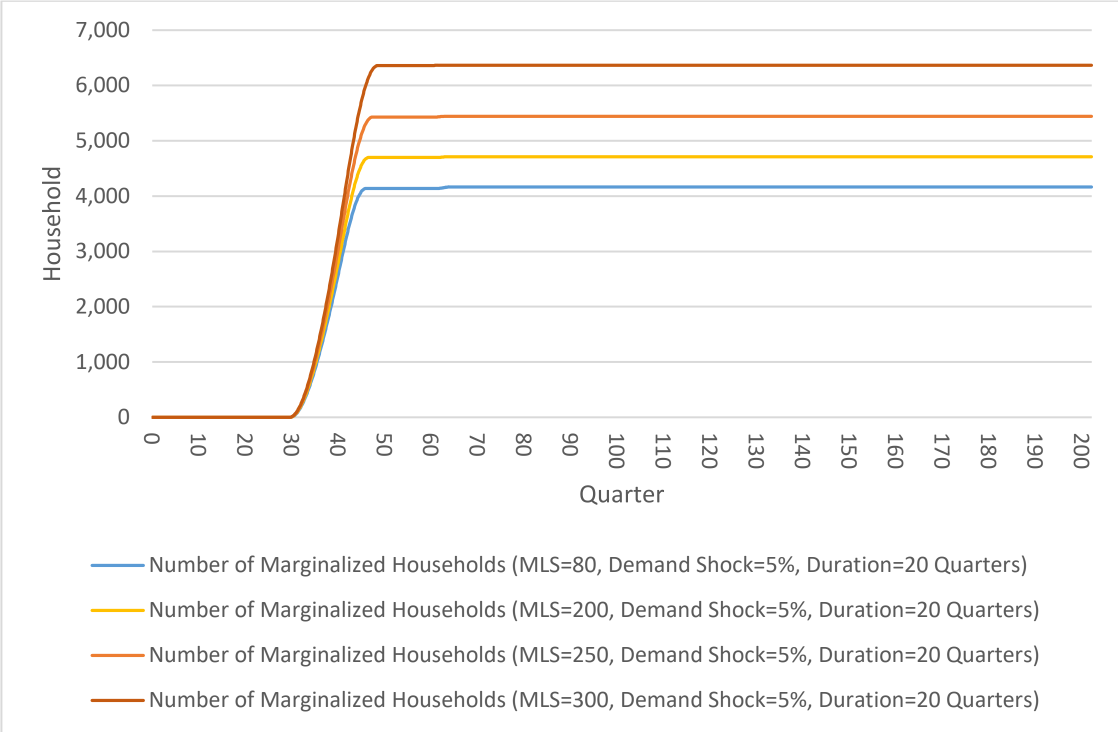


Figure 5-67: The effect of changes in MLS on the number of marginalized households under 5% demand shock lasting for 20 quarters

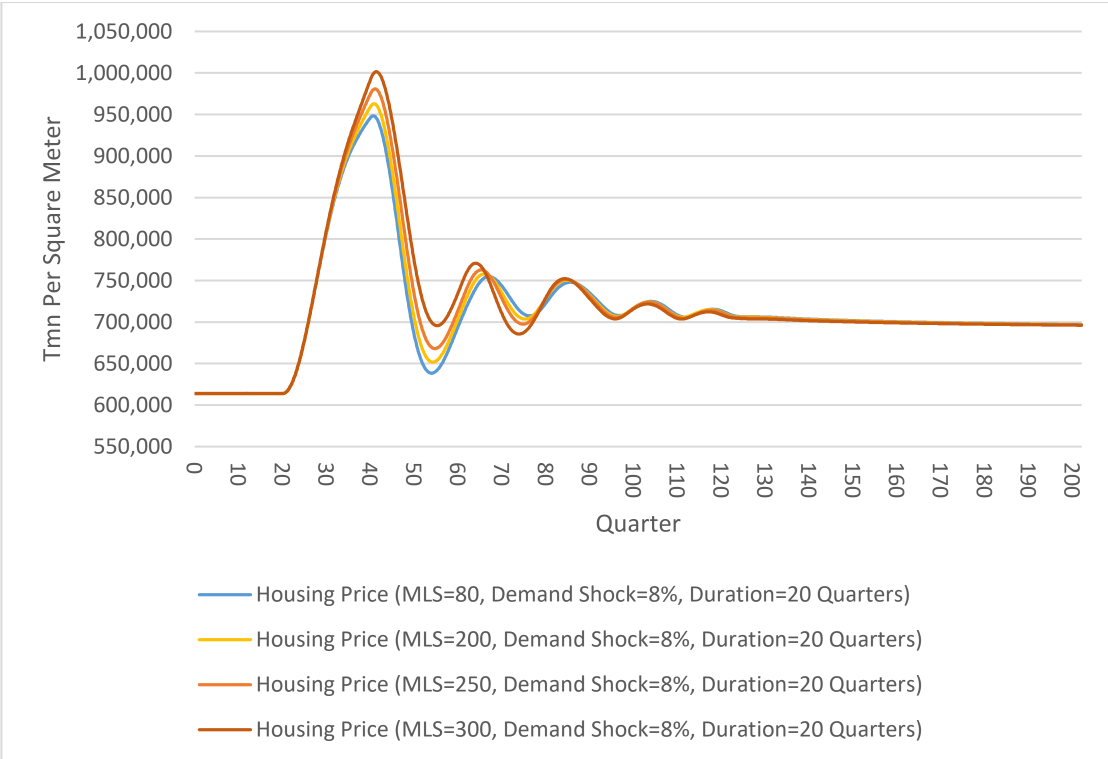


Figure 5-68: The effect of changes in MLS on the housing price under 8% demand shock lasting for 20 quarters

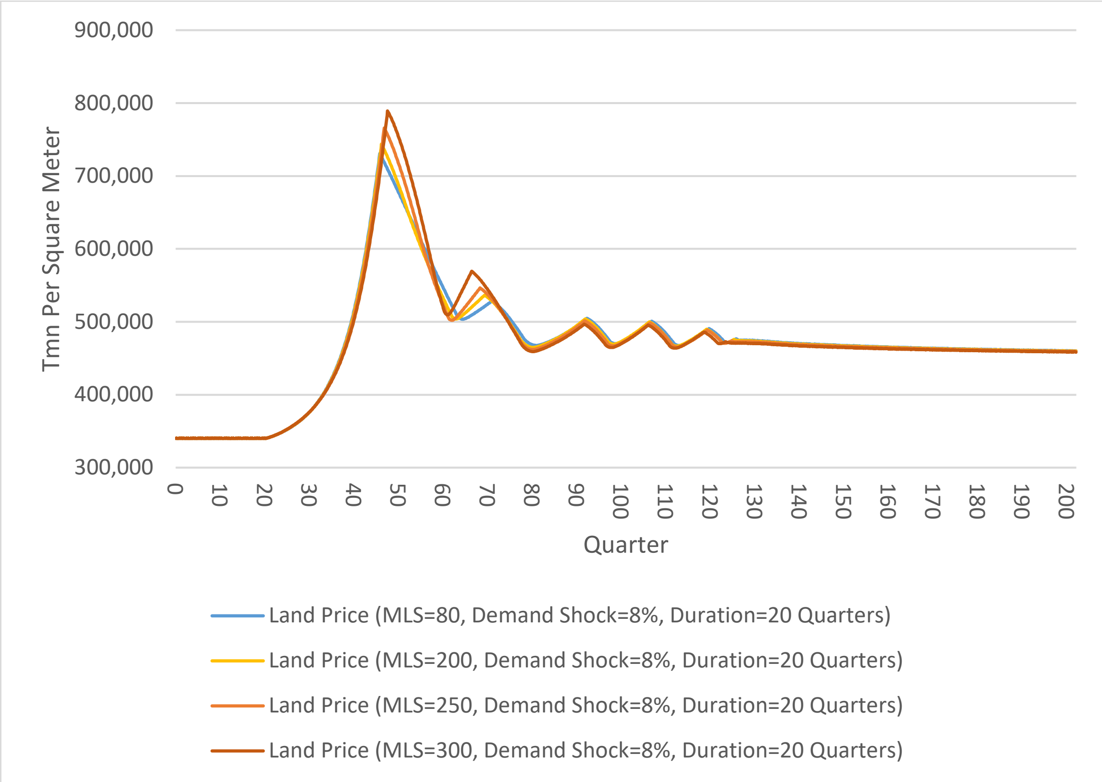


Figure 5-69: The effect of changes in MLS on the land price under 8% demand shock lasting for 20 quarters

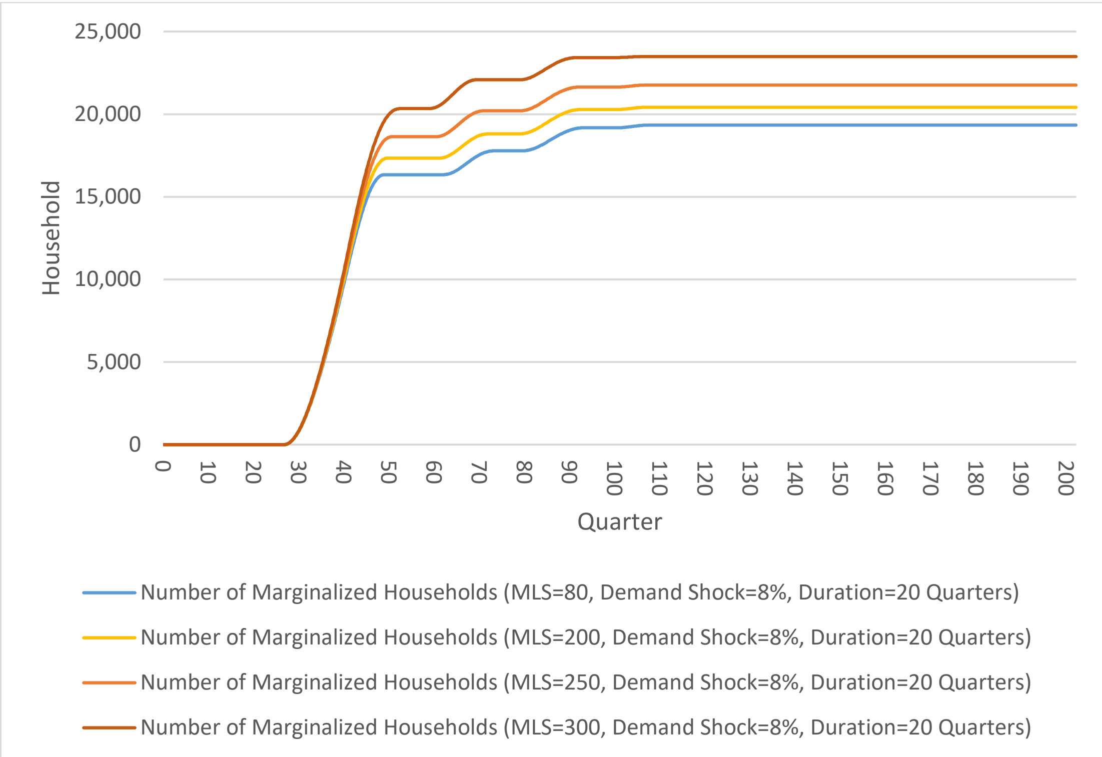


Figure 5-70: The effect of changes in MLS on the number of marginalized households under 38% demand shock lasting for 20 quarters

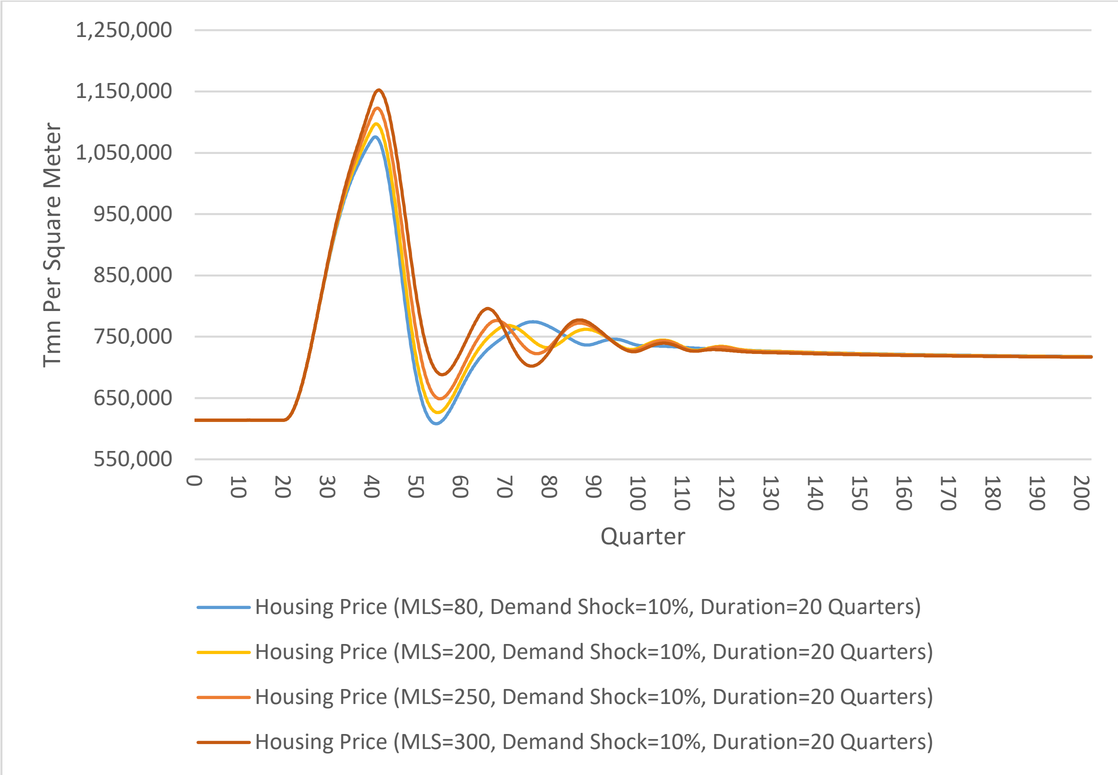


Figure 5-71: The effect of changes in MLS on the housing price under 10% demand shock lasting for 20 quarters

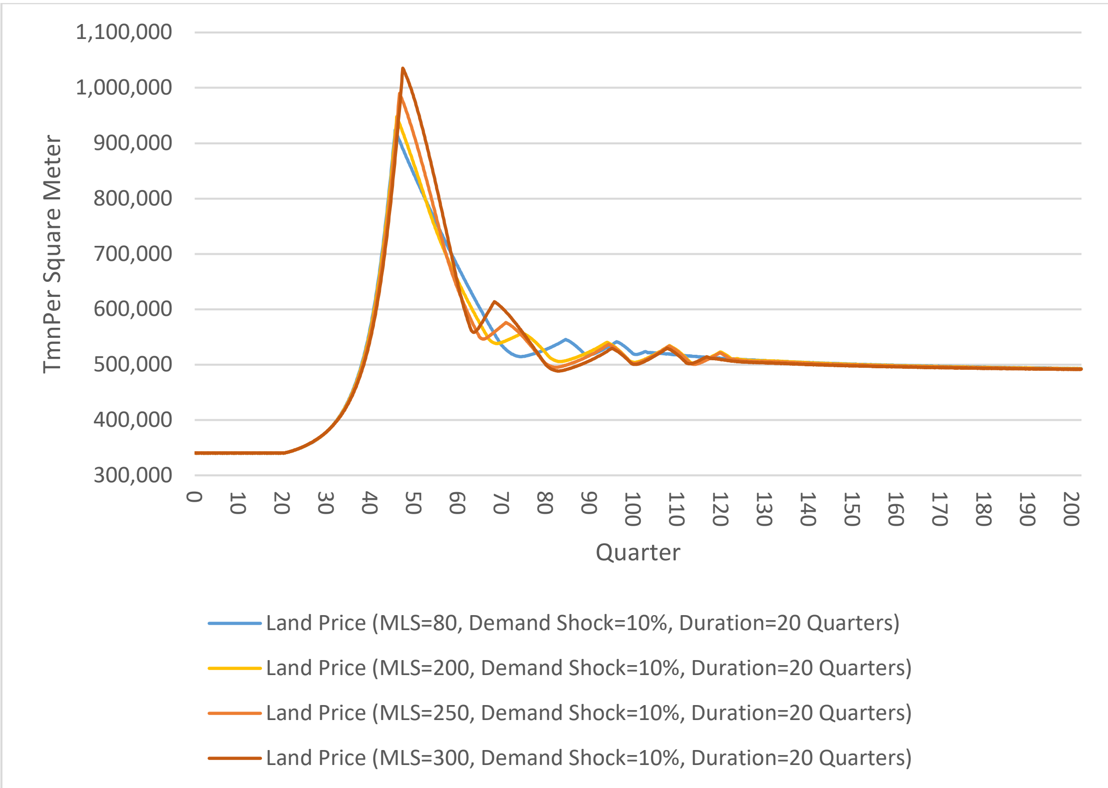


Figure 5-72: The effect of changes in MLS on the land price under 10% demand shock lasting for 20 quarters

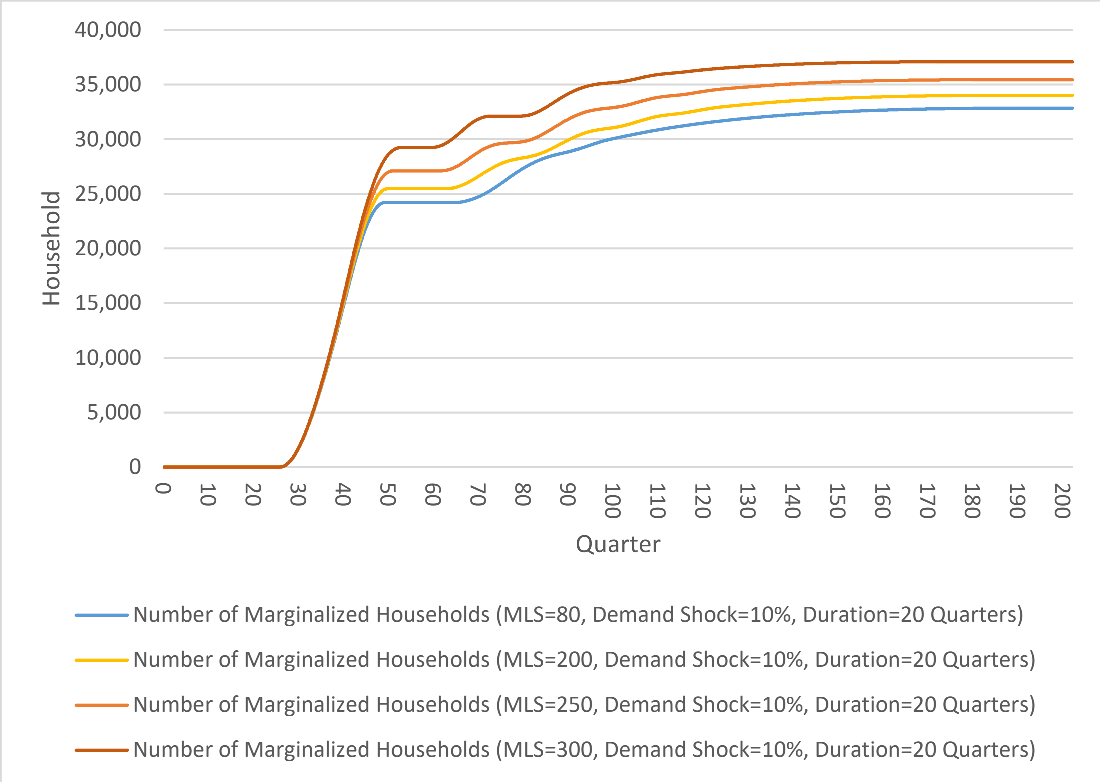


Figure 5-73: The effect of changes in MLS on the number of marginalized households under 10% demand shock lasting for 20 quarters

5-3-3- Combined effect of planning regulations

This section intends to show how the combination of the individual effect of regulations yields their combined effect on the three main variables under investigation. Since the effect of UGB and MLS appears only under the demand shock, in the first stage, I consider the pure effect of demand shock as the base case in which there is no regulation effect. Then, I consider the individual effects of each regulation in a chosen pair of planning regulations under the same demand shock. In the last stage, I test the combined effect of two regulations under the same demand shock and add the result to the results of two earlier stages mentioned above.

I display all four effects on each of the three main variables of the model in one graph. The grey color represents the population effect (with no regulation effect). The red and the yellow colors stand for the individual effect of each of planning regulations in the chosen pair under the same demand shock. Finally, the blue color represents the combined effect of regulations under the demand shock. One of the major points about the combined effect of regulations that I intend to discover is whether it is the linear combination of the individual effects. The control theory applies the superposition principle to identify linear systems. This principle states that if the effect of two or more inputs on a system equates to the summation of the individual effects of those inputs, that system is linear (Mohapatra, 1980b). Regarding the model of this thesis, if it is linear, the combined effect of each pair of regulations should equate to the sum of individual effects. I use the graphs mentioned above to test whether the combined effects of regulations are the linear combinations of their individual effects.

These graphs also help address the contribution of each regulation to the combined effect of each regulation pair. For example, the difference between the combined effect (the blue trend line) and the red line (represents the individual effect of regulation A) shows the contribution of the regulation B (whose individual effect is represented by the yellow line) to their combined effect. On the other hand, the contribution of regulation A (whose effect is represented by the red line) to the combined effect in each point over time is equal to the difference between the yellow line and the blue graph.

5-3-3-1- MBD-UGB combined effect

This subsection analyzes the combined effect of MBD and UGB. Table (5-17) shows the four combinations of these two regulations with different restrictiveness levels and under different demand shocks. It should be mentioned that the MLS restriction is not binding in all these modes. Moreover, the UGB area equal to 150% of the initially developed area is not restrictive. The duration of the demand shock is 20 quarters (5 years).

Table 5-17: The four combinations of two modes of MBD, UGB, and the demand shock

	First Mode	**Second Mode**	**Third Mode**	**Fourth Mode**
MBD	180%	120%	180%	120%
UGB Size	102.5% of developed area	110% of developed area	102.5% of developed area	110% of developed area
Demand Shock	3%	3%	5%	5%

It is unnecessary to check all the points in graphs to test whether the combined effect is a linear combination of individual effects. We can reject the linear combination assumption if we find one instance that contradicts the linearity. Figure (5-73) provides such an example. It is the first-mode graph in Figure (5-74) separated for this purpose. As can be seen, point D measures both the combined effect of MBD and UGB and the individual effect of MBD, and point C refers to the individual effect of UGB. Although both regulations have individual effects on the housing price, the combined effect is equal to the effect of MBD. Based on this, the combined effect of planning regulations is a non-linear combination of their individual effects. Many instances contradicting the linear combination can be easily found by scrutinizing the following graphs.

Although the combination of individual effects does not follow a linear additive form, they can act in the same direction or opposite directions based on their position regarding the base case. In Figure (5-73), considering that both of housing trends affected by individual effects (the yellow and the red lines) are above the base case (the grey line), it can be seen that the graph of the combined effect on the housing price (the blue line) is above all other lines. Here, the individual effects of MBD and UGB act in the same direction and have a synergistic effect when they are combined.

On the other hand, as can be seen in the first-mode graph in Figure (5-75), before the inclination of the land price graphs toward equilibrium prices, the individual effect of MBD reduces the land price (the yellow line) to the level lower than the price level stemming from the demand shock (the grey line) and the individual effect of UGB pushes the land price (the red line) upwards and above the price level in the case of the demand shock. When individual effects counter-balance one another, the combined effect is somewhere between the individual effects. Therefore, as can be seen, in that region, the land price affected by the combination of UGB and MBD (the blue line) is between the land price trends affected by each of these regulations individually. As another example, in the first-mode graph in Figure (5-74), after the 20th quarter until the 50th quarter, the land price affected by the combined effect of MBD and UGB is almost equal to the land price affected by MBD. This overlap means the MBD effect is dominant in the mentioned period.

However, there is a period between the 100th quarter and the 120th quarter when although the individual effects counter-balance one another, the land price affected by their combination is higher than the land prices affected by each of the regulations individually. This evidence again proves the non-linearity of the combined effect and shows that these derived rules can be breached. However, for the rest of the period in which all prices settle down to their long-run equilibrium level, the MBD and the UGB reinforce each other’s effect, and their combined effect is the result of their synergy, and the corresponding land price (the blue line) stands above the land price graphs affected by the UGB and MBD individually (the red line and the yellow line).

The non-linear combination of regulations' individual effects is utterly evident in the marginalization process. The first-mode graph in Figure (5-76) shows that the demand shock alone has no marginalization effect. The individual effect of UGB and MBD is not comparable since the former is infinitesimal, and the latter's effect is enormous. However, when they are combined under the same demand shock, their synergy significantly affects the number of marginalized households even compared to the individual effect of MBD. The main contribution of UGB to the combined effect on marginalization is conducive to reducing the number of fluctuations and prolonging the period that the housing price is above the affordable level for lowest income households. In fact, the discrepancy between the blue line and the yellow line in the first-mode graph in Figure (5-76) depends on the length of the period mentioned above.

The graphs of the other modes of combining MBD and UGB support the results derived from the simulation results of the first mode. The other result is that more restrictive planning regulations make increased contributions to the combined effect. For instance, considering the four modes in Table (5-17), in the first mode compared to the second mode, the UGB is more restrictive, and the MBD is less restrictive. The same comparison can be made between the third and fourth modes. If we compare the first-mode graph with the second-mode graph in Figure (5-76), it will be evident that the contribution of the UGB decreases along with the significant increase in the contribution of the MBD. I can derive the same result if I compare the third-mode graph with the fourth-mode graph in Figure (5-76) for the contribution of the UGB and the MBD. Moreover, in all cases, the contribution of UGB does not exceed the contribution of MBD to their combined effect on the marginalization of low-income households to informal settlements.

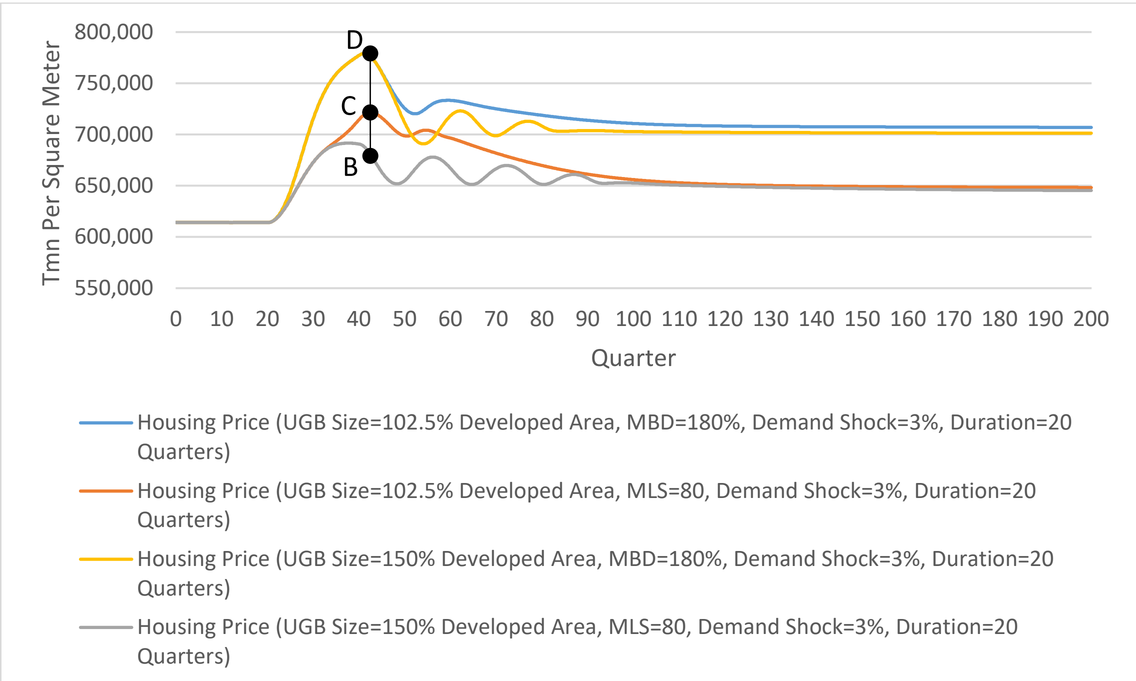


Figure 5-74: The individual and combined effect UGB and MBD on the housing price under the first mode condition

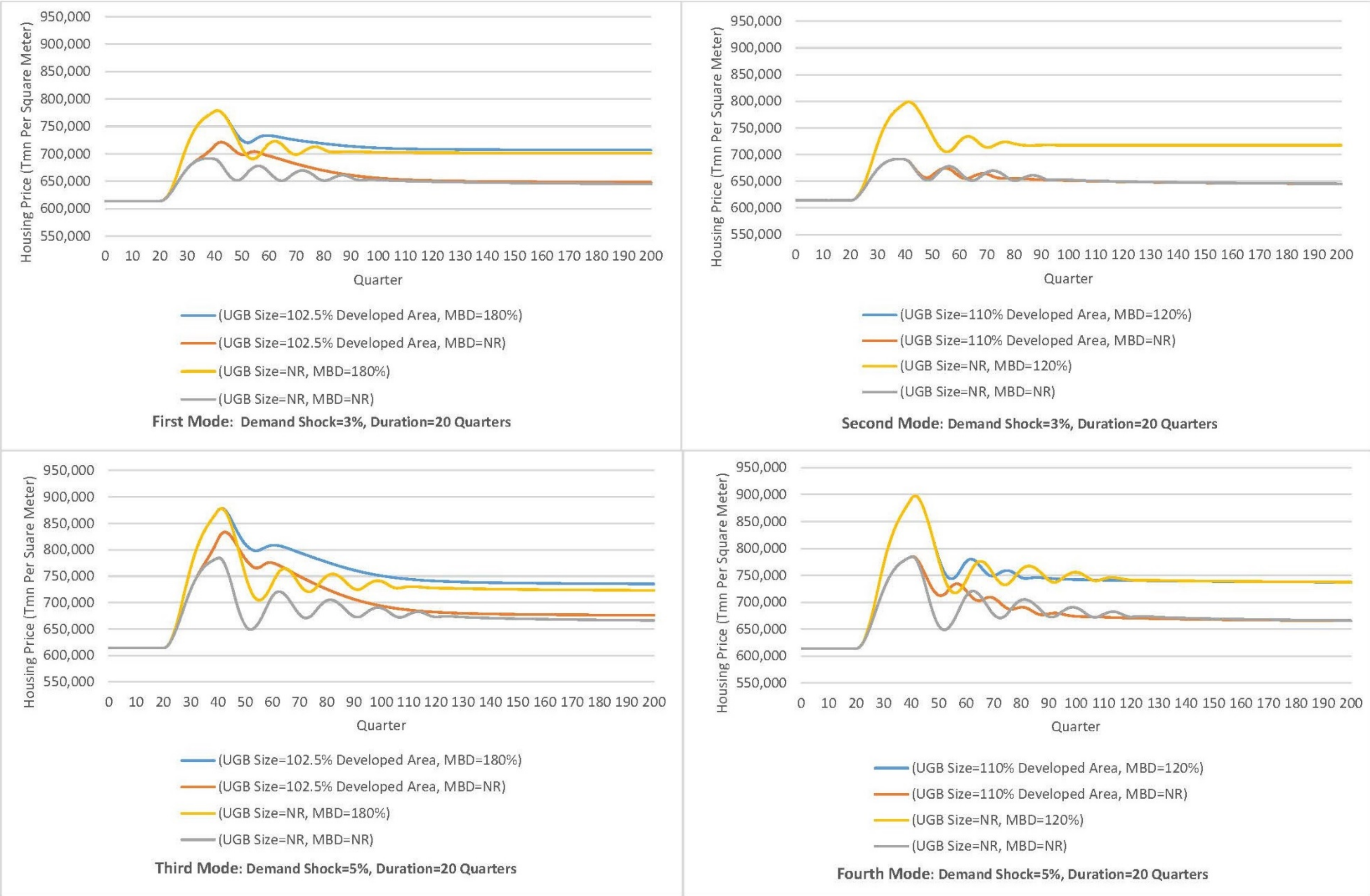


Figure 5-75: The combined effect of UGB and MBD on the housing price under the four modes' conditions

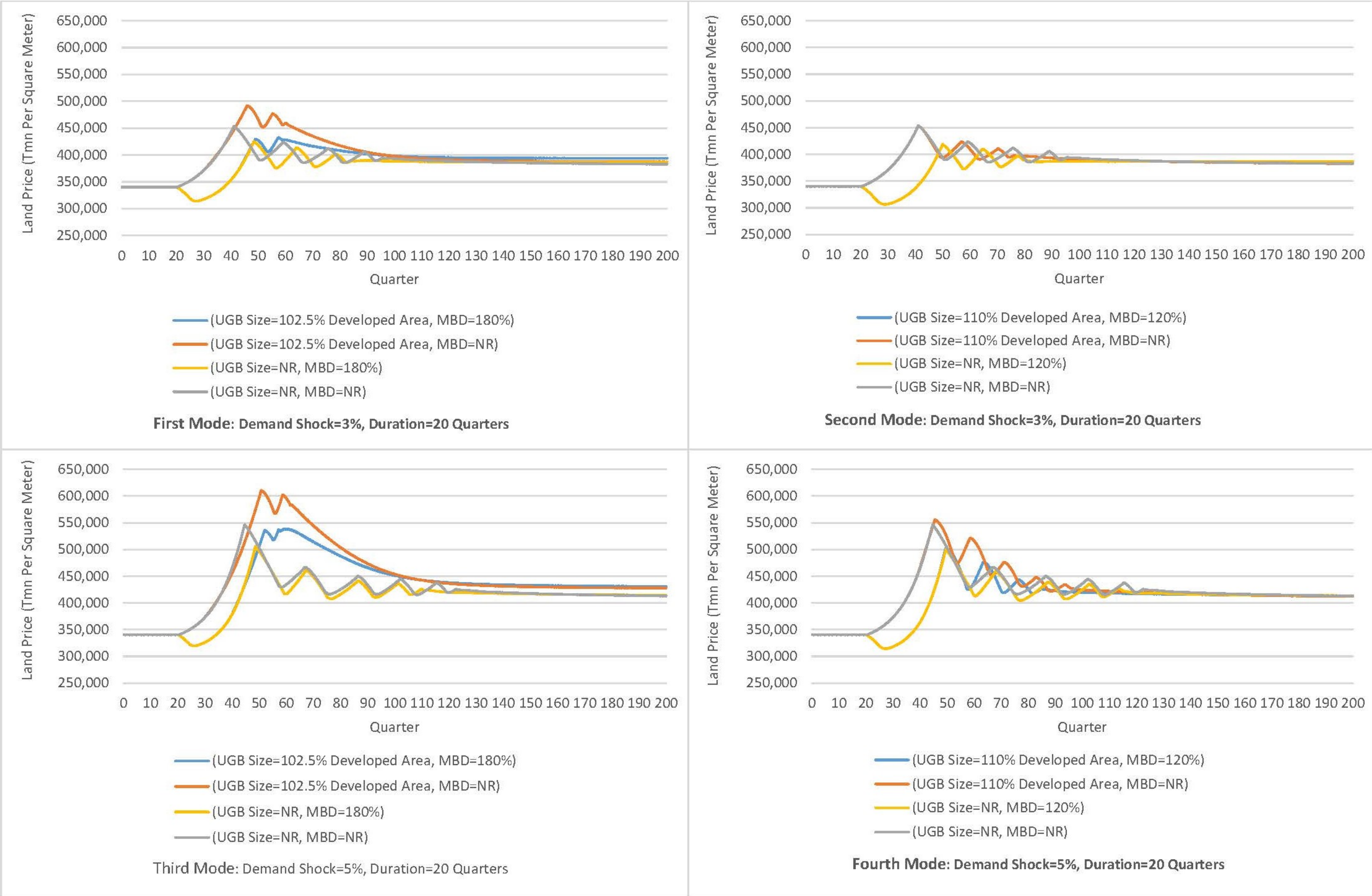


Figure 5-76: The combined effect of UGB and MBD on the land price under the four modes' conditions

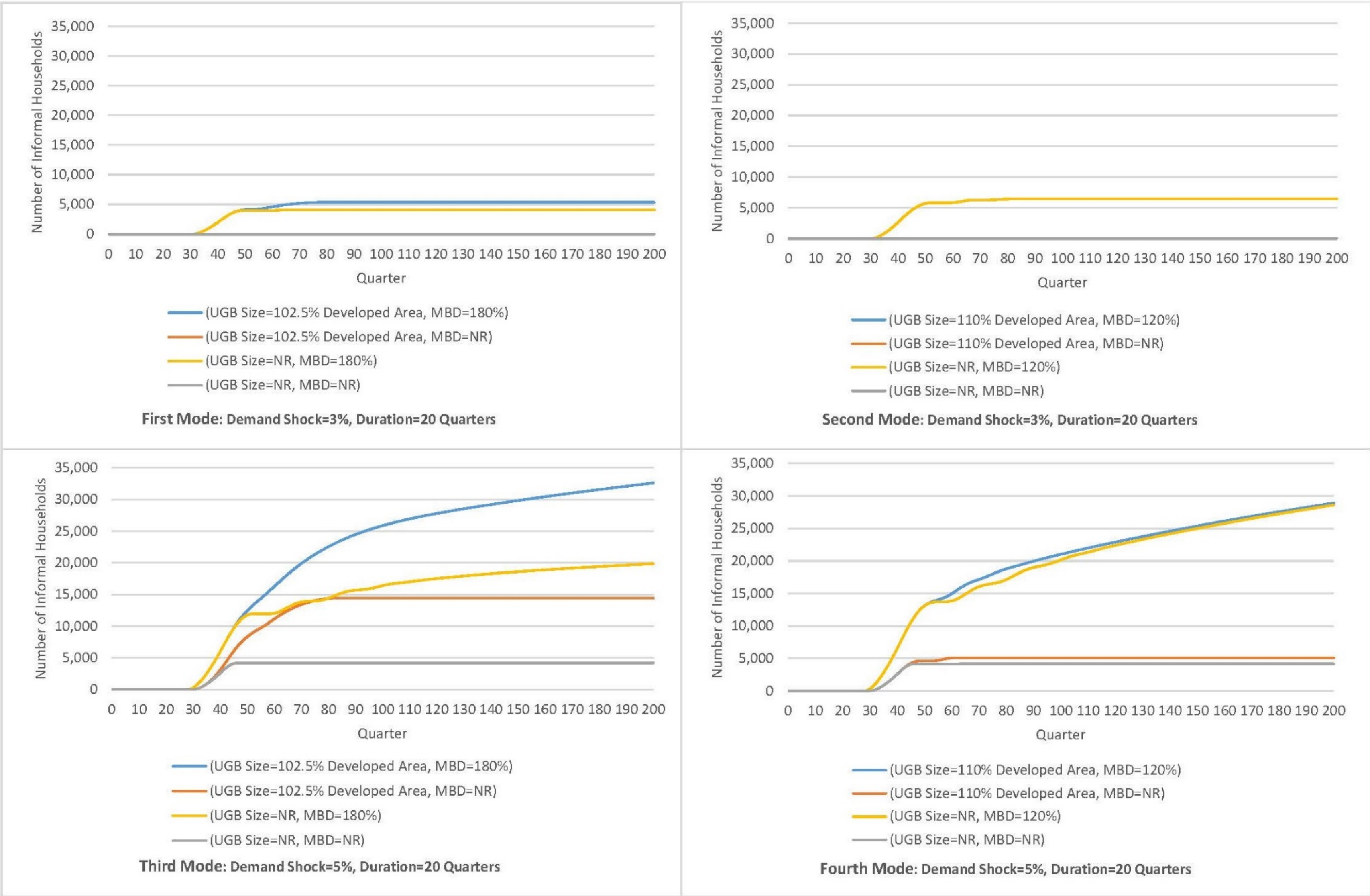


Figure 5-77: The combined effect of UGB and MBD on the number of marginalized households in informal settlements under the four modes' conditions

5-3-3-2- UGB-MLS combined effect

In order to analyze the combined effect of UGB and MLS, I consider four modes of combining the two regulations under different demand shocks. Table (5-18) shows all these modes. Like the previous section, the UGB of 150% size of the initially developed area and 80 square meter MLS are not restrictive. Moreover, the imposed level of MBD is high enough that it is not restrictive.

Table 5-18: The four combinations of two modes of MLS, UGB, and the demand shock

	First Mode	Second Mode	Third Mode	Fourth Mode
MLS	250 m^2	300 m^2	250 m^2	300 m^2
UGB Size	102.5% of developed area	110% of developed area	102.5% of developed area	110% of developed area
Demand Shock	3%	3%	5%	5%

By sectioning the graphs in the first-mode graph in Figure (5-78), it can be seen that the combined effect of the two regulations is not the sum of their individual effects. Scrutinizing all other graphs in this subsection can provide many such instances proving the nonlinearity of the combined effect of UGB and MLS. A key point regarding the combination of UGB and MLS is that these regulations affect the land supply. The former sets a limit on the total supply of land, and the latter does the same with respect to the undeveloped land supply. On this basis, when the UGB is restrictive, it implicitly means that the share of the undeveloped land is limited. Thus, more restrictive UGBs neutralize the effect of MLS. If the UGB is restrictive to the extent that it coincides with the initially developed area of the city, setting lot size restrictions will be meaningless. The first and the third modes in Table (5-18) are the cases in which the UGB is highly restrictive (102% of the initially developed area of the city). Addressing the effects of these modes of combination demonstrates that imposing a highly restrictive UGB can limit the contribution of the MLS to the combined effect.

Referring to the second-and the fourth-mode graphs in figures (5-78) and (5-80), in which the UGB is less restrictive (110% of the initially developed area of the city) and the MLS is restrictive (300 square meters) demonstrates the point mentioned in the previous paragraph. In these cases, the effect of MLS both individually and in combination with UGB is noticeable. The 300-square-meter MLS changes the pattern of housing and land prices fluctuations in these two modes. Although imposing it does not result in the marginalization of the lowest income group when the household growth is relatively low (3% annually), its marginalizing effect is crystal clear when the household growth increases to 5% annually (the fourth-mode graph in Figure (5-80)). Moreover, the contribution of the most restrictive MLS (300 square meters) to the combined effect of the regulation pair on the marginalization of low-income households is higher than the contribution of the relatively less restrictive UGB (110% of the city's initial developed area). In the other two modes (the first and the third modes) in which the UGB is highly restrictive (102.5% of the developed area of the city) and the MLS is less restrictive (250 square meters), the contribution of UGB is higher than the contribution of MLS in their combined effect on the number of informal dwellers.

Despite the neutralizing effect of highly restrictive UGB on MLS in their combination, they also have synergy and can boost each other's effect. The difference between the blue and red lines in the first-mode and the third-mode graphs in Figures (5-80) proves that imposing MLS reinforces the individual effect of the UGB. The best example for this synergistic effect is the first-mode graph in Figure (5-78). As can be seen, although the imposed MLS does not have an individual effect on the marginalization of low-income households, its combination with UGB intensifies the individual effect of UGB on the number of informal dwellers.

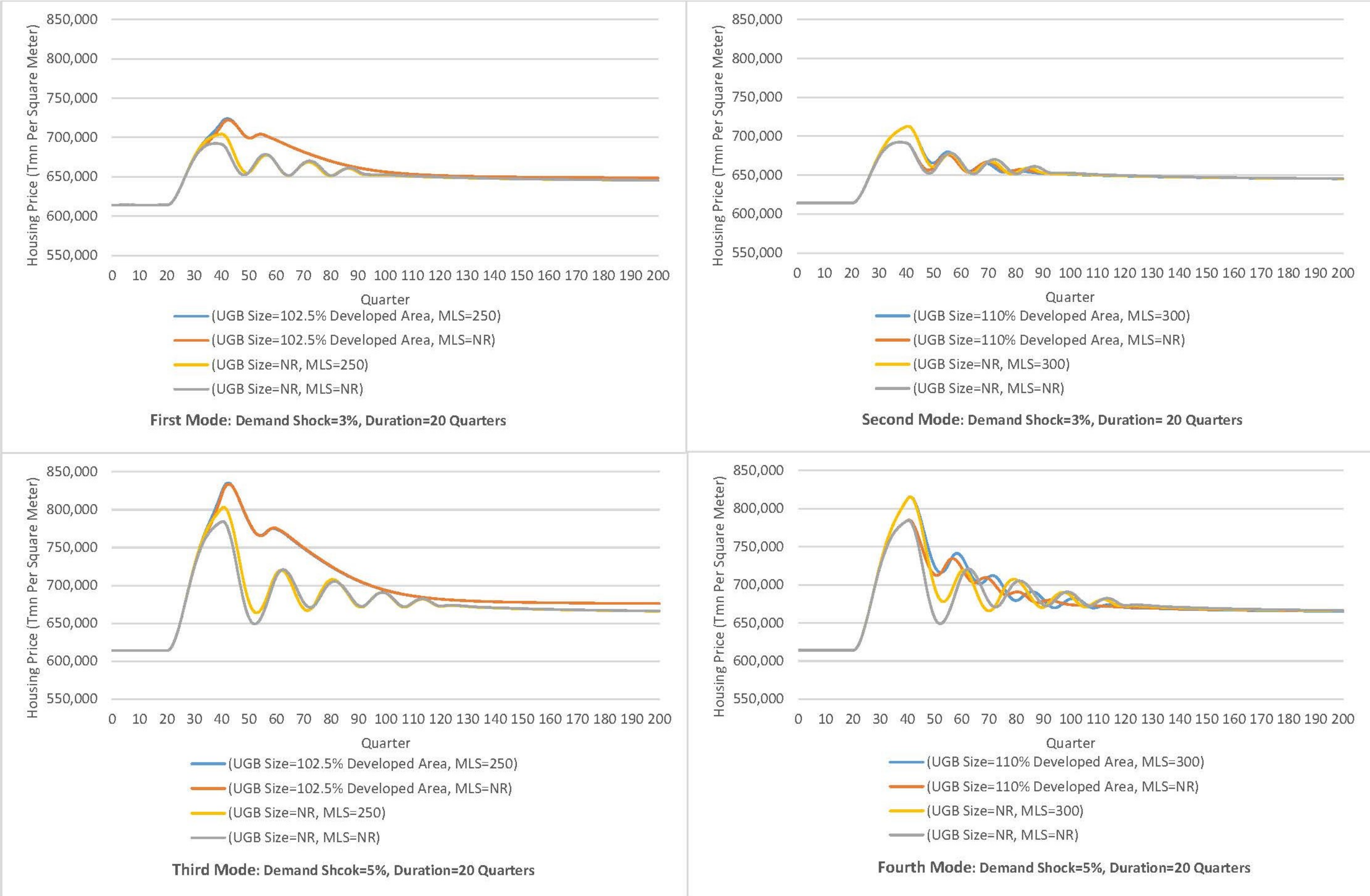


Figure 5-78: The combined effect of UGB and MLS on the housing price under the four modes' conditions

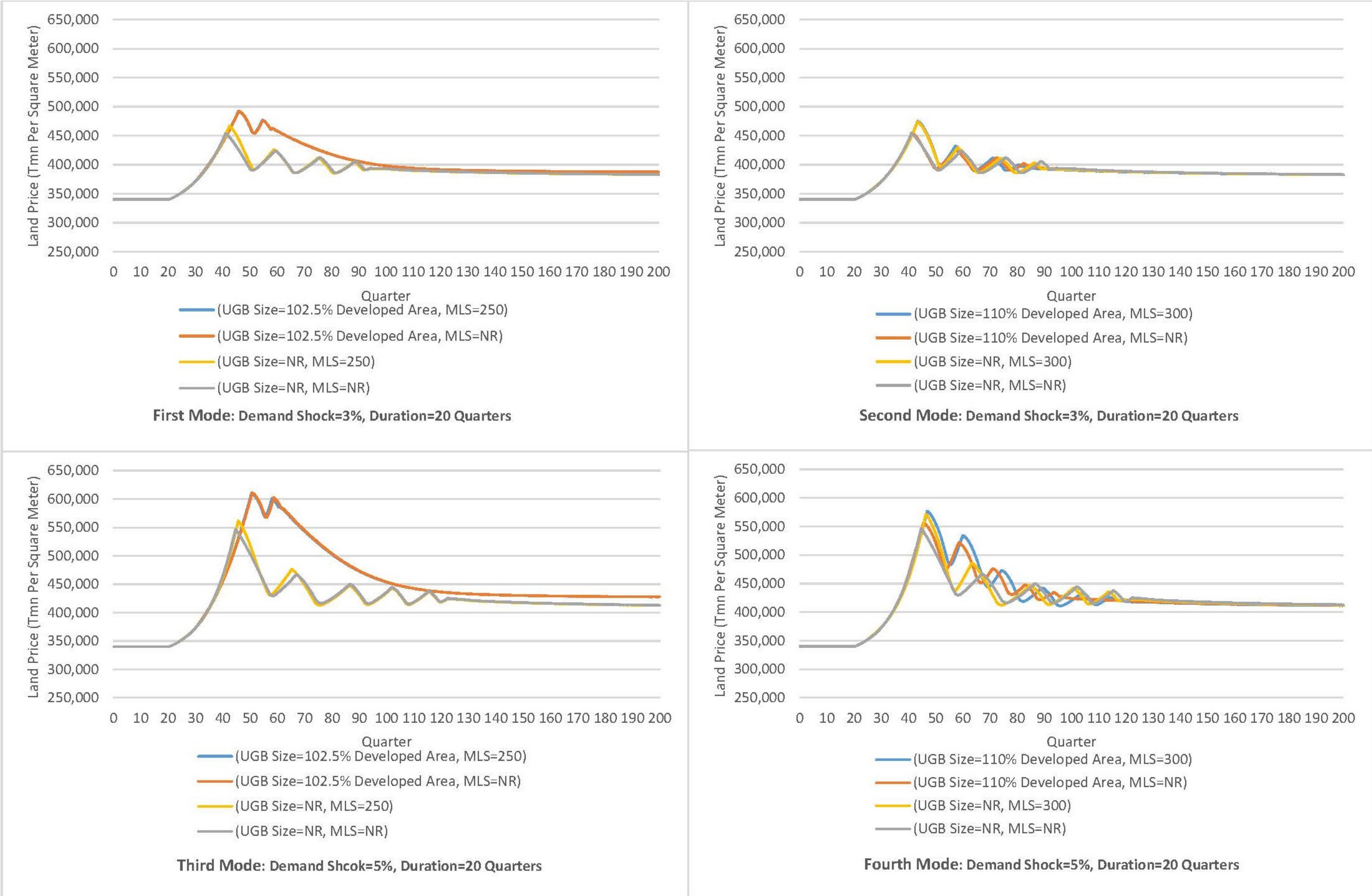


Figure 5-79: The combined effect of UGB and MLS on the land price under the four modes' conditions

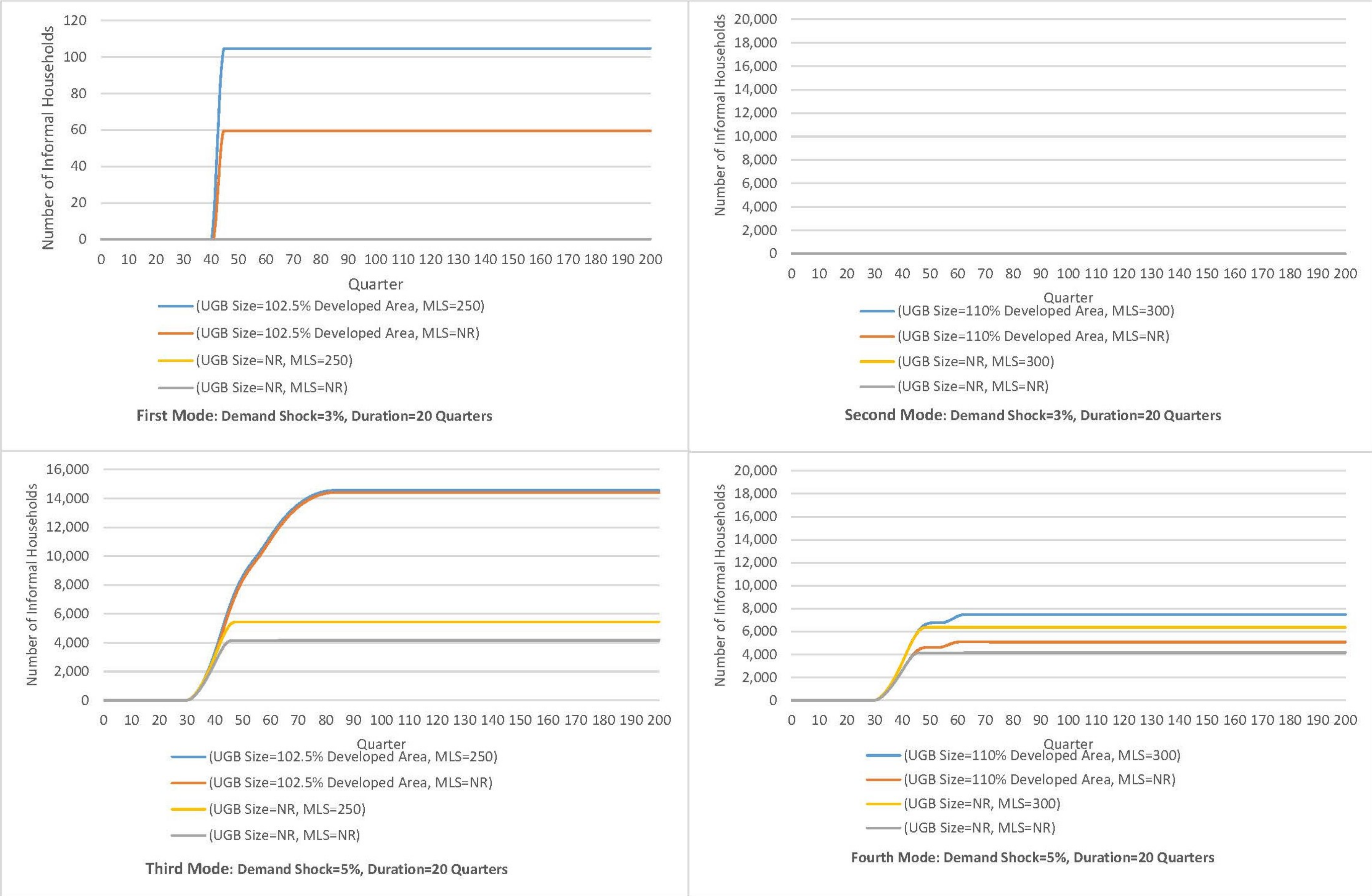


Figure 5-80: The combined effect of UGB and MLS on the number of marginalized households in informal settlements under the four modes' conditions (In the second mode, the combination of regulations does not lead to the marginalization of low-income households)

5-3-3-3- MLS-MBD combined effect

This sub-section follows the same procedure to analyze the combined effect of MLS and MBD. I choose four modes among all the possible combinations of MLS, MBD, and demand shocks, as shown in Table (5-19).

Table 5-19: The four combinations of two modes of MLS, MBD, and the demand shock

	First Mode	Second Mode	Third Mode	Fourth Mode
MLS	250 m^2	300 m^2	250 m^2	300 m^2
MBD	120%	180%	120%	180%
Demand Shock	3%	3%	5%	5%

It is easy to find numerous contradicting instances in the graphs of all the modes mentioned above that the combined effect of MBD and MLS is not the sum of their individual effects. The MBD has the highest contribution to their combined effect in all modes. Regarding the effect on housing and land prices, the MLS changes the pattern of fluctuations. If we compare the combined effect of MLS and MBD with the individual effect of MBD on housing and land prices in all modes, it will be evident that the main contribution of MLS is to reduce the number of fluctuations and to make the inclination of prices towards the equilibrium smoother.

The above-mentioned change in the price trends does not always result in an incremental contribution to the combined effect of regulations on the number of informal dwellers. As can be seen in the first-mode graphs in Figures (5-81) to (5-83), the contribution of MLS in reducing the number of housing price oscillations leads to a decrease in the number of marginalized low-income households in comparison to the individual effect of MBD on the number of informal dwellers. However, in the other modes in which the MLS is restrictive, or the demand shock is significant, the contribution of MLS to the combined effect on the housing price results in an increase in the number of marginalized households to informal settlements.

Lastly, comparing the contribution of MLS and MBD to their combined effect on the marginalization of lowest-income households implies that the MBD's contribution in all modes exceeds the share of MLS.

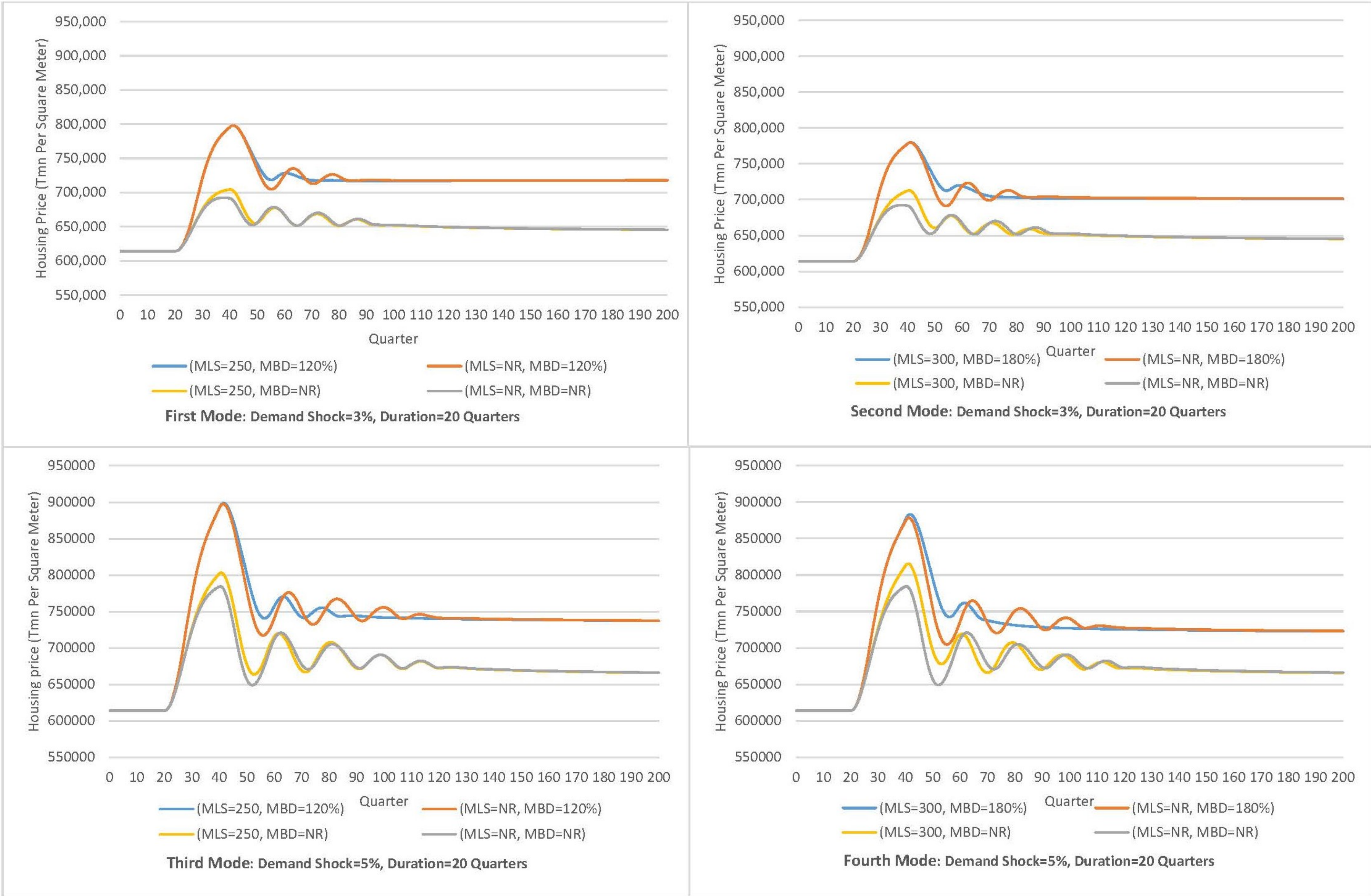


Figure 5-81: The combined effect of MBD and MLS on the housing price under the four modes' conditions

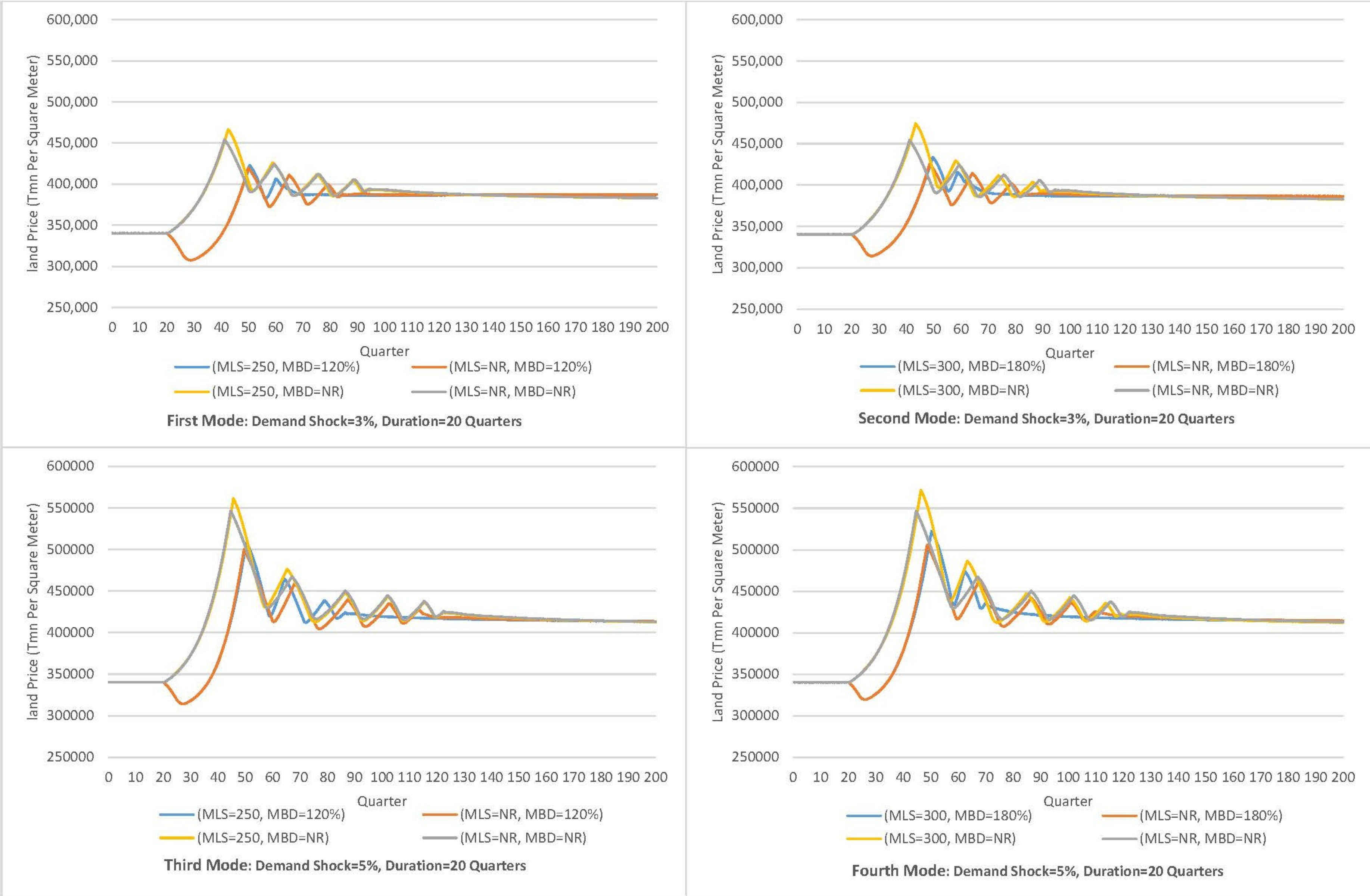


Figure 5-82: The combined effect of MBD and MLS on the land price under the four modes' conditions

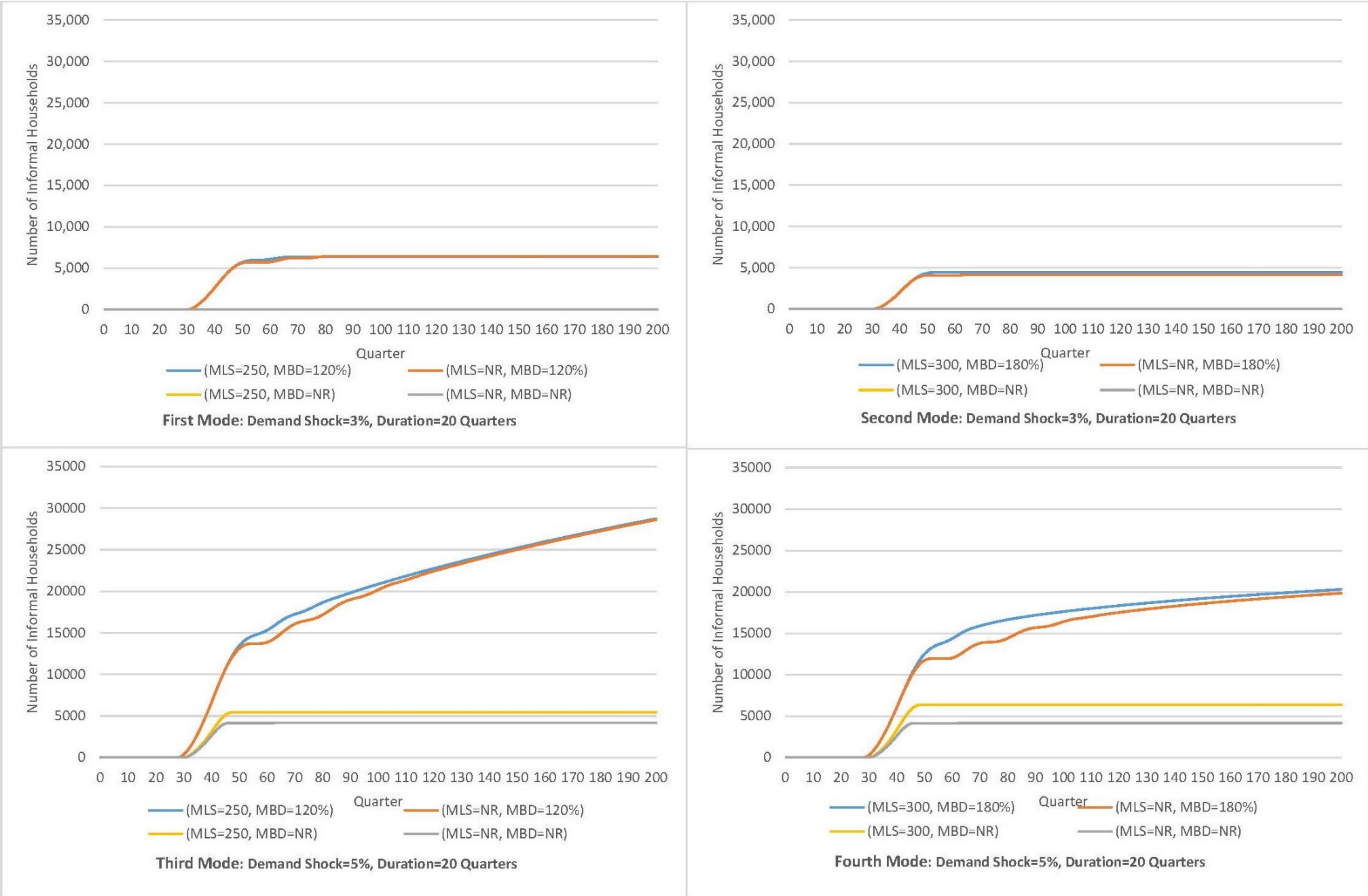


Figure 5-83: The combined effect of MBD and MLS on the number of marginalized households in informal settlements under the four modes' conditions

5-4- Sensitivity Analysis

As explained in the calibration section of this chapter, I defined four parameters based on the mathematical relationships. They are abstract, and there is no real-world counterpart for them. They reflect the elasticity of one variable with respect to the other. Therefore, to avoid bias in choosing to set a parameter as elastic or non-elastic, I set the elasticity parameters equal to one in the analysis section. However, to identify how much our results can be affected by the values of these parameters, it is necessary to do a sensitivity analysis. I compare the analysis results in two extreme modes: one with the moderate level of planning regulations under a typical demand shock and the other with the most restrictive level of planning regulations under a high level of a demand shock. Table (5-20) shows these modes and their corresponding values.

Table 5-20: Two extreme modes of planning regulations and demand shocks

	First Mode	Second Mode
MBD	180%	120%
UGB	110% of developed area	102.5% of developed area
MLS	250 sqm	300 sqm
Demand Shock	3% for 20 Quarters	10% for 20 Quarters

The first stage of the sensitivity analysis is to define the range of values and their distribution parameters. Table (5-21) shows the defined ranges for the four sensitivity parameters. I defined these bounds by trying different values until they reached the point of insignificant change. Higher values of the sensitivity parameters imply more elastic markets resulting in a lower number of marginalized low-income households. Hence, increasing the upper bounds of all these parameters reduces the number of marginalized households. For brevity, I use the abbreviation of the parameters, written in front of their titles in Table (5-21), in this section.

However, it should be mentioned that for SOLELD and SOHEHD, if I set the parameter’s value too high (more than 5), both housing and land markets will be volatile to the extent that both prices will never converge to an equilibrium price and will oscillate divergently. The empirical studies using error-correction models reviewed in Chapter 3 show the diverging oscillations in real-world situations (Capozza et al., 2004). Hence, I do not consider those high values. On the other hand, the lower bounds signify the less elastic markets, leading to more marginalized households.

Table 5-21: The defined ranges for the four sensitivity parameters

Parameter	Uniformly Distributed
Sensitivity of Construction to Profit (**SCP**)	[0.1, 5]
Sensitivity of Objective Land Price to Excess Land Demand (**SOLELD**)	[0.1, 4]
Sensitivity of Objective Housing Rent to Excess Housing Demand (**SOHEHD**)	[0.1, 4]
Sensitivity of the Percent of Change in Household Number (in each income docile) to Relative Affordability Gap (**SCHAG**)	[0.1, 3]

Since there is no study on the empirical distribution of these parameters in the mentioned ranges, I use the uniform distribution. I perform two sensitivity analyses for each parameter: one for each mode described in Table (5-20). Also, there are two extra sensitivity analyses: one considers the first three parameters in Table (5-21) simultaneously, and the other considers all the four parameters simultaneously for each mode described in Table (5-20).

Each sensitivity analysis results from 200 simulation runs based on 200 values randomly taken from the specified ranges in Table (5-21). The resulting sensitivity graph shows the cumulative distribution of the intended output variable in four confidence bounds, including 50%, 75%, 95%, and 100%. The relatively more dispersed simulation results for a specific parameter imply that changes in that parameter can affect the output variable more than the other parameters. Figures (5-83) to (5-85) illustrate the sensitivity analysis results for three output variables: housing price, land price, and the number of marginalized households in informal settlements.

As shown in tiled graphs in Figure (5-83), the most effective parameter on the housing price is SOHEHD. On the other hand, the least effective parameter on the housing price is SCP. The blue line and the black line in each graph represent the simulation result by using one for the value of the sensitivity parameter and the average of the values resulting from sensitivity simulations, respectively. As can be seen, these two lines are very close to each other in all the graphs, which means that one is a proper value for the average sensitivity value for all the parameters. The simulation results dispersed among different confidence bounds are also close to each other, implying that changing these parameters does not lead to a dramatic deviation in the results.

Figure (5-84) shows that the most effective parameter on the land price is SOLELD. Unlike the housing price, SCP is relatively highly effective on the land price, and the less effective parameter is SCHAG. As can be seen in the case of changing all the four parameters in the second mode, confidence bounds are wider, which means the dispersion of simulation results is relatively high among them.

The primary output variable of this research is the number of marginalized households. The sensitivity graphs of this variable in Figure (5-85) show that in the first mode in which the restrictions and the demand shock are mild and regular, the main output variable is sensitive to all the parameters, specifically to the parameter which is directly affecting it: SCHAG. After that, SOLELD, SOHEHD, and SCP are the most effective parameters.

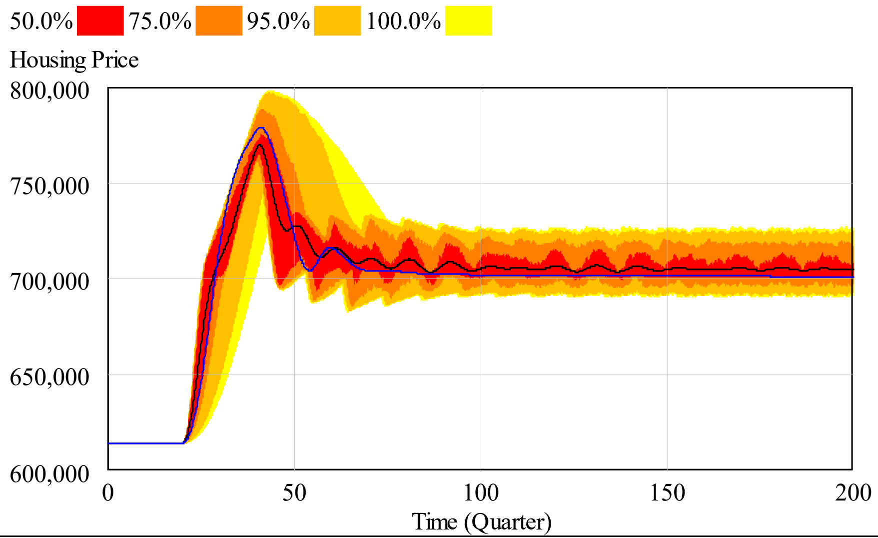
The number of marginalized households ranges from 2500 households to 7000 households. These numbers are high compared to the highest number of marginalized households from sensitivity simulations under the first mode conditions. The difference between the blue line and the black line in the graphs of the sensitivity analysis under the first mode conditions implies a small overestimation when I use one as the value for the sensitivity parameters compared to the average result of all possible values. However, when I perform the sensitivity analysis for all the four parameters under the first mode conditions, the difference between the two lines disappears, which means there is no overestimation.

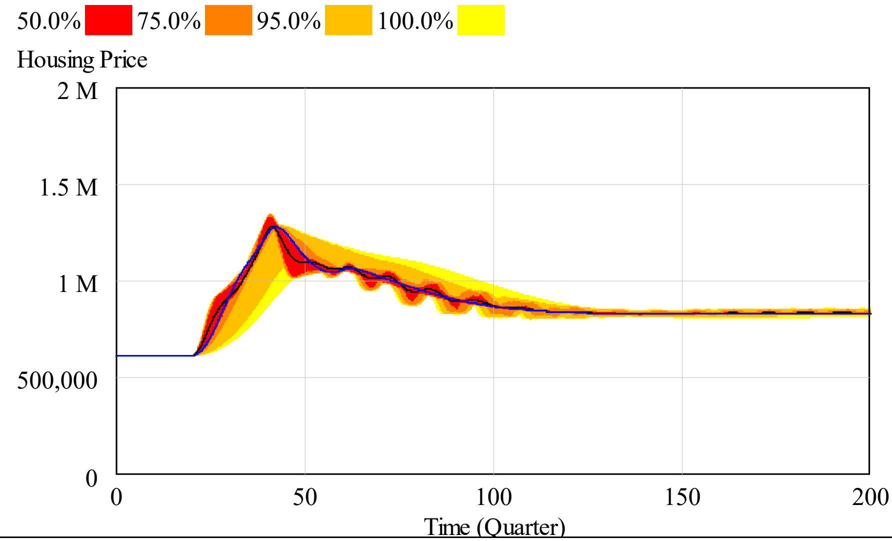
Under the second mode conditions in which the regulations are highly restrictive and there is a high level of a demand shock, the results are not dispersed among the confidence bounds in the case of the first three parameters. However, similar to the results of performing sensitivity analysis under the first mode conditions, SCHAG significantly affects the number of marginalized households.

In the case of the first three parameters in Table (5-21), the blue line and the black line infinitesimally differ from each other, which means there is no overestimation when I use one as the value for the value of the first three sensitivity parameters compared to the average result of all possible values. However, when I do the sensitivity analysis for all the four parameters under the second mode conditions, a considerable difference between the blue line and the black line appears. I interpret this difference as the overestimation of the number of marginalized households when I use one as the value for the corresponding sensitivity parameter compared to the average result of all possible values in the defined range.

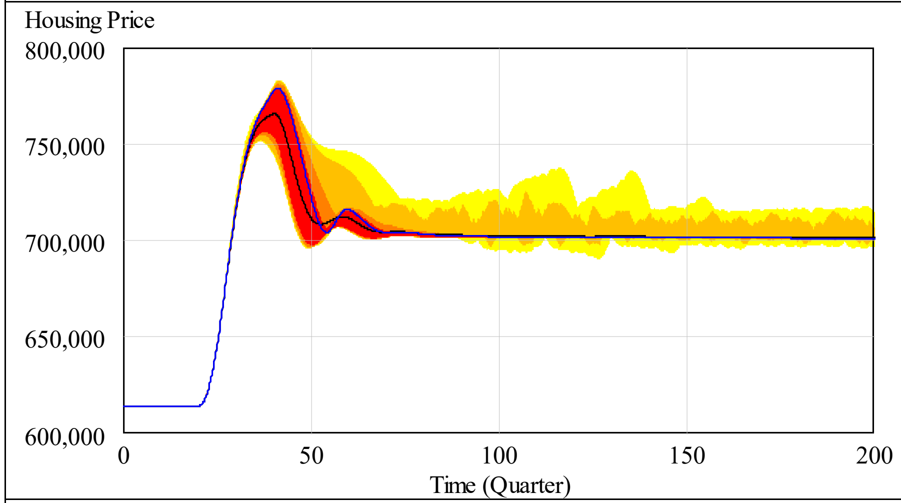
Based on these results, to yield more accurate estimations of the number of marginalized households, empirical studies on the relationship between the growth rate of marginalized households and their housing affordability based on formal housing prices are required. Finally, it should be mentioned that the sensitivity results do not undermine the analysis results of this chapter, including the results on the comparative effects of regulatory and non-regulatory factors.

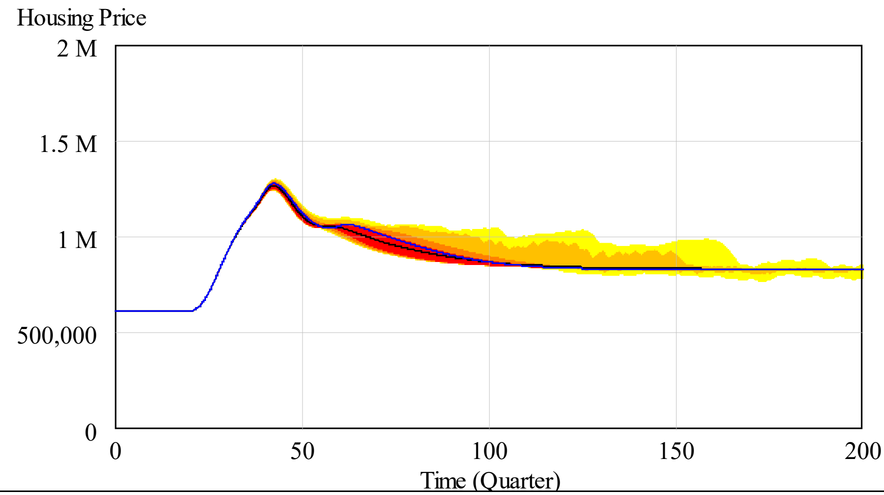
First Mode	Second Mode



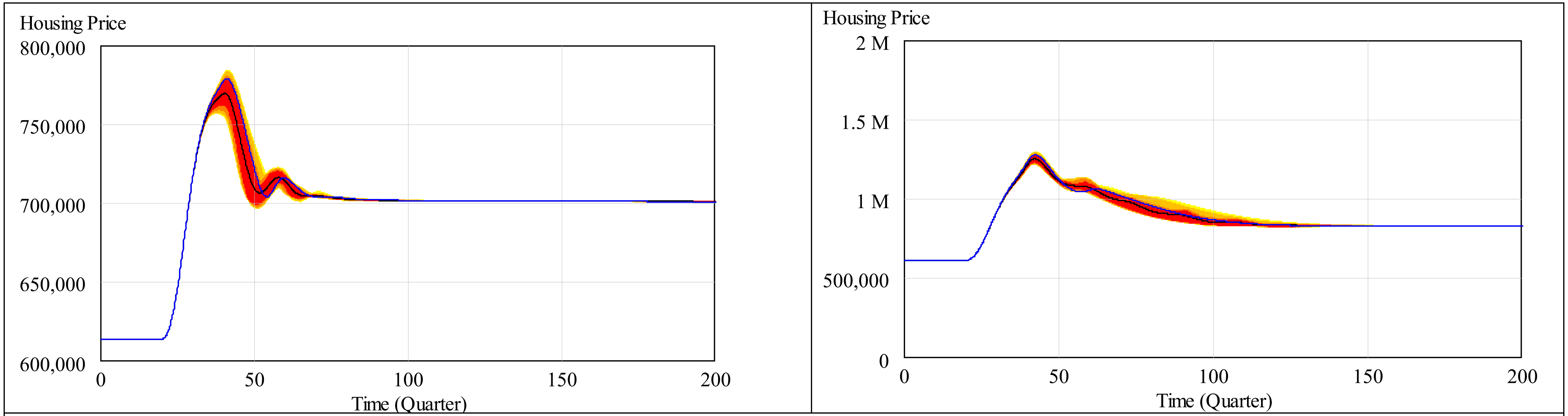


Parameter: SOHEHD

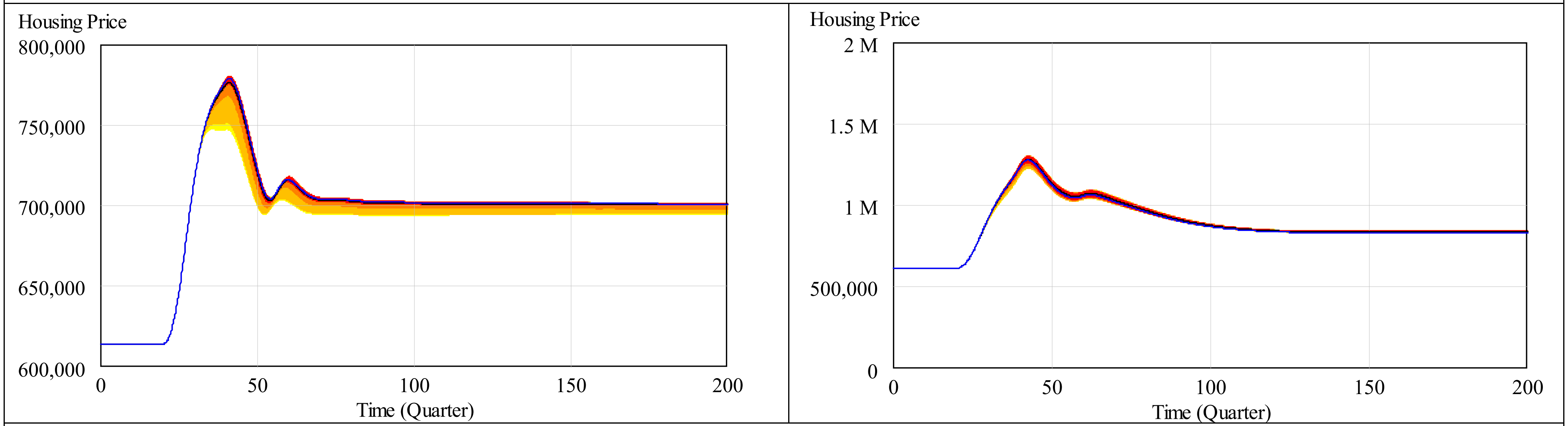




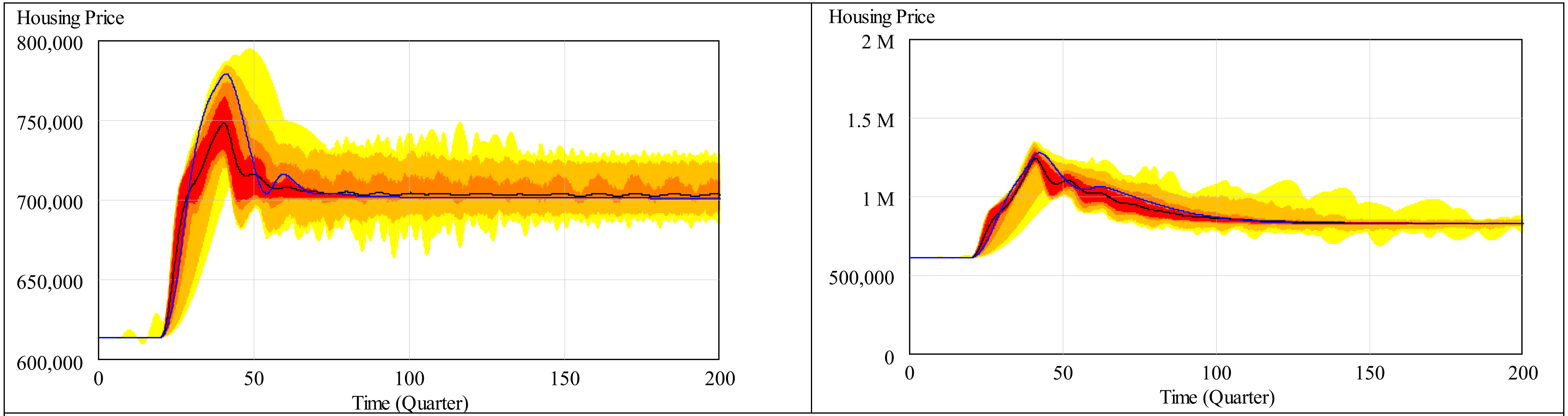
Parameter: SOLELD



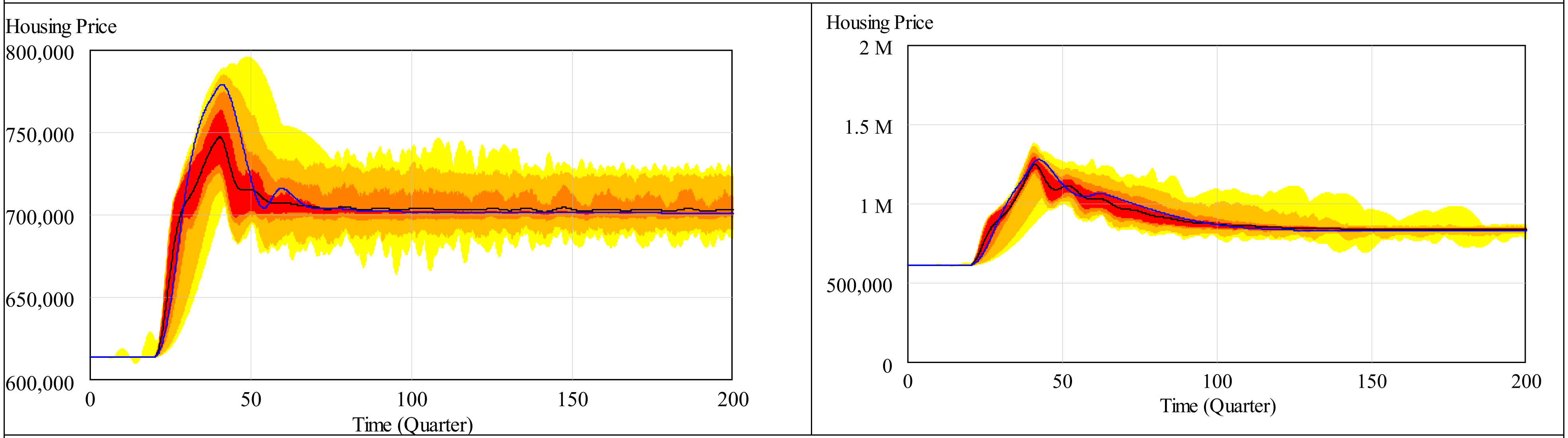
Parameter: SCP



Parameter: SCHAG



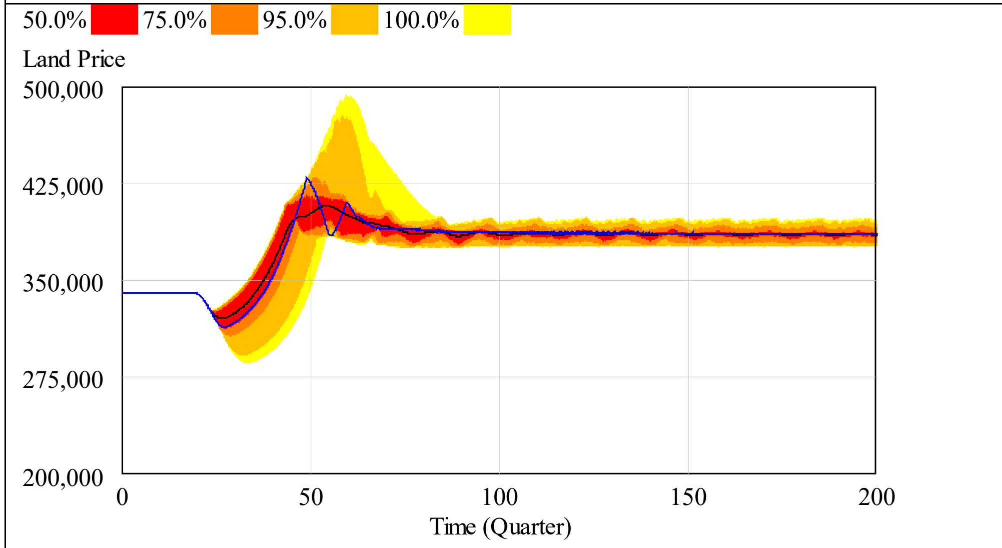
First three parameters

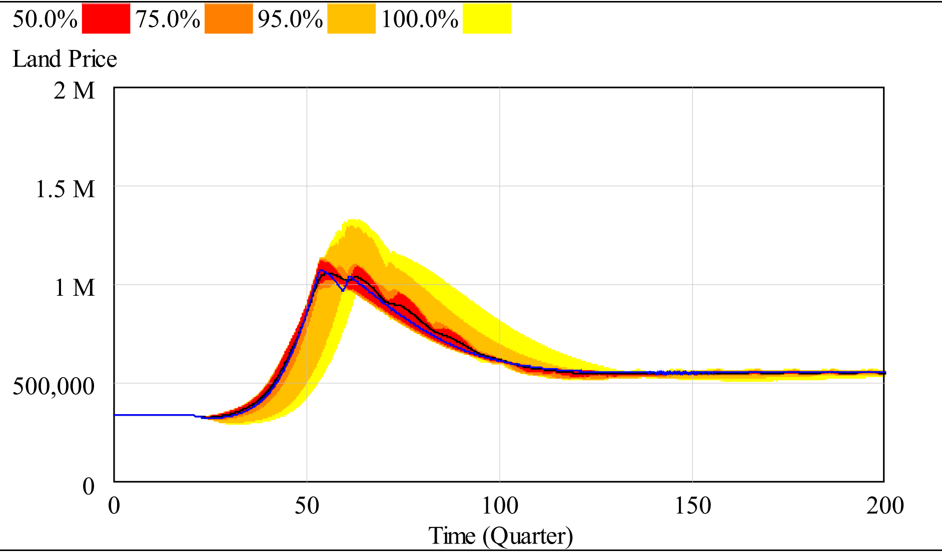


All the four parameters

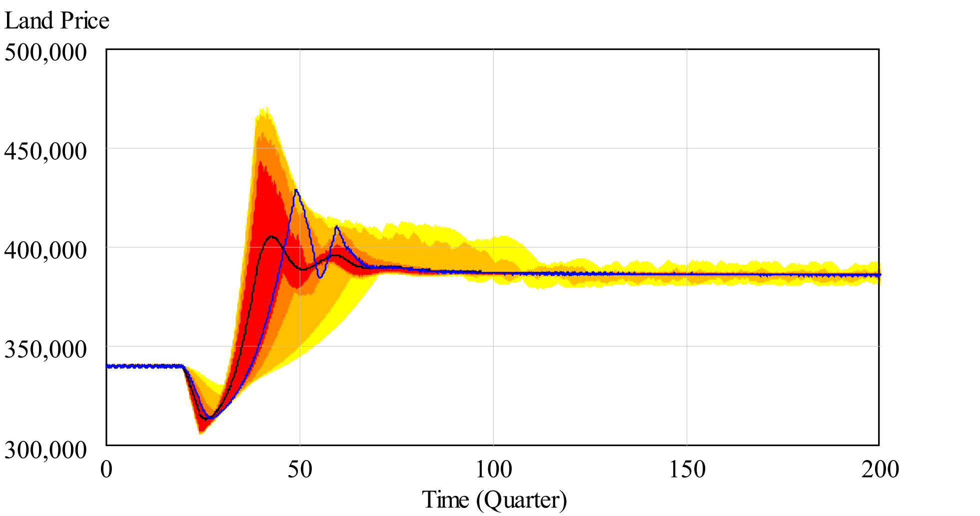
Figure 5-84: The sensitivity of the housing price to four elasticity (sensitivity) parameters of the model under the two modes of regulations and demand shock conditions

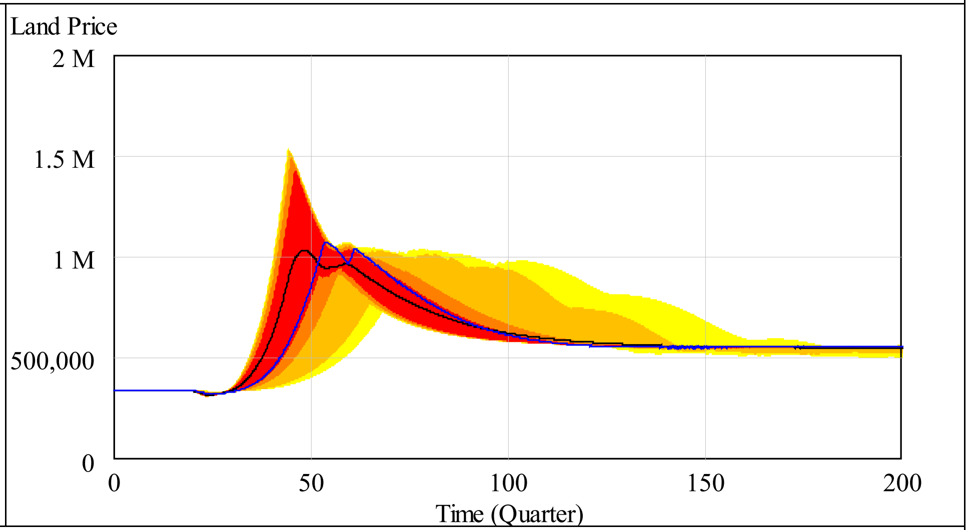
First Mode	Second Mode



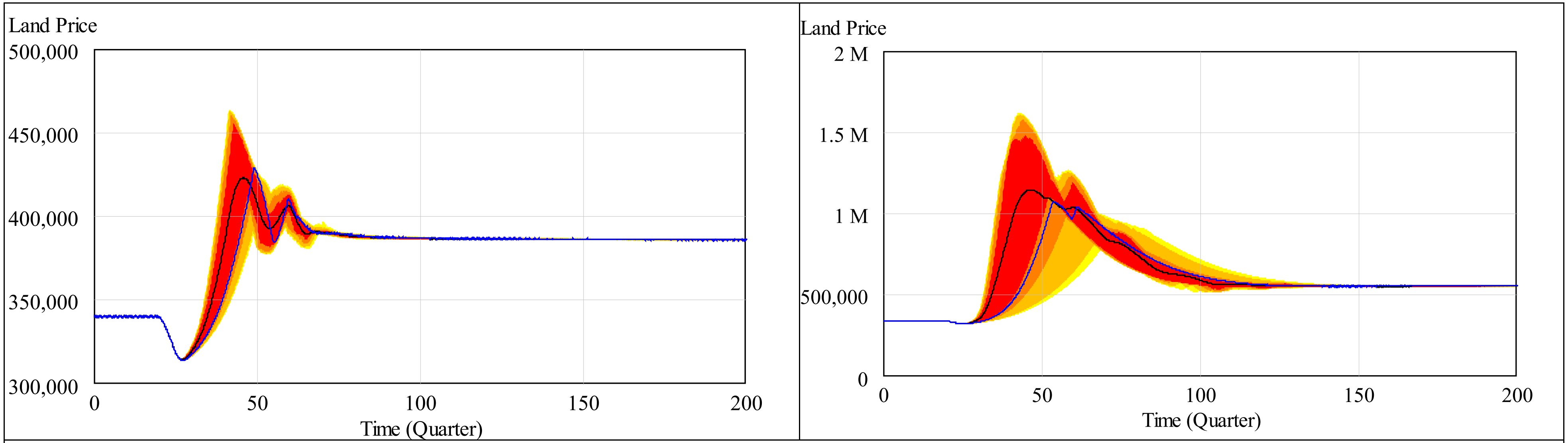


Parameter: SOHEHD

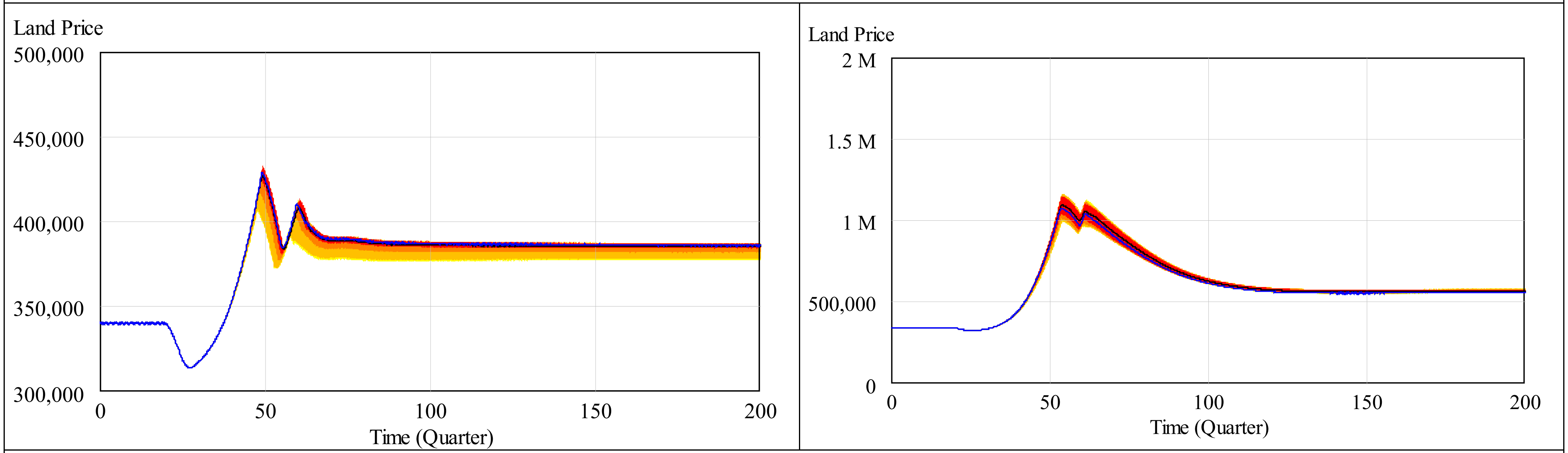




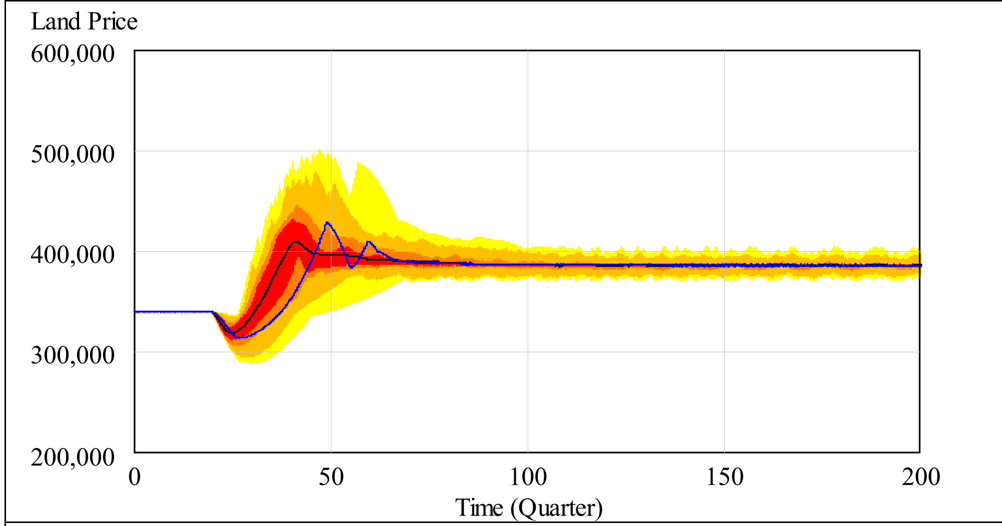
Parameter: SOLELD

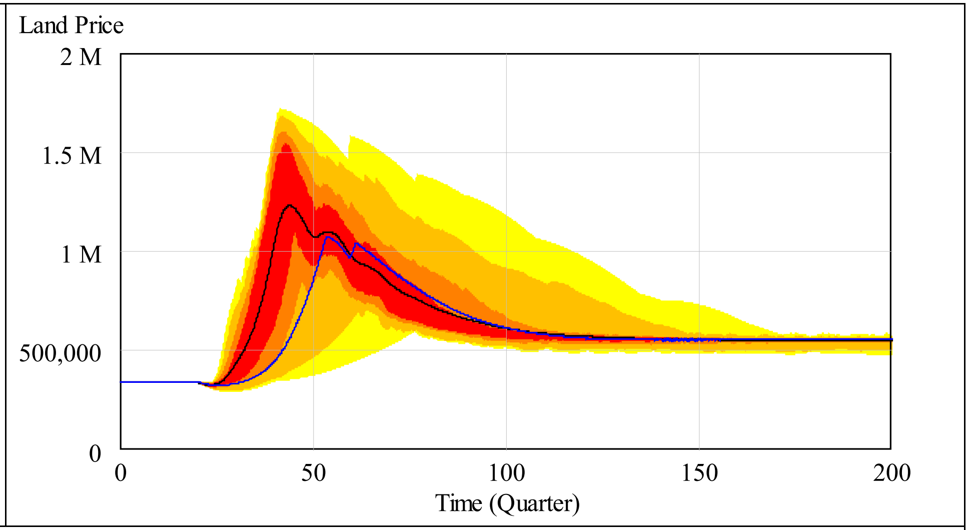


Parameter: SCP

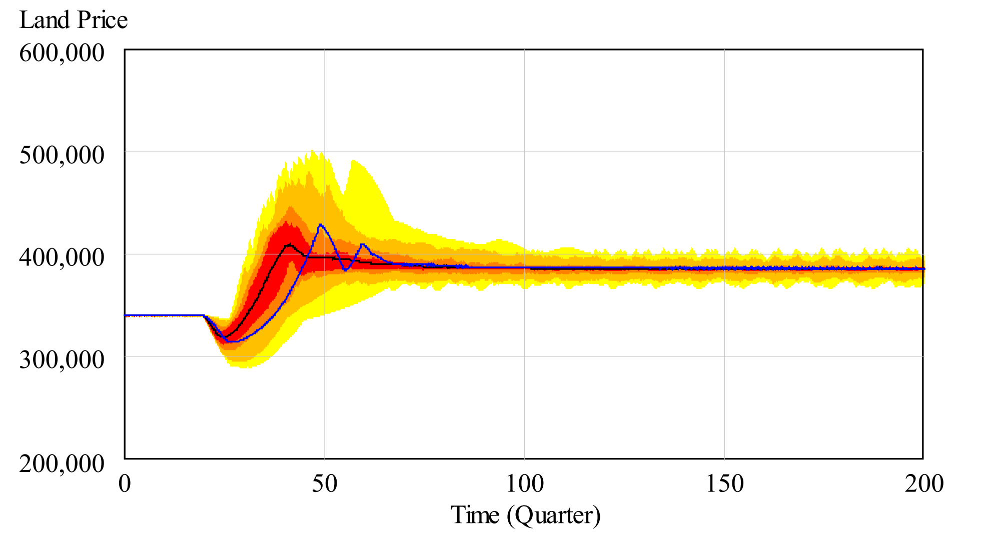


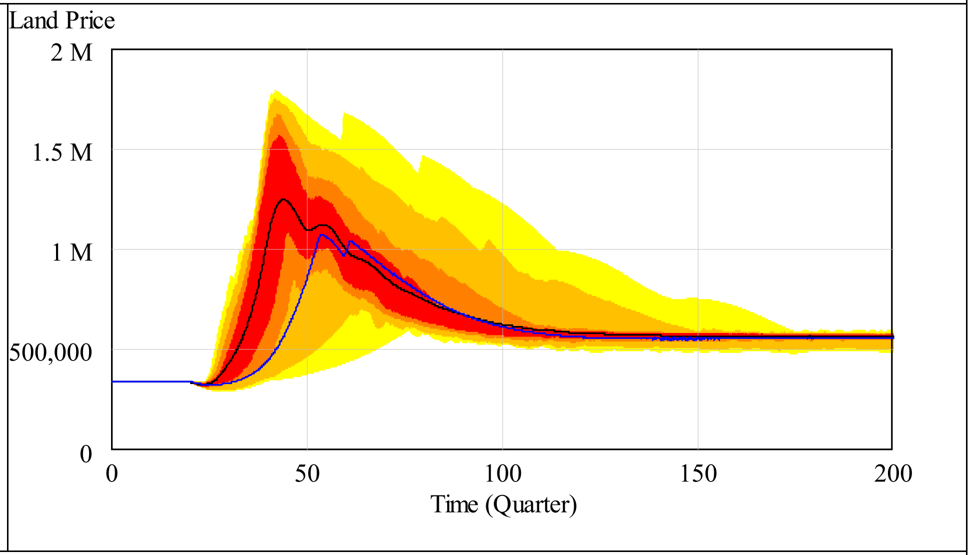
Parameter: SCHAG





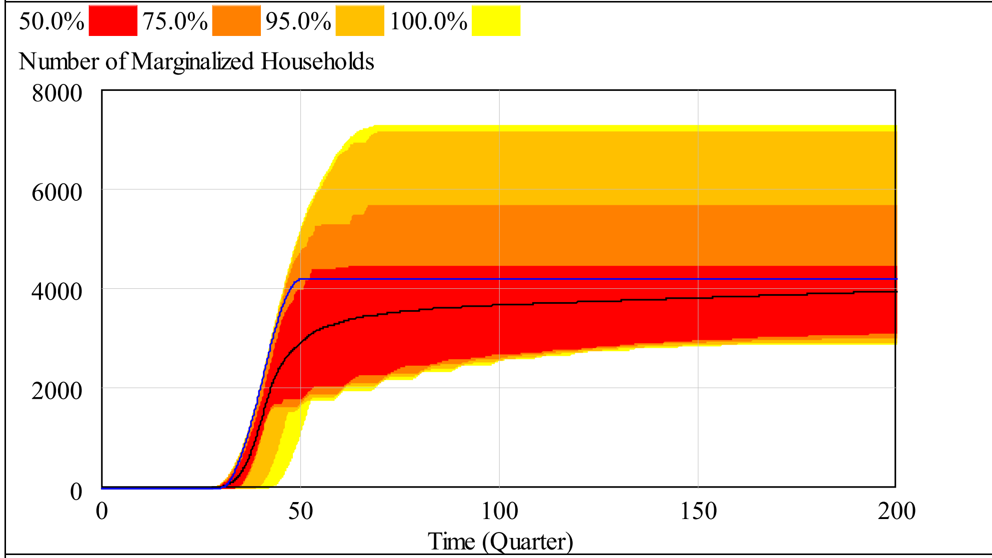
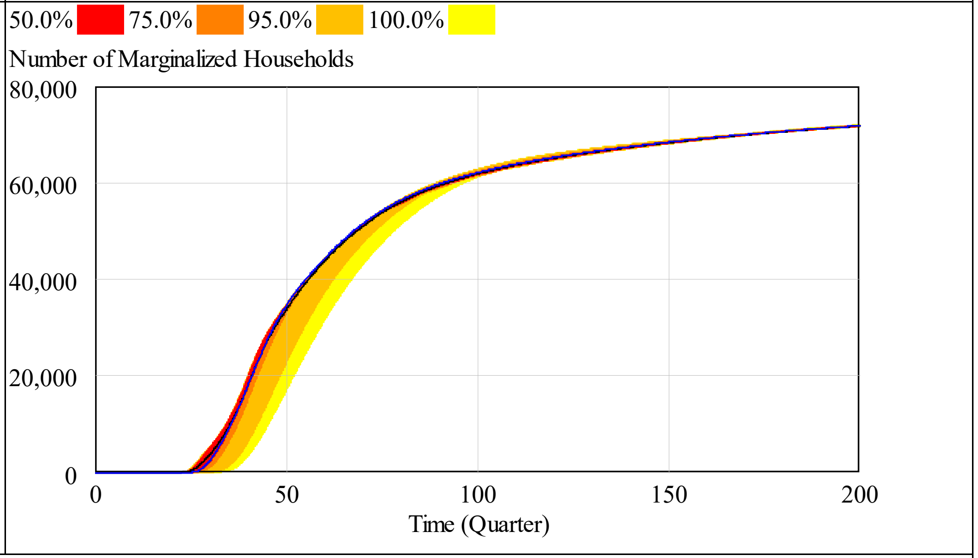
First three parameters



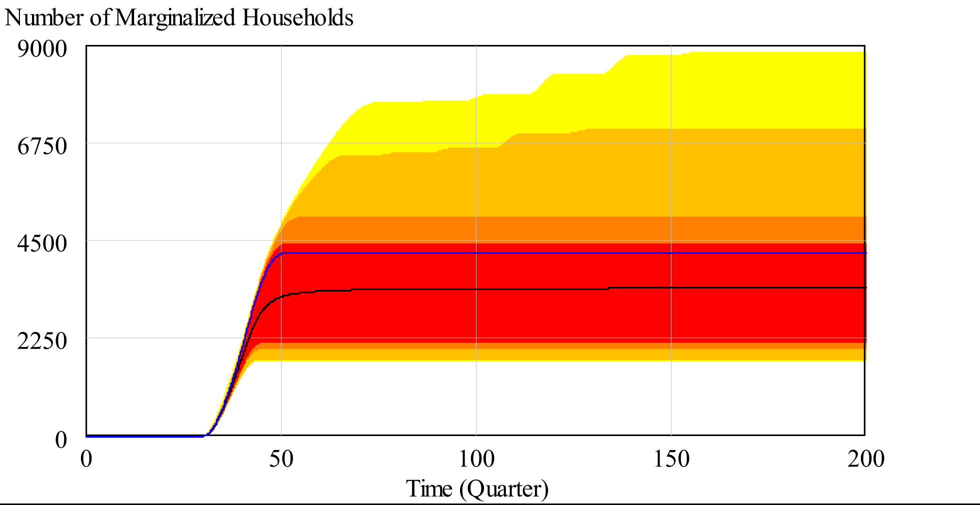
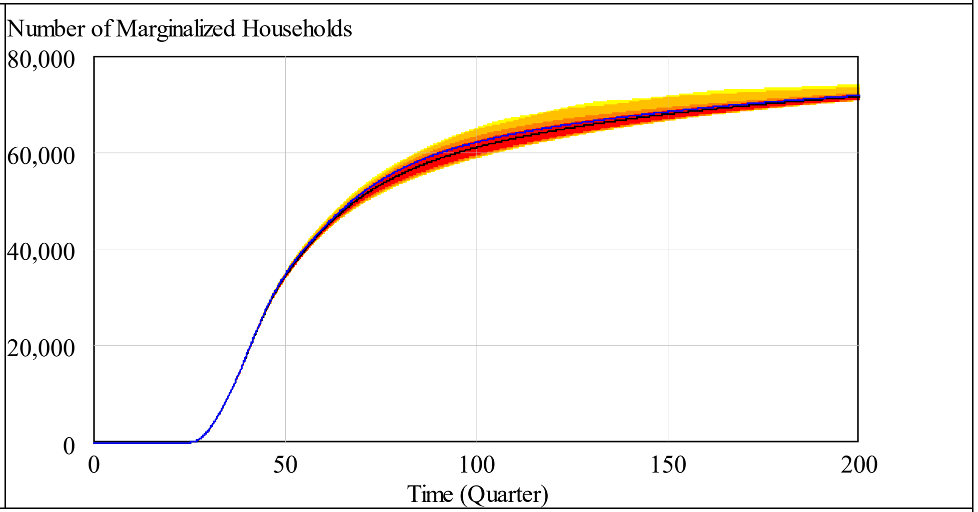


All the four parameters

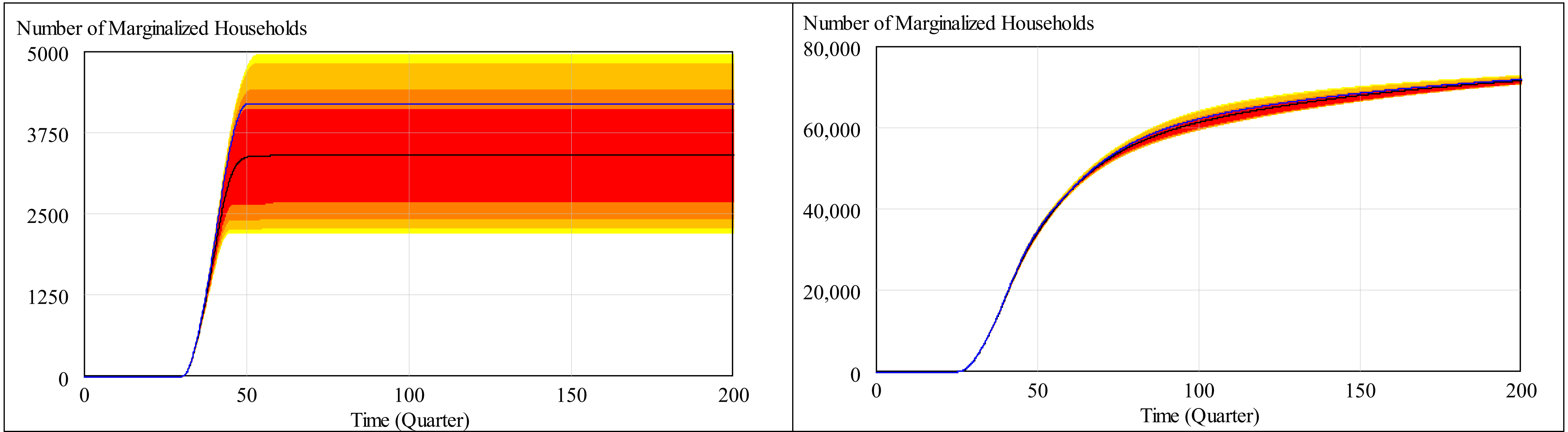
Figure 5-85: The sensitivity of the land price to four elasticity (sensitivity) parameters of the model under the two modes of regulations and demand shock conditions

First Mode	Second Mode
	

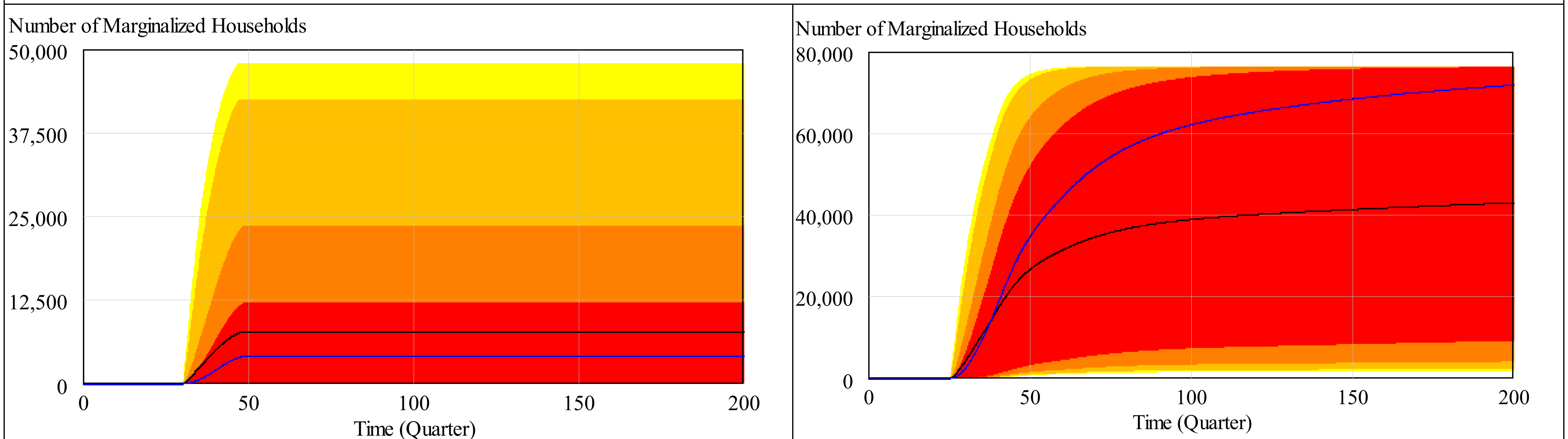
Parameter: SOHEHD

Parameter: SOLELD



Parameter: SCP



Parameter: SCHAG

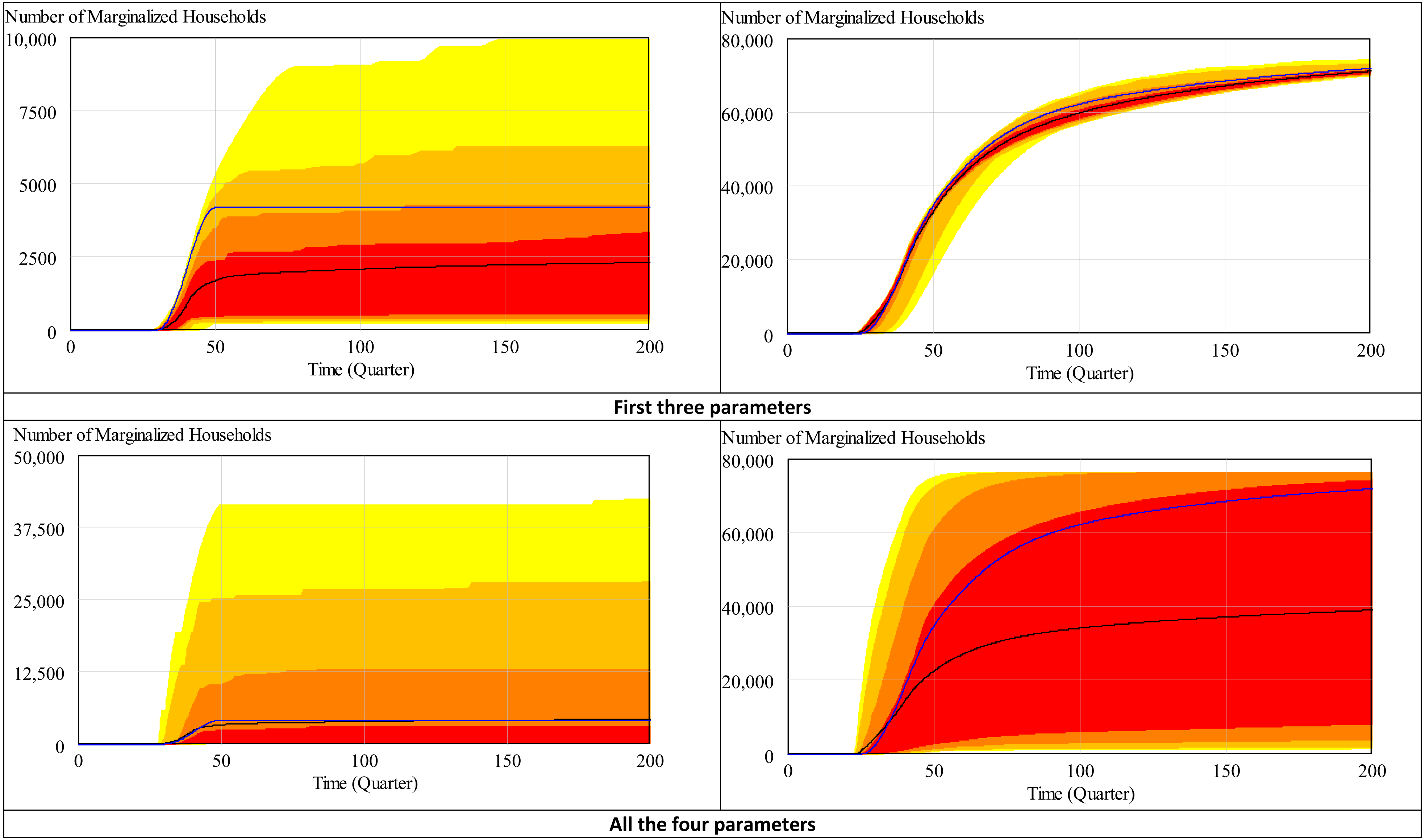


Figure 5-86: The sensitivity of the number of marginalized households to four elasticity (sensitivity) parameters of the model under the two modes of regulations and demand shock conditions

5-5- Conclusions

This Chapter first analyzed the effects of non-regulatory factors, including the population (number of households), the household income, the capital factor price, the cost of capital, and the construction time. Due to the critical role of the population, I analyzed other non-regulatory factors in two modes: with growth in the number of households (the demand shock) and without it. Analyzing the effect of the population shows that increasing the household number growth rate and the duration of the growth can increase the housing prices above the affordable level for the lowest income households and result in relatively high levels of marginalization. Moreover, the boosting effect of an increase in the duration of a demand shock can exceed the effect of a higher-level one-off demand shock.

Regarding the income effect, analyses demonstrate that the level of inequality between the lowest income group and the other two income groups has a critical role in the intensity of marginalization of low-income households to informal settlements. Moreover, among the two forces which can deepen the income gap between the three income categories, the reduction in the income level of low-income households is more effective in the marginalization of low-income households than the increase in the income level of households in the other higher-income categories. Imposing a demand shock, which does not cause marginalization individually, can result in marginalization when it is combined with the levels of the income gap that does not lead to marginalization individually.

Regarding the price of capital factor, an increase of more than a certain threshold increases the housing price to a level that is not affordable for the lowest income households and results in their marginalization in informal settlements. Without any demand shock, the increase in the capital factor price needs to be more than 25% to result in marginalization. However, imposing a typical demand shock (3% annual growth in the number of households for the 20 quarters) reduces the critical threshold to almost 2.5% of the capital factor price in the initial steady state. This level is one-tenth of the capital factor price increase required to drive marginalization without a demand shock.

Analyzing the effect of the cost of capital shows that, after the income gap, which is deepened by decreasing the income level of low-income households, it is the most effective factor among non-regulatory factors. Small increases in the cost of capital result in noticeable increases in the housing rent, causing a considerable effect on marginalization even without any demand shock. On this basis, under a typical demand shock, even a slight increase in the cost of capital leads to the marginalization of lowest income households in informal settlements.

Analyses demonstrate that the construction time has less effect than other non-regulatory factors. Although prolonging the construction time increases housing and land prices, typical construction delays cannot cause marginalization. A 10-year increase in the construction time is the first point resulting in an infinitesimal amount of marginalization. However, combining the prolonging of construction time with a typical demand shock causes the increase in numbers of informal dwellers even with a usual increase in construction time (1 to 2 years).

Analyzing the individual effect of UGB shows that more restrictive UGBs in all modes of demand shock reduce the volatility of both housing and land prices by producing milder fluctuations after the first jump in prices. Depending on the volume of the demand shock, further restricting the UGB not only can change the price trend but can increase the long-run equilibrium price. The effect of UGB on prices and consequently on the marginalization of low-income households depends on the level of the demand shock. In the typical demand shock, only a restrictive UGB can cause a small amount of marginalization. However, in higher demand shocks, even moderate UGB restrictions can intensify the marginalization process.

Among the three regulations, MBD is the only one that can affect housing and land prices if it is changed. However, restricting the MBD in the hypothetical city does not result in the marginalization of low-income households. More restrictive MBD increases the housing price. Also, it increases the long-run equilibrium land price, but, when it is first imposed, it leads to a decrease in the land price due to the unprofitability of the housing construction. Since the rise in the housing price in the absence of any demand shock is not sufficient for triggering the marginalization process, the city remains a closed city, and the land price ultimately increases after its first decline. These results coincide Brueckner et al.'s (2017) model.

Another factor defining the restrictiveness of MBD is the municipal unit charge determined by the municipality for extra development. By changing the unit charge in the most restrictive MBD case, it is possible to elicit the effect of MBD on marginalization without any demand shock.

Analyzing the effect of MBD under demand shocks reveals the same overall pattern in both housing and land prices. Moreover, even under a typical demand shock, imposing MBD marginalizes lowest-income households. However, there is a subtle difference between the pattern of housing and land price trends here, and those patterns elicited when there is no demand shock. Also, there is a difference between the pattern of price trends under the high demand shocks and those created under lower demand shocks. The combination of higher demand shocks with restrictive MBDs causes the housing price to stay at a level higher than the affordable level for the lowest income households. Hence, the marginalization mechanism is always active, and there is always a stream of lowest-income households resorting to the informal housing sector. This outward stream implies the city is a type of open city that can expel the pressure outwards.

On the other hand, when the demand shock is not that great, the housing price temporarily exceeds the critical affordable level and then returns to the affordability zone for the lowest income households, which means the marginalization mechanism is temporarilty active. In the former case, housing and land prices' trends are less differentiated than the latter. Regarding the land price, the trends are superimposed in their long-run equilibrium. This finding proves the intuitional forecast by Brueckner et al. (2017), stating that restricting MBD in the open city model will not change the land price.

Similar to UGB, MLS does not affect housing and land markets in their steady-state. Analyzing the effect of MLS under different modes of demand shock demonstrates that MLS only affects the housing and land markets in the short term, and it does not change long-run equilibrium prices. The reason is that it reduces the land supply elasticity by limiting the supply of undeveloped land lots. Thus, after the absorption of the demand shock, the MLS restriction is not binding anymore, and the land supply revives its price elasticity. Except for the typical demand mode shock (3% household annual growth), more restrictive MLS increases the number of informal dwellers. However, in none of the modes does it cause the housing price to permanently exceed the affordable level for the lowest income group.

Analyzing the combined effects of the three possible regulation pairs demonstrates that they are not the result of linear addition of their individual effects. The analysis of the land price graphs shows that in most cases, the combined effect of two regulations on the marginalization of the lowest income group is higher than the individual effect of each regulation. The only exception is the combined effect of MBD and MLS under the 3% demand shock. Further restricting a regulation increases its contribution to the combined effect.

In addition, this chapter investigated the contribution of each regulation to its combined effect with the other two. When MBD combines with each of the other two regulations, its contribution is always more than them. On this basis, MBD is a dominant regulation. Regarding the combination of UGB and MLS, the contribution of a highly restrictive MLS can dominate the contribution of a less restrictive UGB and vice versa. However, despite the synergic effect that both of them can have in their combinations, UGB also has a neutralizing effect on MLS. Based on this, combining MLS with more restrictive UGBs can limit its contribution to their combined effect since restrictive UGBs reduce the total area of undeveloped land and can even make it zero.

A general result of this analysis is that the number of informal dwellers does not necessarily depend on the long-run equilibrium housing price, as is shown in static analyses. Housing price fluctuations can intensify marginalization stemmed from the equilibrium housing price higher than the affordable level or even trigger it even when the equilibrium price below the critical level of affordability for lowest-income households. The results of analyzing the MLS effect provides the best example for this finding.

Analyzing the sensitivity of the model's behavior to the four elasticity parameters shows that the only parameter to which the main output variable of the model, the number of marginalized households, is highly sensitive to the parameter SCHAG which is defining the Sensitivity of the Percent of Change in the Number of Households to Relative Affordability Gap. The sensitivity analysis shows that the number of marginalized households can depend more on the chosen value for SCHAG under the most restrictive planning regulations and a high level of demand shock. These results suggest more empirical works on the relationship between the growth rate of marginalized households and their housing affordability based on formal housing prices. However, the mentioned result does not affect our major inferences about the individual and combined effects of planning regulations and the impact of non-regulatory factors.

6. Conclusions

6-1- Introduction

This chapter discusses the research findings presented in Chapter 5 in the context of the research problem addressed in this thesis. It starts with a recap of the research problem. Next, it answers the central question of the research. As mentioned in Chapter 1, to address the central question more accurately, the central question has been broken down into five main questions. I organize the findings of the research to answer them. Since this research has used an alternative method for simulation (a System Dynamics model rather than an econometric model[14]), I have posed two methodological questions aimed at comparing these methodological approaches, subsidiary to the main questions of the thesis. In Section 6-3-3, I answer these, and discuss the limitations of the research. The final sections of the chapter discuss potential policy applications of the model, and the questions this study has raised for future research.

6-2- Research problem

This study is aimed at contributing to a significant gap in the research literature regarding the role of planning regulations in the growth of informal settlements. The literature analyzing the growth of informal settlements has two threads. The richer thread focuses on upgrading and empowerment policies aimed at formalising informal settlements in order to reduce their size. The focus is on changing the characteristics of the informal housing/land markets that are the destination for low income households marginalised from formal sector housing options.

The secondary thread focuses on the role of the institutions of the formal housing market as the drivers of growth or decline in informal settlements, in particular through the effects of planning regulations on housing affordability. There are a small number of studies on this theme, and they have several limitations. They focus on the effect of one regulation (MLS). The effect of other major planning regulations, MBD and UGB, is not fully explored. Like studies on the price-inflationary effect of planning regulations, works in this theme have to deal with the three major methodological difficulties: endogeneity, heterogeneity, and temporality. To address these problems, they adopt similar approaches to those in the extensive literature on the price-inflationary effect of regulations. By analyzing the effect of one type of regulation (mostly MLS) or a selection of regulations without considering the temporality of these effects, studies have adopted the selective and the static approaches.

[14] The application of econometric modeling in this thesis, specifically in Chapter 5, has been for parameter estimation purposes and not analysis.

In addition, the extant literature has not addressed the combined effect of planning regulations over time. These problems and shortcomings have hindered a convincingly robust consensus about the effects of regulations on either price inflation, or the consequent growth of informal settlements. This is the gap that the thesis tries to fill, by developing an SD model focusing on the dynamic causal interrelationships among three intersecting systems: the formal housing market, the formal land market, and the housing construction sector.

6-3- Research questions

6-3-1- Central question

The central question this thesis aims to address is:

How and why do planning regulations affect the growth or decline of informal housing settlements in a city?

To answer this question, I developed an SD model of housing and land markets, connected by the intermediation of the housing construction sector. The model elements are connected in a network of causal relationships based on the proofs developed in microeconomics theory, and the observed operation of planning regulations in real-world cases. The structure of the model has been validated by performing behavioral tests. Based on running numerous simulations under different conditions, the behavioral outcomes of this causal structure tell us that:

The imposition of planning regulations can lead to the expansion of informal settlements through their incremental increasing effect on the trend of formal housing prices. Increases in the housing price may exclude low-income households from formal housing markets because they cannot afford the minimum liveable space without sacrificing their other necessities.

In their reviews of studies in the field, Nelson et al. (2002) made this fundamental point that the land demand (both its strength and elasticity) is the primary factor in determining housing prices. Our results proved this point, not only about the housing price but also by demonstrating its applicability to the expansion of informal settlements. The critical condition which accentuates the effect of planning regulations is the demand shock (as an increase in the number of households). I showed that even the most restrictive regulations do not affect housing prices, and consequently the number of informal dwellers, without a demand shock. Also, informal settlements act as a substitute for the lowest-income households. This increases the absolute value of housing demand elasticity for the lowest-income group and prevents the full emergence of the effect of stringent regulations in the form of increased housing prices. However, the dynamic aspect of our results necessitates some minor modifications to Nelson et al.'s (2002) general point. In the dynamic equilibrium in which housing construction compensates for housing demolition, MBD is the only regulation of the three studied that can affect the housing price. This is because MBD can force developers to construct at volumes lower than the equilibrium level. Depending on the size of the demand shock, its duration, and the number of binding planning regulations and their restrictiveness level, the effect of regulations on the number of informal dwellers ranges from no effect to high.

Moreover, other factors can intensify the expansion of informal settlements even if there are no binding regulations or no demand shock. The increase in the price of capital factor and the income gap between the low-income and high-income groups can lead to the marginalization of the lowest-income group to informal settlements even without a demand shock. The typical rise of the capital factor price and lengthening of construction time can result in marginalization when accompanied by typical demand shocks, even in the absence of restrictive regulations. One of the critical outcomes of our dynamic model has been to capture nonlinear effects. Nonlinear effects are those where the combined effect of contributing factors is not simply the summation of their individual effects. As a result, it is possible that while two factors individually do not have any effect on marginalization, their combined effects can marginalize low-income households. Thus, including the effects of other factors can intensify the effect of planning regulations and vice versa, even if each effect is small.

6-3-2- Main questions

In order to answer the central question with more accuracy, theoretical depth, and practicality, I posed five questions. Below, I answer them based on the results of the analysis.

First Question: *What are the individual effects of planning regulations on formal housing prices?*

With a dynamic model, the answer to this question is different to the answer using a static model. The dynamic model not only accounts for the amount of change but also illustrates the pattern of change. In a dynamic equilibrium or in the absence of a demand shock, only changing MBD can affect the housing price positively. The effects of MLS and UGB appear only in the event of a demand shock. With a demand shock, while all the three regulations have an incremental effect on housing prices shortly after the shock, their effects on the long-term equilibrium housing price are different. More restrictive MBDs increase the long-term equilibrium housing price. In the case of UGB, it increases the long-term equilibrium housing prices when the UGB is extremely tight (when the UGB coincides with the city's developed area). For MLS, the long-run equilibrium price does not change. Regarding the course of housing prices, since planning regulations act as constraints on decisions of developers and landowners, they set a limit on their choices and generally the first jump in housing prices comes after a higher demand shock and, consequently, approximate towards their long-term equilibrium level more smoothly with fewer (or milder) fluctuations. These patterns are more evident for UGB and MBD than MLS since the first two impose stricter constraints on all types of land.

Subsidiary Findings: Although I did not pose a question about the individual effect of planning regulations on the land price, the structure of the model makes it possible to answer the same question about the land price. Except for MBD, the results for land prices are similar to the regulations' effect on housing prices. In the case of MBD, more restrictive MBDs decrease the land price more in the short term after the demand shock. In the long term, the incremental effect of MBD is infinitesimal and close to zero since the long-term upward movement of the land price compensates for its short-term fall.

Second Question: *What are the individual effects of planning regulations on the expansion of informal settlements?*

Unlike static models, the effect of planning regulations on the expansion of informal settlements depends on the pattern of housing price changes affected by the imposition of planning regulations. Highly restrictive UGBs can increase the number of informal dwellers. With typical demand shocks, even restrictive UGBs cause the number of people resorting to informal settlements to increase and then stop after a period. This is because they can only hold the housing price temporarily above the price level at which low-income households can afford to rent the minimum liveable space. Only with exceptionally high demand shocks does the number of marginalized households follow an asymptotical growth trend. MLS, on the other hand, even at its most restrictive levels accompanied with high demand shocks, can only temporarily increase the number of marginalized households since it has no effect on the long-term equilibrium housing prices, and only exacerbates the initial jump in the housing price after the demand shock. The effect of MBD is different from the other two. Although it can affect the housing price in the dynamic equilibrium, it is not powerful enough to raise the housing price above the affordable level for low-income groups. In the event of demand shocks, different levels of MBD can increase the number of households marginalized in the informal housing sector. Moreover, restrictive MBDs affect the housing price course to cause the number of marginalized households to grow in an asymptotical pattern.

Third Question: *How can we explain the interaction of different planning regulations, and how they lead to a specific combined effect?*

Incorporating the three planning regulations as they function in a real-world situation, in the form of constraints, introduces nonlinearities into the model. The nonlinearity appears in the combined effects of regulations. To explain how the interaction of different planning regulations leads to a specific combined effect, I juxtaposed the individual effects of each pair of regulations and their combined effect on the target variables (house and land price, and number of marginalized households). The results demonstrate that the combined effect of a pair of regulations is not the linear sum of their individual effects. The contribution of each regulation is the difference between the combined effect and the individual effect of the other regulation in the pair. The contribution of each of the two regulations can identify the dominant regulation. The contribution to a regulatory effect can be changing the long-run equilibrium level of the target variable, or changing the pattern of movement towards the long-run equilibrium level (the amplitude and the number of fluctuations).

Fourth Question: *What are the combined effects of planning regulations on formal sector housing prices?*

The combined effect of MBD and UGB on the long-term housing price is larger than their individual effect alone. Also, restricting MBDs or UGBs increases their contribution to the combined effect of the pair. In the combined effect of these regulations, MBD is the dominant regulation because it makes a larger contribution to changing the long-term equilibrium. This results from its dominant contribution to the initial jump in the housing price stemming from the demand shock. The contribution of UGB to the changes in housing prices intensifies the initial jump in the price and smooths the slope towards the long-term equilibrium level by reducing the number of fluctuations.

The combination of UGB and MLS mainly changes the pattern of housing price changes rather than the long-term equilibrium housing price. The combined effect of these two on the long-term housing price is the same as the individual effect of UGB. Examining the contribution of each regulation in this pair to their combined effect on the long-term price level, UGB is the dominant regulation. However, after the initial jump, a more restrictive MLS may become the dominant regulation. The other contribution of UGB is to smooth the price slope towards its long-term equilibrium level. A more restrictive UGB can neutralize the effect of MLS when they are combined. The contribution of MLS is evident only when the UGB is high enough not to restrict development on undeveloped lands.

The combined effect of MBD and MLS on the long-run equilibrium price is the same as the individual effect of MBD. This is because MLS does not affect the long-term equilibrium housing price. The contribution of MBD appears in the equilibrium price level and the initial jump in the housing price after the demand shock. Thus, MBD is the dominant regulation when it is paired with MLS. MLS contributes to the change in the price course by reducing the number of fluctuations and smoothing the slope towards the long-term equilibrium.

Fifth Question: *What are the combined effects of planning regulations on the expansion of informal settlements?*

The combination of UGB and MBD intensifies their individual effects on the marginalization of low-income households and thus the growth of informal settlements. Increasing the restrictiveness of each of these regulations increases their contribution to the marginalization of the low-income group in informal settlements. The contribution of even a moderately restrictive MBD to the combined incremental effect of both is greater than the contribution of a highly restrictive UGB. A highly restrictive MBD can increase the number of informal dwellers by increasing the long-term equilibrium housing price, maintaining it at a level unaffordable for low-income households.

The combined effect of UGB and MLS on the number of informal dwellers is greater than their individual effects. However, highly restrictive UGBs can reduce the individual contribution of MLS to their combined effect on the number of informal dwellers. Both regulations affect the number of informal dwellers by intensifying the initial jump in the housing price after the demand shock, and maintaining it for a period above the level at which low-income households can afford to rent a minimum liveable space.

The combination of MBD and MLS boosts the individual effect of MLS on the number of informal dwellers; however, this effect is not evident in the individual effect of MBD. Since the contribution of MLS to the combination with MBD is to reduce the number and amplitude of later fluctuations, it may reduce the length of the period during which the housing price is above the level at which low-income households can afford to rent the minimum liveable space. The shorter period of unaffordability results in a reduction in the growth of informal dwellers. When combined, the contribution of MBD to the individual effect of MLS is greater than the contribution of MLS to the MBD's individual effect.

6-3-3- Subsidiary questions

In addition to the substantive research questions addressed above, this study set out to answer two subsidiary questions about the methodological aspect of the research. These questions are answered as follows:

First Subsidiary Question: *What are the potentialities and limitations of neoclassical economic modeling as a method of answering the central question of this research?*

I answer this question based on reviewing studies that used statistical methods in the mainstream approach. The mainstream modeling approach in neoclassical economics uses econometric techniques to estimate a specification based on economic theories. In the specific case of measuring the effect of planning regulations, these methods have to address three complexities inherent to the subject. These are the heterogeneity, endogeneity, and temporality of regulations, described in detail in Chapter 2. These complexities become acute when analyzing the effect of planning regulations on the expansion of informal settlements, since they add another tier to the relationships under investigation. Simultaneously addressing all three complexities is extremely difficult, and most studies have made a trade-off in dealing with these challenges. Generally, the trade-off has resulted in most works selecting a limited range of regulations to investigate, and developing static analytic approaches that exclude consideration of changing regulatory impact over time.

In studies measuring the effect of regulations on informal settlements' growth, the complexities have led to studies omitting the intermediary mechanisms of causality among the three factors: planning regulations, the construction sector, and the housing price by making a simplifying assumption about the direct effect of regulations on dwellers' preferences. The other simplifying assumption is the equivalency between land and housing consumption, implying that MLS is the sole regulation that affects dwellers' preferences. While high quality empirical data can help models address challenges such as the endogeneity of regulations, the temporality of their effects, and controlling other contributing factors to isolate the specific effect of regulations, adequate data is often unavailable in developing countries.

On the other hand, estimated models are useful for policy evaluation purposes. They can be used to quantitatively measure the implications of regulatory policy changes for the dependent variable. There are well-established methods to estimate parameters and validate econometric models. Hence, one can use them for forecasting. The coefficients and their signs can be interpreted to identify the dependent variable's direction and magnitude of change due to independent variables such as regulations. Moreover, these effects are easily comparable across studies.

Second Subsidiary Question: *What are the potentialities and limitations of the SD modeling approach in answering the main question of this research?*

I answer this question based on the direct experience of SD modeling in this study. The SD modeling approach yields a simulation model in which one can control the effect of other contributing factors and isolate the effect of the target variable. The feedback loop structure of SD models works based on the endogeneity of variables. A variable can be endogenously defined if the feedback structure behind it is identified. The causal approach inherent in SD modeling enables us to incorporate each regulation as a separate constraining factor on developers' decisions. In reality, planning regulations act as constraints. Thus, SD modeling captures the heterogeneous nature of regulations in the real world. This is more consistent with what happens in practice, compared to statistical models in which regulations appear in linear combination with other factors. The dynamicity of the model enables the interactions of endogenous variables to occur over time. Thus, one can capture the temporality of regulations' effect on target variables. It is possible to detect the individual and combined effect of regulations on the target variables while controlling other contributing factors. The simulation model can serve as an urban laboratory enabling us to create different situations, control influential factors, and measure the effect of certain variables on endogenous variables.

On the other hand, the resulting model can be very stylized, which means that although the results are generalizable, they do not accurately fit a specific case to enable point-by-point prediction. However, one can alleviate this problem by adopting the modeling-from-scratch approach. An accurate, validated SD model developed based on a real-world case study can offer policy-relevant forecasts for that case study. The econometrics models avoid the endogeneity problem. They mostly handle one endogenous variable by devising substitute instrumental variables. In contrast, the SD methodology relies on finding feedback loops, implying that SD models seek and make use of endogeneity. However, there should be a balance between the number of endogenous and exogenous variables. The excessive reliance on endogenous variables makes internal calibration problematic, since the error-minimizing algorithm will have more variables whose value should fit the observed data. Although the SD model's behavior might be valid and it may be able to reproduce various behaviors predicted by theory and proved by empirical studies, the model may fail to provide an accurate point-by-point forecast of endogenous variables.

The other limitation of SD as a simulation method is that it works based on the aggregation of entities and average values. In our model, an entity can be a developer, a plot of land, a dweller, and a housing unit. SD methodology tends to aggregate entities of the same kind. To represent the heterogeneity in the values of an entity, one can disaggregate it into different stocks, as I did in the case of dwellers by dividing them based on their income level into ten income groups. However, this method has limitations in representing heterogeneity. One example is the incorporation of both rental and owner-occupied markets. It is impossible to accurately represent multi-storey residential buildings where some units are rented, and some are sold. Hence, one must assume that a residential building will be either sold or rented, which is unrealistic and leads to disaggregation of stocks in the land market based on the rental or owner-occupied buildings. In addition, to be more realistic, one can divide the city into zones that each impose regulations with different levels of restrictiveness. Dividing a city into two zones doubles the stock variables, and dividing it into three zones triples their number. Hence, disaggregation makes the resulting model larger to the point where the model can be intractable and challenging to present. Therefore, the ability of SD platforms to represent heterogeneous entities is limited. This constraint reflects in part the limitations of representational technologies, rather than an inherent limitation of the SD modelling approach.

6-4- Contribution to theory

This thesis has several theoretical contributions. Some contributions are to the general theory of property economics. They apply to all contexts. Others are mostly related to the property markets of developing countries. Even in the latter case, the results can be relevant to developed countries since what the informal settlements genuinely do, is to relatively increase the price elasticity of the low-income group's housing demand in the formal housing market, as shown in Subsection 4-8-3-7.

The main contribution of the thesis is the model developed and used for the analysis to answer the thesis' questions. It is the first dynamic simulation model incorporating the optimum building density as an endogenous variable. Zhang et al.'s (2018) system dynamics model, most likely the only case that used building density, defined it exogenously. To this end, this thesis defined a mathematical relationship between the price of housing production factors and the optimum building density. The relationship was extracted from the housing production with the

Cobb-Douglas theoretical form and was estimated empirically using Iran's urban housing market and residential construction sector data. Estimating the parameters of the theoretical relationship proved that the housing production function has a constant return to scale. These are the other contribution of this thesis to housing economics theory.

The model applies planning regulations as constraints on agents' behavior in housing and land markets. This representation is conceptually closer to what regulations are in reality, than studies incorporating regulations in a linear form along with the other variables. Hence, the incongruencies between the statistical studies on the effect of planning regulations on housing and land markets and the simulation results of the current model raise potential points which require more empirical research.

Since some regulations constrain agents' activity in the land market, I modeled the land market and integrated it with the housing market. Due to the lack of data on land prices, even static models in the field have not modeled the land market. Thus, as one of the first dynamic integrated models of land and housing markets, this thesis provides insights into the interaction of housing and land markets and the effect of planning regulations on land prices.

More importantly, the thesis' findings contribute to the theory of the dynamic behavior of housing and land markets under the imposition of planning regulations. For the first time, this thesis shows how and why MBD, UGB, and MLS cause different housing and land price trends. In particular the results provide tangible support for the theoretical prediction of the effect of MBD on the land price and explain how the consideration of closedness or openness of the city to outward migration can change the land price trend (Brueckner et al., 2017). The thesis also complements the extant theoretical prediction of changes to land and housing price trends. It does this by demonstrating how the interaction between the land and the housing markets through feedback loops between the two, and the market effect, can change the direction and magnitude of market trends.

The thesis extends the existing literature on the effect of planning regulations on the growth of informal settlements by providing the first dynamic analysis of the problem and adopting a cause-based approach. The incorporation of dynamicity allows us to show that the housing price trend is a more important indicator of the expansion of informal settlements than the long-term equilibrium housing price. Adopting a causal approach in modeling allowed us to analyze the individual and the combined effects of planning regulations on the informal settlements' growth; to the best of our knowledge this is the first study to do this. The thesis is also one of the first studies to analyze the effect of MBD and UGB on the expansion of informal settlements (rather than the more widely-modeled MLS). The dynamic simulation model makes it possible to compare the contribution of each regulation to their combined effect when they are paired, and to define the dominant planning regulation in different combinations.

Finally, the model's simulations have provided insightful results about the effect of non-regulatory factors, including population growth, the cost of capital, construction time, the price of capital factor, and income inequality, on the expansion of informal settlements. It also identifies the comparative impact of these factors on the growth of informal dwellers. The existing literature has not analyzed most of these non-regulatory factors' effects on the growth of informal settlements.

6-5- Potential uses of the model

Although the developed SD model does not provide a precise forecast of target variables in the form of time series data, it can show the implications of adopting different policies over time. The model can check for the speed of changes in target variables and identify when the target variables exceed particular thresholds. That picture of policy implications can capture the uncertainties of parameters based on the probabilistic distribution of different parameters' values. The SD model can function as a policy-making laboratory by allowing policymakers to control any number of variables to see the implications of changing or combining other variables. Although it will not show the exact housing price in a particular year in the future, the model can identify for policymakers the weight of each regulatory or financial parameter in the observed effect.

The model offers realistic expectations about the impacts of specific regulatory policies to local policymakers. The model demonstrated that factors such as the income gap, the cost of capital, and the price of capital factor, predominantly determined by the central government policies, can be more influential than planning regulations at the local level on the number of informal dwellers. The model's visual representation of the connections between variables makes it easier for practitioners and other non-academic users to understand the dynamics of how regulatory policies interact with externally set conditions. The model can play the role of a collaborative platform in which practitioners of different disciplines can test out the effects of parameters of interest and see the combined results. Such a model contributes to a more intelligent, more objective, and collaborative policy-making process. Also, the observability of the constructing elements and the causal relationships of the model makes it possible for planners and policymakers in a different context to tailor the model based on the situation of the target city, the type of planning regulations, and the data availability in the chosen context.

6-6- Future research directions

To the best of our knowledge, the current model is the first dynamic simulation model which has integrated the housing and land markets with the construction sector, and incorporated three main planning regulations. It has also incorporated the concept of optimum building density as an endogenous variable. However, to clarify the explanation of the model I have made simplifying assumptions. If I could eliminate those assumptions the model would more closely reflect the real world, and provide more accurate results. Discarding each of these simplifying assumptions is equivalent to conducting a new avenue of research. Below, I explain the major lines of research that could be pursued in future.

Assumption 1: Construction is undertaken by commercial developers only, not self-builders

Our model assumed that housing construction is the specific responsibility of developers who form a construction sector. Although this arrangement is pervasive in most developed and developing countries (including Iran), people can choose to build their own houses as in most developing countries. They may build a multi-storey residential building to generate income in addition to their residence, or a single-family home for their own use. In the latter case, households would be more affected by MLS. Since the capital factor is almost fixed, increasing the lot size to comply with MLS has the same effect that MBD has on multi-storey buildings. Thus, we could expect that by adding self-build to the construction sector in the model, MLS would have a greater impact on target variables compared to the current model's results.

Assumption 2: Municipality has consistent and predictable goals when setting levels of MBD restrictiveness

In our model, developers pay an additional development charge (commonly known as a density bonus) to the municipality if they want to build above the MBD. It is assumed that the housing market condition does not affect the amount of development charge levied by the municipality or the level of MBD restriction set and enforced by the municipality. In reality, municipalities may set MBD to raise revenue, and this goal sometimes outweighs other objectives such as improving the quality of life (Karampour, 2021). Therefore, MBD may change endogenously when it is enforced for revenue-raising purposes. Consequently, the dynamicity of the housing price and its effect on the number of informal dwellers could be affected in ways that this analysis does not capture, because it does not consider the feedback loop from the housing price to the MBD and the development charge. To account for the endogeneity of MBD, one should implement the municipal finance system which is out of the scope of this thesis.

Assumption 3: Rental housing market owner-occupied housing market are in equilibrium

One of our key assumptions was that the rental and owner-occupied housing markets were in equilibrium, which means households are indifferent between buying and renting a similar housing unit. However, in reality, these markets are not in equilibrium. Moreover, different income groups have different preferences for housing tenure types. Low-income households may not afford to buy a housing unit. They may incline towards renting a unit. For example, based on surveying three informal settlements around Tehran metropolis, Zebardast (2006) showed that the share of informal dwellers (between about 3% to 38%) in those settlements follow a step-wise migration. This means that they first moved to Tehran and after some years of staying in the metropolis, they migrate to their target informal settlements. In this case, staying in the rental market of the metropolis provides a time buffer to save money for purchasing a plot in the informal market. Considering disequilibrium between rental and owner-occupied housing markets may yield a different pattern of rental volatility which directly affects the low-income households. Therefore, the model would provide more realistic results about number of informal dwellers.

Assumption 4: Regulations do not differ within the city

In our model, regulations were enforced across the city uniformly. In reality, cities consist of several zones differing in the restrictiveness of planning regulations. This discrepancy can help to account for another important effect of regulations known as the amenity effect. Different levels of regulatory restrictiveness in different city districts provide different levels of amenity for their residents. Hence, the housing market becomes fragmented, as it is in the real world. Detecting the differential marginalizing effect of regulation, for instance when people at relatively higher income levels are pushed out of districts with higher levels of restrictiveness, would be closer to reality. The actual displacement of households from the formal to the informal sector may reflect downstream effects of increased competition for districts with less restrictive regulation. The fragmented housing market offers a range of housing prices some of which are affordable for low-income groups even though the average price is not affordable to them.

Assumption 5: There is no land speculation and housing speculation

Speculative behavior in both the housing and land markets changes the pattern of volatility. They may exacerbate the housing booms and maintain the housing price above the level which is affordable for the lowest-income group to rent a minimum liveable space for a relatively longer time. Accordingly, this will intensify the marginalization of the low-income households.

Assumption 6: The informal settlement is the last resort for the marginalized lowest-income households rather than a choice

Considering the informal settlement as a last resort for the marginalized lowest-income households is the basic mode of considering it as a choice. That is, the informal settlement is an inevitable choice for those households in the lowest income decile who cannot afford to rent a minimum liveable space in the formal housing market without sacrificing their other basic needs. However, if one considers the owner-occupied and rental markets as two separate markets, the informal housing market would become a choice for those who can still bear the high rents in the formal housing market but cannot purchase a formal housing unit. Thus, households will choose between living as a tenant for a long time in the formal housing market or as a tenant for some years in the formal housing market, saving enough money to purchase a land plot in the informal land market and develop a housing unit on it. In this case, the number of informal dwellers will be more than when the owner-occupied and the rental housing market are in equilibrium, and households are indifferent between them. Therefore, further development of the model could discard assumption six, whose prerequisite is to set assumption four aside. However, we have minimal knowledge about the nature of this choice, (whether it is a dichotomous or a polytomous one), and the factors that influence it. What the limited number of models assumed is a simplistic theoretical presumption. Hence, more empirical research is necessary to improve our knowledge about informal settlement as a choice.

To abandon the majority of the abovementioned simplifying assumptions would increase the heterogeneity of entities in the SD model to an unmanageable level. Further research could explore the potential to use other simulation methods to deal with heterogeneous agents. Agent-based Modeling (ABM) is a specific simulation method to model systems when the heterogeneity of entities matters for the analysis. In ABM, the behavior of each type of agent is defined by determining a set of behavioral rules. Then, these agents interact with one another, and their micro-level interactions determine the macro-level behavior of the whole system. The findings of ABM and SD modeling are comparable. If the results of the two approaches were consistent, that might be regarded as an extra validation. Any contradictions between the outcomes of the two approaches might offer insights into the potentials and limitations of SD and ABM methodology. However, it is worth mentioning that modeling the interaction of all the agents prevents the simulation model to implement the full number of agents in large case studies. The reason is that the real scale simulation has no difference with the real case, which makes the simulation and modeling meaningless. Therefore, the scale of the analysis is the main point on which ABM economizes. For example, Magliocca et al. (2012) ran their agent-based model for a hypothetical suburban region with 334 households. The smaller is the scale of simulation, the more stylized are the results of analysis. SD modeling, in contrast, has a high level of flexibility in respect of analysis scale making it ideal for all the levels of analysis. Forrester's efforts in Industrial Dynamics, Urban Dynamics, and World Dynamics, have proven the advantage of SD in modeling all scales (Forrester, 1969; Forrester, 1971; Forrester, 1985).

The final area for further research is based on the sensitivity analysis results. Among the five elasticity parameters in the model, the sensitivity of the change in the number of marginalized households to the relative discrepancy between the objective individual housing demand and the minimum liveable space is the one with the greatest effects. Empirical research on the relationship between the number of informal dwellers, the affordable housing available to them in the formal housing market, and the minimum liveable space, can provide invaluable information for reducing the amount of uncertainty around the true value of the parameter.

7. Appendices

Appendix A: Model's equations

$LDN_t = TIC_t/\tilde{F}_t^*$	(1)
$LD_t = BL_t + UL_t + LDN_t$	(2)
$asjLD_t = LD_t - (SA_t - adjSA_t)$	(3)
$adjLS_t = LSadjUGB\&MLS_t - (SA_t - adjSA_t)$	(4)
$LS_t = RLS.(PL_t/RPL)^{el}$	(5)
$DAC_t = BL_t + UL_t + DL_t$	(6)
$BL_t = dv_t - (dm_t.(BL_{t-1}/BH_{t-1})) + BL_{t-1}$	(7)
$dvr_t = UL_{t-1}/T_{comp}$	(8)
$UL_t = dls_t + udls_t - dv_t + UL_{t-1}$	(9)
$DL_t = (dm_t.(BL_{t-1}/BH_{t-1})) - dls_t + DL_{t-1}$	(10)
$LSaugUGB_t = \begin{cases} SLinUGB, & LS_t > SLinUGB \\ LS_t, & LS_t \leq SLinUGB \end{cases}$	(11)
$LSadjUGB\&MLS_t = \begin{cases} \left((1-\theta).(LSadjUGB_t - DAC_t)\right) + DAC_t, & LSadjUGB_t > DAC_t \\ LSadjUGB_t, & LSadjUGB_t \leq DAC_t \end{cases}$	(12)
$\theta = ([(0{,}0) - (10{,}10)], (1{,}0), (1.5{,}0.1), (3{,}0.3), (3.5{,}0.6), (4{,}0.8))$ $MLS/LLS = \{1, 1.5, 3, 3.5, 4\}$ $MLS = \{100, 150, 300, 350, 400\}$ $LLS = 100$	(13)
$SA_t = Min(LDN_t, Max(LSadjUGB\&MLS_t - BL_t - UL_t, 0))$	(14)
$DLS_t = \begin{cases} SA_t, & SA_t \leq DL_t \\ DL_t, & SA_t > DL_t \end{cases}$	(15)
$dls_t = DLS_{t-1}/T_{sell}$	(16)
$UDLS_t = Max\ (SA_t - DLS_t, 0)$	(17)
$adjUDLS_t = \begin{cases} UDLS_t, & UDLS_t \geq MLS \\ 0, & UDLS_t < MLS \end{cases}$	(18)

$udls_t = adjUDLS_{t-1}/T_{sell}$	(19)
$PL_t^* = PL_{t-1}.(adjLD_{t-1}/adjLS_{t-1})^{\sigma l}$	(20)
$PL_t = \left((PL_t^* - PL_{t-1})/T_{adjl}\right) + PL_{t-1}$	(21)
$adjSA_t = DLS_t + adjUDLS_t$	(22)
$ac_t = \left(adjS_{t-1}.\tilde{F}_t^*\right)/T_{start}$	(23)
$UH_t = ac_t - cc_t + UH_{t-1}$	(24)
$cc_t = UH_{t-1}/T_{comp}$	(25)
$HS_t = BH_t = cc_t - dm_t + BH_{t-1}$	(26)
$dm_t = (\delta.BH_{t-1})/T_{dem}$	(27)
$\overleftarrow{EL}_t = \left[Max\left(\left(adjUDLS_t.\tilde{F}_t^*/IIC_t\right) - (adjUDLS_t/MLS), 0\right)\right] + \left[IF\ THEN\ ELES\left(\begin{matrix}(SA_t - adjSA_t)/MLS > INTEGER\left((SA_t - adjSA_t)/M\right. \\ INTEGER((SA_t - adjSA_t)/MLS) + 1, INTEGER\left((SA_t - adjS\right.\end{matrix}\right.\right.$	(28)
$ND_t = \left(\overrightarrow{ed}_t - (\overleftarrow{ed}_t + \overleftarrow{el}_t)\right) + ND_{t-1}$	(29)
$\overrightarrow{ed}_t = \overrightarrow{ED}_{t-1}/T_{enter}$	(30)
$\overrightarrow{ED}_t = EP_t.PND$	(31)
$\overleftarrow{ed}_t = ND_{t-1}/T_{comp}$	(32)
$\overleftarrow{el}_t = \overleftarrow{EL}_{t-1}/T_{enter}$	(33)
$AUL_t = UL_t/ND_t$	(34)
$NIC_t = AUL_t.\tilde{F}_t^*$	(35)
$IIC_t = NCM_t.NIC_t$	(36)
$TIC_t = \overrightarrow{ED}_t.IIC_t$	(37)
$NCM_t = \left((NCM_t^* - NCM_{t-1})/T_{adjc}\right) + NCM_{t-1}$	(38)
$NCM_t^* = EP_{t-1}.(NCM_{t-1} + 1)$	(39)
$CP_t = PH_t/(CUC_t + LUC_t)$	(40)

$EP_t = \begin{cases} CP_t^{\beta}, & CP_t > 1 \\ 0, & CP_t \leq 1 \end{cases}$	(41)
$CUC_t = \left((1/A)^{(1/\alpha)}\right).PC_t.\tilde{F}_t^{*(1-\alpha/\alpha)}$	(42)
$LUC_t = PL_t/\tilde{F}_t^*$	(43)
$F_t^* = RF^*.\left((PL_{t-1}/RPL).(RPC/PC_{t-1})\right)^{\alpha}$	(44)
$\tilde{F}_t^* = \left((F_t^* - \tilde{F}_{t-1}^*)/T_{perceive}\right) + \tilde{F}_{t-1}^*$	(45)
$C_t = AUL_t.\left(PC_0/(A.\alpha.P_h)\right)^{(1/(\alpha-1))}$	(46)
$DC_t = Max\left(\left(\left(\left(\tilde{F}_t^*.AUL_t\right) - (MBD_t.AUL_t)\right).MUC_t\right)/C_t, 0\right)$	
$EDC_t = \begin{cases} DC_t, & \tilde{F}_t^* > MBD \\ 0, & \tilde{F}_t^* \leq MBD \end{cases}$	(47)
$PC_t = PC_0 + EDC_t$	(48)
$PH_t = RH_t/\rho$	(49)
$RH_t = \left((RH_t^* - RH_{t-1})/T_{adjr}\right) + RH_{t-1}$	(50)
$RH_t^* = RH_{t-1}.(THD_{t-1}/HS_{t-1})^{\sigma h}$	(51)
$IHD_{t,j}^* = B_h + \frac{d.\left(I_j - RH_t.B_h - B_o\right)}{RH_t}$ $\forall\, j \in \{1,2,3,\ldots,10\}$, Number of Income Groups	(52)
$IHD_{t,j} = \left((IHD_{t,j}^* - IHD_{t-1,j})/T_{adjd,j}\right) + IHD_{t-1,j}$	(53)
$mhn_{t,j} = \left(Min\left(sgn(IHD_{t,j}^* - B_h).\left(HN_{t-1,j}.\left(\frac{\lvert IHD_{t,j}^* - B_h\rvert}{B_h}\right)^{ed}\right), 0\right)\Big/ Texit\right)$	(54)
$IHN_t = IHN_{t-1} + \sum_{j=1}^{10} mhn_{t,j}$	(55)
$THD_t = \sum_{j=1}^{10} HN_{t,j}.IHD_{t,j}$	(56)

Notations

LDN	Land Demand for New Construction
LD	Land Demand
BL	Built-up Land Stock
UL	Under-Construction Land Stock
$adjLD$	Adjusted Land Demand
SA	Land Sales
$adjSA$	Adjusted Land Sales
LS	Initial Land Supply
$LSadjUGB\&MLS$	Land Supply Adjusted by UGB and MLS
$adjLS$	Adjusted Land Supply
dv	Land Development Rate
dm	Demolition Rate
T_{comp}	Time for Completing Construction
DL	Post-demolition Land Stock
dls	Post-demolition Land Sales Rate
$udls$	Sales Rate of Undeveloped Land
RLS	Reference Land Supply
θ	Fraction of Decrease in Supply Due to MLS Restriction
σl	Sensitivity of Land Price Adjustment to the Demand-and-Supply Imbalance
PL	Land Price
RPL	Reference Land Price
el	Price Elasticity of Land Supply
$SLinUGB$	Total Suppliable Land Inside UGB
DAC	Developed Area of the City
DLS	Post-demolition Land Sales
T_{sell}	Time for Selling
$UDLS$	Undeveloped Land Sales
$adjUDLS$	Adjusted Undeveloped Land Sales
MLS	Minimum Lot Size
LLS	Lower Bound Lot Size
PL^{*}	Objective Land Price
T_{adjl}	Time for Adjusting Land Price
ac	Actual Construction Start Rate
T_{start}	Time for Starting Construction
δ	Fractional Demolition Rate
T_{dem}	Time Needed for Demolition
cc	Construction Completion Rate
UH	Under Construction Housing Stock
BH	Built Housing Stock
$\overleftarrow{EL}$	Number of Developers Leaving the Market
$\overleftarrow{el}$	Developers Rate of Leave
T_{enter}	Time for Entering the Market
$\overrightarrow{ED}$	Number of Developers Entering the Market
$\overrightarrow{ed}$	Developers Entrance Rate
PND	Potential Number of Developers
$\overleftarrow{ed}$	Developers Exit Rate

ND	Number of Developers Active in the Market
AUL	Average Under-Construction Land Lot
NIC	Normal Individual Construction
NCM	Normal Construction Multiplier
TIC	Aggregate Intended Construction
IIC	Individual Intended Construction
NCM^*	Objective Normal Construction Multiplier
T_{adjc}	Time for Adjusting Normal Construction Multiplier
EP	Effect of Profit on Construction
CP	Construction Profit
β	Sensitivity of Construction to Profit
CUC	Construction Cost Per Square Meter of Building
LUC	Land Cost Per Square Meter of Building
PH	Housing Price
A	Production Scale
α	Sensitivity of Housing Production to Capital Factor
PC	Price of capital Factor
PC_0	Initial Price of Capital Factor
MBD	Maximum Building Density
$\tilde{F}^*$	Perceived Optimum Building Density
F^*	Optimum Building Density
RF^*	Reference Optimum Building Density
RPC	Reference Price of Capital Factor
DC	Development Charge
MUC	Municipal Unit Charge
C	Capital Factor
σh	Sensitivity of Housing Rent Adjustment to the Demand-and-Supply Imbalance
RH	Housing Rent
ρ	Cost of Capital
T_{adjr}	Time for Adjusting Housing Rent
RH^*	Objective Housing Rent
THD	Aggregate Housing Demand
HN	Number of Households
IHD	Actual Individual Housing Demand
IHD^*	Objective Individual Housing Demand
T_{adjd}	Time for Adjusting Individual Housing Demand
I_j	Income Level of Households in j income category
$T_{perceive}$	Time for Perceiving Optimum Building Density
ed	the elasticity of number of marginalized households to the relative discrepancy between the objective individual housing demand and the minimum liveable space
d	Share of Supernumerary Income Devoted to Rent Housing Space
B_o	Monetary Value of the Necessary Amount of All Other Goods
B_h	Minimum Liveable Space
mhn_j	Marginalization Rate of Households in j income category
T_{adjh}	Time for Adjusting Household Number
$IF\ THEN\ ELSE$	If Function
$INTEGER$	Integer Part of a Real Figure

Max	Maximum Function
Min	Minimum Function
sgn	Sign Function

Appendix B: Parameters and stock variables' initial values

I have used four sources to define the values of parameters: existing data or estimations, direct statistical estimation, determining a reasonable value, and determining a reasonable range of values. I have defined most of the parameters by using the first two sources for the parameters. However, for some of the parameters, there is no estimation. These parameters can be divided into two categories: the first category is time-related parameters, and the second is sensitivity. I have defined reasonable values for these parameters. I have defined a reasonable range of values for three types of planning regulations to perform the sensitivity analysis.

Notation	Parameter Title	Value	Unit
T_{comp}	Time for Completing Construction	8	Quarter
δ	Fractional Demolition Rate	1	Percent per Quarter
MUC	Municipal Unit Charge	100,000	Toman per Square Meter
I_1	Income Level of Households in the First Income Category	3,152,239	Toman
I_2	Income Level of Households in the Second Income Category	5,302,855	Toman
I_3	Income Level of Households in the Third Income Category	6,693,526	Toman
I_4	Income Level of Households in the Fourth Income Category	7,959,819	Toman
I_5	Income Level of Households in the Fifth Income Category	9,288,787	Toman
I_6	Income Level of Households in the Sixth Income Category	10,790,121	Toman
I_7	Income Level of Households in the Seventh Income Category	12,597,622	Toman
I_8	Income Level of Households in the Eighth Income Category	15,086,164	Toman
I_9	Income Level of Households in the Ninth Income Category	19,560,440	Toman
I_{10}	Income Level of Households in the Tenth Income Category	29,433,470	Toman
d_1	Share of Supernumerary Income Devoted to Rent Housing Space by Households in the First Income Category	32.2	Percent
d_2	Share of Supernumerary Income Devoted to Rent Housing Space by Households in the Second Income Category	30.4	Percent
d_3	Share of Supernumerary Income Devoted to Rent Housing Space by Households in the Third Income Category	29.5	Percent

Notation	Parameter Title	Value	Unit
d_4	Share of Supernumerary Income Devoted to Rent Housing Space by Households in the Fourth Income Category	29.3	Percent
d_5	Share of Supernumerary Income Devoted to Rent Housing Space by Households in the Fifth Income Category	28.5	Percent
d_6	Share of Supernumerary Income Devoted to Rent Housing Space by Households in the Sixth Income Category	28.6	Percent
d_7	Share of Supernumerary Income Devoted to Rent Housing Space by Households in the Seventh Income Category	27.9	Percent
d_8	Share of Supernumerary Income Devoted to Rent Housing Space by Households in the Eighth Income Category	28.0	Percent
d_9	Share of Supernumerary Income Devoted to Rent Housing Space by Households in the Ninth Income Category	27.3	Percent
d_{10}	Share of Supernumerary Income Devoted to Rent Housing Space by Households in the Tenth Income Category	27.8	Percent
B_o	Monetary Value of the Necessary Amount of All Other Goods	1,859,100	Toman
B_h	Minimum Liveable Space	30	Square Meter
AUL	Average Under-construction Land Lot	202	Square Meter
RP_l	Reference Land Price**	346,658	Toman per Square Meter
RF^*	Reference Optimum Building Density**	327	Percent
T_{adjr}	Time for Adjusting Housing Rent	2	Quarter
T_{adjl}	Time for Adjusting Land Price	2	Quarter
el	Price Elasticity of Land Supply	0.4	Dimensionless
ρ	Cost of Capital	0.06	Dimensionless
A	Production Scale	1.17	Dimensionless
α	Sensitivity of Housing Production to Capital Factor	0.58	Dimensionless
PC	Price of capital Factor	285,000	Toman per Square Meter
PC_0	Initial Price of Capital Factor	285,000	Toman per Square Meter
T_{sell}	Time for Selling	1	Quarter
T_{start}	Time for Starting Construction	1	Quarter
T_{dem}	Time Needed for Demolition	1	Quarter
T_{enter}	Time for Entering the Market	1	Quarter
T_{adjc}	Time for Adjusting Normal Construction Multiplier	8	Quarter
T_{adjd}	Time for Adjusting Individual Housing Demand	4	Quarter
T_{adjh}	Time for Adjusting Household Number	4	Quarter
$T_{perceive}$	Time for Perceiving Optimum Building Density	1	Quarter
β	Sensitivity of Construction to Profit	1	Dimensionless

Notation	Parameter Title	Value	Unit
σl	Sensitivity of Land Price Adjustment to the Demand-and-Supply Imbalance	1	Dimensionless
σh	Sensitivity of Housing Rent Adjustment to the Demand-and-Supply Imbalance	1	Dimensionless
ed	Sensitivity of Number of Marginalized Households to the Relative Discrepancy between the Objective Individual Housing Demand and the Minimum Liveable Space	1	Dimensionless
PND	Potential Number of Developers**	1,150	Dimensionless
MLS	Minimum Lot Size	{80*, 200, 250, 300}	Square Meter
θ	Fraction of Decrease in Supply Due to MLS Restriction	{0*, 50, 72, 84}	Percent
MBD	Maximum Building Density	{1000*, 300, 240, 180, 120}	Percent
$SLinUGB$	Total Suppliable Land inside UGB	{23,760,750*, 19,800,625 17,424,550, 16,236,513}	Square Meter

*Non-binding modes of regulations
**Defined through the tuning process.

Notation	Stock Variable Title	Initial Value	Unit
BL	Built-up Land Stock	14,345,700	Square Meter
DL	Post-demolition Land Stock	346,925	Square Meter
UL	Under Construction Land Stock	1,147,880	Square Meter
RLS	Reference Land Supply	15,840,500	Square Meter
PL	Land Price	340,222	Toman per Square Meter
UH	Under Construction Housing Stock	3,715,490	Square Meter
BH	Built Housing Stock	46,435,000	Square Meter
ND	Number of Developers Active in the Market	5,684	Dimensionless
NCM	Normal Construction Multiplier	1.6	Dimensionless
RH	Housing Rent	36,845	Toman per Square Meter
IHD_1	Actual Individual Housing Demand of Households in the First Income Category	31.6	Square Meter
IHD_2	Actual Individual Housing Demand of Households in the Second Income Category	49.3	Square Meter
IHD_3	Actual Individual Housing Demand of Households in the Third Income Category	59.8	Square Meter
IHD_4	Actual Individual Housing Demand of Households in the Fourth Income Category	69.7	Square Meter
IHD_5	Actual Individual Housing Demand of Households in the Fifth Income Category	78.9	Square Meter
IHD_6	Actual Individual Housing Demand of Households in the Sixth Income Category	90.7	Square Meter

Notation	Stock Variable Title	Initial Value	Unit
IHD_7	Actual Individual Housing Demand of Households in the Seventh Income Category	102.9	Square Meter
IHD_8	Actual Individual Housing Demand of Households in the Eighth Income Category	122	Square Meter
IHD_9	Actual Individual Housing Demand of Households in the Ninth Income Category	153.1	Square Meter
IHD_{10}	Actual Individual Housing Demand of Households in the Tenth Income Category	229.9	Square Meter
$\tilde{F}^*$	Perceived Optimum Building Density	323	Percent
HN_j	Number of Households in Each Income Category	47,000	Dimensionless

Appendix C: Vensim Formulas

Formulas/Parameters/Initial Values	Units
a=0.58	Dimensionless
Absolute High Income Groups Household Increase=353	1/Quarter
Absolute Low Income Group Household Increase=353	1/Quarter
Absolute Middle Income Groups Household Increase=353	1/Quarter
Actual Building Density=Housing Stock/Built Land Stock	Dimensionless
Actual Individual Housing Demand1= INTEG (Change in Housing Demand1,31.6401)	Square Meter
Actual Individual Housing Demand10= INTEG (Change in Housing Demand10,229.963)	Square Meter
Actual Individual Housing Demand2= INTEG (Change in Housing Demand2,49.2908)	Square Meter
Actual Individual Housing Demand3= INTEG (Change in Housing Demand3,59.8286)	Square Meter
Actual Individual Housing Demand4= INTEG (Change in Housing Demand4,69.6804)	Square Meter
Actual Individual Housing Demand5= INTEG (Change in Housing Demand5,78.8811)	Square Meter
Actual Individual Housing Demand6= INTEG (Change in Housing Demand6,90.6727)	Square Meter
Actual Individual Housing Demand7= INTEG (Change in Housing Demand7,102.906)	Square Meter
Actual Individual Housing Demand8= INTEG (Change in Housing Demand8,122.007)	Square Meter
Actual Individual Housing Demand9= INTEG (Change in Housing Demand9,153.11)	Square Meter
Adjusted Land Demand=Land Demand-(Land Sales-Adjusted Land Sales)	Square Meter

Formulas/Parameters/Initial Values	Units
Adjusted Land Sales=Demolished Buildings Land Sales+Adjusted Undeveloped Land Sales	Square Meter
Adjusted Land Supply=Land Supply-(Land Sales-Adjusted Land Sales)	Square Meter
Adjusted Undeveloped Land Sales=IF THEN ELSE(Undeveloped Land Sales>=Minimum Lot Size,Undeveloped Land Sales,0)	Square Meter
Aggregate Intended Construction Rate=Entering Developers*Individual Intended Construction Rate	Square Meter
Annual Growth Rate=0.03	Dimensionless
Average Actual Housing Demand=((Actual Individual Housing Demand1*Household Number1)+(Actual Individual Housing Demand2*Household Number2)+(Actual Individual Housing Demand3*Household Number3)+(Actual Individual Housing Demand4*Household Number4)+(Actual Individual Housing Demand5*Household Number5)+(Actual Individual Housing Demand6*Household Number6)+(Actual Individual Housing Demand7*Household Number7)+(Actual Individual Housing Demand8*Household Number8)+(Actual Individual Housing Demand9*Household Number9)+(Actual Individual Housing Demand10*Household Number10))/Total Number of Household	Square Meter
Average Household Income=((Household Income1*Household Number1)+(Household Income2*Household Number2)+(Household Income3*Household Number3)+(Household Income4*Household Number4)+(Household Income5*Household Number5)+(Household Income6*Household Number6)+(Household Income7*Household Number7)+(Household Income8*Household Number8)+(Household Income9*Household Number9)+(Household Income10*Household Number10))/Total Number of Household	Toman
Average new construction lot size=IF THEN ELSE(Entering Developers=0,0,Land Sales/Entering Developers)	Square Meter
"Average Under-Construction Land Lot"=Under Construction Land Stock/Number of Developers	Square Meter
Built Land Clearation Rate=Demolition Rate/Actual Building Density	Square Meter/Quarter
Built Land Stock= INTEG (Land Development Rate-Built Land Clearation Rate,1.43457e+07)	Square Meter
Capital Factor=((Initial Price of Capital Factor/(Production Scale*a*(Housing Price+0.0001)))^(1/(a-1)))*Normal Construction Rate Multiplier*"Average Under-Construction Land Lot"	Square Meter
Change in Household Number1=MIN(((((ABS(Objective Individual Household Demand1-Minimum Liveable Space))/Minimum Liveable Space)^Sensitivity of Informal Household Number to Affordability Gap)*((ABS(Objective Individual Household Demand1-Minimum Liveable Space))/(Objective Individual Household Demand1-Minimum Liveable Space))*Household Number1)/Time for Adjusting Household Number1,0)	1/Quarter
Change in Household Number10=MIN((((Objective Individual Housing Demand10-Minimum Liveable Space)/Minimum Liveable Space)*Household Number10)/Time for Adjusting Household Number10,0)	1/Quarter

Formulas/Parameters/Initial Values	Units
Change in Household Number2=MIN((((Objective Individual Household Demand2-Minimum Liveable Space)/Minimum Liveable Space)*Household Number2)/Time for Adjusting Household Number2,0)	1/Quarter
Change in Household Number3=MIN((((Objective Individual Household Demand3-Minimum Liveable Space)/Minimum Liveable Space)*Household Number3)/Time for Adjusting Household Number3,0)	1/Quarter
Change in Household Number4=MIN((((Objective Individual Housing Demand4-Minimum Liveable Space)/Minimum Liveable Space)*Household Number4)/Time for Adjusting Household Number4,0)	1/Quarter
Change in Household Number5=MIN((((Objective Individual Housing Demand5-Minimum Liveable Space)/Minimum Liveable Space)*Household Number5)/Time for Adjusting Household Number5,0)	1/Quarter
Change in Household Number6=MIN((((Objective Individual Housing Demand6-Minimum Liveable Space)/Minimum Liveable Space)*Household Number6)/Time for Adjusting Household Number6,0)	1/Quarter
Change in Household Number7=MIN((((Objective Individual Housing Demand7-Minimum Liveable Space)/Minimum Liveable Space)*Household Number7)/Time for Adjusting Household Number7,0)	1/Quarter
Change in Household Number8=MIN((((Objective Individual Housing Demand8-Minimum Liveable Space)/Minimum Liveable Space)*Household Number8)/Time for Adjusting Household number8,0)	1/Quarter
Change in Household Number9=MIN((((Objective Individual Housing Demand9-Minimum Liveable Space)/Minimum Liveable Space)*Household Number9)/Time for Adjusting Household Number9,0)	1/Quarter
Change in Housing Demand1=(Objective Individual Household Demand1-Actual Individual Housing Demand1)/Time for Adjusting Housing demand1	Square Meter/Quarter
Change in Housing Demand10=(Objective Individual Housing Demand10-Actual Individual Housing Demand10)/Time for Adjusting Housing Demand10	Square Meter/Quarter
Change in Housing Demand2=(Objective Individual Household Demand2-Actual Individual Housing Demand2)/Time for Adjusting Housing Demand2	Square Meter/Quarter
Change in Housing Demand3=(Objective Individual Household Demand3-Actual Individual Housing Demand3)/Time for Adjusting Housing Demand3	Square Meter/Quarter
Change in Housing Demand4=(Objective Individual Housing Demand4-Actual Individual Housing Demand4)/Time for Adjusting Housing Demand4	Square Meter/Quarter
Change in Housing Demand5=(Objective Individual Housing Demand5-Actual Individual Housing Demand5)/Time for Adjusting Housing Demand5	Square Meter/Quarter
Change in Housing Demand6=(Objective Individual Housing Demand6-Actual Individual Housing Demand6)/Time for Adjusting Housing Demand6	Square Meter/Quarter
Change in Housing Demand7=(Objective Individual Housing Demand7-Actual Individual Housing Demand7)/Time for Adjusting Housing Demand7	Square Meter/Quarter

Formulas/Parameters/Initial Values	Units
Change in Housing Demand8=(Objective Individual Housing Demand8-Actual Individual Housing Demand8)/Time for Adjusting Housing Demand8	Square Meter/Quarter
Change in Housing Demand9=(Objective Individual Housing Demand9-Actual Individual Housing Demand9)/Time for Adjusting Housing Demand9	Square Meter/Quarter
Change in Housing Rent=(Objective Housing Rent-Housing Rent)/Time to Adjust Housing Rent	Toman/Square Meter/Quarter
Change in Land Price=(Objective Land Price-Land Price)/Time to Adjust Land Price	Toman/(Square Meter*Quarter)
Change in Normal Construction Rate Multiplier=(Objective Normal Construction Rate Multiplier-Normal Construction Rate Multiplier)/Time to Adjust Normal Construction Rate Multiplier	1/Quarter
Change in Optimum Building Density=(Optimum Building Density-Perceived Optimum Building Density)/Time to Perceive Optimum Building Density	1/Quarter
Construction Completion Rate=Under Construction Housing Stock/Time for Completing Construction	Square Meter/Quarter
Construction Cost=((1/Production Scale)^(1/a))*Price of capital Factor*(Perceived Optimum Building Density^((1-a)/a))	Toman/Square Meter
Construction Profit=Housing Price/(Construction Cost+Land Cost)	Dimensionless
Construction Start Rate=(Adjusted Land Sales*Perceived Optimum Building Density)/Time to Start Construction	Square Meter/Quarter
Cost of Capital=0.06+STEP(0,20)	Dimensionless
Demolished Building Land Sales Rate=Demolished Buildings Land Sales/Time to Sell	Square Meter/Quarter
Demolished Buildings Land Sales=IF THEN ELSE(Land Sales<=Demolished Buildings Land Stock,Land Sales,Demolished Buildings Land Stock)	Square Meter
Demolished Buildings Land Stock= INTEG (Built Land Clearation Rate-Demolished Building Land Sales Rate,346925)	Square Meter
Demolition Rate=(Housing Stock*Fractional Demolition Rate)/Time Needed for Demolition	Square Meter/Quarter
Developed Area of the City=Built Land Stock+Demolished Buildings Land Stock+Under Construction Land Stock	Square Meter
Developers Entrance Rate=Entering Developers/Time to Entrance	1/Quarter
Developers Exit Rate=Number of Developers/Time for Completing Construction	1/Quarter
Developers Exit Rate2=(Exiting Developers)/Time to Entrance	1/Quarter
Development Charge=MAX((((Perceived Optimum Building Density*"Average Under-Construction Land Lot"*Normal Construction Rate Multiplier)-(Maximum Building Density*"Average Under-Construction Land Lot"*Normal Construction Rate Multiplier))*Municipal Unit Charge)/(Capital Factor+0.0001),0)	Toman/Square Meter
Duration Period of High Income Groups Household Increase=20	Quarter
Duration Period of Low Income Groups Household Increase=20	Quarter
Duration Period of Middle Income Groups Household Increase=20	Quarter
Effect of Profit on Construction=IF THEN ELSE(Construction Profit<=1,0,Construction Profit^Sensitivity of Construction to Profit)	Dimensionless

Formulas/Parameters/Initial Values	Units
Entering Developers=Effect of Profit on Construction*Potential Number of Developers	Dimensionless
Exiting Developers=Exiting Developrs3+Exiting Developers2+Number of Exiting Developers1	Dimensionless
Exiting Developers2=IF THEN ELSE(((Land Sales-Adjusted Land Sales)/Minimum Lot Size)>INTEGER((Land Sales-Adjusted Land Sales)/Minimum Lot Size),INTEGER((Land Sales-Adjusted Land Sales)/Minimum Lot Size)+1,INTEGER((Land Sales-Adjusted Land Sales)/Minimum Lot Size))	Dimensionless
Exiting Developrs3=IF THEN ELSE(Entering Developers>0,IF THEN ELSE(Adjusted Land Sales/Entering Developers<Minimum Available Lot Size,Entering Developers-(Adjusted Land Sales/Minimum Available Lot Size),0),0)	Dimensionless
Fraction of Decrease in Supply = WITH LOOKUP (Minimum Lot Size/Minimum Available Lot Size,([(0,0)-(10,10)],(1,0),(1.25,0.05),(1.875,0.2),(2.5,0.5),(3.125,0.72),(3.75,0.84)))	Dimensionless
Fractional Demolition Rate=0.01+STEP(0,20)	Dimensionless
Household Income1=Initial Household Income1+STEP(Income Growth Rate of Low Income Groups*Initial Household Income1,20)	Toman
Household Income10=Initial Household Income10+STEP(Income Growth Rate of High Income Groups*Initial Household Income10,20)	Toman
Household Income2=Initial Household Income2+STEP(Income Growth Rate of Low Income Groups*Initial Household Income2,20)	Toman
Household Income3=Initial Household Income3+STEP(Income Growth Rate of Low Income Groups*Initial Household Income3,20)	Toman
Household Income4=Initial Household Income4+STEP(Income Growth Rate of Middle Income Groups*Initial Household Income4,20)	Toman
Household Income5=Initial Household Income5+STEP(Income Growth Rate of Middle Income Groups*Initial Household Income5,20)	Toman
Household Income6=Initial Household income6+STEP(Income Growth Rate of Middle Income Groups*Initial Household income6,20)	Toman
Household Income7=Initial Household Income7+STEP(Income Growth Rate of Middle Income Groups*Initial Household Income7,20)	Toman
Household Income8=Initial Household Income8+STEP(Income Growth Rate of High Income Groups*Initial Household Income8,20)	Toman
Household Income9=Initial Household Income9+STEP(Income Growth Rate of High Income Groups*Initial Household Income9,20)	Toman
Household Increase1=IF THEN ELSE(Duration Period of Low Income Groups Household Increase=20,0+STEP(Absolute Low Income Group Household Increase,20)+STEP(-Absolute Low Income Group Household Increase,24)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^2),28)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^2)),32)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^3),32)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^3)),36)+STEP(Absolute Low Income Group Household	1/Quarter

Formulas/Parameters/Initial Values	Units
Increase*((1+Annual Growth Rate)^5),36)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^5)),40),0+STEP(Absolute Low Income Group Household Increase,20)+STEP(-Absolute Low Income Group Household Increase,24)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1.5),28)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1.5)),30))	
Units: Household Increase10=IF THEN ELSE(Duration Period of High Income Groups Household Increase=20,0+STEP(Absolute High Income Groups Household Increase,20)+STEP(-Absolute High Income Groups Household Increase,24)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^2),28)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^2)),32)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^3),32)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^3)),36)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^5),36)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^5)),40),0+STEP(Absolute High Income Groups Household Increase,20)+STEP(-Absolute High Income Groups Household Increase,24)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1.5),28)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1.5)),30))	1/Quarter
Household Increase2=IF THEN ELSE(Duration Period of Low Income Groups Household Increase=20,0+STEP(Absolute Low Income Group Household Increase,20)+STEP(-Absolute Low Income Group Household Increase,24)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^2),28)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^2)),32)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^3),32)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^3)),36)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^5),36)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth	1/Quarter

Formulas/Parameters/Initial Values	Units
Rate)^5)),40),0+STEP(Absolute Low Income Group Household Increase,20)+STEP(-Absolute Low Income Group Household Increase,24)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1.5),28)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1.5)),30))	
Household Increase3=IF THEN ELSE(Duration Period of Low Income Groups Household Increase=20,0+STEP(Absolute Low Income Group Household Increase,20)+STEP(-Absolute Low Income Group Household Increase,24)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^2),28)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^2)),32)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^3),32)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^3)),36)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^5),36)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^5)),40),0+STEP(Absolute Low Income Group Household Increase,20)+STEP(-Absolute Low Income Group Household Increase,24)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1.5),28)+STEP(-(Absolute Low Income Group Household Increase*((1+Annual Growth Rate)^1.5)),30))	1/Quarter
Household Increase4=IF THEN ELSE(Duration Period of Middle Income Groups Household Increase=20,0+STEP(Absolute Middle Income Groups Household Increase,20)+STEP(-Absolute Middle Income Groups Household Increase,24)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^2),28)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^2)),32)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^3),32)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^3)),36)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^5),36)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^5)),40),0+STEP(Absolute Middle Income Groups Household Increase,20)+STEP(-Absolute Middle Income Groups Household Increase,24)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Middle	1/Quarter

Formulas/Parameters/Initial Values	Units
Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1.5),28)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1.5)),30))	
Household Increase5=IF THEN ELSE(Duration Period of Middle Income Groups Household Increase=20,0+STEP(Absolute Middle Income Groups Household Increase,20)+STEP(-Absolute Middle Income Groups Household Increase,24)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^2),28)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^2)),32)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^3),32)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^3)),36)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^5),36)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^5)),40),0+STEP(Absolute Middle Income Groups Household Increase,20)+STEP(-Absolute Middle Income Groups Household Increase,24)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1.5),28)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1.5)),30))	1/Quarter
Household Increase6=IF THEN ELSE(Duration Period of Middle Income Groups Household Increase=20,0+STEP(Absolute Middle Income Groups Household Increase,20)+STEP(-Absolute Middle Income Groups Household Increase,24)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^2),28)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^2)),32)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^3),32)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^3)),36)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^5),36)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^5)),40),0+STEP(Absolute Middle Income Groups Household Increase,20)+STEP(-Absolute Middle Income Groups Household Increase,24)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Middle Income Groups Household	1/Quarter

Formulas/Parameters/Initial Values	Units
Increase*((1+Annual Growth Rate)^1.5),28)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1.5)),30))	
Household Increase7=IF THEN ELSE(Duration Period of Middle Income Groups Household Increase=20,0+STEP(Absolute Middle Income Groups Household Increase,20)+STEP(-Absolute Middle Income Groups Household Increase,24)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^2),28)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^2)),32)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^3),32)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^3)),36)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^5),36)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^5)),40),0+STEP(Absolute Middle Income Groups Household Increase,20)+STEP(-Absolute Middle Income Groups Household Increase,24)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1.5),28)+STEP(-(Absolute Middle Income Groups Household Increase*((1+Annual Growth Rate)^1.5)),30))	1/Quarter
Household Increase8=IF THEN ELSE(Duration Period of High Income Groups Household Increase=20,0+STEP(Absolute High Income Groups Household Increase,20)+STEP(-Absolute High Income Groups Household Increase,24)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^2),28)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^2)),32)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^3),32)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^3)),36)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^5),36)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^5)),40),0+STEP(Absolute High Income Groups Household Increase,20)+STEP(-Absolute High Income Groups Household Increase,24)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1.5),28)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1.5)),30))	1/Quarter

Formulas/Parameters/Initial Values	Units
Household Increase9=IF THEN ELSE(Duration Period of High Income Groups Household Increase=20,0+STEP(Absolute High Income Groups Household Increase,20)+STEP(-Absolute High Income Groups Household Increase,24)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^2),28)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^2)),32)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^3),32)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^3)),36)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^5),36)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^5)),40),0+STEP(Absolute High Income Groups Household Increase,20)+STEP(-Absolute High Income Groups Household Increase,24)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1),24)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1)),28)+STEP(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1.5),28)+STEP(-(Absolute High Income Groups Household Increase*((1+Annual Growth Rate)^1.5)),30))	1/Quarter
Household Number1= INTEG (Change in Household Number1+Household Increase1,47000)	Dimensionless
Household Number10= INTEG (Change in Household Number10+Household Increase10,47000)	Dimensionless
Household Number2= INTEG (Change in Household Number2+Household Increase2,47000)	Dimensionless
Household Number3= INTEG (Change in Household Number3+Household Increase3,47000)	Dimensionless
Household Number4= INTEG (Change in Household Number4+Household Increase4,47000)	Dimensionless
Household Number5= INTEG (Change in Household Number5+Household Increase5,47000)	Dimensionless
Household Number6= INTEG (Change in Household Number6+Household Increase6,47000)	Dimensionless
Household Number7= INTEG (Change in Household Number7+Household Increase7,47000)	Dimensionless
Household Number8= INTEG (Change in Household Number8+Household Increase8,47000)	Dimensionless
Household Number9= INTEG (Change in Household Number9+Household Increase9,47000)	Dimensionless
"Housing Demand/Supply Balance"=Total Demand/Housing Stock	Dimensionless
Housing Price=Housing Rent/Cost of Capital	Toman/Square Meter
Housing Rent= INTEG (Change in Housing Rent,36844.5)	Toman/Square Meter
Housing Stock= INTEG (Construction Completion Rate-Demolition Rate,4.6435e+07)	Square Meter

Formulas/Parameters/Initial Values	Units
Income Growth Rate of High Income Groups=0	Dimensionless
Income Growth Rate of Low Income Groups=0	Dimensionless
Income Growth Rate of Middle Income Groups=0	Dimensionless
Individual Intended Construction Rate=Normal Construction Rate Multiplier*Normal Individual Construction Rate	Square Meter
Initial Household Income1=3.15224e+06	Toman
Initial Household Income10=2.94335e+07	Toman
Initial Household Income2=5.30286e+06	Toman
Initial Household Income3=6.69353e+06	Toman
Initial Household Income4=7.95982e+06	Toman
Initial Household Income4=7.95982e+06	Toman
Initial Household Income5=9.28879e+06	Toman
Initial Household income6=1.07901e+07	Toman
Initial Household Income7=1.25976e+07	Toman
Initial Household Income8=1.50862e+07	Toman
Initial Household Income9=1.95604e+07	Toman
Initial Land Supply=Reference Land Supply*((Land Price/Reference Land Price)^Price Elasticity of Land Supply)	Square Meter
Initial Price of Capital Factor=285000+STEP(0,20)+STEP(0,24)	Toman/Square Meter
Land Cost=Land Price/Perceived Optimum Building Density	Toman/Square Meter
Land Demand=Built Land Stock+Land Demand for New Construction+Under Construction Land Stock	Square Meter
Land Demand for New Construction=Aggregate Intended Construction Rate/Perceived Optimum Building Density	Square Meter
Land Development Rate=Under Construction Land Stock/Time for Completing Construction	Square Meter/Quarter
Land Price= INTEG (Change in Land Price,340222)	Toman/Square Meter
Land Sales=MIN(Land Demand for New Construction,MAX((Land Supply-Built Land Stock-Under Construction Land Stock),0))	Square Meter
Land Supply=Land Supply Adjusted by MLS	Square Meter
Land Supply Adjusted by MLS=IF THEN ELSE(Land Supply Adjusted by UGB>Developed Area of the City,((1-Fraction of Decrease in Supply)*(Land Supply Adjusted by UGB-Developed Area of the City))+Developed Area of the City,Land Supply Adjusted by UGB)	Square Meter
Land Supply Adjusted by UGB=IF THEN ELSE(Initial Land Supply>Total Suppliable Land Inside UGB,Total Suppliable Land Inside UGB,Initial Land Supply)	Square Meter
Maximum Building Density=10+STEP(-8.2,20)	Dimensionless
Minimum Available Lot Size=80	Square Meter
Minimum Liveable Space=30	Square Meter
Minimum Lot Size=200	Square Meter
Municipal Unit Charge=100000	Toman/Square Meter
Normal Construction Rate Multiplier= INTEG (Change in Normal Construction Rate Multiplier,1.60247)	Dimensionless

Formulas/Parameters/Initial Values	Units
Normal Individual Construction Rate=MAX("Average Under-Construction Land Lot",Minimum Available Lot Size)*Perceived Optimum Building Density	Square Meter
Number of Developers= INTEG (Developers Entrance Rate-Developers Exit Rate-Developers Exit Rate2,5683.53)	Dimensionless
Number of Exiting Developers1=MAX(((Adjusted Undeveloped Land Sales*Perceived Optimum Building Density)/Individual Intended Construction Rate)-(Adjusted Undeveloped Land Sales/Minimum Lot Size),0)	Dimensionless
Number of Marginalized Households= INTEG (Resorting Rate,0)	Dimensionless
Objective Housing Rent=Housing Rent*("Housing Demand/Supply Balance"^Sensitivity of Objective Housing Rent to Excess Demand)	Toman/Square Meter
Objective Individual Household Demand1=MAX(Minimum Liveable Space+((Share of Income on Housing1*(Household Income1-(Minimum Liveable Space*Housing Rent)-Total Expenditure on Necessary amount of other Goods))/(Housing Rent+0.001)),0)	Square Meter
Objective Individual Household Demand2=MAX(Minimum Liveable Space+((Share of Income on Housing2*(Household Income2-(Minimum Liveable Space*Housing Rent)-Total Expenditure on Necessary amount of other Goods))/(Housing Rent+0.001)),0)	Square Meter
Objective Individual Household Demand3=MAX(Minimum Liveable Space+((Share of Income on Housing3*(Household Income3-(Minimum Liveable Space*Housing Rent)-Total Expenditure on Necessary amount of other Goods))/(Housing Rent+0.001)),0)	Square Meter
Objective Individual Housing Demand10=MAX(Minimum Liveable Space+((Share of Income on Housing10*(Household Income10-(Minimum Liveable Space*Housing Rent)-Total Expenditure on Necessary amount of other Goods))/(Housing Rent+0.001)),0)	Square Meter
Objective Individual Housing Demand4=MAX(Minimum Liveable Space+((Share of Income on Housing4*(Household Income4-(Minimum Liveable Space*Housing Rent)-Total Expenditure on Necessary amount of other Goods))/(Housing Rent+0.001)),0)	Square Meter
Objective Individual Housing Demand5=MAX(Minimum Liveable Space+((Share of Income on Housing5*(Household Income5-(Minimum Liveable Space*Housing Rent)-Total Expenditure on Necessary amount of other Goods))/(Housing Rent+0.001)),0)	Square Meter
Objective Individual Housing Demand6=MAX(Minimum Liveable Space+((Share of Income on Housing6*(Household Income6-(Minimum Liveable Space*Housing Rent)-Total Expenditure on Necessary amount of other Goods))/(Housing Rent+0.001)),0)	Square Meter
Objective Individual Housing Demand7=MAX(Minimum Liveable Space+((Share of Income on Housing7*(Household Income7-(Minimum Liveable Space*Housing Rent)-Total Expenditure on Necessary amount of other Goods))/(Housing Rent+0.001)),0)	Square Meter
Objective Individual Housing Demand8=MAX(Minimum Liveable Space+((Share of Income on Housing8*(Household Income8-(Minimum Liveable Space*Housing Rent)-Total Expenditure on Necessary amount of other Goods))/(Housing Rent+0.001)),0)	Square Meter
Objective Individual Housing Demand9=MAX(Minimum Liveable Space+((Share of Income on Housing9*(Household Income9-(Minimum	Square Meter

Formulas/Parameters/Initial Values	Units
Liveable Space*Housing Rent)-Total Expenditure on Necessary amount of other Goods))/(Housing Rent+0.001)),0)	
Objective Land Price=Land Price*("Total Land Demand/Supply Balance"^Sensitivity of Objective Land Price to Excess Demand)	Toman/Square Meter
Objective Normal Construction Rate Multiplier=(Normal Construction Rate Multiplier+1)*Effect of Profit on Construction	Dimensionless
Optimum Building Density=Reference Optimum Building Density*(((Land Price/Reference Land Price)*(Reference Price of Capital Factor/Price of capital Factor))^a)	Dimensionless
Perceived Optimum Building Density= INTEG (Change in Optimum Building Density,3.23679)	Dimensionless
Potential Number of Developers=1150	Dimensionless
Price Elasticity of Land Supply=0.4+STEP(0,20)	Dimensionless
Price of capital Factor=Initial Price of Capital Factor+IF THEN ELSE(Perceived Optimum Building Density>Maximum Building Density,Development Charge,0) Production Scale=1.17	Toman/Square Meter
Reference Land Price=346658	Toman/Square Meter
Reference Land Supply=1.58405e+07	Square Meter
Reference Optimum Building Density=3.27223	Dimensionless
Reference Price of Capital Factor=285000	Toman/Square Meter
Resorting Rate=-1*(Change in Household Number1+Change in Household Number2+Change in Household Number3+Change in Household Number4+Change in Household Number5+Change in Household Number6+Change in Household Number7+Change in Household Number8+Change in Household Number9+Change in Household Number10)	1/Quarter
Sales Rate of Undeveloped Land=Adjusted Undeveloped Land Sales/Time to Sell	Square Meter/Quarter
Sensitivity of Objective Housing Rent to Excess Demand=1	Dimensionless
Sensitivity of Objective Land Price to Excess Demand=1	Dimensionless
Sensitivity of Construction to Profit=1	Dimensionless
Sensitivity of Informal Household Number to Affordability Gap=1	Dimensionless
Share of Income on Housing1=0.321755	Dimensionless
Share of Income on Housing10=0.278345	Dimensionless
Share of Income on Housing2=0.303949	Dimensionless
Share of Income on Housing3=0.294715	Dimensionless
Share of Income on Housing4=0.292671	Dimensionless
Share of Income on Housing5=0.284772	Dimensionless
Share of Income on Housing6=0.285657	Dimensionless
Share of Income on Housing7=0.278848	Dimensionless
Share of Income on Housing8=0.279659	Dimensionless
Share of Income on Housing9=0.273316	Dimensionless
Time for Adjusting Household Number1=4	Quarter
Time for Adjusting Household Number10=4	Quarter
Time for Adjusting Household Number2=4	Quarter
Time for Adjusting Household Number3=4	Quarter

Formulas/Parameters/Initial Values	Units
Time for Adjusting Household Number4=4	Quarter
Time for Adjusting Household Number5=4	Quarter
Time for Adjusting Household Number6=4	Quarter
Time for Adjusting Household Number7=4	Quarter
Time for Adjusting Household number8=4	Quarter
Time for Adjusting Household Number9=4	Quarter
Time for Adjusting Housing demand1=4	Quarter
Time for Adjusting Housing Demand10=4	Quarter
Time for Adjusting Housing Demand2=4	Quarter
Time for Adjusting Housing Demand3=4	Quarter
Time for Adjusting Housing Demand4=4	Quarter
Time for Adjusting Housing Demand5=4	Quarter
Time for Adjusting Housing Demand6=4	Quarter
Time for Adjusting Housing Demand7=4	Quarter
Time for Adjusting Housing Demand8=4	Quarter
Time for Adjusting Housing Demand9=4	Quarter
Time for Completing Construction=8+STEP(0,20)	Quarter
Time Needed for Demolition=1	Quarter
Time to Adjust Housing Rent=2	Quarter
Time to Adjust Land Price=2	Quarter
Time to Adjust Normal Construction Rate Multiplier=8	Quarter
Time to Entrance=1	Quarter
Time to Perceive Optimum Building Density=1	Quarter
Time to Start Construction=1	Quarter
Time to Sell=1	Quarter
Total Demand=Total Demand1+Total Demand2+Total Demand3+Total Demand4+Total Demand5+Total Demand6+Total Demand7+Total Demand8+Total Demand9+Total Demand10	Square Meter
Total Demand1=Actual Individual Housing Demand1*Household Number1	Square Meter
Total Demand10=Actual Individual Housing Demand10*Household Number10	Square Meter
Total Demand2=Actual Individual Housing Demand2*Household Number2	Square Meter
Total Demand3=Actual Individual Housing Demand3*Household Number3	Square Meter
Total Demand4=Actual Individual Housing Demand4*Household Number4	Square Meter
Total Demand5=Actual Individual Housing Demand5*Household Number5	Square Meter
Total Demand6=Actual Individual Housing Demand6*Household Number6	Square Meter
Total Demand7=Actual Individual Housing Demand7*Household Number7	Square Meter
Total Demand8=Actual Individual Housing Demand8*Household Number8	Square Meter
Total Demand9=Actual Individual Housing Demand9*Household Number9	Square Meter
Total Expenditure on Necessary amount of other Goods=1.8591e+06	Toman

Formulas/Parameters/Initial Values	**Units**
"Total Land Demand/Supply Balance"=Adjusted Land Demand/Adjusted Land Supply	Dimensionless
Total Number of Household=Household Number1+Household Number2+Household Number3+Household Number4+Household Number5+Household Number6+Household Number7+Household Number8+Household Number9+Household Number10	Dimensionless
Total Suppliable Land Inside UGB=1.62365e+07	Square Meter
Total Unit Cost=Construction Cost+Land Cost	Toman/Square Meter
Under Construction Housing Stock= INTEG (Construction Start Rate-Construction Completion Rate,3.71549e+06)	Square Meter
Under Construction Land Stock= INTEG (Demolished Building Land Sales Rate+Sales Rate of Undeveloped Land-Land Development Rate,1.14788e+06)	Square Meter
Undeveloped Land Sales=MAX(Land Sales-Demolished Buildings Land Sales,0)	Square Meter

Appendix C: Results of Combined Effects of Regulations on Three Major Output Variables

Table 8-1: Modes of combining each pair of three major planning regulations and the population growth rate

Population Growth Rate (%)	Duration of Population Growth (Quarter)	UGB-MBD Combination Modes		UGB-MLS Combination Modes		MBD-MLS Combination Modes	
		UGB Size (% of Initial Developed Area of the City)	MBD (% of Land Area)	UGB Size (% of Initial Developed Area of the City)	MLS (Square Meter)	MBD (% of Land Area)	MLS (Square Meter)
3	20	110	180	110	250	180	250
3	20	102.5	180	102.5	250	120	250
3	20	110	120	110	300	180	300
3	20	102.5	120	102.5	300	120	300
5	20	110	180	110	250	180	250
5	20	102.5	180	102.5	250	120	250
5	20	110	120	110	300	180	300
5	20	102.5	120	102.5	300	120	300
8	20	110	180	110	250	180	250
8	20	102.5	180	102.5	250	120	250
8	20	110	120	110	300	180	300
8	20	102.5	120	102.5	300	120	300
10	20	110	180	110	250	180	250
10	20	102.5	180	102.5	250	120	250
10	20	110	120	110	300	180	300
10	20	102.5	120	102.5	300	120	300

MBD-UGB Results

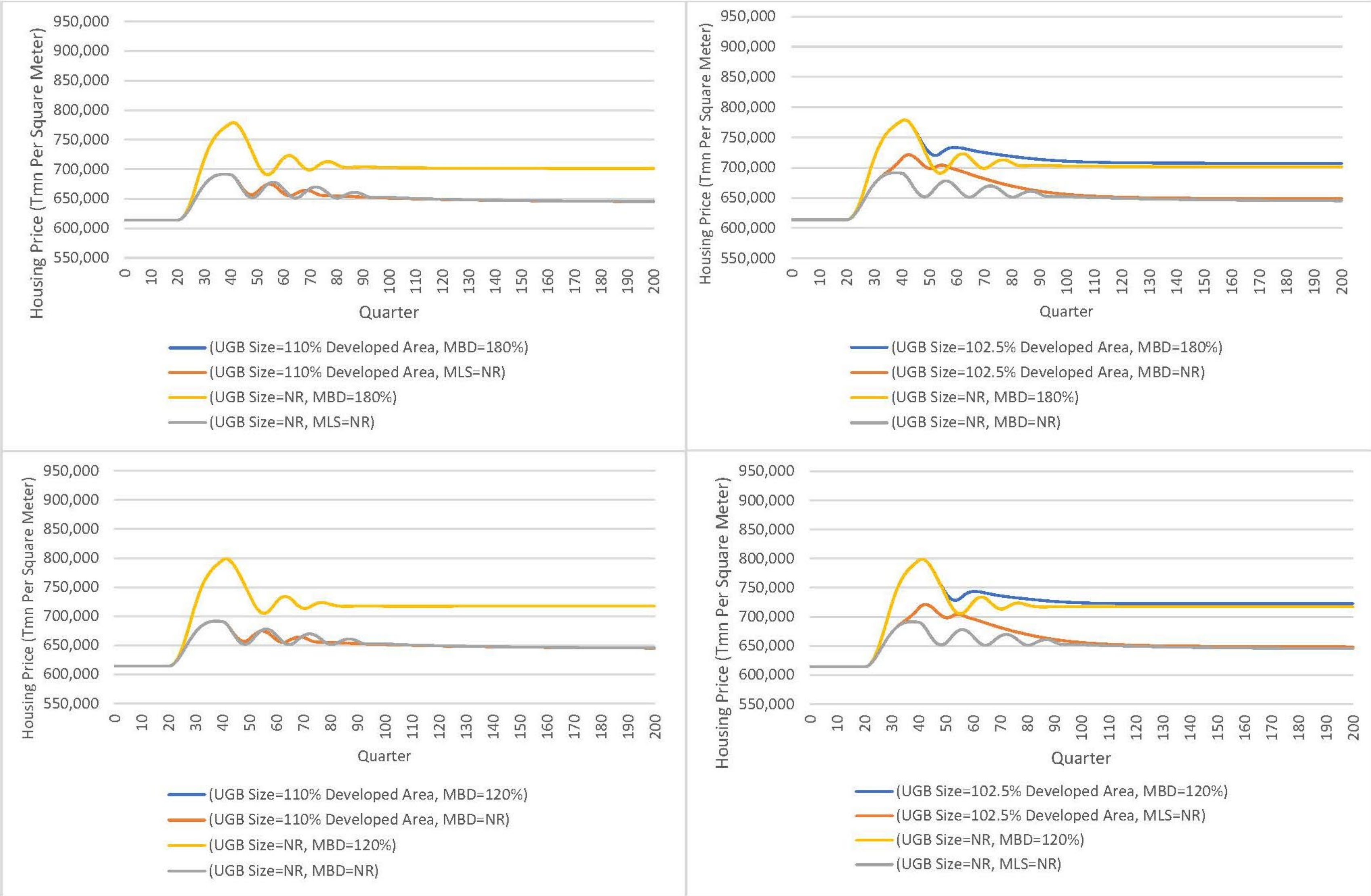


Figure 8-1: The combined effect of MBD and UGB on the housing price under the 3% growth in household number

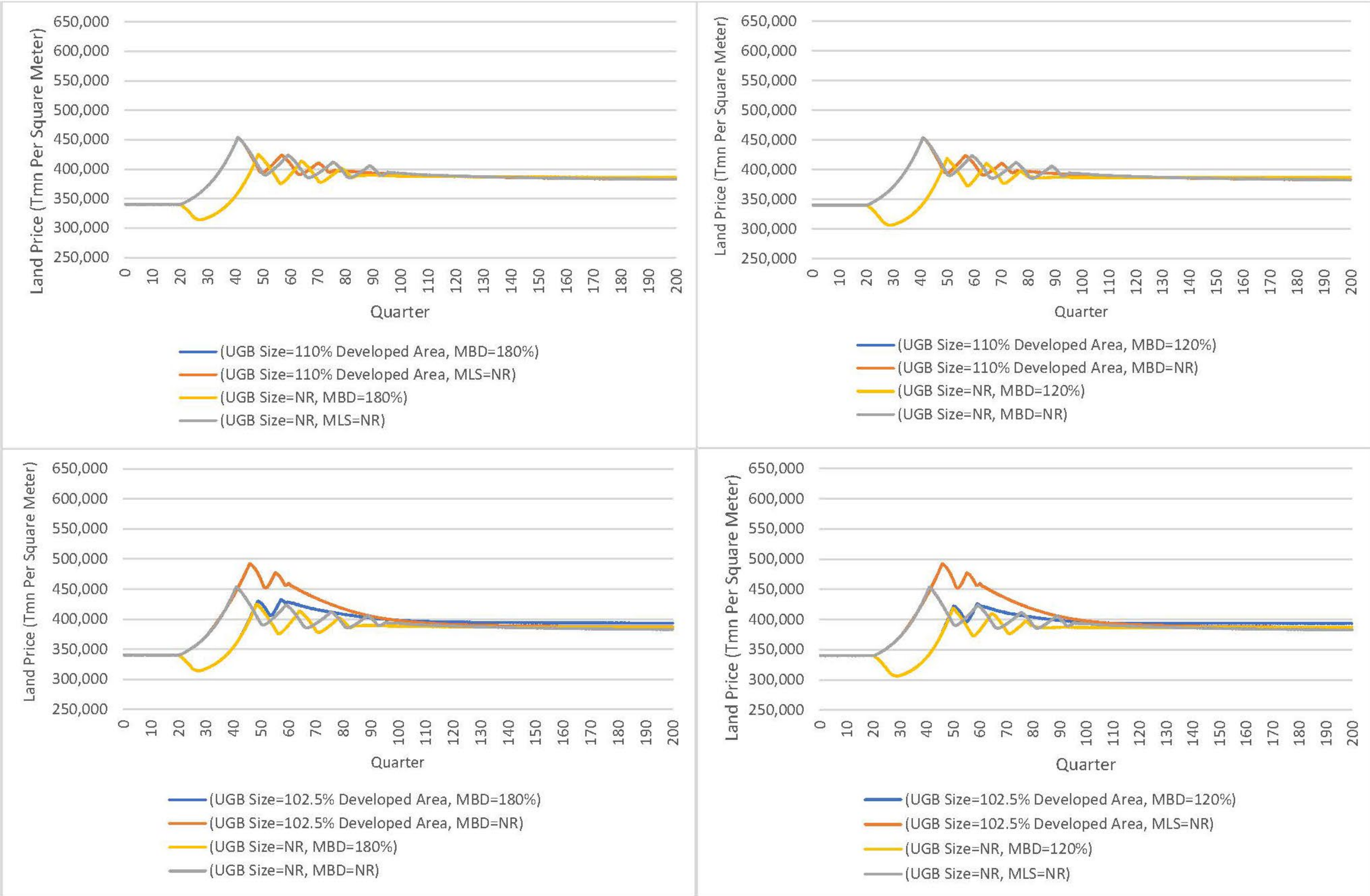


Figure 8-2: The combined effect of MBD and UGB on the land price under the 3% growth in household number

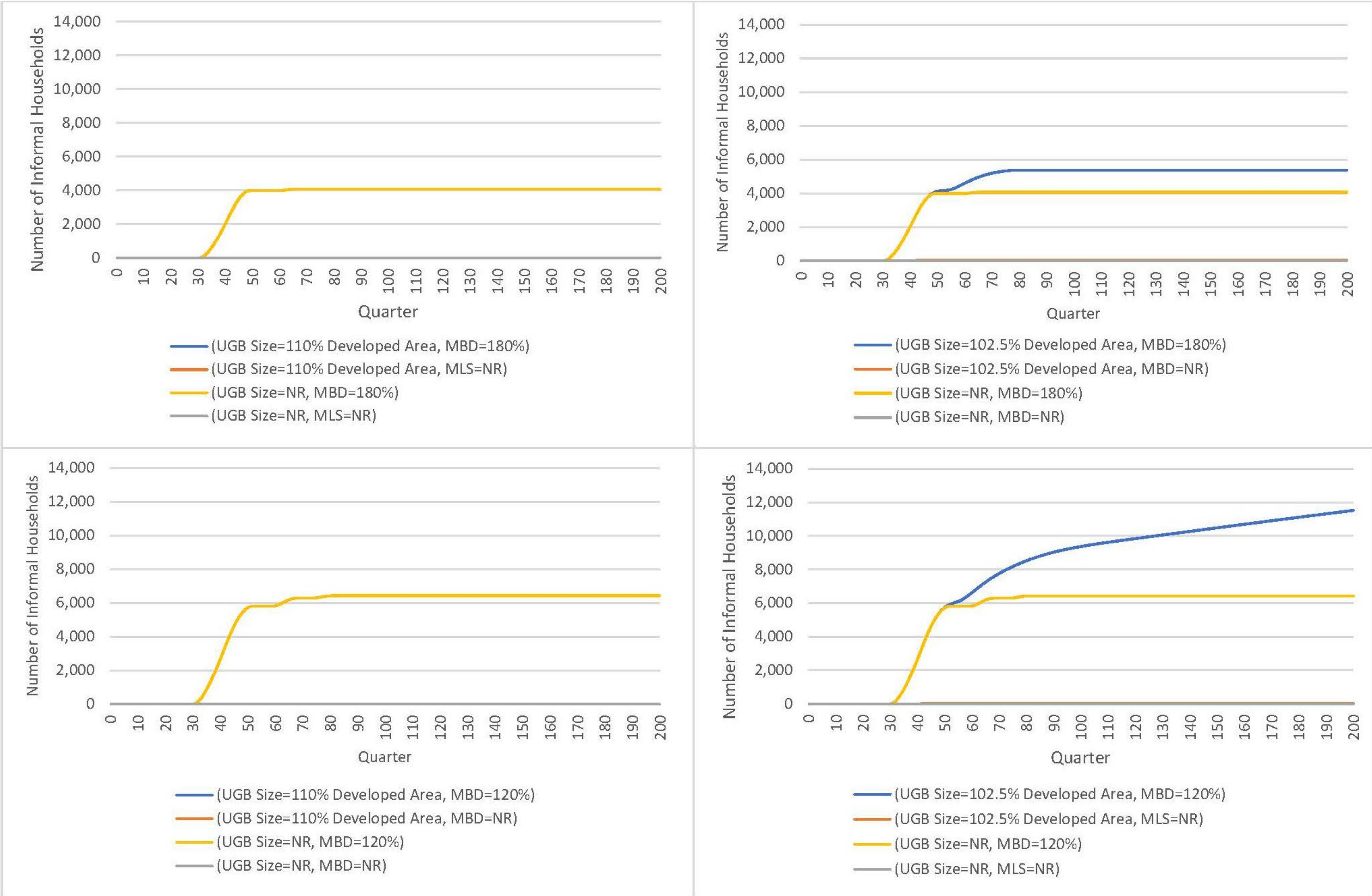


Figure 8-3: The combined effect of MBD and UGB on the number of marginalized households in informal settlements under the 3% growth in household number

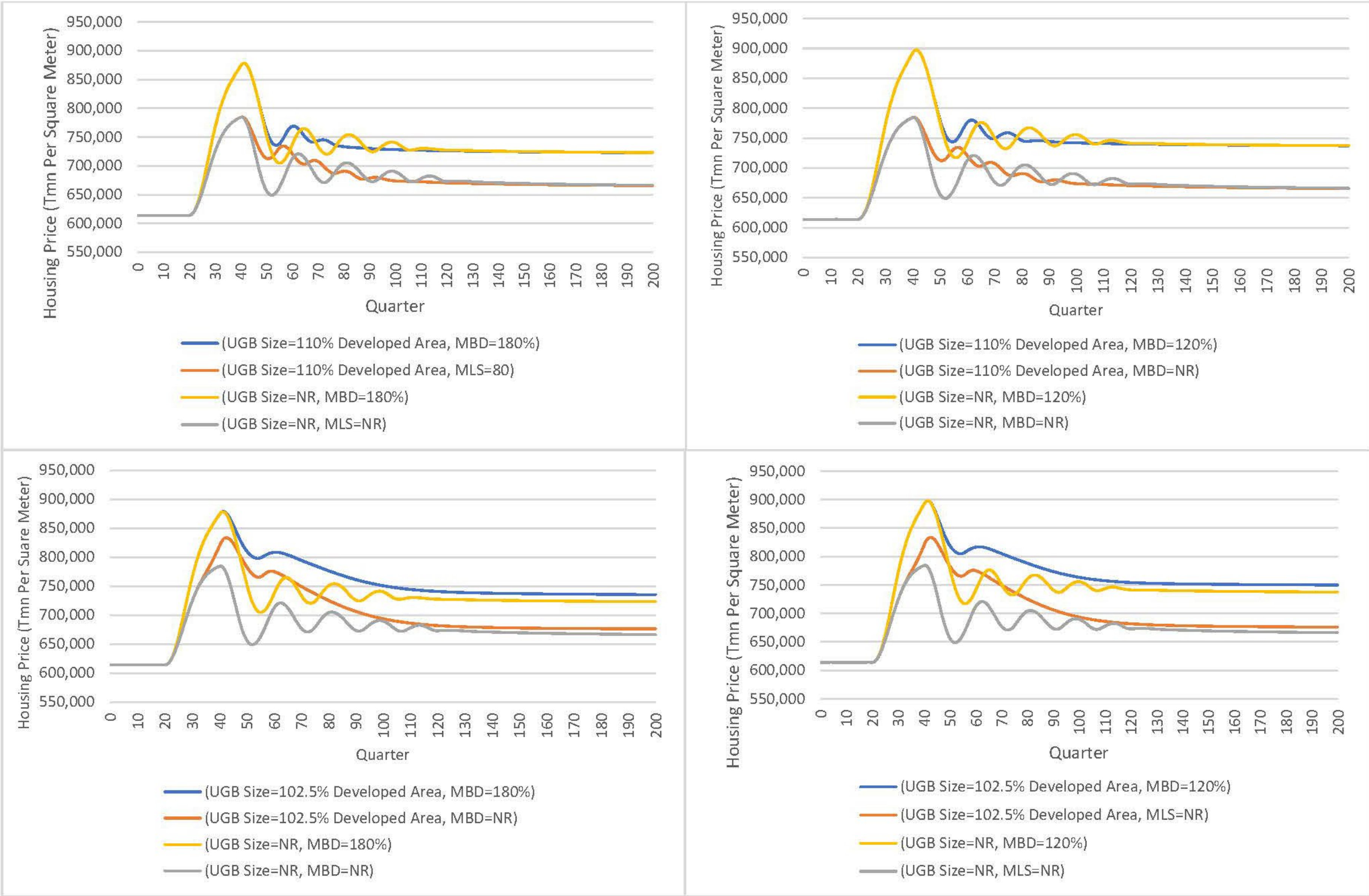


Figure 8-4: The combined effect of MBD and UGB on the housing price under the 5% growth in household number

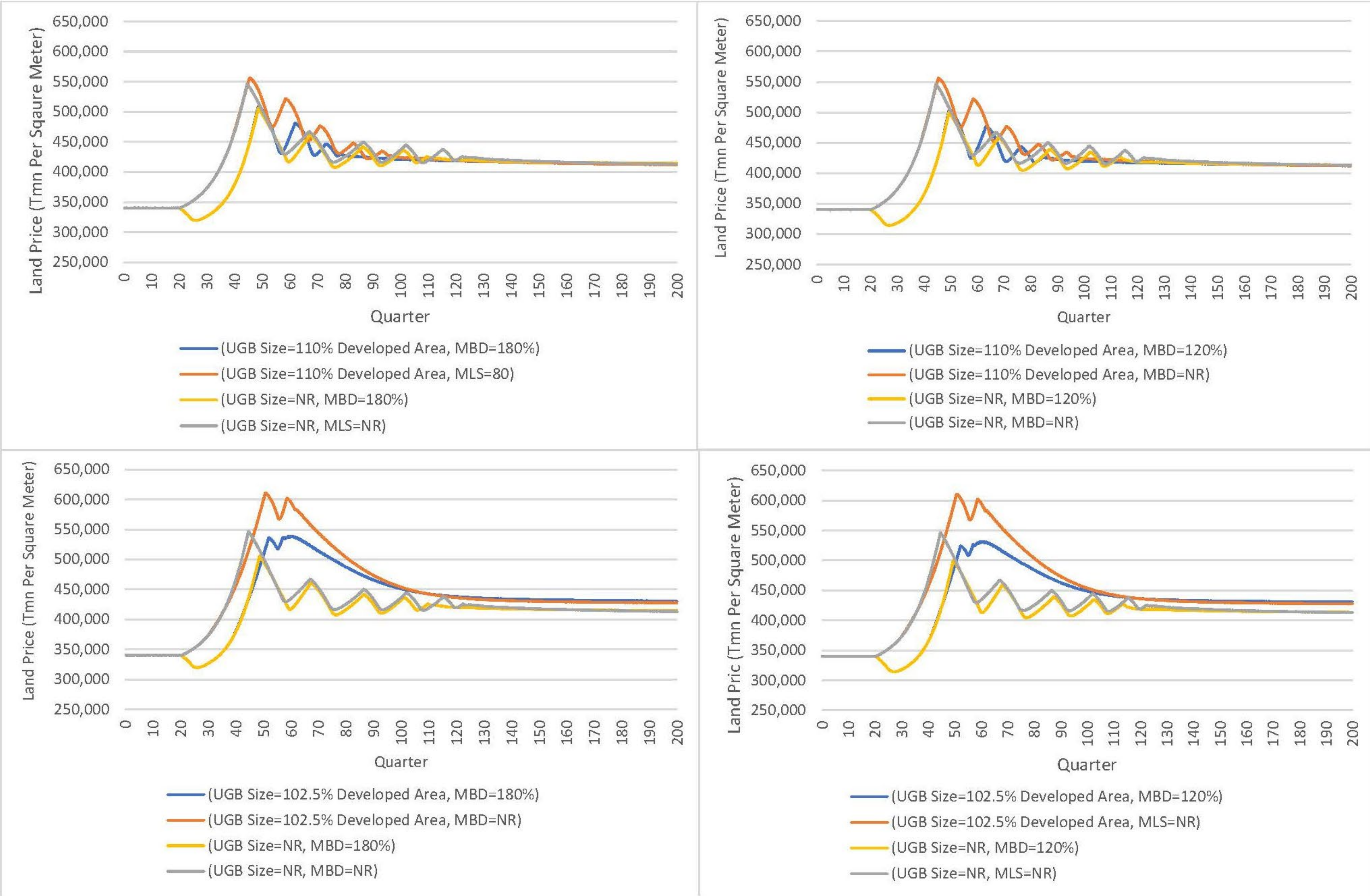


Figure 8-5: The combined effect of MBD and UGB on the land price under the 5% growth in household number

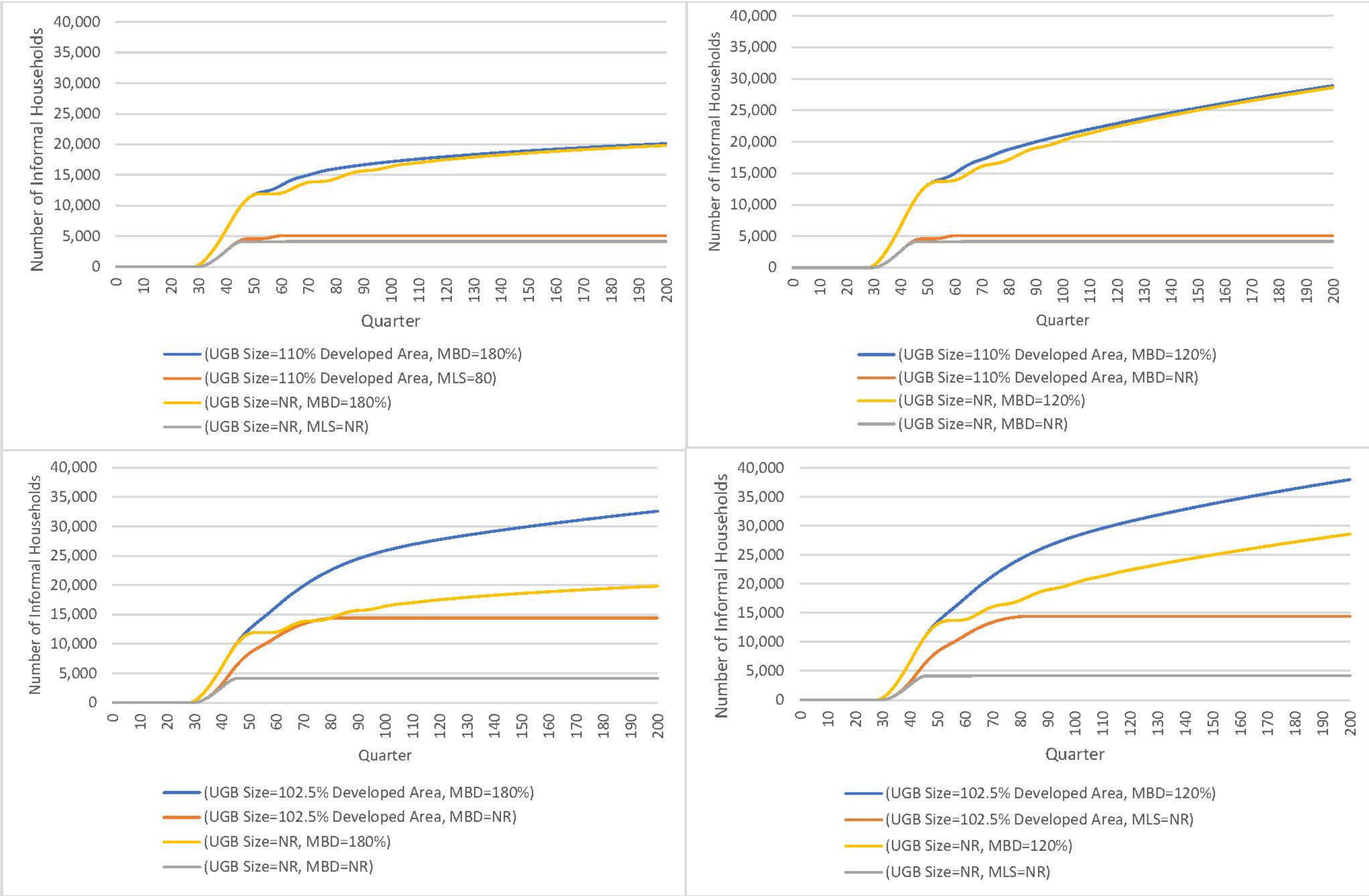


Figure 8-6: The combined effect of MBD and UGB on the number of marginalized households in informal settlements under the 5% growth in household number

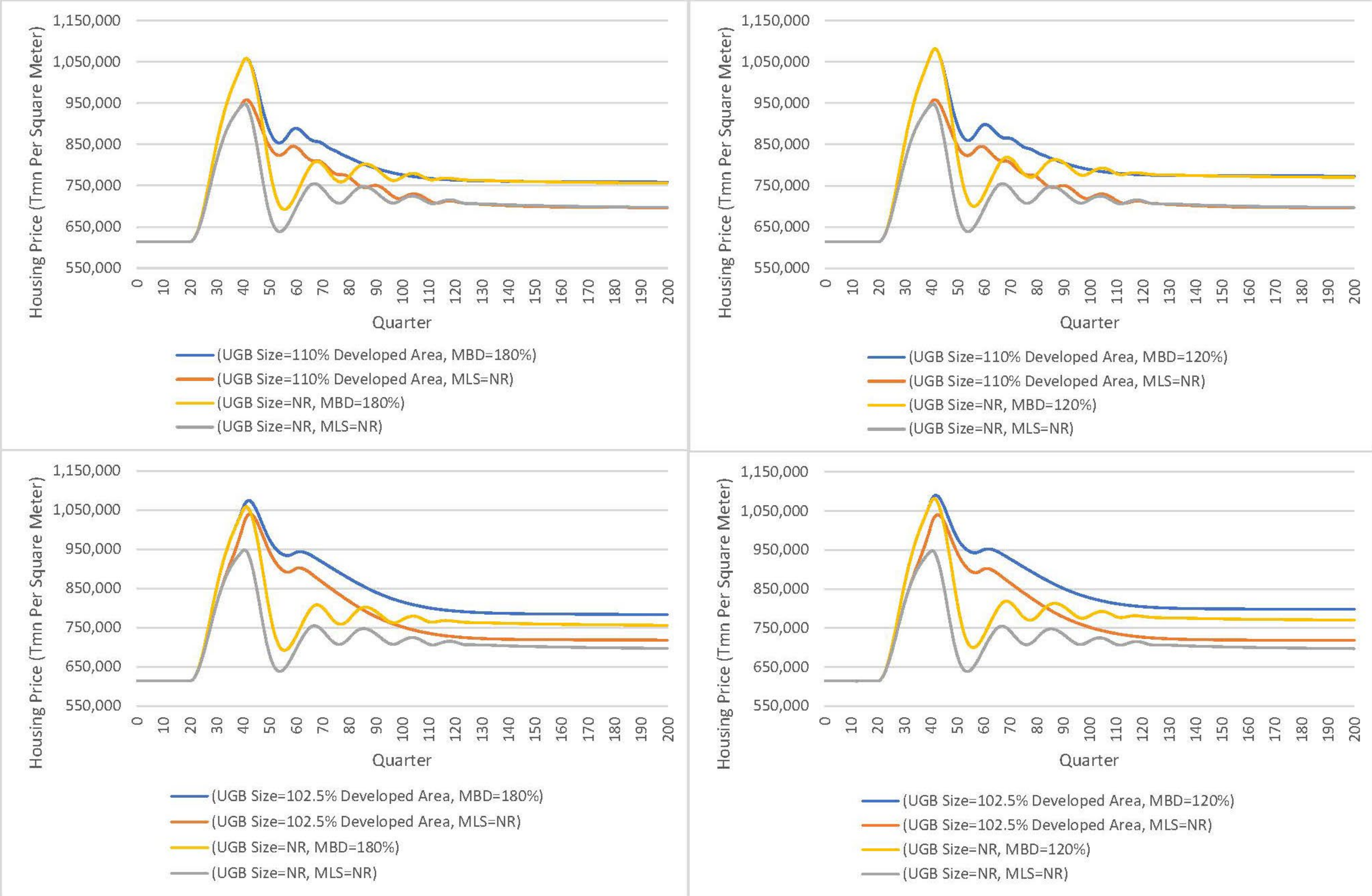


Figure 8-7: The combined effect of MBD and UGB on the housing price under the 8% growth in household number

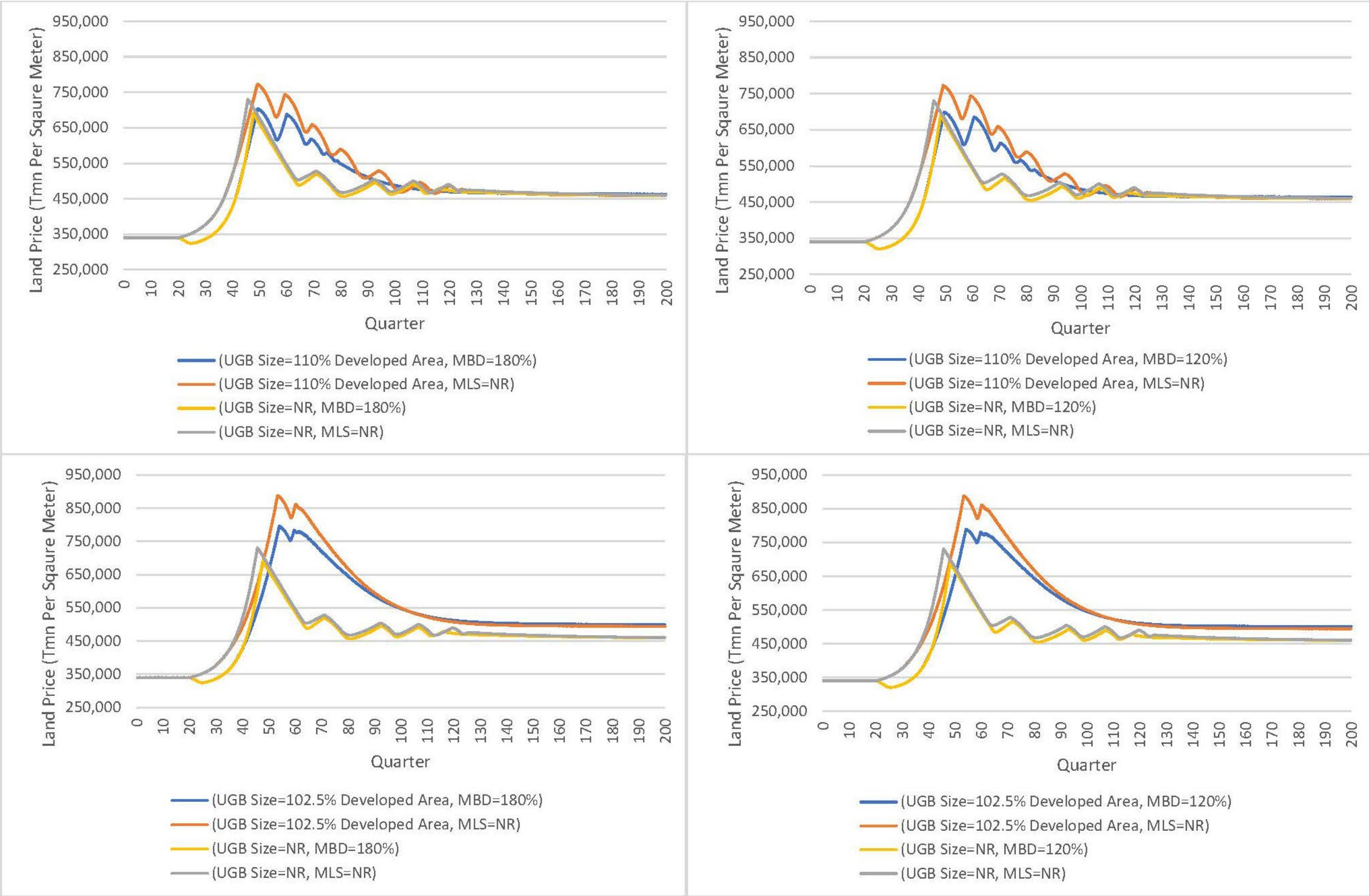


Figure 8-8: The combined effect of MBD and UGB on the land price under the 8% growth in household number

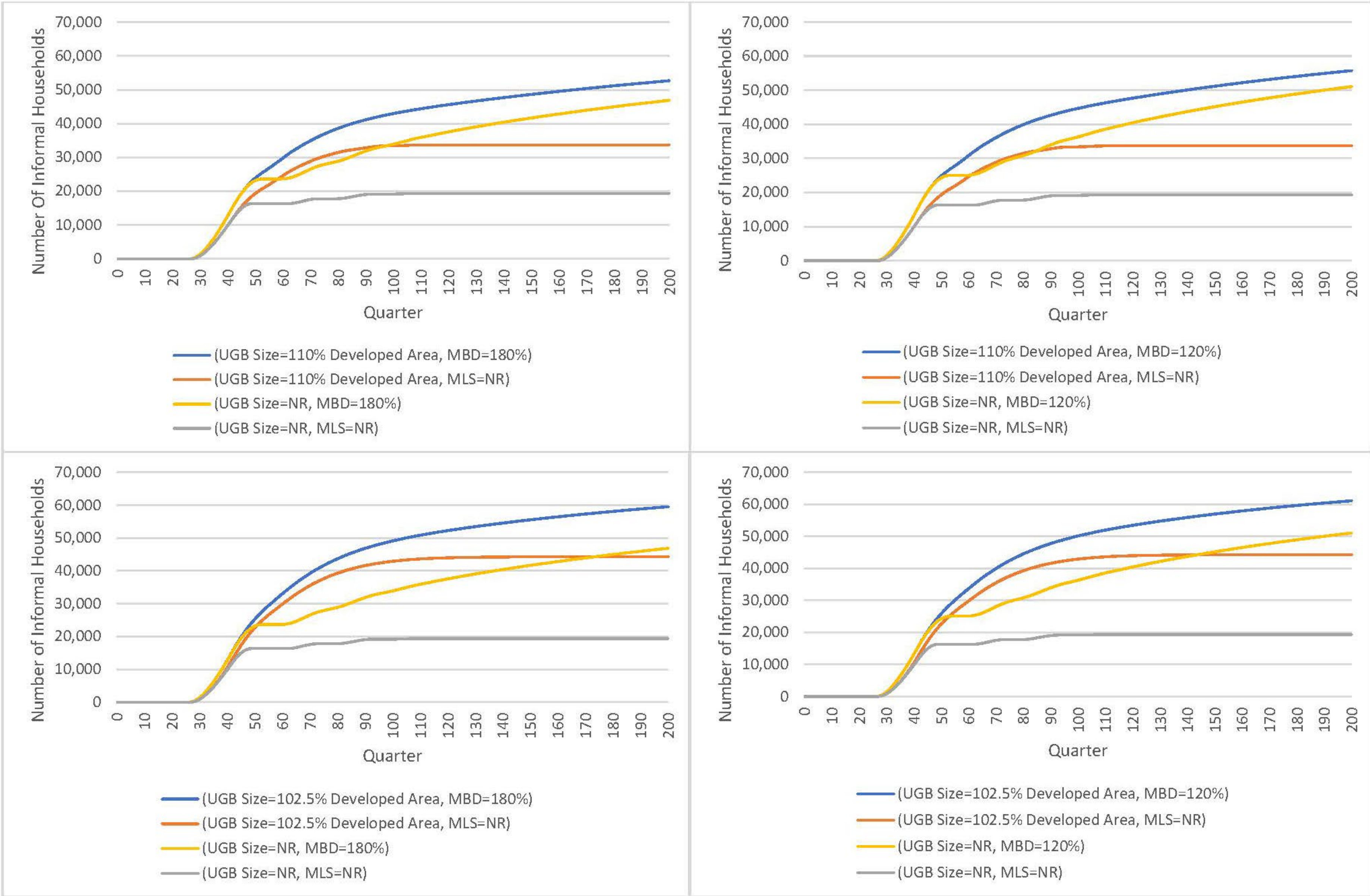


Figure 8-9: The combined effect of MBD and UGB on the number of marginalized households in informal settlements under the 8% growth in household number

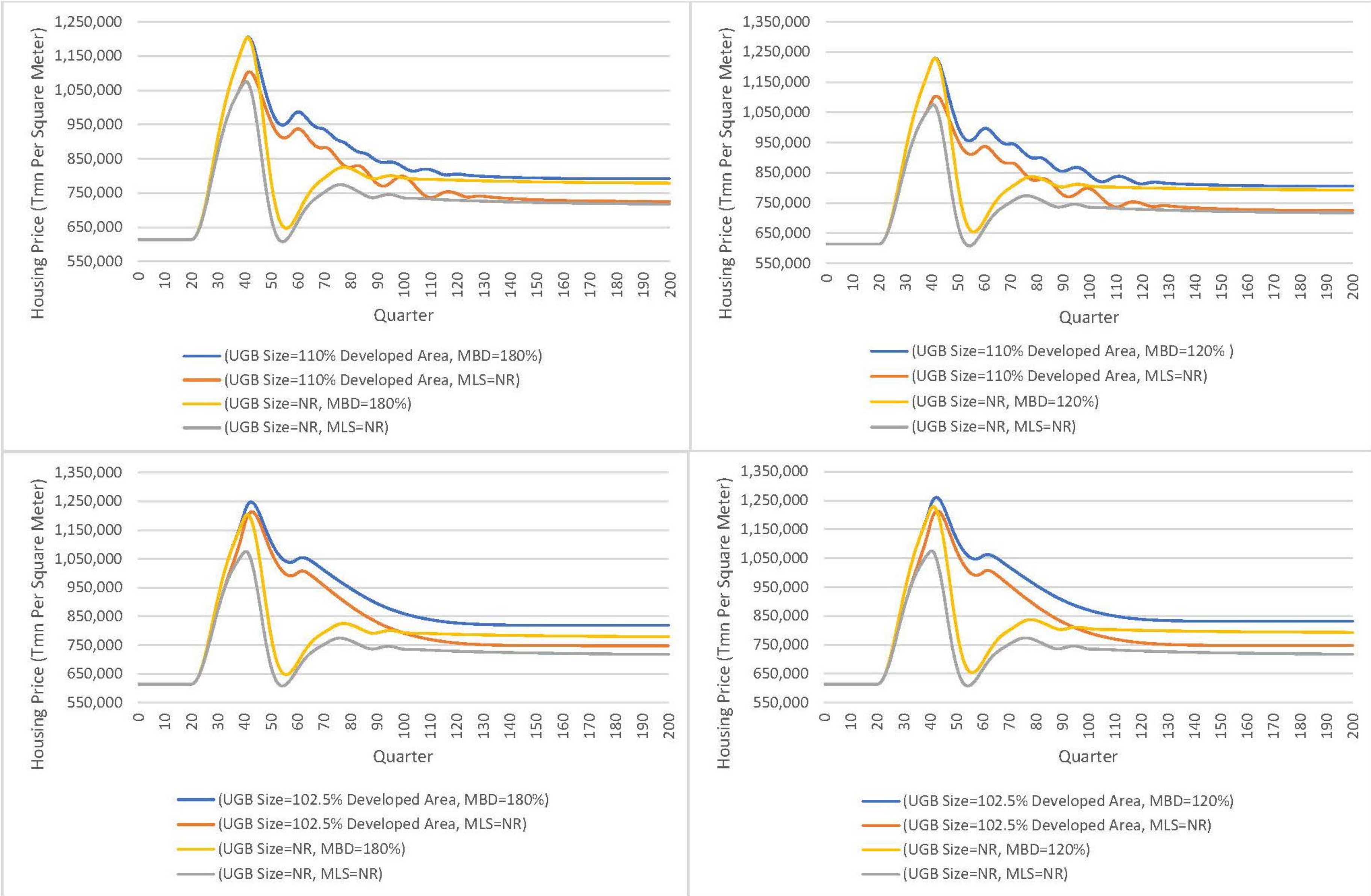


Figure 8-10: The combined effect of MBD and UGB on the housing price under the 10% growth in household number

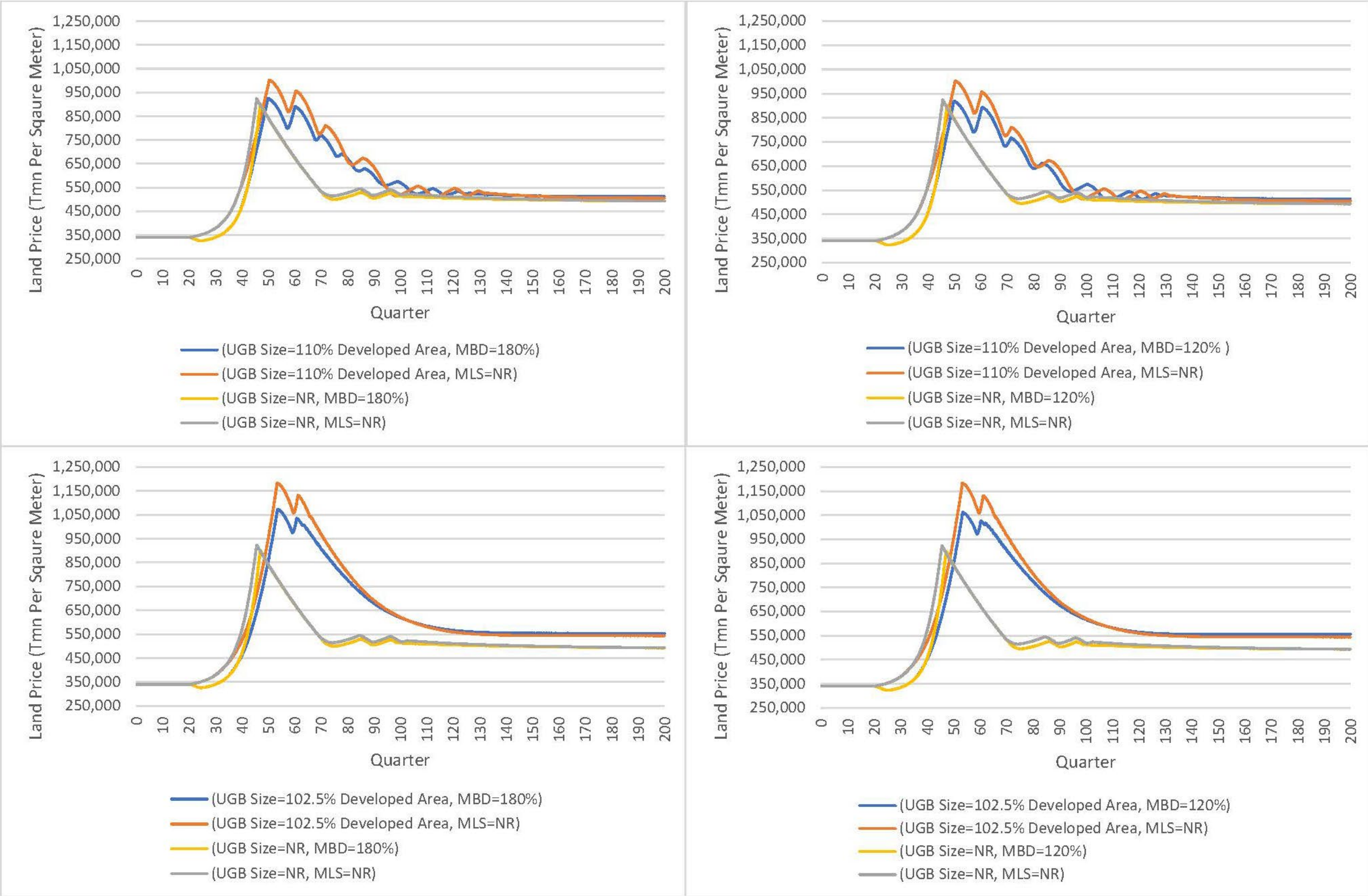


Figure 8-11: The combined effect of MBD and UGB on the land price under the 10% growth in household number

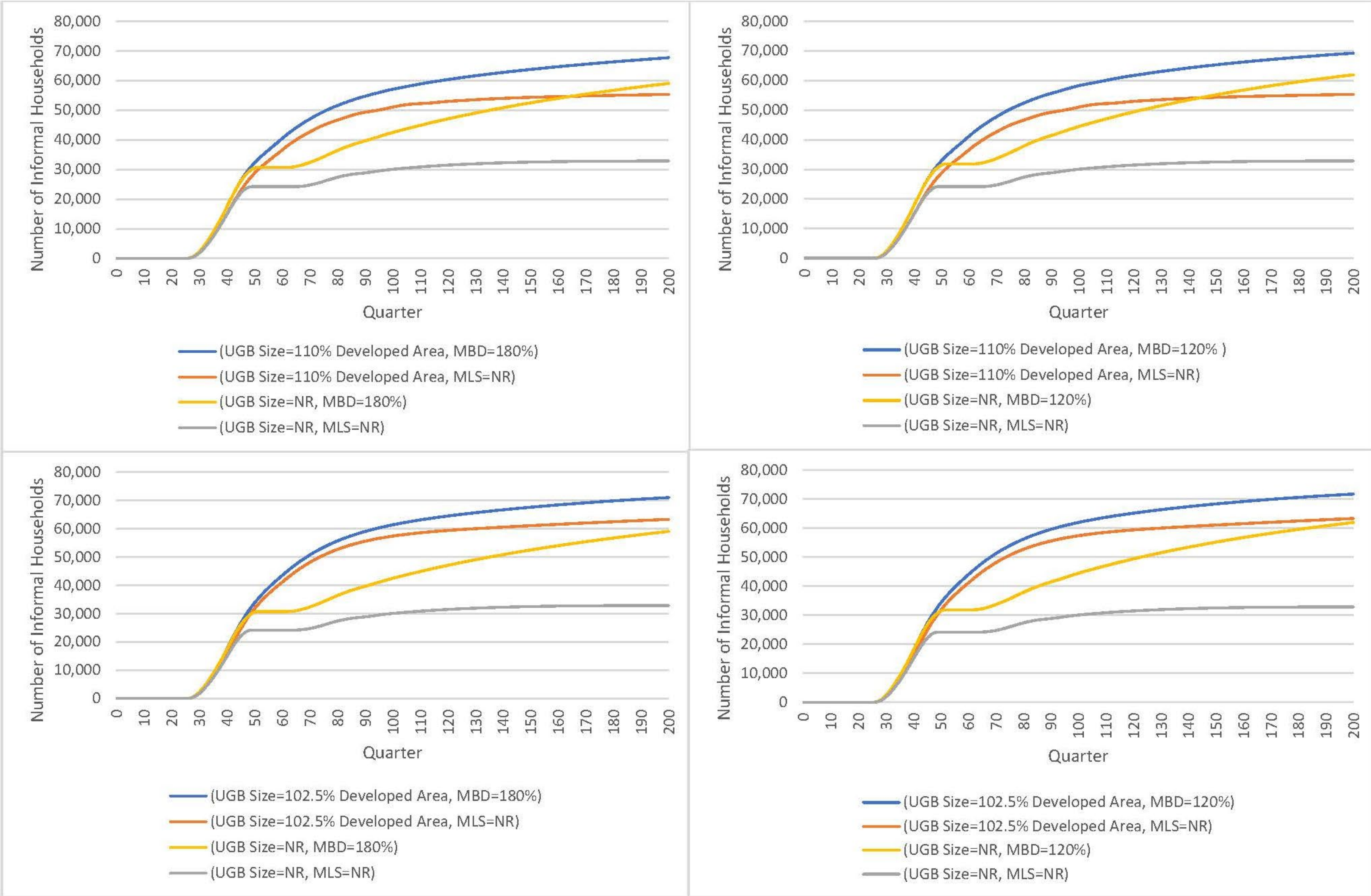


Figure 8-12: The combined effect of MBD and UGB on the number of marginalized households in informal settlements under the 10% growth in household number

UGB-MLS Results

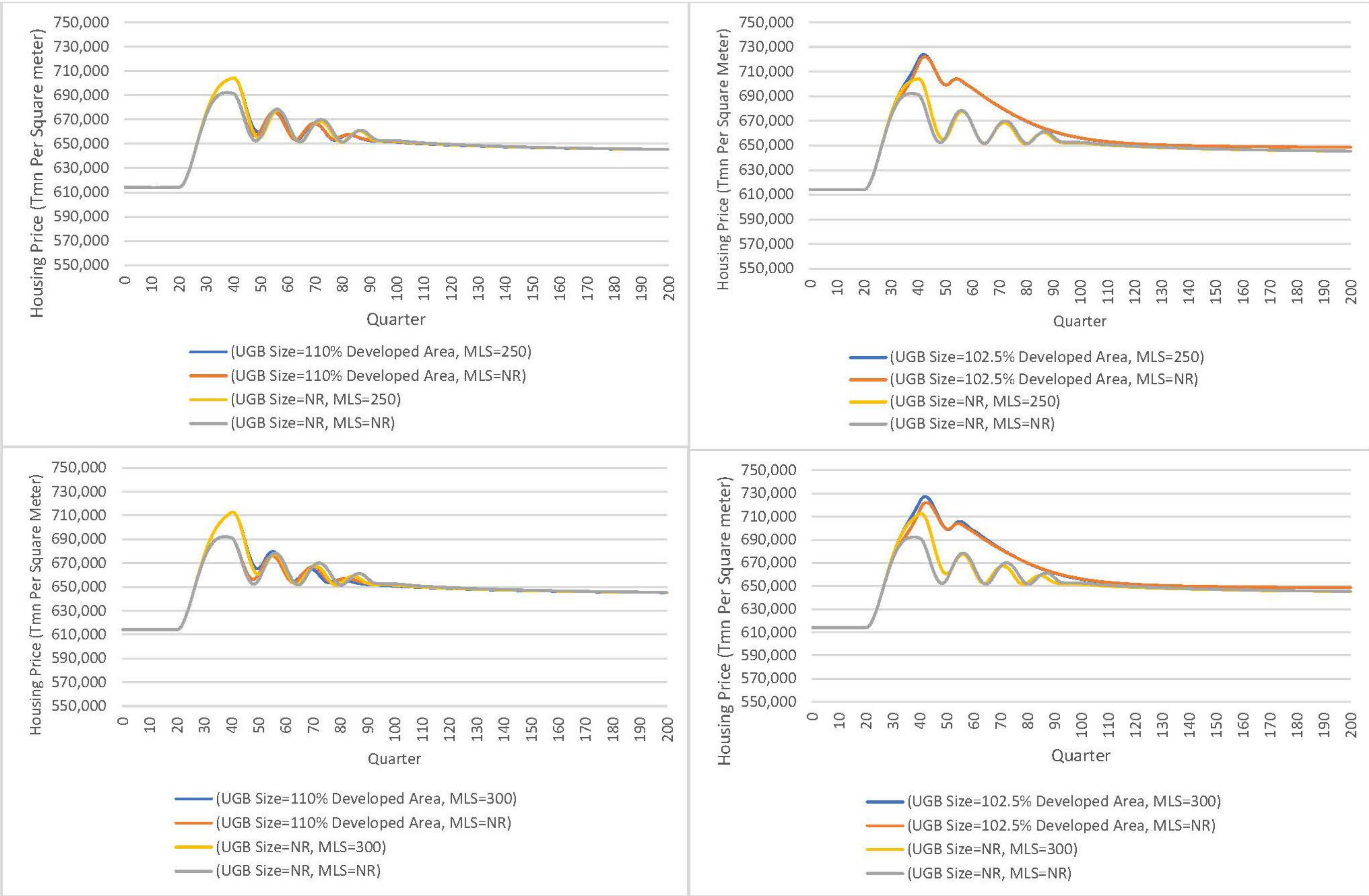


Figure 8-13: The combined effect of UGB and MLS on the housing price under the 3% growth in household number

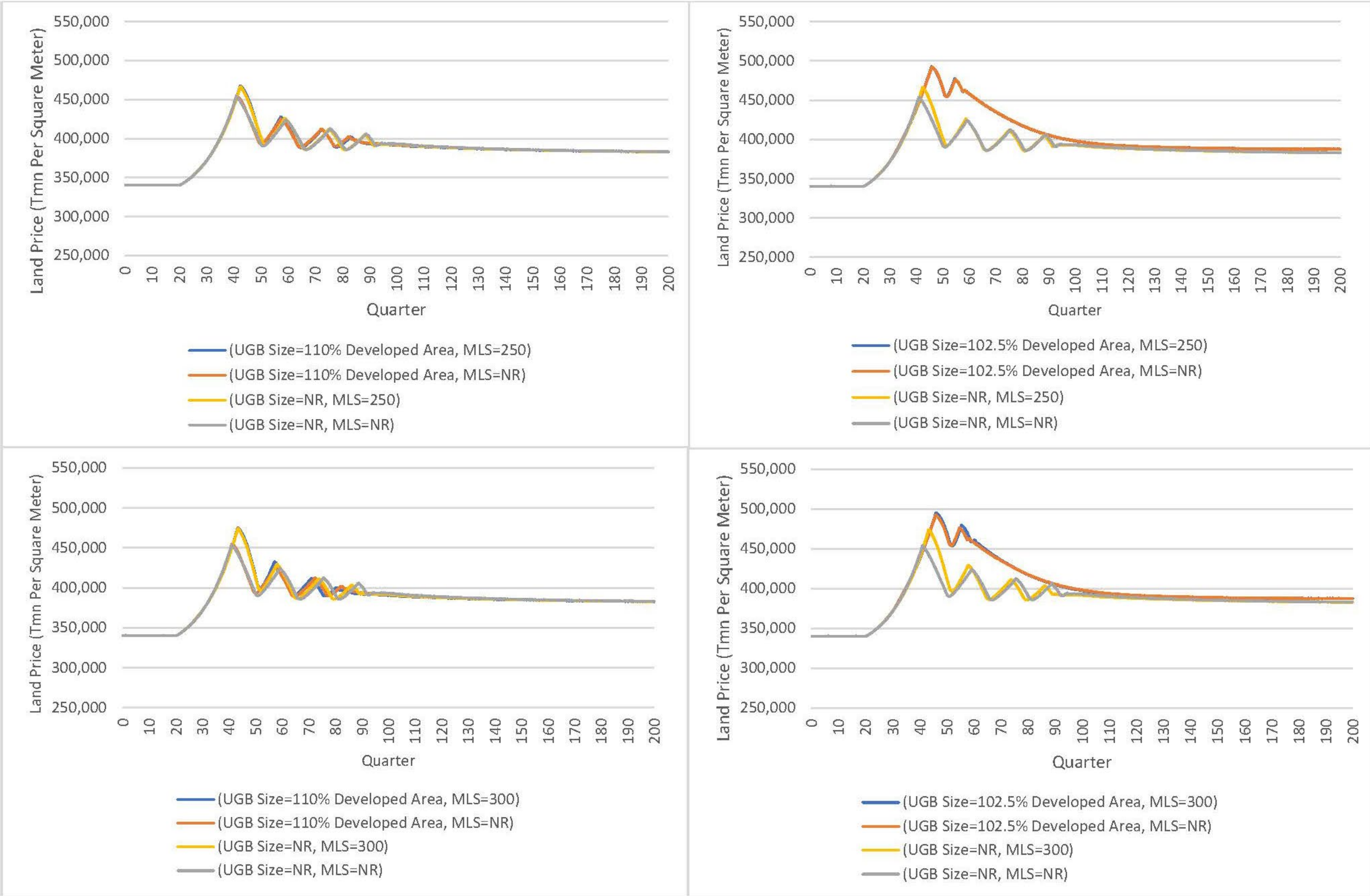


Figure 8-14: The combined effect of UGB and MLS on the land price under the 3% growth in household number

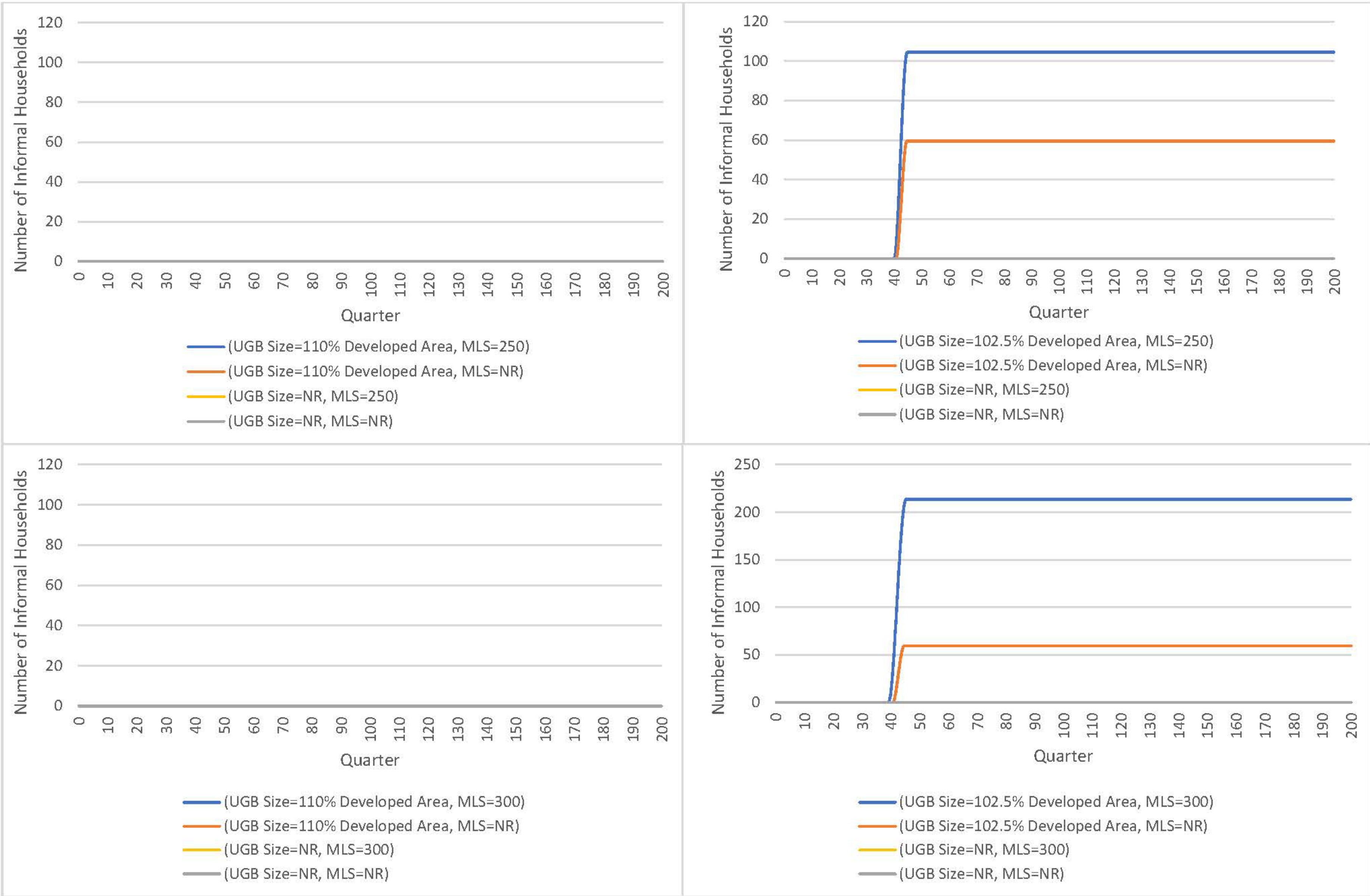


Figure 8-15: The combined effect of UGB and MLS on the number of marginalized households in informal settlements under the 3% growth in household number (In the upper left graph, the combination of regulations does not lead to the marginalization of low-income households)

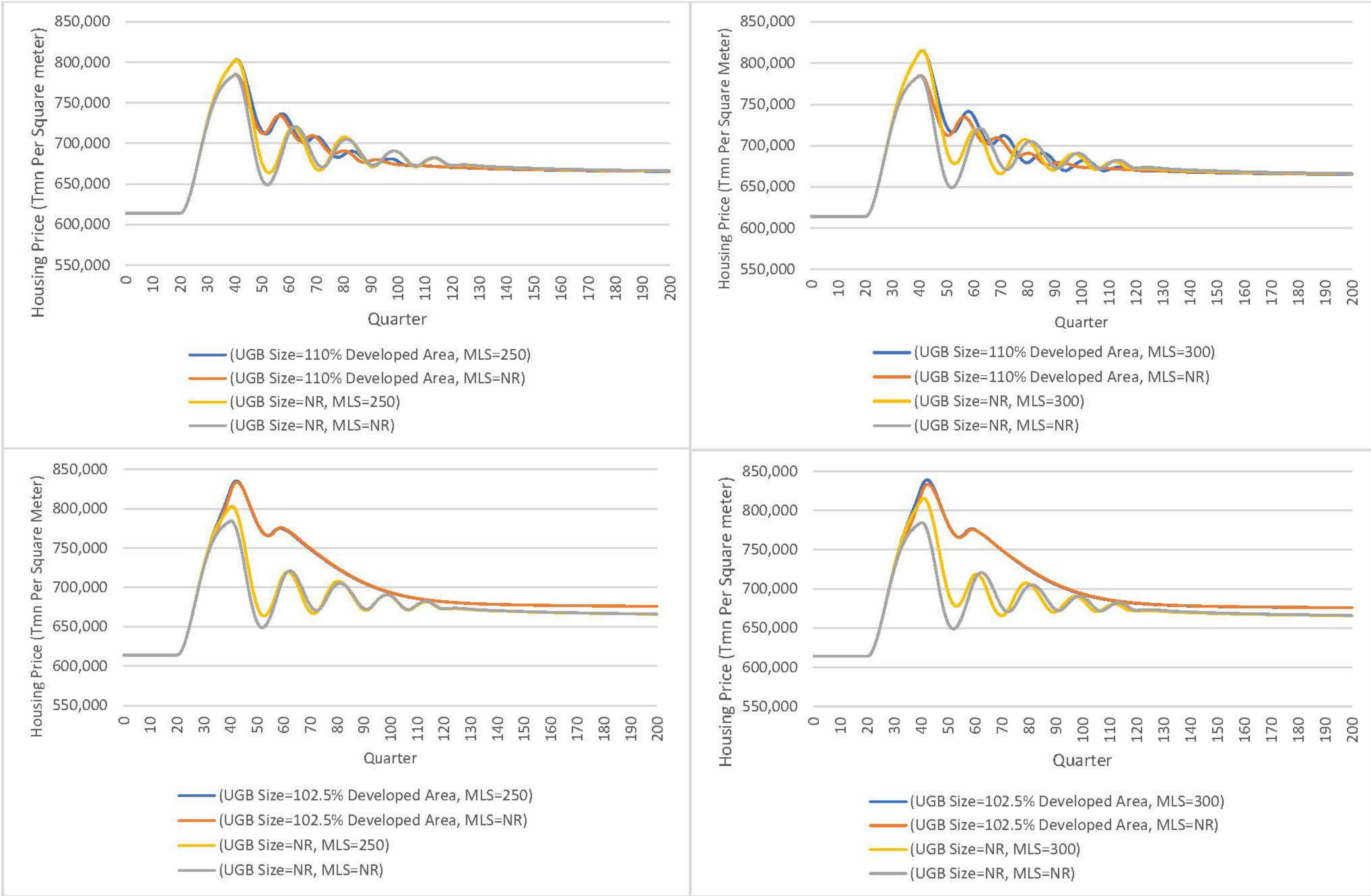


Figure 8-16: The combined effect of UGB and MLS on the housing price under the 5% growth in household number

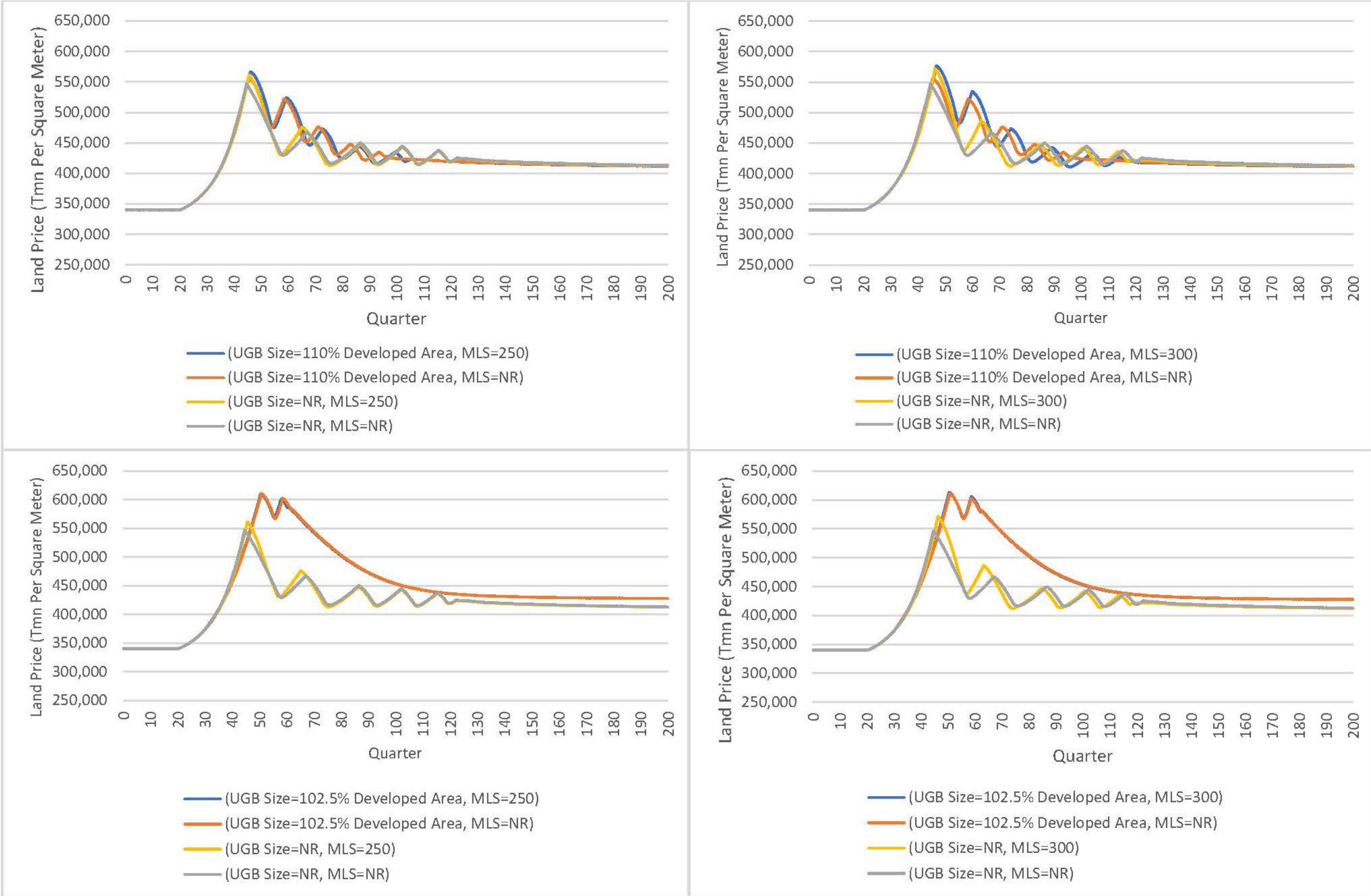


Figure 8-17: The combined effect of UGB and MLS on the land price under the 5% growth in household number

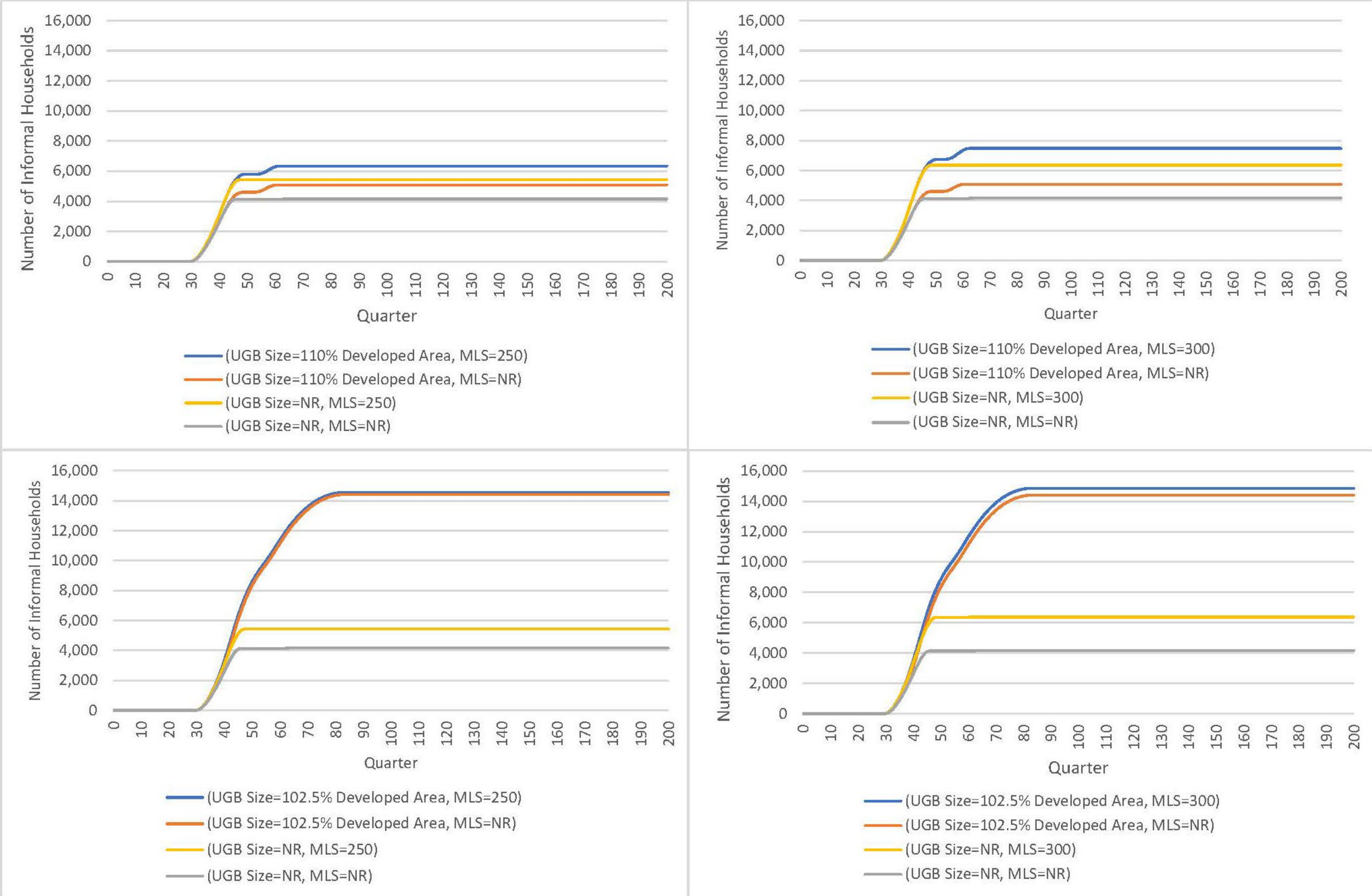


Figure 8-18: The combined effect of UGB and MLS on the number of marginalized households in informal settlements under the 5% growth in household number

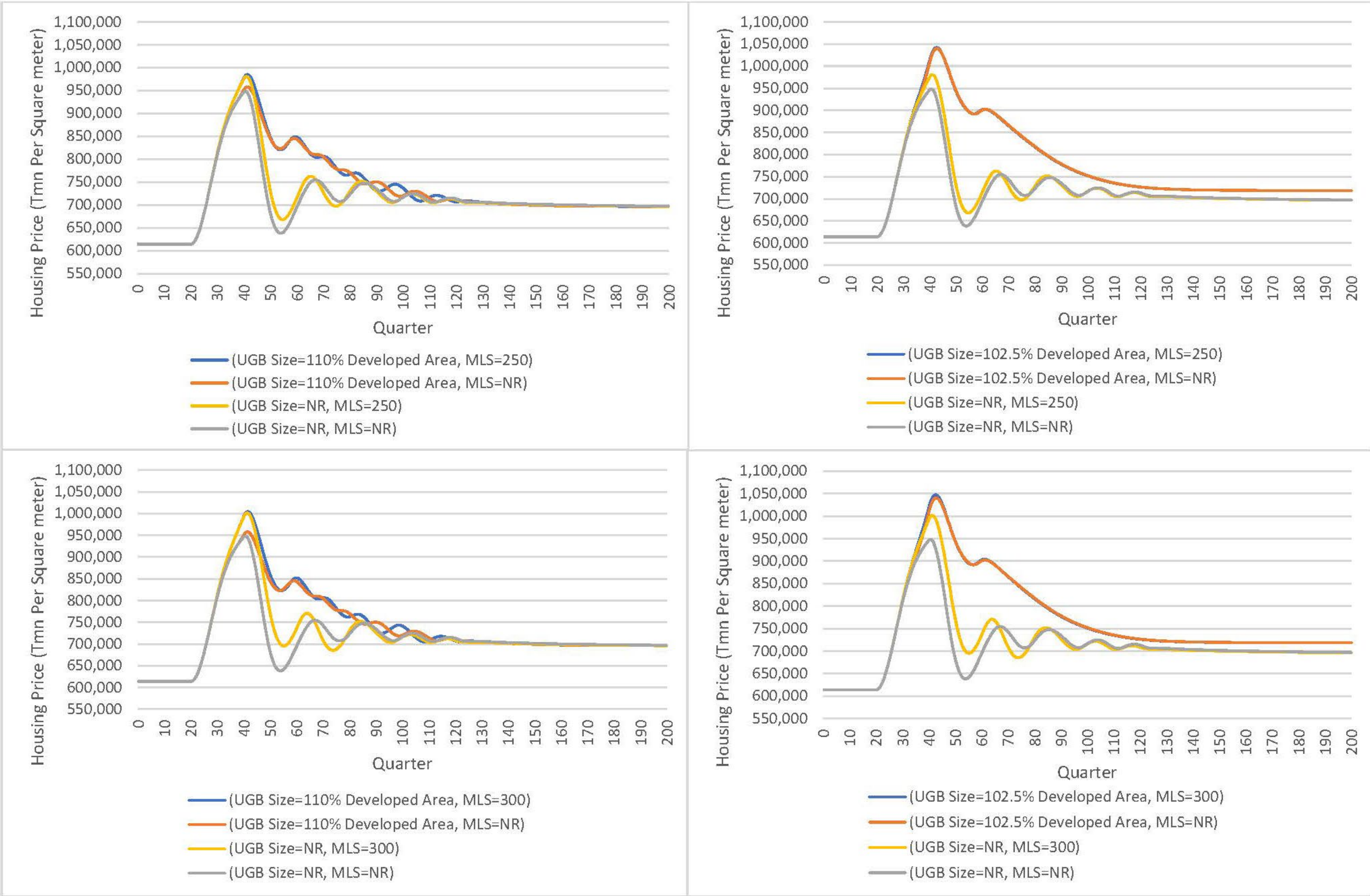


Figure 8-19: The combined effect of UGB and MLS on the housing price under the 8% growth in household number

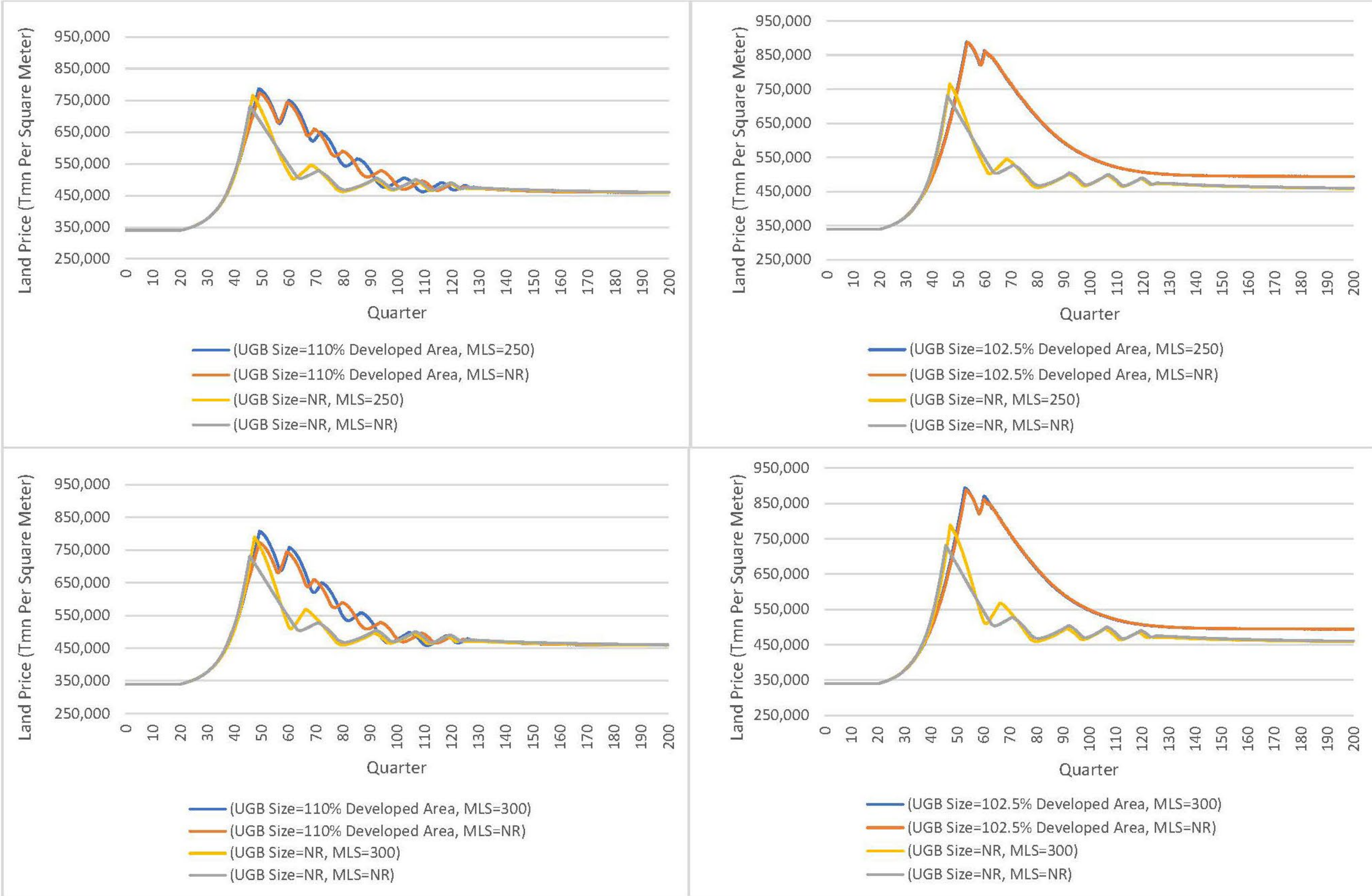


Figure 8-20: The combined effect of UGB and MLS on the land price under the 8% growth in household number

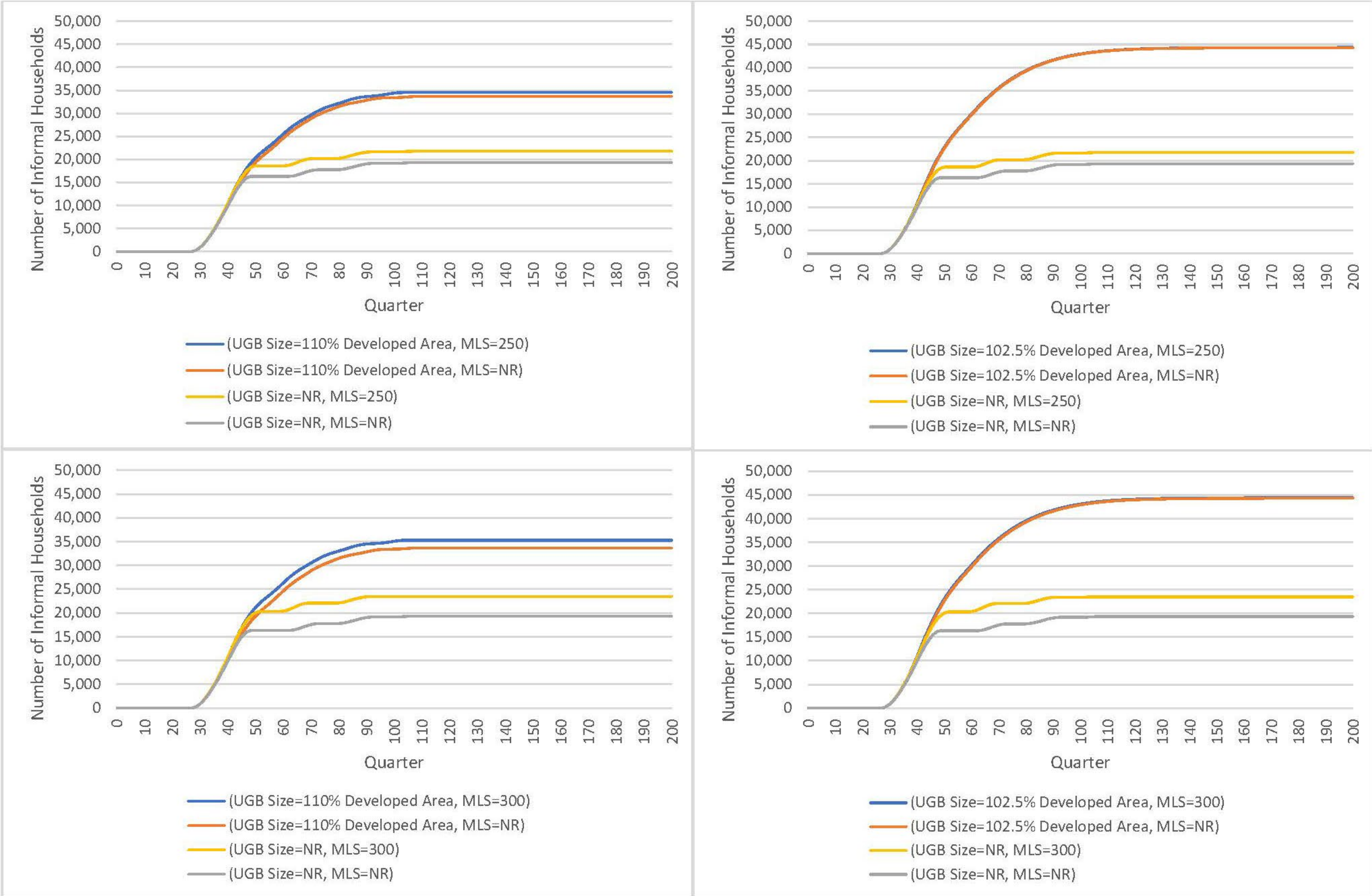


Figure 8-21: The combined effect of UGB and MLS on the number of marginalized households in informal settlements under the 8% growth in household number

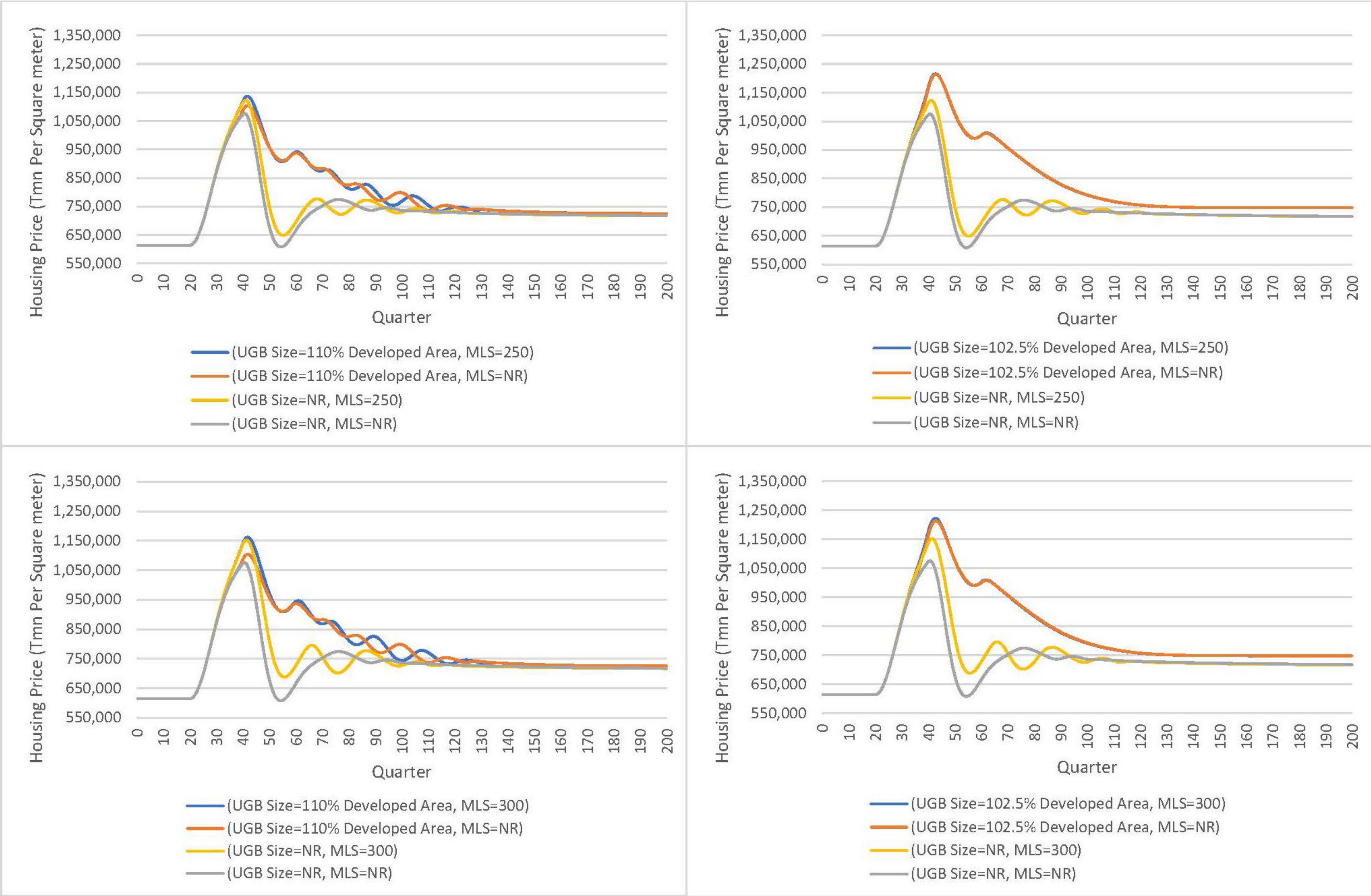


Figure 8-22: The combined effect of UGB and MLS on the housing price under the 10% growth in household number

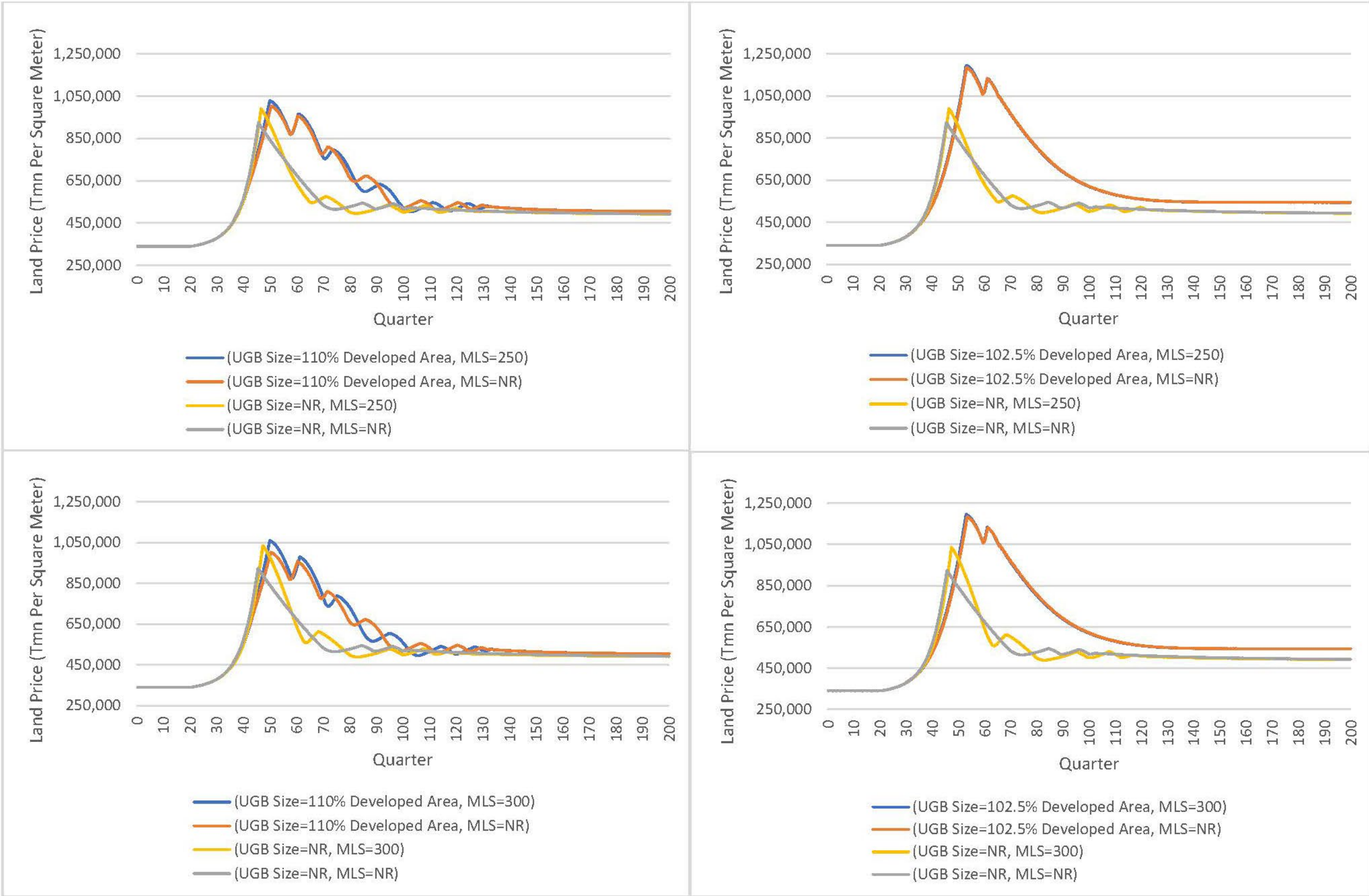


Figure 8-23: The combined effect of UGB and MLS on the land price under the 10% growth in household number

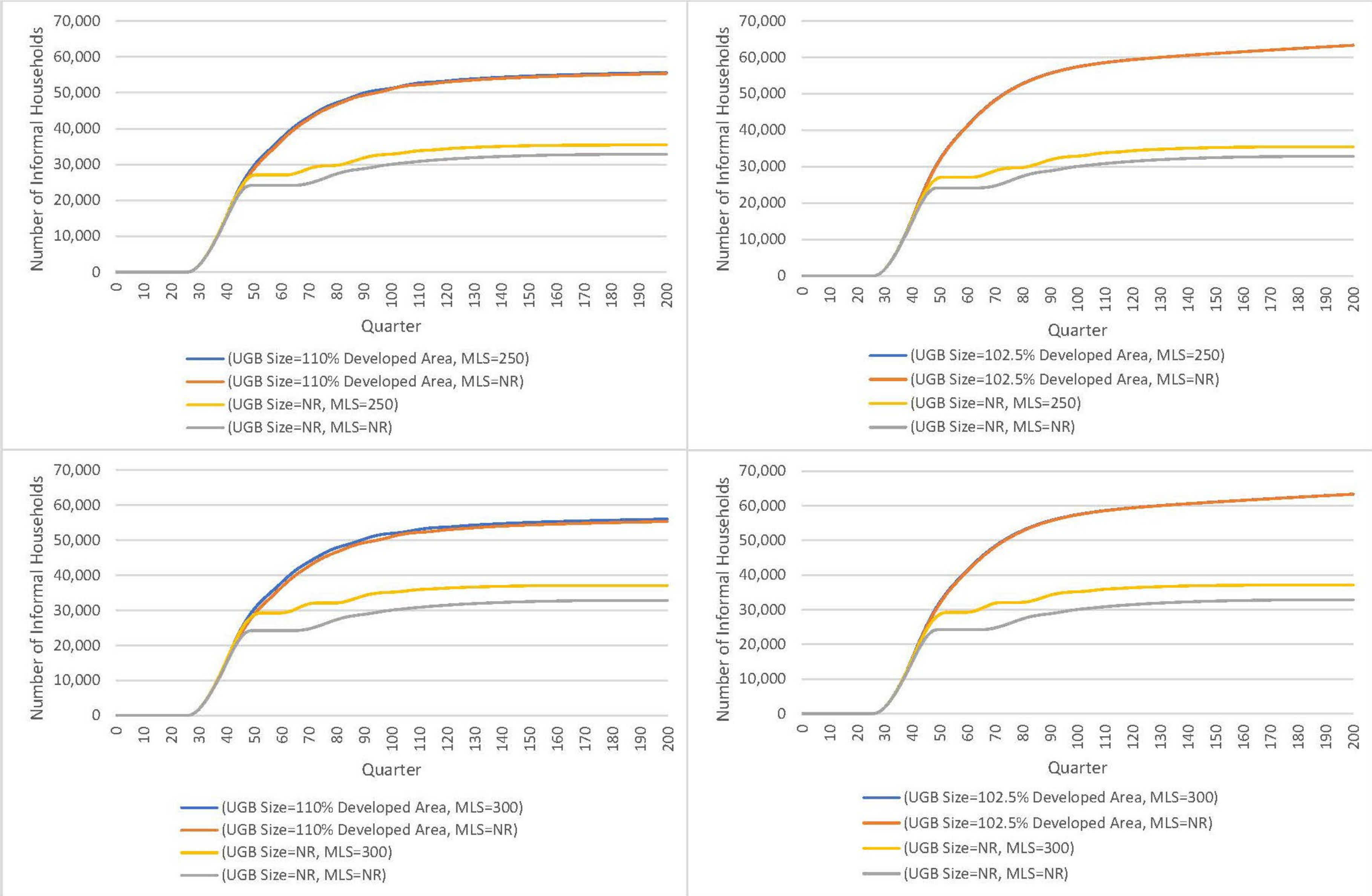


Figure 8-24: The combined effect of UGB and MLS on the number of marginalized households in informal settlements under the 10% growth in household number

MLS-MBD Results

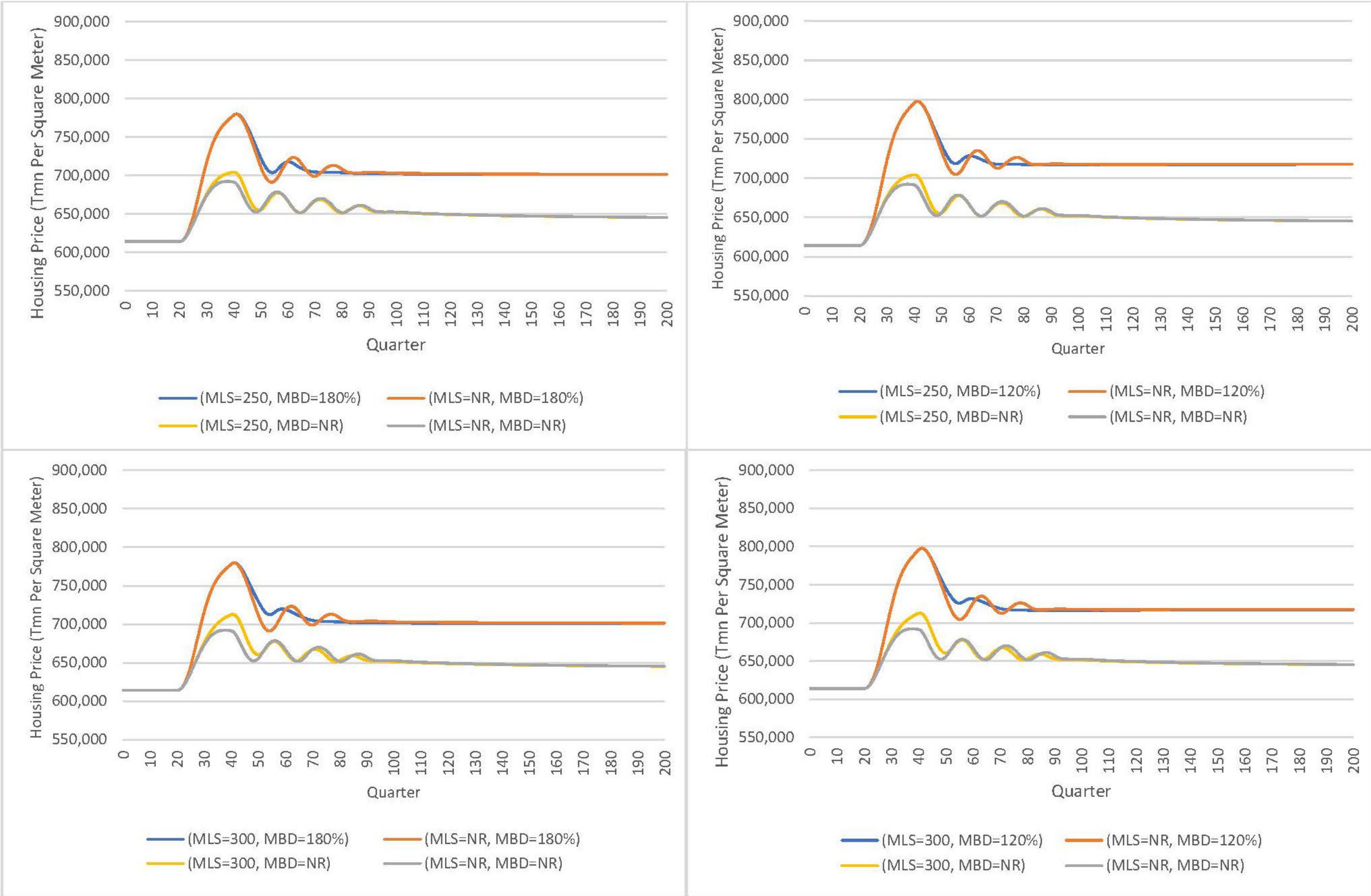


Figure 8-25: The combined effect of MLS and MBD on the housing price under the 3% growth in household number

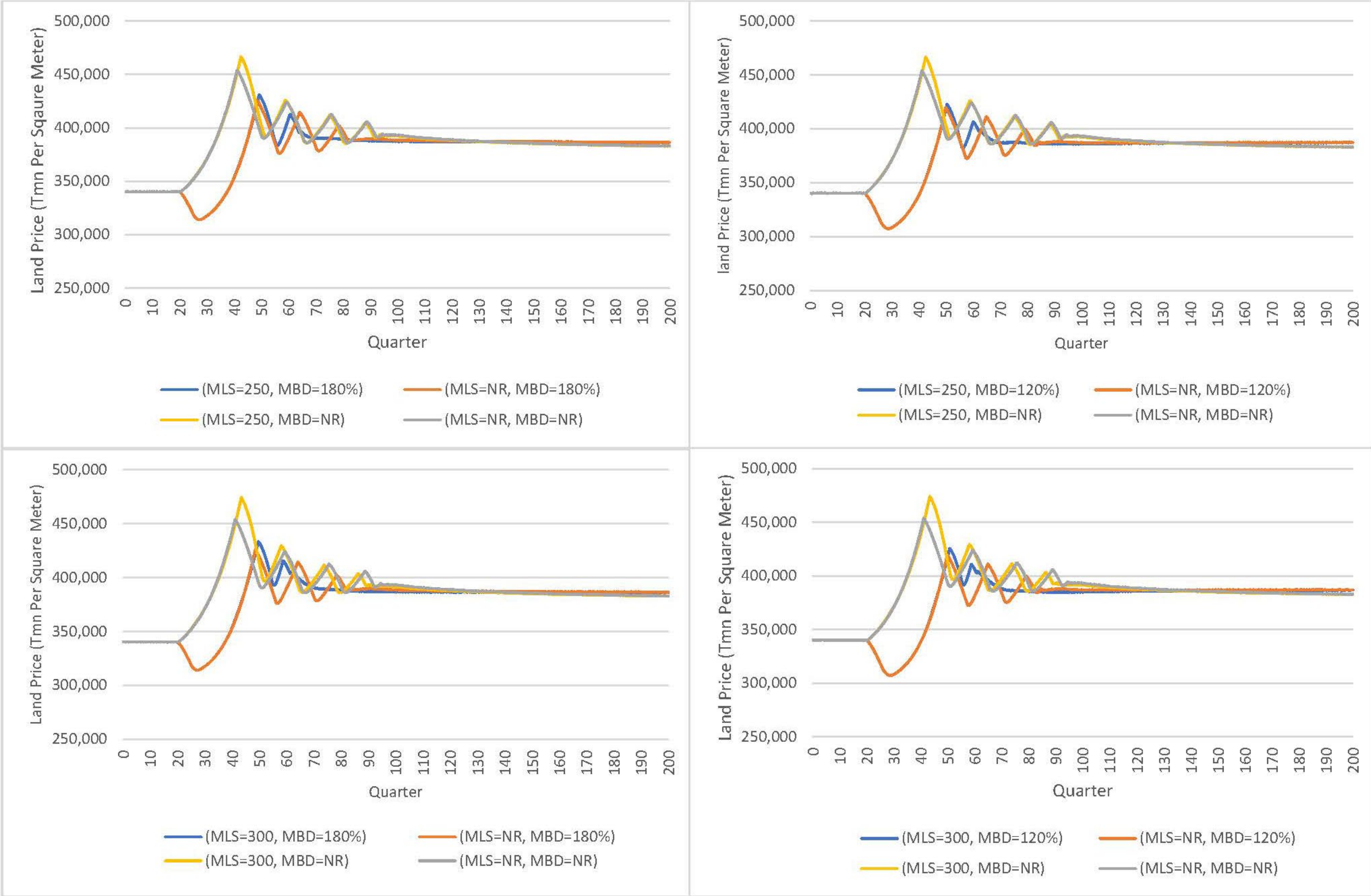


Figure 8-26: The combined effect of MLS and MBD on the land price under the 3% growth in household number

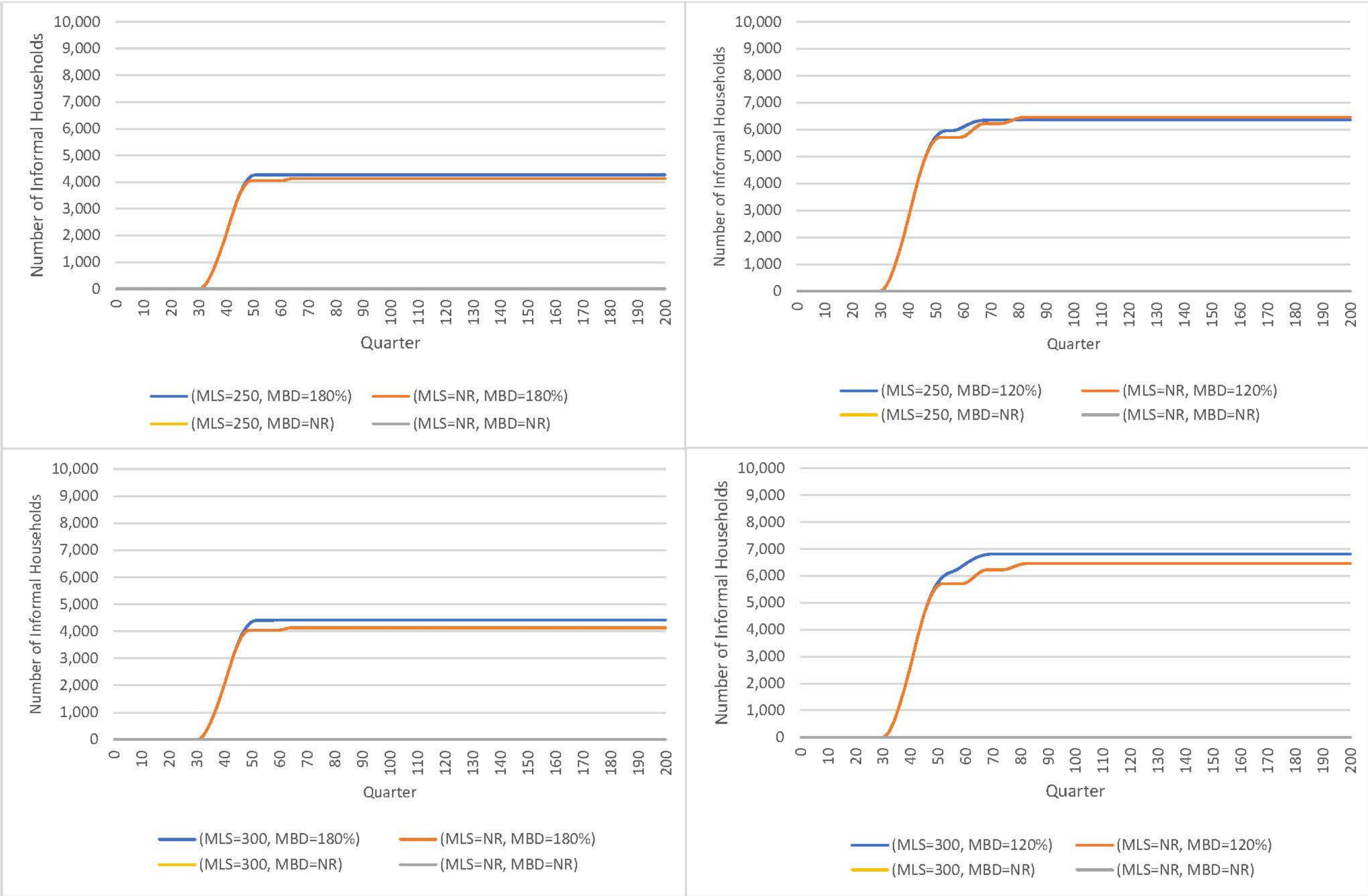


Figure 8-27: The combined effect of MLS and MBD on the number of marginalized households in informal settlements under the 3% growth in household number

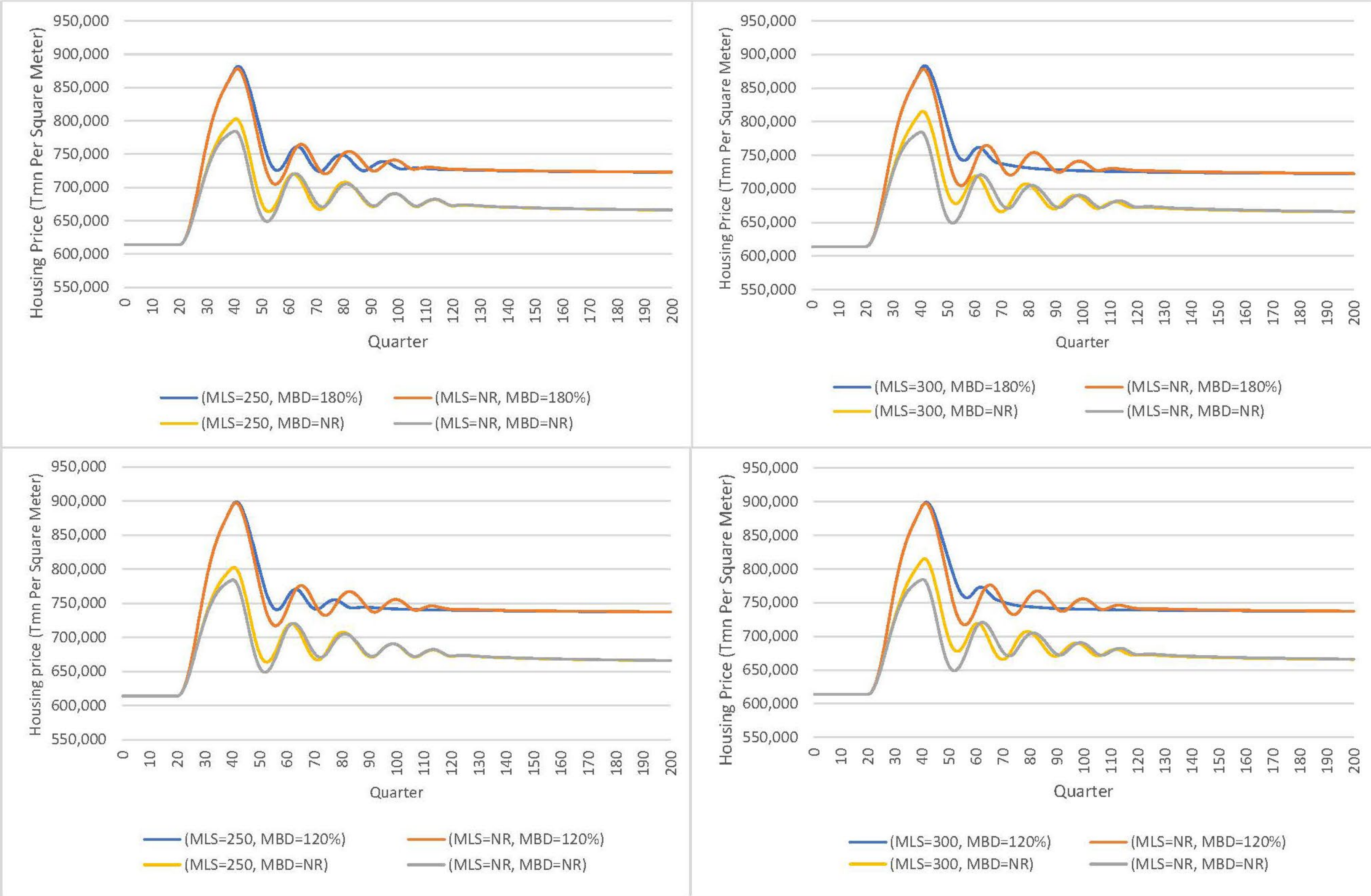


Figure 8-28: The combined effect of MLS and MBD on the housing price under the 5% growth in household number

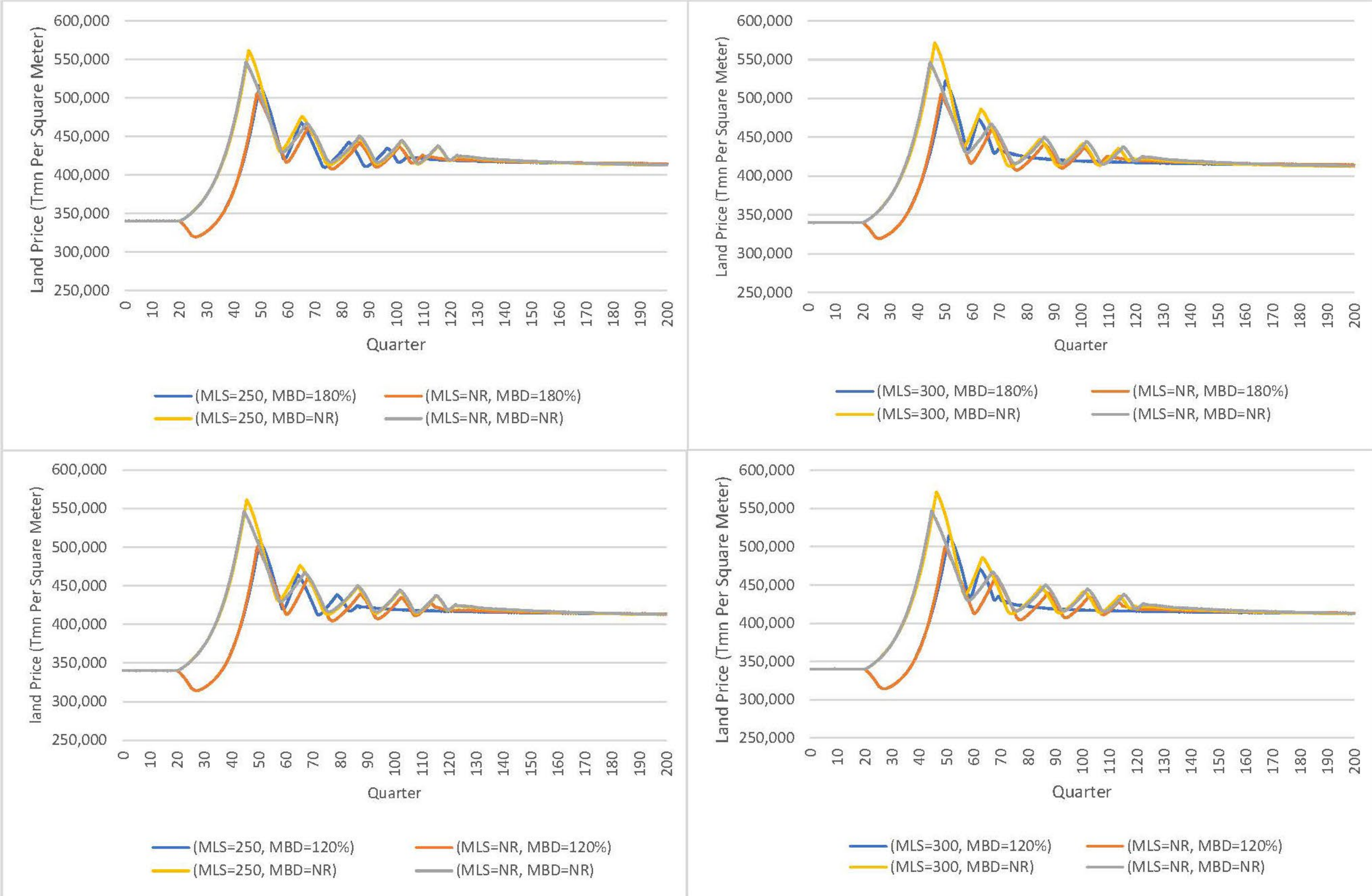


Figure 8-29: The combined effect of MLS and MBD on the land price under the 5% growth in household number

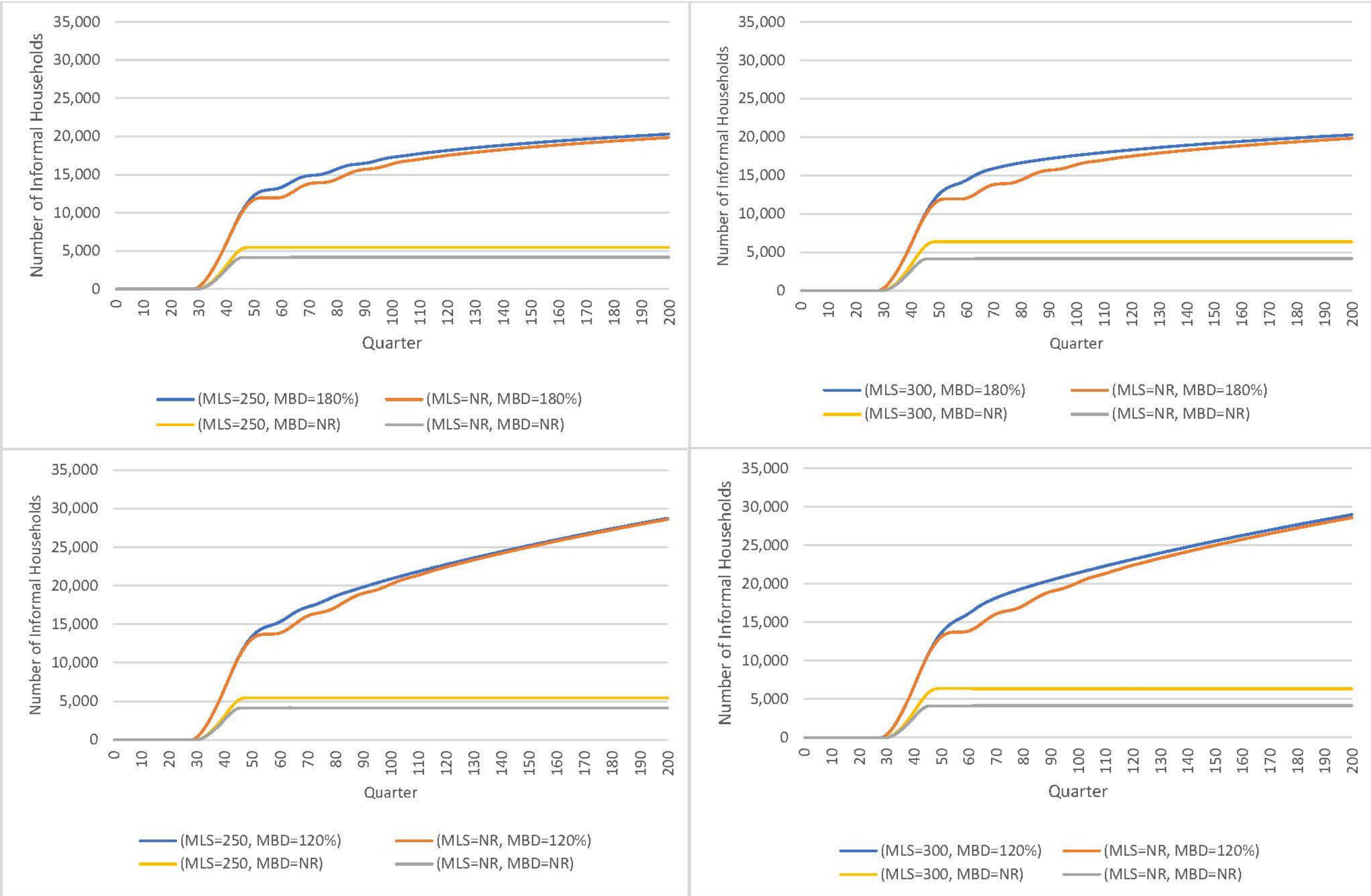


Figure 8-30: The combined effect of MLS and MBD on the number of marginalized households in informal settlements under the 5% growth in household number

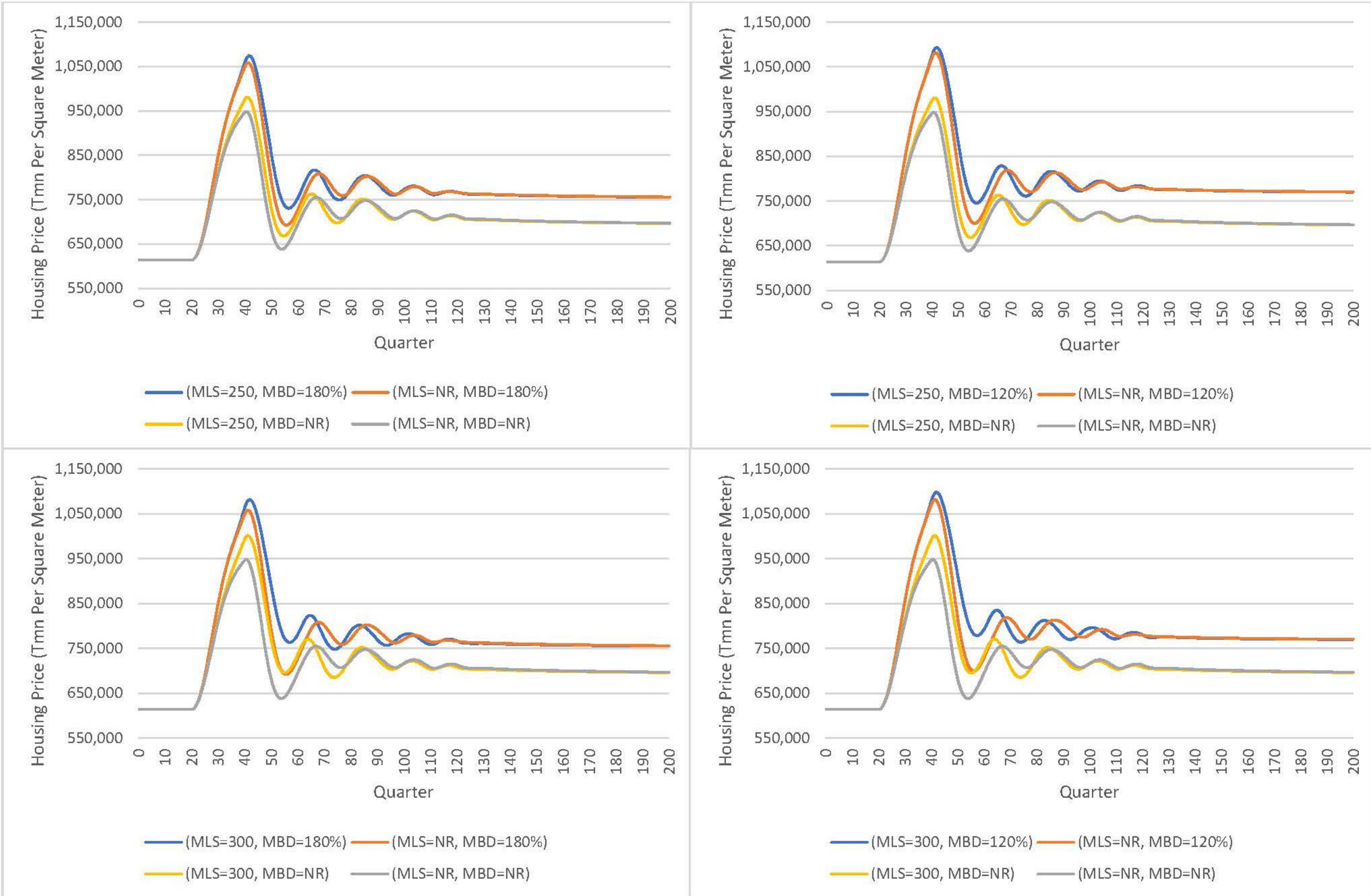


Figure 8-31: The combined effect of MLS and MBD on the housing price under the 8% growth in household number

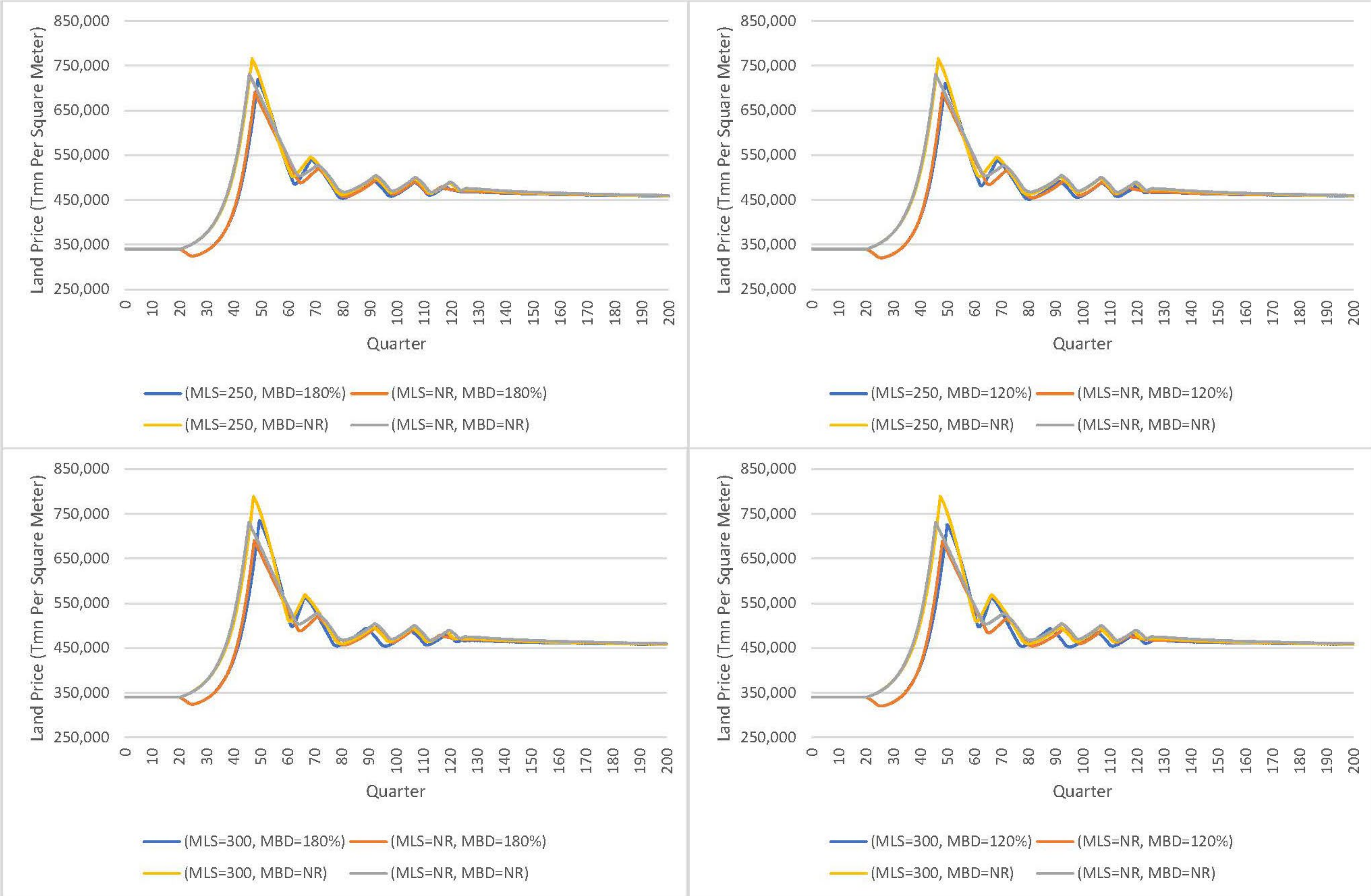


Figure 8-32: The combined effect of MLS and MBD on the land price under the 8% growth in household number

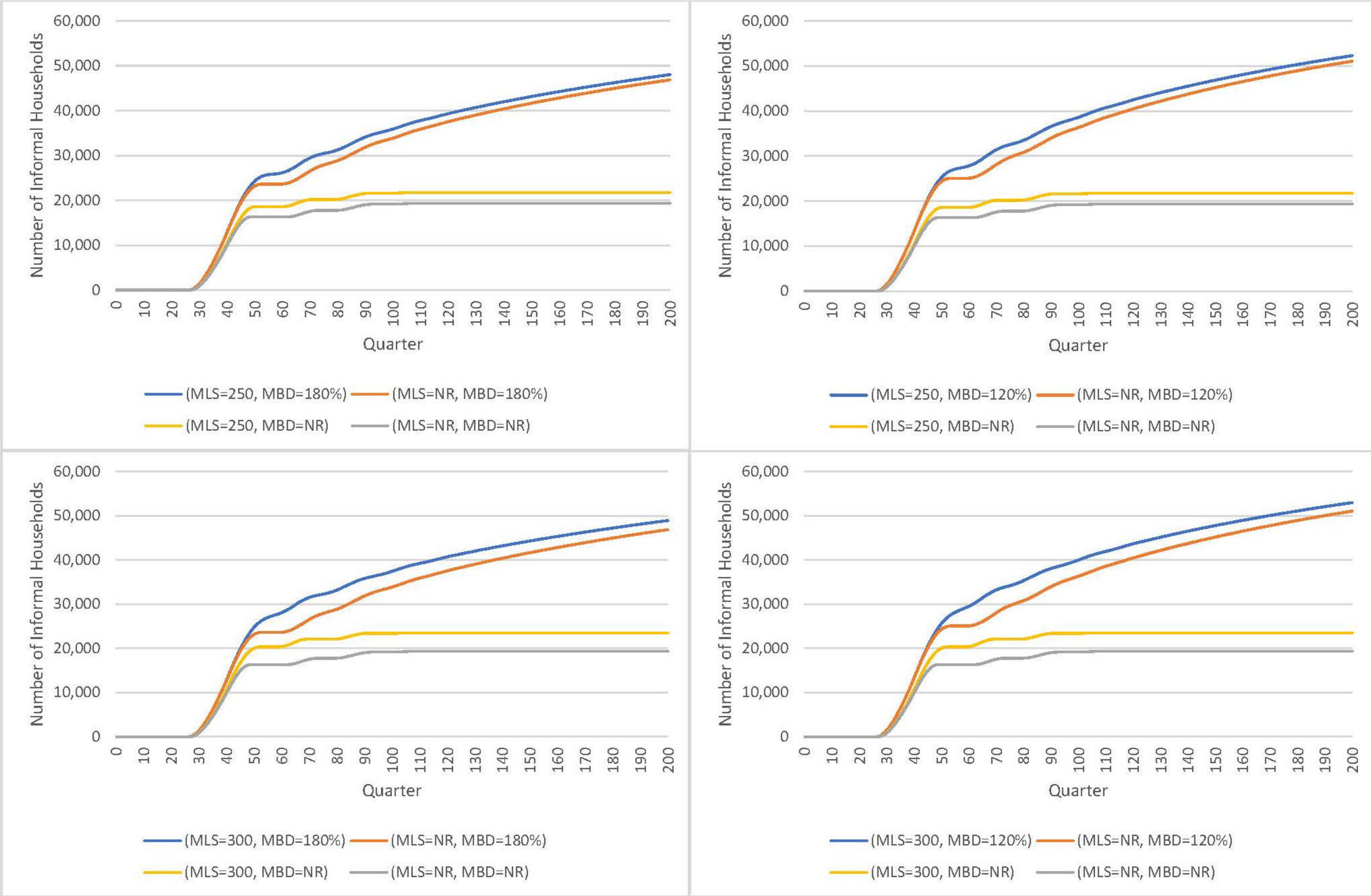


Figure 8-33: The combined effect of MLS and MBD on the number of marginalized households in informal settlements under the 8% growth in household number

Figure 8-34: The combined effect of MLS and MBD on the housing price under the 10% growth in household number

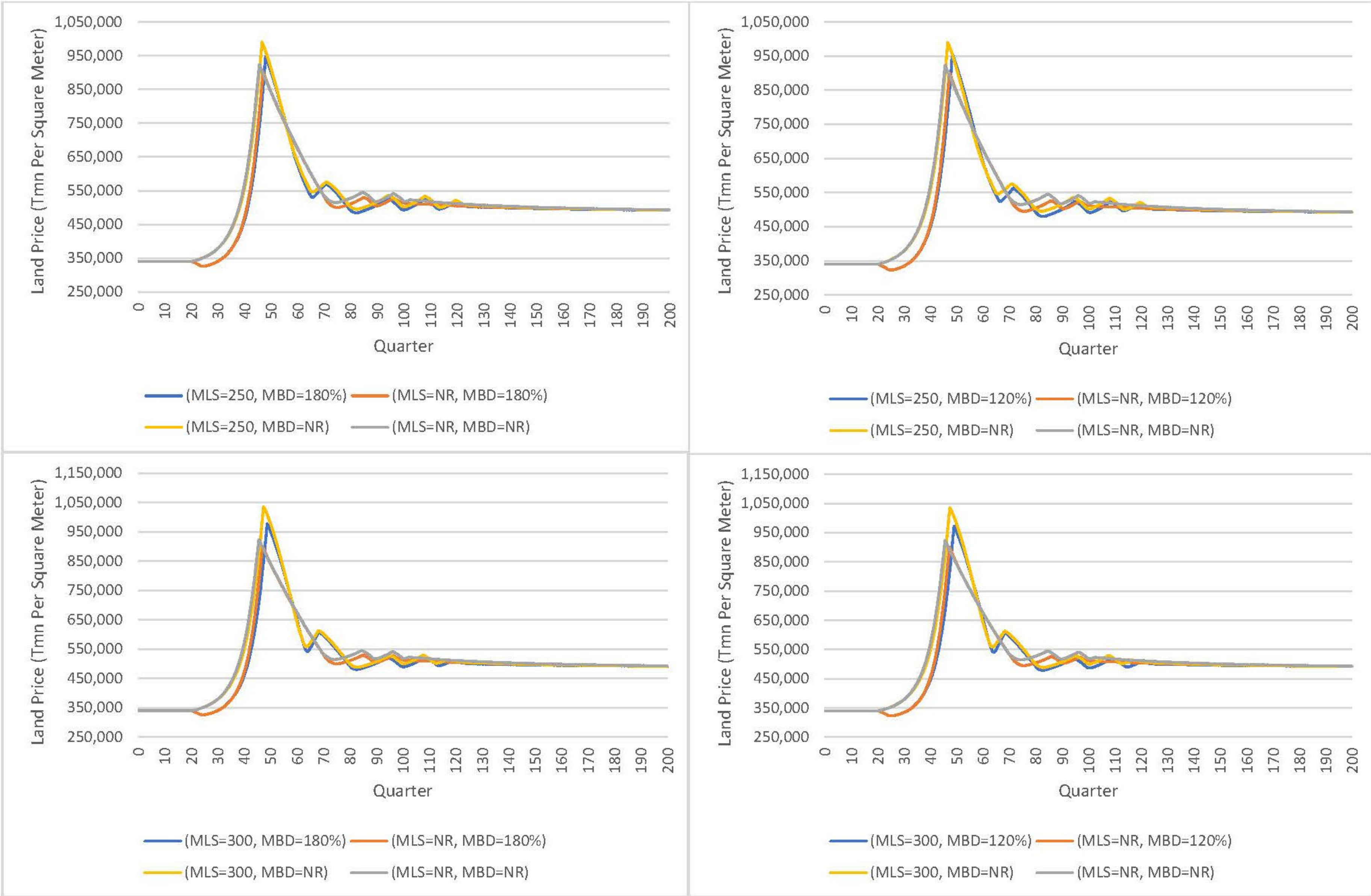


Figure 8-35: The combined effect of MLS and MBD on the land price under the 10% growth in household number

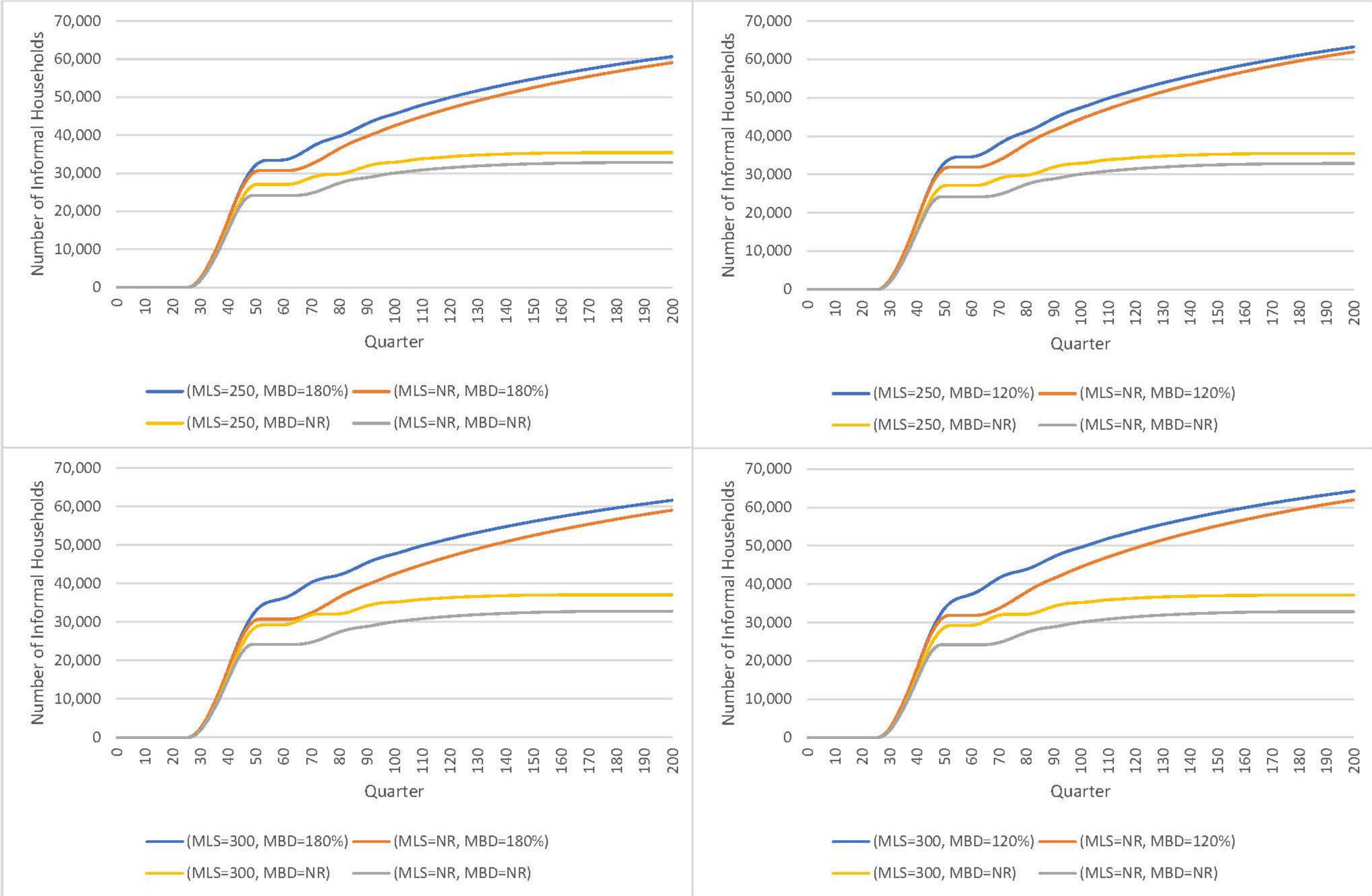


Figure 8-36: The combined effect of MLS and MBD on the number of marginalized households in informal settlements under the 10% growth in household number

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9. Publications

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Effects of planning regulations on housing and land markets: A system dynamics modeling approach

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ABSTRACT

The effect of planning regulations on housing and land markets has been a long-lasting concern. The inherent complexities of incorporating regulations into models, including the heterogeneity of regulations and their temporal effect, have resulted in different approaches, and consensus has been elusive. Few studies have addressed the effect of regulations in a dynamic framework of the housing and land markets. In these studies, different regulations or the indices capturing their restrictiveness are assumed to have a linear additive effect along with the other factors. The results have been contradictory. This paper aims to model the dynamic effect of regulations by incorporating them in a causal rather than correlational form of relationships. To this end, we adopted the system dynamics approach to model the individual effect of three important types of regulation widely used in urban planning systems: maximum building density, minimum lot size, and urban growth boundary. We use the concept of optimum building density to integrate the housing market and the land market through the construction sector, providing clearer causal links among the related markets. To our knowledge this is the first use of this concept in a dynamic model. We ran the simulations (using hypothetical parameters) to analyze the effect of each regulation on housing and land price changes. The simulation results show that by imposing more restrictive UGBs, housing and land prices increase. A more restrictive MBD first results in a decrease in the land price and, then, due to its effect on the whole housing market, increases both housing and land prices. A more restrictive MLS has a short-term impact on land and housing prices, but it does not change long-run price levels. The common feature of the market under more restrictive forms of all three regulations is lower volatility.

1. Introduction

Pigovian economists argue that planning regulations are necessary to compensate for market failures. But zoning regulations can act as a double-edged sword. While they aim to improve residents' life quality, such an improvement often results in distortion in the housing and land markets, which can cause further consequences. Before addressing these unintended consequences, it is necessary to determine the effect of regulations on housing and land prices. Despite numerous studies on these effects, the real-world complexities of the subject and discrepancies among approaches to overcome the difficulties have not brought consensus (Anthony, 2017; Nelson et al., 2002; Pogodzinski & Sass, 1990; Pogodzinski, Sass, 1991a; Quigley & Rosenthal, 2005). Three main complexities are: the endogeneity of regulations, the heterogeneity of regulations, and the temporal dimension of regulations' effect. Attitudes towards these complexities and strategies for dealing with them have differed. The endogeneity problem has been addressed using statistical methods to eradicate any possible mutual interrelationship between regulations and housing and land prices. However, the heterogeneity of regulations and their temporal effect have attracted attention during the last two decades, dividing the literature based on approaches towards them (Jackson, 2016).

The heterogeneity of regulations stems from the fact that the regulatory systems, specifically in the US (the research context for most studies) are heterogeneous. Each jurisdiction imposes a different set of regulations. Two approaches have emerged, namely: the selective and the comprehensive. The selective approach restricts the investigation to analyzing the impact of one or a selection of regulations on housing and land markets in a limited number of jurisdictions with similar regulatory systems. The major issue with studies adopting this approach is that

Abbreviations: MBD, Maximum building density; MLS, Minimum lot size; UGB, Urban growth boundary.

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