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# TOWARDS HOUSING SYSTEM DYNAMICS

PROJECTS ON EMBEDDING  
SYSTEM DYNAMICS  
IN HOUSING  
POLICY RESEARCH

MARTIJN ESKINASI



## TOWARDS HOUSING SYSTEM DYNAMICS

*Projects on embedding system dynamics in housing policy research*



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*Projects on embedding system dynamics in  
housing policy research*

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# PREFACE

The approximate fifteen-year time trajectory of the making of this PhD thesis can be adequately described with system dynamics. In the first fourteen years, a reinforcing loop was dominant. When my fixes to a data-congested model failed, when I properly learnt system dynamics at Nijmegen University and acquired the taste in the Haaglanden project, progress was present though not very noticeable. Later on, with Houdini, Middle Incomes and the Mortgage model in full swing, progress was steep and visible.

But no real world system contains only reinforcing feedback. In the fifteenth year I also suffered from that balancing feedback most PhD students encounter in the final stage: the stock of new ideas becomes depleted, the to-do list apparently keeps growing and the mind definitely needs some rest, but stays relentlessly occupied with the thesis.

All good things gratefully received in life are threefold in nature: support, inspiration and practical arrangements.

Gratefulness for their loving and lasting support belongs especially to the most important women in my life: my wife Zuzana, my mother Ineke and my daughters Charlotte and Justine. Also many friends, relatives and colleagues helped me to keep it up and two of them, Jörgen van de Langkruis and Keshen Mathura, are my defense assistants today. All of you deserve my warmest love and friendship!

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And finally I wish that all scientific research contributes to the well-being of mankind and planet earth. So be it!

# SUMMARY

The purpose of this PhD thesis is to contribute to a systematic connection between housing research and system dynamics. Housing research is a vast field focusing on housing markets, residential behavior, industrial organization and government intervention. System dynamics is a method for learning about dynamic complexity of social systems with a strong emphasis on computer simulation. These fields share several common characteristics, but there is no systematic cooperation yet.

Given this state of affairs, the thesis must lay some groundwork by means of exploratory research and case studies applying system dynamics to housing research issues. The thesis seeks to answer six research questions. These concern literature research into 1) contemporary housing research issues suitable for applying system dynamics 2) causes for the lack of and recommendations for improving systematic cooperation 3) the accumulated knowledge base of system dynamics on housing markets and 4) systematic analysis of this base for the purpose of improving cooperation. The case studies encompass system dynamics projects in close cooperation with housing researchers and seek to define the added value of such projects 5) related to housing content and 6) structural cooperation between disciplines.

The thesis explores contemporary housing research literature for the presence of complexity-related issues. These were found in the special characteristics of housing, the different time frames of housing market processes, the need to deal with non-equilibrium situations, the dynamics of household choice and demographics, the complex structure of the housing supply market and the presence of institutional and policy feedback loops. It further clarifies the system dynamics perspective and method and illustrates it with two examples. The main causes of the isolated position of system dynamics were found in the tendency to specialize in method rather than content and in historical debates between system dynamics and traditional economics. Small, comprehensible models in the language and concepts of the field of application are generally conducive to cooperation.

System dynamics literature on housing encompasses over 150 entries, ranging from groundbreaking publications to average conference papers. A first group revolves around the 1969 cornerstone project Urban Dynamics and is still productive. A second group focuses on changing government policies exists in the Netherland. A third group emerged after the 2008 financial crisis and connects system dynamics to mainstream real estate economics literature. Finally, several isolated entries were catalogued.

Four case studies were carried out for this thesis. A Group Model Building project in the Haaglanden region helped regional policy makers to settle a policy conflict and to improve understanding of the dynamics of the regional housing market. The second case study reports the building of Houdini, a system dynamics model based on mainstream real estate economics with several added institutional features, like zoning, residual land pricing, fiscal mortgage support and rent regulation. The third project named 'Middle Incomes' focused on making an impact analysis of a much contested new regulation on



the accessibility of the social rental sector. The fourth and final case study is concerned with a model of the dynamics of the national mortgage debt.

Next to the main answers to the research questions summarized above, the findings of the thesis encompass a set of building blocks or modeling ideas for further application in housing research. Content-related conclusions support existing ideas that housing allocation systems are relatively weak in stimulating housing vacancy chains, that demographic dynamics are a predominant force, that policy actors tend to underestimate the impact of time delays and that generic housing market structures can display widely varying time trajectories under different (regional) parameter sets. Questions for further research focus on identifying alternative and additional building blocks, rigorous simulation, closer comparison of existing empirical findings and system dynamics simulations and the exact demarcation of system dynamics and other simulation methods.

As to the cooperation between housing researchers and system dynamics, it is proposed that the acceptance of system dynamics in social sciences is isomorphic to validation on the project level: it is a process of gradual confidence building. Embedding system dynamics in regular research projects means to be selective in applying system dynamics to the proper issues and in cross-examining model outcomes with other types of research. It requires that system dynamics practitioners deeply understand the content issues and know where to make small, comprehensible system dynamics models excel. The case studies furthermore indicate that properly framing and communicating the scope, purpose and limitations of models contribute to successful projects. The thesis is concluded with a dynamic hypothesis how embedded system dynamics may contribute to close cooperation and integration of the method into regular social science.

# SAMENVATTING

Naar “Housing System Dynamics”<sup>1</sup>

*Projecten rond de inbedding van system dynamics in woningmarktbeleidsonderzoek*

Doel van dit proefschrift is bij te dragen aan een systematische verbinding van woningmarktonderzoek en system dynamics. Woningmarktonderzoek is een breed gebied met onder andere thema's als woningmarkten, woonvoorkeuren en verhuisgedrag, de woningbouwsector, overheidsinterventie. System dynamics is een op computersimulatie gebaseerde methodiek om het inzicht in dynamisch gedrag van complexe sociale systemen te vergroten. De disciplines kennen de nodige overeenkomsten, maar systematische samenwerking is er eigenlijk nog niet.

Daarom dient dit proefschrift een eerste basis te leggen via verkennend onderzoek en case studies. Er staan zes vragen centraal over 1) onderzoeksvragen geschikt voor system dynamics, 2) oorzaken van het gebrek aan samenwerking en bestaande aanbevelingen voor samenwerking, 3) de tot nu toe opgebouwde system dynamics-kennis over woningmarkten 4) een systematische analyse van deze kennis met betere samenwerking ten doel. De case studies zijn toepassingen van system dynamics in samenwerking met woningmarktonderzoekers met als doel de toegevoegde waarde in beeld te brengen betreffende 5) de inhoud en 6) de samenwerking.

Het proefschrift verkent recente woningmarktliteratuur op de aanwezigheid van onderzoeksvragen waar complexiteit een rol speelt. Deze zijn te vinden in de specifieke eigenschappen van woningen, verschillen in tijdshorizon van diverse woningmarktprocessen, de noodzaak om ook systemen buiten evenwicht te onderzoeken, dynamiek van woonvoorkeuren, keuzeprocessen en demografie, structuur van de woningbouwketen en de invloed van overheidsbeleid en instituties. Belangrijke oorzaken van de geïsoleerde positie van system dynamics zijn methodische specialisatie en historische discussies tussen de system dynamics wereld en traditionele economen. Kleine simulatiemodellen in de taal van het toepassingsgebied zijn aan de andere kant vaak zeer ondersteunend aan samenwerking.

De system dynamics-literatuur over woningmarkten telt ruim 150 bijdragen, variërend van klassiekers tot conferentiepapers. Een eerste groep bouwt voort op het Urban Dynamics model uit 1969 en levert nog steeds nieuwe bijdragen op. Een tweede groep legt de nadruk op de beleidswijzigingen in Nederland. De derde groep is ontstaan na de kredietcrisis uit 2008 en maakt meer gebruik van vastgoedeconomische literatuur. Tot slot zijn ook alle losse bijdragen vastgelegd.

Vier case studies vormen het empirische deel van dit proefschrift. Een Group Model Building project in Haaglanden heeft beleidsmakers geholpen een beleidsconflict op te lossen en meer inzicht in de dynamiek van de regionale woningmarkt te krijgen. De tweede case study betreft de ontwikkeling van Houdini, een system dynamics model

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1 'Housing systems' en 'system dynamics' zijn gebruikelijke begrippen in de Engelse vaktaal. 'Housing system dynamics' als samengesteld begrip is een niet goed in het Nederlands te vertalen woordgrapje.

gebaseerd op vastgoedeconomische literatuur met toevoeging van diverse institutionele elementen als ruimtelijke ordening, residuele grondprijzen, huurregulering en hypotheekrenteaf trek. Het derde project 'Middeninkomens' omvat een impactanalyse van een omstreden nieuwe regeling over de toegankelijkheid van de sociale huursector. De vierde en laatste case study betreft een model over de nationale hypotheekschuld.

Naast de hierboven samengevatte antwoorden op de zes onderzoeksvragen rapporteert dit proefschrift bevindingen in de vorm van bouwstenen voor system dynamics modellen van woningmarkten. Inhoudelijke conclusies bevestigen het belang van demografie voor de woningmarkt, dat woningtoewijzing nauwelijks effect heeft op de doorstroming, dat beleidsmakers het effect van vertragingen onderschatten en dat generieke woningmarktstructuren onder verschillende (regionale parameters) wijd uiteenlopende tijdspaden van centrale variabelen kunnen vertonen. Vragen voor verder onderzoek betreffen onder meer het ontwikkelen van alternatieve en aanvullende bouwstenen, grondige gevoeligheidsanalyses van de gepresenteerde modellen, meer vergelijking tussen empirische bevindingen en modeluitkomsten en de afbakening van system dynamics en andere simulatiemethoden.

Ten aanzien van samenwerking tussen woningmarktonderzoekers en system dynamicists wordt gesteld dat bredere acceptatie van system dynamics isomorf is aan de validatie op projectniveau: er is sprake van een geleidelijke opbouw van vertrouwen in de methodiek c.q. het model. Verdere inbedding in onderzoeksprojecten vereist een selectieve inzet van system dynamics op de juiste vraagstukken en voldoende kruiscontrole van de simulatieresultaten met andere methoden en bronnen. De betrokken system dynamicists dienen diep genoeg in de inhoud te zitten om kleine, begrijpelijke modellen te maken op relevante onderzoeksvragen die anders niet of moeilijk te beantwoorden zijn. De case studies tonen ook de noodzaak om scope, doel en beperkingen van de modellen duidelijk te communiceren. Het proefschrift wordt besloten met een dynamische hypothese hoe 'embedded system dynamics' kan bijdragen aan nauwere samenwerking en acceptatie van de methode binnen de sociale wetenschappen.



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# I INTRODUCTION

## I.1 PURPOSE OF THE THESIS AND INTRODUCTION TO THE RESEARCH THEME

Many contemporary housing research issues could fruitfully benefit from the use of the system dynamics method. System dynamics, however, operates largely in isolation of other social sciences. The purpose of this PhD thesis is therefore to contribute to a systematic connection between housing research and system dynamics.

*Housing research*<sup>2</sup> studies a vast array of phenomena like residential mobility, neighborhood development, the working of housing markets and the interaction with the overall economy, the relation between household demographics and residential patterns, socio-economic issues like affordability, social housing management, poverty and segregation, housing construction, urban design, sustainable building and more.

Housing research is multidisciplinary and draws, among others, from different strands of economics, from sociology, human geography, gender and development studies and from political science. Housing research is a mixed-method discipline, using statistical and econometric techniques, qualitative methods, large scale surveys, demographic forecasting and other modeling techniques. Housing research is in many cases related to housing policy making, as the provision of housing contains both market mechanisms and public policy interventions in most Western countries. As housing, housing markets and housing policy are extremely multi-faceted, references to housing as a complex issue are omnipresent.

Such housing market complexities stem mostly from the particular properties of housing. Houses represent many characteristics, some related to physical properties (e.g. size, number of rooms, amenities, quality), some related to vicinity of services, transport, work locations and areas for recreation and some related to social issues like neighborhood quality, safety and the like (Gibb, 2012). The housing supply sector is fragmented over different types of actors like land developers, property developers and contractors (Ball 2013), all reacting on market impulses, government decisions and internal risk/feasibility considerations.

Behavior of households towards housing and residential mobility highly depends on households characteristics such as age, household composition, income, education and culture. Housing has also been subject to government intervention ever since medieval aldermen started to intervene for preventing catastrophic city fires. Regulation regards construction, land use planning, affordability issues and others. These government measures interact with the other processes on the housing market and add to the complexity of its behavior.

*System dynamics* is a method to enhance learning about dynamic behavior of such complex systems and developing more effective policies for influencing them. It helps understanding and managing complex systems by using computer simulation models

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2 Throughout this thesis, the terms 'housing research' and 'housing studies' will be used as synonyms.

as management flight simulators, just as aviation uses simulation for training pilots and air traffic controllers (Sterman, 2000, pp. 4-5). System dynamics is solidly grounded in theories of feedback and nonlinear dynamics initially developed in mathematics and engineering. It applies these ideas to social systems using insights from human sciences like psychology, economics, housing research, ecology, medical science etc. Most notably, since its inception, system dynamics has also been studying housing and urban development.

Central to system dynamics is the *feedback perspective*. System dynamics emerged in the 1950's from operations research, which aimed at supporting management decision making by means of mathematical and statistical analysis. Operations research, however, proved to be ineffective for solving broad, strategic questions, because of its open-loop approach where no feedback exists between the system to be influenced and the decision to be made. Founding father Jay Forrester proposed a closed-loop approach as an alternative: decisions are made on basis of information on the state of the system to be influenced. Changes in the system, brought about by these decisions, then influence future decisions. In other words: decision making for influencing a social system is intrinsically a part of the system. Causes and effects are not linear but circular: there is mutual feedback between system and decision (Vennix, 1996, p. 43).

System dynamics is a method to enhance *learning* about behavior of and improving policies and decisions within complex systems. It does so by building computer simulations of the complex system involved, simulating proposed and alternative decisions, confronting decision makers with the outcomes and helping them understand why intended and unintended consequences emerge from the system structure. System dynamics relies on computer modeling as its main methodology, but perceives computer models only as imperfect mathematical representations of imperfect human mental models of real-world systems. Therefore, models are mere tools for incremental improvement in understanding a particular dynamic problem. All models are subject to limitations in scope of use, detail, boundaries, context etc. Put aphoristically: *all models are wrong, but some models are useful*. System dynamics models are useful when they help actors to better understand the system they are dealing with.

Judging from the above, housing research and system dynamics share many aspects in order to make close cooperation mutually beneficial. Housing markets or housing systems consist of many parties interacting with one another on the basis of information streams. They are exactly the complex social feedback systems studied by system dynamics. Some housing processes involve long time delays and moreover, stocks and flows are common conceptual elements in both disciplines. Finally, system dynamics is strongly focused on devising better policies through better understanding of feedback processes.

But surprisingly, there is no systematic cooperation between both disciplines yet. Housing research gets by with other methodologies, even if some contemporary research issues could benefit, at least potentially, from the system dynamics approach. System dynamics gets by in relative isolation from other social sciences, but thriving in managerial applications and ecology and with a scattered but not unsubstantial knowledge base in the field of housing and real estate, largely unnoticed by the housing research and policy community. Hence the purpose of this thesis.



## I.2 RESEARCH QUESTIONS, METHODOLOGY AND RELEVANCE

But if there is only an intuitively sensed potential for applying system dynamics in housing research systematically, we must conclude that the terrain of systematic connection between the two disciplines is virtually *terra incognita*. This conclusion defines the starting point for the research questions.

### Research questions

Granted the above conclusion, research into a systematic connection must start at the bare basics. First, we must identify clearly for what issues in housing research system dynamics offers the most fruitful perspective. We should also be aware that both disciplines have coexisted in virtual isolation of one another for nearly half a century. We must therefore understand the causes of this counterintuitive situation. The first two research questions revolve around these issues:

1. Which contemporary research issues in housing studies are particularly fit for tackling with system dynamics?
2. What factors have contributed to the lack of systematic cooperation between housing research and system dynamics up to the present? What practices and recommendations are present in existing literature for improving cooperation?

As mentioned above, system dynamics does have a certain track record in our field of interest. We must explore the existing system dynamics literature base on housing, real estate and urban development, which unfortunately is available only in a fragmented way. This literature base needs initial cataloguing of books, journal articles, conference presentations and other sources, in order to provide oversight for future research. However basic, this is a fundamental first step. Furthermore, we must endeavor into an initial attempt to integrate and systematize the insights from this literature in such a fashion that they become useful for the purpose of this thesis, i.e. by taking into account the relevant housing research issues and the lessons and recommendations for improving systematic cooperation. This main task is worded in the following research questions:

3. What is the accumulated knowledge of system dynamics on housing related issues up to now?
4. How can it be systematized and integrated into a form that is supportive of the research purpose of this study?

Another set of research questions connects to the projects mentioned in the subtitle of this thesis. If the system dynamics project on housing have been conducted mostly in isolation from mainstream housing research, it is necessary to explore the use of system dynamics in a housing policy research context. This will help generate model content closely linked to mainstream housing research. It will also add experience in cooperation between both disciplines.

5. What system dynamics models can be built in close connection to mainstream housing research? What is their added value to the existing knowledge base of both system dynamics and housing research regarding content?
6. What lessons can be learnt from the model building experiences in research question 5 about fruitful cooperation between system dynamicists and housing researchers?

## Research methodology

*Terrae incognitae* require discovery in the first place. Exploratory research is primarily concerned with such discovery and with generating insights and/or building theories (Davies, 2006, p. 110). Confirmatory research on the other hand is focused on theory verification through thorough, rigorous hypotheses testing on basis of solid well-defined (statistical) procedures. However, it necessarily assumes the a-priori existence of theories. Exploratory research precedes the stage of theory testing and is involved in the actual development of theory on the basis of unrelated and scattered data or observations of the real world. Exploratory research is broad and thorough in its own particular sense and requires flexibility and pragmatism<sup>3</sup> rather than solid (statistical or deductive) rigor. Exploratory and confirmatory represent different but indissolubly connected phases of scientific endeavor, like yin and yang in Chinese philosophy. The limitations of exploratory research mean that no definitive answers will be provided to the issues above.

The most suitable methodology for research questions 1 to 4 is literature study. It should concentrate on finding those contemporary challenges in housing research that best match the niche of system dynamics. Next to lessons and insights on cooperation between social science in general and system dynamics, a main section of this work consists of literature research on the existing system dynamics knowledge base on housing related issues. Where necessary, literature research will be complemented with additional techniques such as causal loop diagramming and system archetype analysis.

Research question 5 and 6 requires the use of several methodologies. First, all methodologies for building system dynamics models in cooperation with housing researchers are needed. System dynamics modeling and related techniques will presumably play an important role, but should not -in light of the purpose of contributing to systematic connections- a priori be taken as the dominant or only methodology to the exclusion of others.

The modeling projects must fulfill some basic requirements:

1. Obviously, they cover housing related themes and use concepts found in mainstream housing studies.
2. They should adhere to standards and guidelines of properly conducted system dynamics projects.
3. Housing experts and/or researchers participate in these projects.

It is also necessary to have some reference or standard for measuring the success or impact of the system dynamics projects, as the basic requirements only test whether they were conducted properly. High standards for quality were set by Forrester (2007b). The founding father is critical of the state of affairs and claims that system dynamics is at a 'rather aimless plateau' (p. 350), that it lacks proper impact on government due to its inability to find new high leverage policies for addressing the big issues in society.

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3 Many anecdotes circulate about the exploratory research methods of history's greatest scientists. Archimedes used bathing techniques, Newton slept under an apple tree, Einstein contemplated accelerating elevators in space when bored with his daytime job. This led science philosopher Feyerabend to provocatively suggest that well-established methods can even obstruct scientific progress. Other methodologists like Kuhn and Lakatos propagate more moderate stances where scientific theories and related methods evolve in schools of thought and are being replaced in innovative bursts of scientific revolutions.

He set nine criteria that help unfold the full potential of system dynamics. He claims that most works fall short of these standards because most practitioners have no opportunity of receiving system dynamics training beyond a basic level. He opposes tendencies to simplify system dynamics as it will dilute its powerful potential. The criteria include identification of the problems in the real world system, a compact dynamic hypothesis (or model) with strong generic and endogenous properties leading to new, different defensible policy options, including a discourse on expected resistance and how to overcome it. These standards will be used for assessing the quality of work presented here. In the overall framework of this thesis, the use of these modeling projects is a form of case study research. Case study research “allows the investigators to retain the holistic and meaningful characteristics of real-life events” (Yin, 2003, p. 2), which is very appropriate given the open character of research questions 5 and 6. Case study research is generally seen as suitable for exploratory research in situations where control over behavioral events is limited or absent. As opposed to controlled experiments with many subjects, modeling projects require a large endeavor and are not easily replicated.

### **Relevance**

This research thesis is relevant for science because of its perspective to connect two previously unrelated subjects. The literature review in the first main task will make system dynamics insights on housing, urban development and real estate accessible to a wider audience. The pilot projects will in any case contribute to the knowledge base of system dynamics, but will also generate relevant insights for the researchers and other stakeholders involved in them and contribute to a positive image of system dynamics among housing researchers. In the ideal case, they will be an initial stepping stone for future breakthrough research in housing studies, but it is beyond the scope of this thesis to judge whether these high hopes are realistic.

The relevance for society lies in the important role of housing in the overall economy and the recent economic collapse. In retrospect, the great financial crisis of 2008 is the dynamic behavior of a complex feedback system encompassing the financial market, the housing market, government budgets and the overall economy. This complex system displayed a rapid shift in loop dominance from growth through overshoot into collapse. This study focuses on connecting such a paramount aspect of human life and well-being i.e. housing with a method potentially capable of improving insight into the dynamics of complex socioeconomic systems as the housing market. The system dynamics method helps human actors to improve their understanding and policies towards such systems. Therefore, even if this study contributes only small specks of improved understanding and better or less detrimental policies, it holds relevance for society.

### **I.3 STRUCTURE OF THE THESIS**

Chapters II and III cover the literature research necessary for fulfilling the purpose of the thesis. Chapter II first relates to research question 1. It identifies those housing research issues suitable for system dynamics modeling and provides a more elaborate introduction to the system dynamics method, however, without being a full tutorial. Several excellent

textbooks are available for learning system dynamics, e.g. Fisher (2004), Sterman (2000) and Vennix (1996). Chapter II also covers research question 2: it explains historical and conceptual causes of the isolated position of system dynamics and summarizes existing recommendations on cooperation with social scientists.

Chapter III answers research questions 3 and 4. It starts with overall metrics of the system dynamics literature base on housing, real estate, urban development and related themes. It discerns three main schools or groups of system dynamics projects. First, it covers the rich literature surrounding Urban Dynamics, the controversial cornerstone project that still influences the relationship of system dynamics and other social sciences, mainly economics. The second school is locally based in the Netherlands, a country with a strong history of housing policy and a focal point of system dynamics research. The third school relates to the post-2008 output of system dynamics on housing, real estate and the great financial crisis. Chapter III also catalogues remaining isolated studies.

Chapters IV to VII cover the projects mentioned in the title of this thesis. These pilot projects are supportive of the second batch of work. The pilot projects represent a decade of professional involvement with housing, system dynamics modeling and applied policy research. In hindsight, their conceptual bases evolved towards increased use of academic housing market conceptualizations, even if the descriptions of the respective modeling contexts are mostly narrative and common-sense based. The projects were published earlier as applied policy research reports of two institutes, as contributions to housing and system dynamics conferences and in an academic journal. They provide the groundwork for answering research questions 5 and 6.

Chapter IV presents the Haaglanden project, carried out in the region around The Hague in the Netherlands around 2002-2003. Central to the modeling problem were the effects of urban transformation and greenfield construction on the chance of households finding a new rental dwelling. The participating stakeholders gained new insights in housing market dynamics and succeeded in reconciling a policy conflict. The project is relevant as it demonstrates proper application of system dynamics and models realistic housing market processes such as waiting lists, vacancy chains and redlining. It was published as Eskinasi, Rouwette, and Vennix (2009). Content-wise, the Haaglanden project is largely based on the mental models of regional housing policy makers and consultants, rather than on existing academic conceptualizations. As it contributed to organizational learning, it is a relatively successful system dynamics case. It contributes several initial modeling building blocks and insights on application of the system dynamics method to the purpose of this thesis.

The second case study (see chapter V) focuses on the model development of Houdini. Houdini connects to the national discussion on housing policy effectiveness. In distance to the Haaglanden model, Houdini is solidly founded on a well-known housing economics model and added institutional aspects like land use planning, rent regulation, fiscal mortgage support and residual land pricing policy. Furthermore, it adds slow changes on the demand side moving from growth to population shrinkage and tells of debates with main stream economists and how this contributed to model improvements. Houdini itself is documented in several publications, i.e. Eskinasi, Rouwette, and Vennix (2011) and Eskinasi (2011b). Institutional and/or policy modeling components of Houdini were

also used in the Middle Incomes and Mortgage model. Bare essentials of Houdini are contained in the second illustration in section II.2.

The third modeling project named Middle Incomes sprang from the debate on new regulations for state support to housing associations which affected housing availability for middle income households (see chapter VI). Model construction was embedded in a mixed methodology research project with political exposure. The model is a descendant of Houdini, adding further refinement of demographic and housing choice processes, housing allocation systems and behavior of different types of supply side actors on the basis of academic housing literature. The model gained sufficient confidence of leading academics and high ranking policy officials to be used in debates with Parliament. Some of the new insights still reverberate among policy makers. The full project report was published as Eskinasi, De Groot, Van Middelkoop, Verwest, and Conijn (2012). A shorter report on the model is available in Eskinasi (2013). Some important insights were integrated in De Groot and Eskinasi (2013); De Groot, Van Dam, and Daalhuizen (2013).

The final project reported in chapter VII focuses on the dynamics of the mortgage debts of Dutch households and the impossibility of significant reductions. The model was developed in close cooperation with housing economists and its findings were circulated with policy officials. Research reports are available in Dutch in Schilder, Conijn, and Eskinasi (2012) and Schilder and Conijn (2012a). The model adds new elements of mortgage debts to the knowledge base.

The thesis concludes with preliminary findings on successful application of system dynamics in housing research, open discussions and questions for further research. The appendices contain full model specifications and experimental setups.



## II HOUSING RESEARCH ISSUES AND SYSTEM DYNAMICS

The purpose of this chapter is to find answers to the first and second research questions. It describes what contemporary housing research issues could possibly benefit from a system dynamics approach in section II.1. This first section therefore focuses on exploring the presence of complexity-related research issues in a wide range of housing studies, rather than on critically cross-examining the varying and sometimes opposing stances within the housing literature, the latter being outside the scope of this thesis.

Section II.2 explains and illustrates the nature of system dynamics modeling in more detail. This part covers research question 1 and also provides hands-on illustrations how system dynamics can be applied in housing research. Section II.3 then contemplates the alleged isolated position of system dynamics among social sciences and tries to draw lessons for fruitful cooperation with housing researchers, thus providing at least partial answers to research question 2.

### II.1 CONTEMPORARY RESEARCH ISSUES IN HOUSING STUDIES

#### **A common conceptualization of the housing market**

A common economic conceptualization of housing and real estate markets is the four quadrant model (further: 4QM) by Di Pasquale and Wheaton (1996). This model discerns three important and closely interacting submarkets (see figure 1). It is useful in the light of the purpose of this thesis, as it is stock and flow based and includes a basic feedback structure.



**Figure 1** The four quadrant model

Source: Di Pasquale and Wheaton (1996)

The upper right quadrant represents the market for housing services. Here, consumers bid periodical payments or rent to acquire consumption of housing services. The demand curve is negatively sloped and parameterized by the total housing stock and demand fundamentals like number of households, household incomes etc. The upper left quadrant represents the housing asset market, where these periodical rents are being capitalized into real estate asset prices. The angle of the positively sloped curve represents the capitalization factor used. The lower left quadrant is the housing construction market. Here, housing prices, construction and development costs and characteristics of the building industry determine the level of new construction. Finally, the lower right quadrant adjusts the total housing stock on basis of new construction and depreciation or demolition.

The overall structure of the four quadrant model is equilibrium seeking or a balancing feedback loop, which is in line with neoclassical microeconomic theory. Di Pasquale and Wheaton (1996, pp. 12-18) demonstrate the effect of different exogenous shocks to the model (i.e. a demand shift, changing capitalization rate, different construction costs), which bring the model into new equilibriums. The shocks have different results on the sets of the four axes of the model (stock, rent, price and construction).

### **Modeling of real housing market processes**

Maclennan (2012), however, stresses that not only modeling based on neoclassical microeconomics is instrumental to improving understanding of housing market dynamics. He proposes a complementary modeling approach with stronger emphasis on modeling the actual processes on housing markets. He points out several arguments why such an approach is valuable next to mainstream neoclassical microeconomic analysis assuming perfectly informed and competitive markets.

Housing has many innate complexities due to product variety, its fixation in space and its longevity. It therefore differs from other consumption goods. These characteristics make housing markets more complex than stylized markets. Maclennan (2012) suggests that, imperfect and delayed market information makes expectations of consumers and experts (like brokers) matter for the overall dynamics on the short run and that these factors are therefore relevant for analysis. He supports his arguments (2012, p. 6) by pointing at “unsettling gaps” between common academic conceptualizations and the notions of serious market parties on the working of the housing market.

He also argues that for actual housing policy making, the common microeconomic perspective of *long-run* equilibrium may not be satisfactory. Policy issues may after all arise from the fact that housing markets *are not* in equilibrium, or that institutional characteristics obstruct equilibrium seeking behavior (Maclennan, 2012). Yet another issue is the potential difference between the outcome of efficient market processes and politically defined desirable outcomes.

Paramount to the dynamics of the housing market is the small size of supply through new construction in relation to the existing housing stock (Ball, Meen, & Nygaard, 2010). Also *vacant existing housing* plays an important role in matching house-hunters and houses. Vacant housing and sale time were demonstrated to have a strong impact on housing prices (Di Pasquale, 1999; Di Pasquale & Wheaton, 1996). It is plausible to claim that the housing market has multiple clearing processes: through new construction



and through supply of existing housing, stemming from migration, demographic change and others.

Residential mobility of households triggers vacancy chains which link mobility with (socio-economic) change in urban areas (Clark, 2012). On such a local level, *reinforcing processes* may lead to nonlinear, complex and chaotic behavior, e.g. when neighborhoods undergo rapid processes of filtering up or down (Galster, 2012).

Furthermore, the spatial fixity, durability and capital intensive nature of both the construction process and real estate ownership make owners (Galster, 2012; Maclennan, 2012) and contractors (Ball, 2012) susceptible to risks and adjust their behavior to these risks. Home owners tend to display loss aversion (Van Dijk, 2013b) and value housing equity differently from other forms of equity when deciding on housing consumption (Van Dijk, 2013a).

### **Complexities and white spots on the supply side**

Di Pasquale (1999) reviewed real estate economics literature and wondered why we don't know more about housing supply. Her review yielded several solid conclusions, but also some difficult puzzles. Even though more material is available on the supply of single-family houses than of multi-family rental dwellings, she claims that overall empirical evidence on the working of the supply side is "far less convincing" than on the demand side.

From the viewpoint of mainstream microeconomic theory, the explanatory power of the most obvious independent variables is insufficient. Neither house prices nor construction costs matter to the extent the neoclassical model predicts. On the other hand, the impact of *sale time* and of inflation is larger than expected (Di Pasquale, 1999). Construction apparently responds more to changes in house prices rather than to the price level (Ball et al., 2010). Home improvements were found to have higher income elasticity than repair expenditures.

Considering government intervention in the housing market, Di Pasquale (1999) found that subsidies for rental housing for middle-income families tend to displace private investments. Providing public or social housing for low-income groups, on the other hand, generally increases the housing stock and does not exhibit a displacement effect. Tax treatments for rental housing significantly affect the level of construction.

The common notion is that housing supply is slow and sluggish due to a) product characteristics b) the lengthy, complex and risky nature of the development process c) the dependence on *land availability* and d) the presence of *land use or planning systems*. Housing literature shows little agreement on the proper way of measuring price elasticity of supply and consequently, estimates vary widely from zero to infinity. But even with comparable methodologies, significant variation remains when comparing nations with different spatial and institutional characteristics, when comparing local situations with diverse land use regulations and spatial conditions and even between differently sized construction firms (Ball et al., 2010).

Ball (2012) claims that much less research effort has been concentrated on the actual house building industry than on the impact of land availability, local land monopolies and planning restrictions. Maclennan (2012, p. 13) expects that supply side sluggishness

cannot be attributed to planning restrictions alone: “.. the challenge for applied analysis is to identify the balance of ‘market’ failure versus planning restrictions”.

But most of all, the mainstream literature on housing supply is lacking in “thorough understanding of the complex decision making processes of developers and suppliers in the market” (Di Pasquale, 1999, p. 21). More precisely, developers and others function (and make decisions on basis of market information) only within the framework of the real estate market and its economic and institutional context, so that feedback processes emerge from the interaction between parties (Trevillion, 2002). House-building involves a *chain of specialized, interrelated* firms rather than theoretical monolithic suppliers. These linkages between these enterprises are crucial for understanding the nature of housing supply (Ball, 2012). One apparent obstruction for such research is the lack of statistical data on the company level, which is unfortunately time consuming and expensive (Di Pasquale, 1999).

### **Dynamics of housing demand and behavior**

There is a vast body of literature surveying the relationship between age, life events and housing behavior of households or individuals. Life events include demographic events like leaving the parental home, partnership and household formation, childbirth and separation through divorces or death. Life events and household decisions also relate to the educational and labor career. Housing behavior includes decisions on e.g. residential mobility, tenure and neighborhood choice and housing expenditure (Van Ham, 2012).

Under the current *dynamic life-course approach* (Clark, 2012), factors from both the macro context and from the individual level determine (revealed or stated) housing preferences and actual housing decisions or behavior. Household resources and restrictions (like income, health, family size, social networks, job location) and factors from the macro-context like housing availability and affordability determine and sometimes significantly limit the realistic set of options of a household.

The dynamic life-course approach stems from the older life-cycle approach with a rather fixed, linear progression of life and housing stages. The newer approach allows for multiple paths throughout life (e.g. the increasing number of singles, childless couples, divorce and remarriage etc.). Moreover, individual life and housing events (labeled ‘micro time’) are embedded in the macro context (or ‘macro time’) or history of the economic, social, political, institutional and spatial development on the society level (Van Ham, 2012).

The role of *micro and macro time* in housing careers is explicitly named as one of the areas of future research for housing studies (Van Ham, 2012, p. 59). Different birth cohorts experience historical or macro time events at different stages in their housing life-course, for instance a housing boom or bust. Moreover, the simultaneous concurrence of life-course events of one cohort may constitute a major event in macro time for other cohorts. As an example, when the large cohort of baby boomers will start leaving the housing market at old age, the high number of vacant dwellings may provide ample opportunities for young households to enter into home ownership in regions with tensed market, or plunge regions with already weak demand into a housing bust (Mankiw & Weil, 1988; Myers & Ryu, 2008). Generational dynamics, macro and micro time then interlock into a complex process determining the real options for house-hunting families,

couples and singles and possibly even influencing the macroeconomics of the housing market.

Certain dynamics interfere with the process of households optimizing their housing situation under a given set of preferences and restrictions. First, the high cost of moving house (financially and otherwise) may cause *significant inertia* in the process of adapting the housing situation to the preferences. Second, evidence exists that households adapt preferences to what they perceive as realistic options (Van Ham, 2012, p. 48). Third, as neighborhoods express the social situation of their inhabitants and many households tend to seek out people like themselves, such decisions become interrelated, allowing for reinforcing feedback and fast changes in neighborhood composition (Gibb, 2012).

### **Housing cycles and institutional feedback loops**

House prices portray significant volatility relative to changes in fundamentals like interest rates and demographic and economic growth (Glaeser, Gyourko, & Saiz, 2008). Wheaton (1999) explored the fundamental conditions under which real estate cycles occur in the analytically solvable 4QM. He confined himself to this single-feedback loop model based on mainstream microeconomic theory with fully rational agents, as more complex feedback structures are difficult to handle analytically (Wheaton, 1999, p. 212). He reconfirmed that such models do not exhibit *endogenous* cycles, but that cycles can be produced as the model reacts to *periodical external* shocks. It should be noted that older macroeconomic models predating the strict application of microeconomic foundations (e.g. the 1936 Tinbergen model (Dhaene & Barten, 1989) or Keynesian models) were perfectly capable of generating endogenous business cycles and out-of-equilibrium dynamics (Boumans, 2011).

Adaptively or myopically acting agents (i.e. make systematic mistakes in forecasting the results of shocks e.g. using current or historic values for forecasts) are only a precondition for endogenous cycles. In this case, the occurrence of cycles “critically depends on the important features that characterize different types of real estate” (Wheaton 1999 p. 210), such as the ratio of demand versus supply elasticity, growth and depreciation rates and supply delays. Glaeser et al. (2008), for instance, found that temporary bubbles can occur when buyers and suppliers are overly optimistic about future prices, until the delayed supply response rebalances demand. Areas with more elastic supply have shorter bubbles, but face more risk of overbuilding with negative consequences for overall welfare. There is some evidence that real-world behavior of housing consumers does not fully comply with the rationality axiom of neoclassical models (Case & Shiller, 1989; Glaeser, 2013; Hamilton & Schwab, 1985).

Finally, even with fully rational agents, institutional features and/or institutional feedback relationships (Wheaton, 1999, p. 210;225) may cause the 4QM to exhibit endogenous oscillation. Such institutional feedback may consist of government interventions (Di Pasquale, 1999), but also of feedback mechanisms with other markets, like the financial market (Anundsen & Jansen, 2013), construction, development and land markets (Ball, 2012; Di Pasquale & Wheaton, 1996, pp. 35-36; Trevillion, 2002)

### **In summary: what contemporary housing research issues exist?**

In summary and in light of the purpose of this thesis, the following research issues in contemporary housing studies were found, which may potentially benefit from using system dynamics:

1. Due to the specific characteristics of housing (spatial fixity, durability and capital intensive nature), real-world processes in the housing market may not necessarily match the assumptions of neoclassical microeconomics and therefore exhibit different dynamics.
2. Realistic housing markets have processes running in different timeframes (e.g. short-run price dynamics, medium-run supply responses and long-run demographics changes) in interaction.
3. The time horizon of research for housing policy issues may not necessarily match the long-run horizon of microeconomic equilibrium. It may therefore be productive to also model and analyze trajectories towards equilibrium and out-of-equilibrium situations.
4. The housing supply sector does not consist of monolithic suppliers but is rather a supply chain consisting of many specialized and interacting entities. Feedback between these entities adds to the complexity of dynamic behavior of the supply chain.
5. Housing supply results both from new construction and from vacancies within the existing stock. These two clearing processes can alternately dominate the dynamics of the housing market.
6. Due to several factors, households do not continuously adapt the housing situation to the preferences, but links exist with life stages, job decisions, age, health etc. Social status aspects of housing create reinforcing feedback on local or neighborhood level.
7. The housing market is indissolubly connected with the land, construction, development and financial markets and with the institutional context, which most presumably add to the complexity of feedback and may induce booms and busts.

## **II.2 THE SYSTEM DYNAMICS PERSPECTIVE AND METHOD**

Granted the assumption that the above research issues exist in contemporary housing studies, we must proceed to investigate whether system dynamics has suitable characteristics for addressing these research issues. We first describe the general conceptual nature of system dynamics.

### **Conceptual cornerstones of system dynamics**

System dynamics is the science of understanding dynamic behavior of complex systems by means of computer simulation. Its purpose is to aid policy making in social, economic, managerial and other settings. Fundamental to system dynamics is the *endogenous perspective*: problematic behavior of complex systems stems from its internal feedback structure and exogenous impulses are mere triggers (Richardson, 2011). This key issue is commonly formulated as the aphorism “*structure drives behavior*”. Systems with comparable feedback structures will exhibit comparable dynamic behavior, even if

the respective contents are wide apart (so-called isomorphism). This perspective gave rise to the development of sets of so-called system archetypes. Senge, Ross, Smith, Roberts, and Kleiner (1994) presented well-known narrative archetypes like ‘fixes that fail’, ‘success to the successful’ and ‘tragedy of the commons’. Wolstenholme (2003) restructured the system archetypes into a more analytical core set.

The *syntax* or mathematical specification of system dynamics models is based on several elements: the closed boundary around the system; the central feedback loops; stock (also known as levels or accumulations) and flow variables (or rates); goals, observed conditions, discrepancies and finally actions or decisions (Forrester, 1969; Vennix, 1996). The closed boundary around the system does not imply a system in isolation, it is rather that a particular strand of dynamic behavior can be explained from the system structure within these boundaries. The addition of goals, observed conditions, discrepancies and actor decision into the models serves to embed human actors into the complex feedback structures of social systems.

#### *Policies of human actors are a fundamental part of the complex social system*

The counterintuitive behavior and policy resistance of complex social systems stems from the inability of human decision makers -embedded in the system- to properly understand *all* feedback relations within the system. The human actors in the system strive to pursue their goals on basis of information about the stock variables through influencing flow rates (Vennix, 1996, p. 45). Their policies and decision rules are therefore endogenous and a fundamental part of the system.

So-called policy resistance, side effects or adverse effects stem purely from the *imperfect perception* of causes, effects and feedback by the actors striving to attain certain goals: the system itself just reacts as defined by its feedback structure and does not discern at all between intended and unintended or adverse effects (Sterman, 2000, p. 10).

There is ample empirical evidence that human beings systematically misestimate the behavior of higher-level feedback systems (Forrester, 2007b, p. 363). Their actions and policies may be detrimental to the final outcomes. System dynamics computer simulation help human actors understand how feedback loop configurations cause tenacious resistance of systems against policies, how decisions and policies propagate and what policy alternatives are most effective. Because system dynamics helps human actors understand and adapt social systems, it is not deterministic or structuralist but takes a middle position in the structure-agency continuum (Lane, 2001, p. 113).

#### *System dynamics and housing (economic) research share many concepts*

Even though the system dynamics community tends to emphasize difference with other methodologies (most notably with statistical econometric modeling), system dynamics shares many tacit underlying assumptions with most other modeling and simulation techniques (Meadows, 1980). They are based on a logical, scientific, western mode of thought, in which events and social processes have causes that can be understood and possibly altered. Furthermore, the worldview is managerial: problems should be actively solved, not passively endured. All methods rely on computers for assisting the human brain and on computer models as the best representations of social systems. Finally, they

are based on the idea that human behavior is to some extent predictable and can be represented by means of equations.

Furthermore, stocks, flows and (balancing) feedback loops are *by no means exclusively used* in system dynamics, but are also common in housing and economic theory, e.g. in Tinbergen's 1936 macroeconomic model (Dhaene & Barten, 1989), Poterba (1984) and others. Computer simulation over time is also prominent in cellular automata and agent based simulation (Benenson & Torrens, 2004), in cohort component based demographic forecasts (e.g. De Jong et al., 2005) and in economic dynamic modeling (e.g. Donders, Van Dijk, & Romijn, 2010). It is common parlance to talk about the housing *stock* and to perceive new construction as an annual addition or inflow to this stock. Equilibrium seeking is the fundamental property of so-called balancing feedback loops. So-called reinforcing feedback loops exhibit exponential growth, e.g. a savings account with interest or a wage-price spiral with out-of-control inflation.

But for relatively simple models without feedback or with a single feedback loop, there is not much added value of system dynamics over standard analytical solutions. System dynamics excels at so-called 'higher order feedback' problems where two or more feedback loops interact in non-linear fashions. Such structures easily surpass the possibilities of analytical solutions and are very difficult to handle statistically. System dynamics therefore resorts to computer simulation with dedicated software packages<sup>4</sup>.

Wheaton (1999) exactly identified this demarcation line when he found that, even with models adhering to strict microeconomic foundations, additional institutional feedback loops may bring an otherwise equilibrium seeking system into endogenous cyclicity. With higher order feedback as its home territory, system dynamics differs from other methodologies in the scope of answers it delivers, in information bases, mathematical procedures and validation approaches.

### *System dynamics focuses on understanding dynamic behavior and not on point prediction*

System dynamics focuses on the longer term and general understanding of the dynamic nature of problems. It focuses on identifying behavior-driving structures, effective pressure points for and side effects of policies. It is helpful in discerning sensitive and insensitive parameters and can help focusing statistical analysis on those parameters that really matter.

On the other hand, system dynamics is not concerned with short-term, rather precise predictions or forecasts of economic or other variables nor with detailed implementation of policies. Furthermore, it is of limited value for problems of distribution over classes, persons or geographical areas (Meadows, 1980). Neither is system dynamics an innately spatial simulation methodology as cellular automata and agent based simulations (Benenson & Torrens, 2004). Many authors, however, (e.g. BenDor & Kaza, 2012; Despotakis & Giaoutzi, 1996; Hovmand, 2005; Jutila, 1981; Lowry & Taylor, 2009; Sancar & Allenstein, 1989; Singhasaneh, Lukens, Eiumnoh, & Demaine, 1991) have

<sup>4</sup> Commonly used software packages include Vensim by Ventana Systems, IThink / Stella by ISee Systems and Powersim by the homonymous Norwegian software company.



worked on integrating system dynamics with spatially oriented simulation methodologies, GIS-based analysis and visualization methodologies.

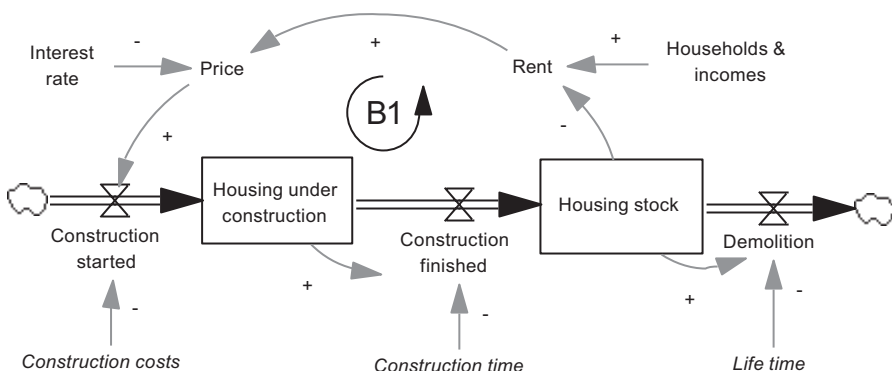
Statistical and econometric analysis is more suitable for short-term precise prediction. Linear causal relationships allow for extensive use of statistical data and a multitude of techniques for validating the fit of model outcomes to observed trends (Meadows, 1980). These methods critically depend on good statistical data sources and are somewhat limited to situations not too different from those represented by the data. This is exactly what Di Pasquale (1999) hinted at.

System dynamics, on the other hand, focuses more on feedback structures driving behavior. It is therefore less dependent on high quality statistical data for parameter estimates and is capable of working with both quantitative, qualitative, explicit and implicit sources of knowledge, with the process approach of system dynamics being a cornerstone (Meadows, 1980). Validation of system dynamics models puts strong emphasis on structural and behavioral properties of models and not on statistical fit to observed trends alone (Forrester & Senge, 1980; Sterman, 1984).

Prominent technical differences are in most cases related to differences in focus and purpose of the techniques. Meadows (1980, p. 47) suggested that econometric analysis and system dynamics represent different niches in modeling techniques with methodological discussions “tending to degenerate in classical cross-paradigm confusion”.

### A first illustration: the 4QM in system dynamics notation

A first illustration will help clarify the pictography of system dynamics<sup>5</sup> and the easy translation of the 4QM from a mathematical into a system dynamics form. For the basic 4QM with one feedback loop, translation into system dynamics form does not add much value, possibly apart from time simulation and the clear designation of the feedback structure. Conversely, we should conclude that the 4QM with its single balancing loop is a useable embryonic system dynamics model and that added value may follow when adding more (institutional) feedback.



**Figure 2** The 4QM in system dynamics notation

5 Several excellent textbooks on system dynamics are readily available, e.g. Fisher (2004); Sterman (2000).

Figure 2 presents the 4QM in the common notation of system dynamics. Boxes represent stock variables. Double arrows with valves depict flow variables and the small clouds on the far left and far right represent system boundaries. The stocks and flows connect into a so-called supply chain.

The single arrows represent causal links between variables. Pluses and minuses designate the polarity of these relationships. The polarity of the link between incomes and rent is positive as higher incomes lead *ceteris paribus* to higher rents. Increasing interest rates lead to lower real estate prices, and therefore, this relation has negative polarity.

Feedback loops are found where several individual links connect into a circle. The main balancing feedback loop of the 4QM runs from stock through rent, price and construction back into stock<sup>6</sup>. For the sake of diagram clarity, loops are numbered and designated with B for balancing and R for reinforcing. Diagram clarity also requires verbose variable names.

On the far right of the figure, the flow variable ‘demolition’ is regulated by an auxiliary variable ‘life time’. The original 4QM has ‘depreciation rate’ instead. Even though both specifications are mathematically equivalent<sup>7</sup>, system dynamics prefers time variables. The use of time variables allows to easily model delays in the supply chain of the 4QM, as the cautious reader already noticed.

Constructing an actual model in system dynamics software requires entering equations, parameters and startup values for all elements in the causal diagram and adding optional graphs, tables and controls for a model user interface. This first illustration used the equations in Di Pasquale and Wheaton (1996, pp. 8-18).

As an innately time simulation based method, system dynamics allows to model processes running with different time frames. The common dichotomy between long-term and short-term (or instantaneous) processes found in mainstream microeconomic models is somewhat artificial from the system dynamics point of view: system dynamics modeling automatically enforces time integrity, even if short run processes on the housing services market work on monthly time scales, supply reactions take years and demographic processes reshaping demand unfold over decades. A simulation run calculates the time trajectory of all variables using Euler’s or Runge-Kutta’s numerical integration methods with an arbitrarily small time step.

This focus on time simulation allows system dynamics models to be in equilibrium, to be moving towards a stable or moving equilibrium or be in a state of oscillation or even random chaos. This is important as Maclennan (2012) expressed doubt to the relevance of *ex-ante* long-run equilibrium assumptions for applied policy research. Using time simulations allows system dynamics to transcend these limitations.

### Modeling processes , validation and reporting aspects

The process of constructing a system dynamics model generally involves a number of steps (a.o. Vennix, 1996). The first step is the *definition of the problematic issue* and the

6 Smaller feedback loops exist around the stocks and the flows. Demolition, being an outflow, decreases the housing stock. Demolition, in turn, is proportional to and therefore dependent on the size of the housing stock. A balancing feedback loop emerges, exponentially depleting the housing stock (*ceteris paribus*). A similar structure governs housing under construction and construction finished.

7 If life time  $l = 100$  years, then depreciation rate  $\delta = 1 / l = 0,01$  / year.



purpose of the model, by means of describing the dynamics of central variables over time, the so-called *reference mode of behavior*. This is not necessarily straightforward, as Vennix (1996, p. 13) argues that different stakeholders may hold very different opinions on the core problem involved. Furthermore, system dynamics does not necessarily equate the reference mode of behavior with the exact numerical time trajectory of variable. Defining a reference mode of behavior as a particular trend or relative movement of variables is equally acceptable. The second illustration will provide an example of such a definition.

In the second step, the system conceptualization or *dynamic hypothesis* connects all relevant variables causally into the feedback structure of the system. The third step takes the conceptualization further to a *formal quantitative model* in terms of equations and parameters.

These stages are crucial in the construction and validation of system dynamics models. System dynamics does not provide the substantive content for its model. The content must be elicited from other sources and properly translated into a valid model structure adequately capturing the dynamic behavior under scrutiny. In validation, proper representation of the system structure is emphasized more than precise fits to historical data.

Knowledge elicitation techniques are crucial for these first three steps. In system dynamics parlance, knowledge elicitation serves to make the mental models of content experts on the social system under scrutiny explicit. Mental models include conceptual models (e.g. the 4QM), policy logic, knowledge stored in descriptive statistics and statistical models, opinions, guesses, estimates and intuitions of experts and professionals in the fields. Some mental models may be explicit and well-documented in written sources like academic and professional literature, policy documents and statistical databases (Forrester, 1992). Other information and mental models may be tacit.

System dynamics applies a multitude of methods to elicit knowledge, like structured interviews, literature desk research and cross examination of sources. Many authors contributed to documenting, systematizing and testing elicitation methods for effectiveness (a.o. Andersen, Richardson, & Vennix, 1997; Ford & Sterman, 1997; Rouwette, 2003; Vennix, 1996).

Participative methods are important in system dynamics for eliciting the more tacit knowledge and mental models. Participation techniques include informal techniques like brainstorming and open discussion, but also well-structured methods like Delphi, Nominal Group Technique and especially Group Model Building (Rouwette, Vennix, & Van Mullekom, 2002; Vennix, 1996). It has been demonstrated that actors learn most from system dynamics projects when they are deeply involved in the model construction process (Lane, Monefelt, & Husemann, 2003; Meadows & Robinson, 1985; Rouwette, 2003).

In the fourth step, the model undergoes rigorous *testing and sensitivity analysis* in the fourth step. *Assessing and accepting (or rejecting) model validity* is central to the fifth step. As models are mere mathematical representations of imperfect human mental models of real world problems, validity is not absolute but rather a process of gradual confidence building in the suitability of a model for a given well-defined purpose and

the problem it seeks to address (Forrester & Senge, 1980). This is comparable to the Popperian increasing degree of corroboration of scientific theories.

Forrester and Senge (1980) provide an array of eighteen specific tests for the non-linear system dynamics models, focusing on three important aspects: structure verification, behavior reproduction and policy implication tests. Ten out of these eighteen are considered core tests.

Proper structure verification is a crucial step in validation. From within a substantive social science, this aspect is often left implicit, but for a multi-content methodology like system dynamics, testing for content-wise proper model structure is indispensable and must be made explicit. The first test is that the modeled system structure must not contradict existing knowledge of the real world system. This is where the mentioned knowledge elicitation techniques come into play. Parameters in the model must conceptually and numerically correspond and the model should respond properly to extreme conditions.

The very important boundary adequacy test relates the model structure to its dynamic behavior. The test is passed when the model includes all relevant components to reliably reproduce the reference mode of behavior. If not, important system components might be missing. Finally, dimensional consistency checks against the inclusion of artificial parameters with so-called exotic units, often revealing flawed structural specification.

In many modeling projects, validation and the modeling process steps are closely linked. Especially the steps of structure verification, model conceptualization and formal specification are in many cases intertwined.

The second aspect of validation refers to model behavior. First of all, anomalous model behavior (contradicting behavior of the real world system) is unacceptable. Moreover, the model should accurately reproduce the specific symptoms of the reference mode of behavior that motivated model construction, including periodicities of cyclical behavior and relative phases of variables without the extensive use of exogenous time series driving the model. After all, system dynamics focuses on modeling endogenous causes of dynamic behavior. Reliance on exogenous time series would then invalidate the model. The model should also *qualitatively* predict plausible future pattern and events.

Statistical testing of model outcomes to historical data with the Theil statistics of inequality (Sterman, 1984) is common, but not regarded as the most important aspect of validation. Founding father (Forrester, 2007b, pp. 363-364) even opposes strong reliance on statistical fit with historic data for validation purposes.

Policy tests of the model focus on whether changing policies in the system generate plausible responses. Furthermore, it should be tested whether uncertainty in parameter values would change the policy recommendations based upon the model experiments. The ultimate test, however, is when policy recommendations from the model lead to improvement of the performance of the real world system. Unfortunately, this ultimate test is difficult to perform.

Once the model attained a certain level of credibility (on basis of the above tests and in participative processes, the acceptance by the problem holders), modelers carry out *policy experiments* and evaluate them in the sixth step. Simulation of policy experiments in the presence of stakeholders is the point in the process where most learning effects occur

and where system dynamics has most influence on the mental models of the stakeholders (Rouwette, 2003).

Finally and hopefully, involved stakeholders will use their conclusions from the modeling project in daily decision making or in improving the studied system.

### *Modeling project reporting guidelines*

System dynamics projects are very varied and multi-faceted regarding themes and approaches. In order to systematize approaches and project reports for cumulative knowledge building, theories on effectiveness of guidelines for reporting (group) modeling projects were laid out by e.g. Andersen et al. (1997), Andersen, Vennix, Richardson, and Rouwette (2007), Rouwette et al. (2002) and Rouwette and Vennix (2006). These guidelines include a wide range of aspects, from the problem background, through selection of the group of participants and model description to the assessment of the influence of the group model building project on the participants' perception of the core issue involved. Furthermore, Rahmandad and Sterman (2012) developed guidelines for the reporting of the actual models, including parameter sources and policy experiment setup.

### *Advanced modeling and analysis techniques*

In addition to the standard approach described above, several more advanced system dynamics techniques exist. The most common system dynamics software packages support more complex sensitivity analysis with stochastic parameter values, Monte Carlo and Latin hypercube simulation. Certain software packages implement objective optimization by means of the Covariance Matrix Adaptation Evolution Strategy algorithm (Hansen, 2010). Exploratory System Dynamics Modeling and Analysis combines traditional system dynamics modeling with the deep uncertainty concept, where no agreement exists on the proper conceptual model to address a certain research or policy issue (Pruyt, 2010). Loop dominance analysis focuses on identifying the feedback loop dominating system behavior over a certain time interval by means of both structural and behavioral techniques (Ford, 1998).

## **A second illustration: moving towards institutional feedback**

This example illustrates several aspects of the system modeling process, i.e. the identification of a problem context, reference mode of behavior and modeling purpose. It demonstrates how system dynamics incorporates institutional feedback and moreover, clarifies the abstraction level and focus on understanding dynamic behavior.

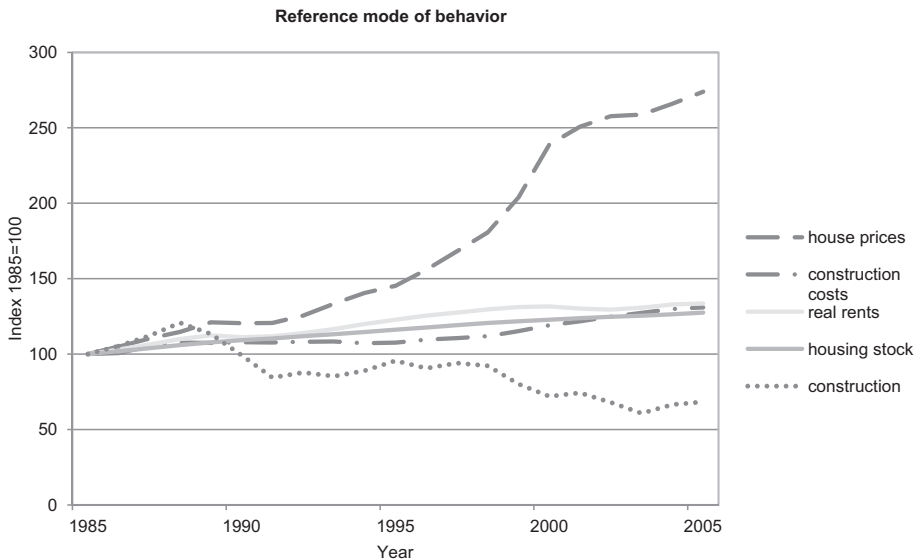
The *problem context* is found in strong perception changes in the early 2000's on the success of Dutch housing policy after the Second World War. Traditionally, housing was conceived of as a merit good and many state support programs existed for housing associations, urban renewal, housing allowances, mortgage tax breaks etc., not to mention the close-knit relation between housing policy and land use planning.

From 2005 onwards, however, (institutional) economists increasingly criticized state interventions. Rent regulation and implicit subsidies to tenants were said to strongly increase demand for social housing and fiscal support to home owners was held responsible for inflating house prices (Conijn, 2008; Donders et al., 2010). Spatial planning, building regulation and municipal land pricing allegedly restricted new construction

too much so that prices would increase even more (Besseling, Bovenberg, Romijn, & Vermeulen, 2008; Buitelaar, 2010; Eichholtz & Lindenthal, 2008; Renes, Thissen, & Segeren, 2006). Financial innovations allowed higher and more risky leveraging of households with interest-only mortgages and saving schemes (Van Ewijk & Ter Rele, 2008). Most authors advocated far-reaching reforms towards market liberalization. This context is suitable for system dynamic analysis as the critical economists claim policy resistance of the housing market and as the issue involves complex institutional feedback loops.

System dynamics analysis starts with defining a *reference model of behavior*, a description of the problematic behavior of the system over time in one or several main variables. A suitable reference mode of behavior for this example is found in the dynamics of house prices, construction volumes and construction costs in figure 3.

It demonstrates rapid price increases of houses, whereas rents and construction costs show far more moderate increases. But most striking is that construction moves in the *opposite* direction of house prices, which is in contradiction with mainstream micro-economic theory. We define *this particular symptom* as the reference mode of behavior. The economic authors identified four institutional factors (rent regulation, subsidies, land use planning, active municipal land policies), that *may* potentially (and partially) explain the reference mode of behavior. They do not, however, clearly demonstrate which factor is essential for the opposite movement of construction and house prices. This illustrates the point made by Maclennan (2012, p. 13), calling for more balanced analysis of market failure and planning or policy restrictions.



**Figure 3 Reference mode of behavior for second illustration**

Source: Besseling et al. (2008).

The *modeling purpose* will therefore be to simulate these factors in order to determine the most probable cause(s) for the reference behavior. In proper system dynamics practice, this means developing structural modifications to the basic 4QM in figure 2 and testing whether these capture the essence of the reference mode of behavior, i.e. opposite movement of construction and prices in an otherwise balancing loop structure. The quintessence of system dynamics is in finding stock and flow structures causing a particular dynamic behavioral trait and not in fully matching a given reference trajectory of a variable<sup>8</sup>.

The model in figure 2 is suitable as a departure point for creating a *baseline simulation* and adding the four structural modifications<sup>9</sup>. Its initial values are set up to static equilibrium and output variables are presented as indices with their initial values at 100%. This will allow to focus properly on dynamic patterns without distraction from actual numerical values.

In the 1990's demand growth and decreasing interest rate had triggered the Dutch housing market to exhibit the criticized reference mode of behavior. This illustration will use a simple demand and interest rate shift in simulation years 10 to 20. The simulation horizon is set at 100 years in order to allow the effects of these stimuli and the structural modifications to play out. Di Pasquale and Wheaton (1996) already documented the effects of single parameter changes on the final equilibrium values. Our baseline (see figure 4) therefore only adds insights on the time trajectory towards new equilibrium and the balance between the different stimuli. The interest rate decrease appears stronger than demand growth, as rents equilibrate to a new level below 100%.

Crude as it may appear, the baseline is only a starting point for investigating the effects of the structural modifications on the trajectories of prices and construction. After all, we are testing for structures exhibiting opposite movement of construction and prices, i.e. the fundamental problematic aspect of the reference mode of behavior. It is repeatedly emphasized that this is the quintessential purpose of system dynamics modeling.

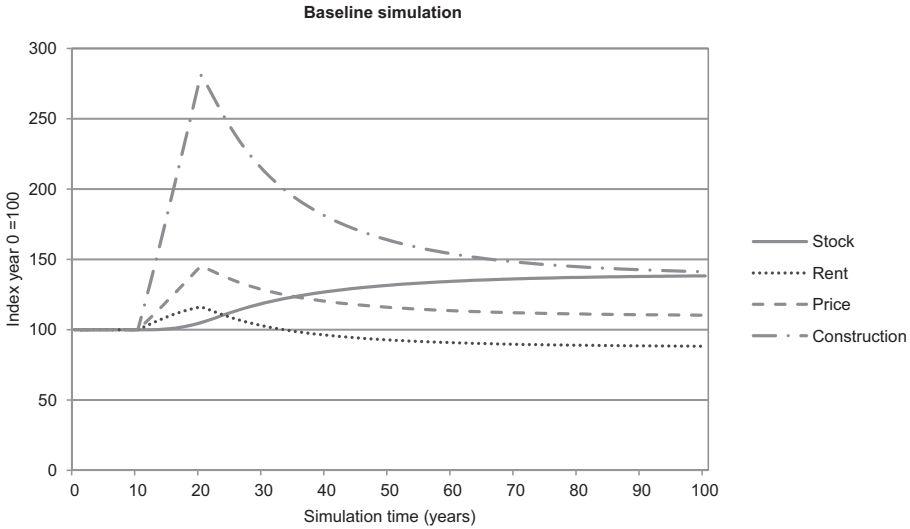
The first and second structural modification mimic rent regulation and fiscal mortgage support respectively<sup>10</sup>. Their time trajectories are compared to the baseline. In the former case, a rent ceiling variable is added prohibiting rent to exceed its initial value. Rent does not react anymore to stimulated demand so that boosted prices and construction can

8 Forrester (2007b) claims that any model with enough parameters can be manipulated to match (nearly) any historical curve. His stance is that fit to historical data is even misleading when parameter manipulation precedes over careful analysis of underlying stock & flow and feedback structures. The demonstration model here is rather crude at capturing the reference mode of behavior. It nevertheless inherited its essential institutional system structures from Houdini (see chapter 0). Houdini takes more exogenous parameters like income and household development and interest rate. It matches its reference mode of behavior in a statistically significant sense. This supports Forrester's argument.

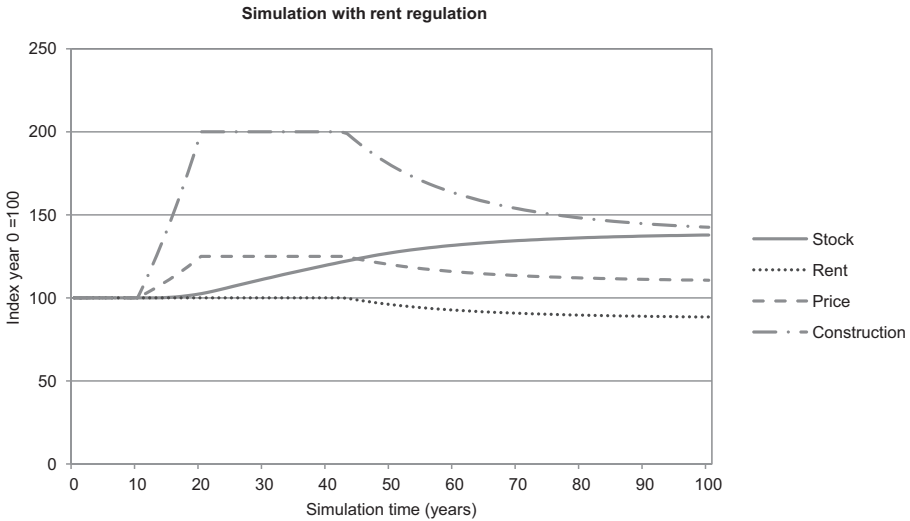
9 The equations of Di Pasquale and Wheaton (1996, pp. 8-10) contain several elements with so-called exotic units in the rent and construction equations. System dynamics modeling requires operational thinking and insists on using only variables with a clear real-world representation and comprehensible units. Adding statistically convenient variables (like elasticity or regression parameters) is not accepted in good system dynamics practice. The problematic equations, however, can be easily re-specified. The demand function of a Cobb Douglas utility function under budget restriction leads to fixed proportional expenditure. Establishing a lookup relation between profits (prices minus construction costs) and construction volumes corrects the construction equation. These re-specifications improve both unit consistency and compatibility with microeconomic theory.

10 The model diagrams for rent regulation and fiscal mortgage support do not fundamentally differ from the basic model. Therefore, they are not depicted.

be solely attributed to the decreasing interest rate. As increased demand is not accommodated, rents start decreasing below the 100% mark about 15 years later than in the baseline simulation.

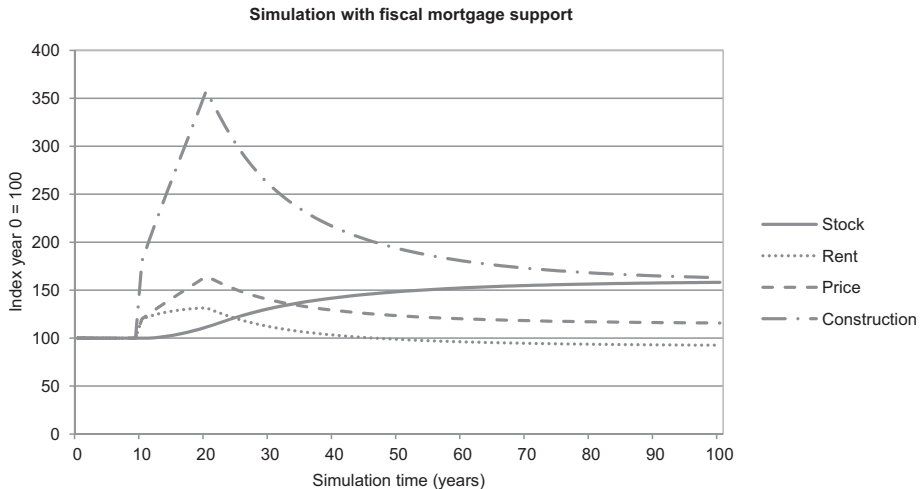


**Figure 4 Baseline simulation results**



**Figure 5 Simulations results with rent regulation**

In the latter case, fiscal mortgage support is modeled as a 20% subsidy on annual payment for housing services as in Donders et al. (2010). When suddenly introduced in year 10, fiscal mortgage supports spurs prices and construction even more. Its dynamic response is similar to demand stimulation, even if it differs in peak amplitudes and final equilibrium.



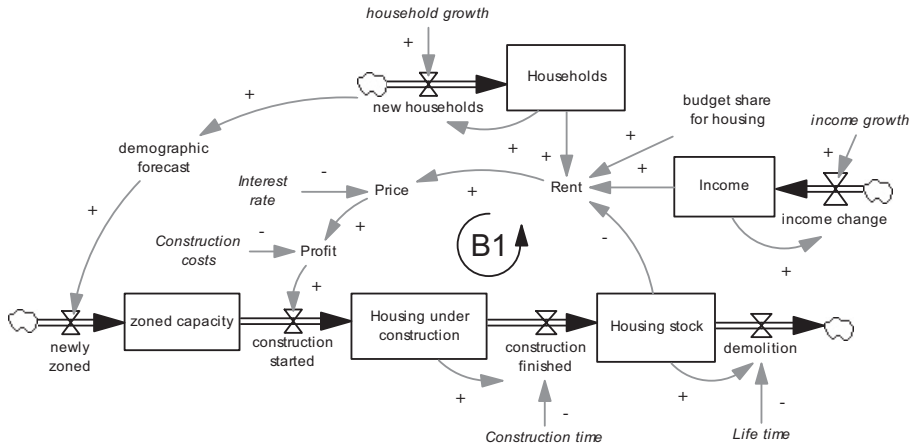
**Figure 6 Simulation results with fiscal mortgage support**

Both simulations have prices and construction move in the same direction (see figure 5 and figure 6), so from a system dynamics point of view, we must conclude that these institutional structures do not explain the reference mode of behavior, i.e. opposite movement of these two indicators.

The two other institutional factors, land use planning and municipal land price policies, involve more elaborate modifications to the model structure. In the Netherlands, land use planning for housing is traditionally strongly focused on accommodating demographic growth. Eichholtz and Lindenthal (2008) claim it disregards other (economic) pressures, whereas Renes et al. (2006) suggest it is over restrictive in economically strong regions. But will a simulated land use planning system show opposite movement of prices and construction?

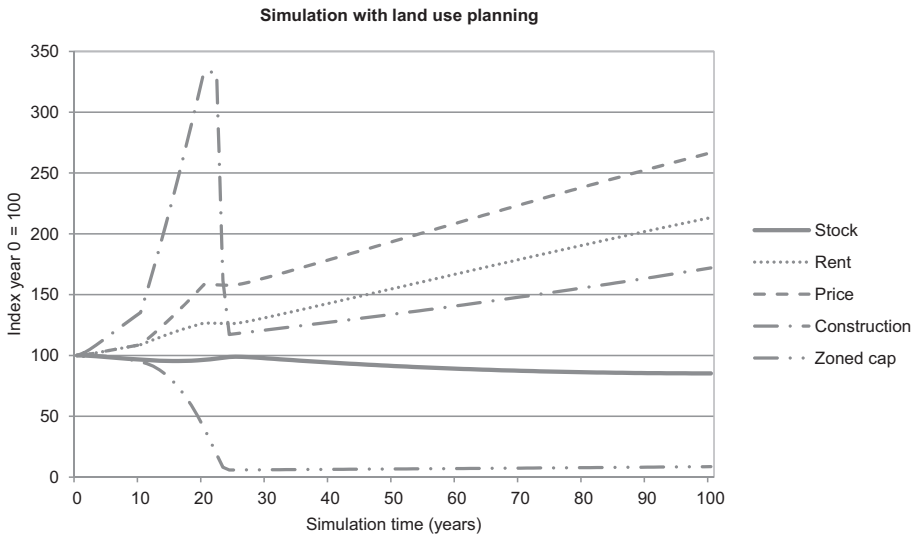
Figure 7 presents the modified model. The housing supply chain is extended with an stock variable for zoned housing capacity<sup>11</sup> and an inflow for newly zoned capacity. We amend household growth to a fixed annual percentage and add an auxiliary variable forecasting the population ten years ahead. This auxiliary governs the inflow of zoned housing capacity into the system. The modification does not add feedback to the system, but imposes a resource constraint to the operation of the main balancing loop.

<sup>11</sup> A more elaborate model might discern between land area zoned in hectares and the proposed housing density, which may also vary. For the sake of simplicity and in light of its purpose, this model directly adds zoned housing capacity in terms of houses.



**Figure 7 Modified 4QM with land use planning**

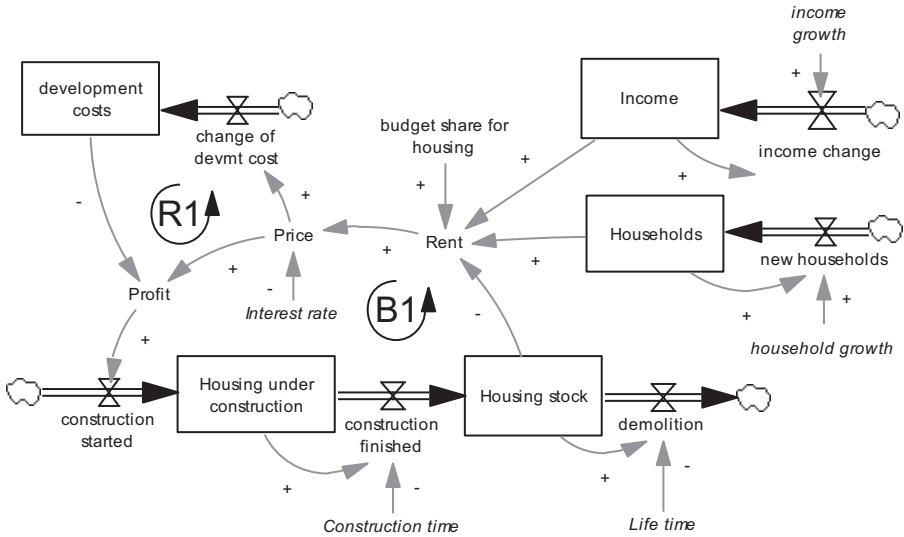
This third simulation shows radically different behavior. Figure 8 shows that in the first decade, this pushes up rents, prices and construction only slightly. In year 10 income growth and interest decrease kick in and rents, prices and construction accelerate. This depletes the zoned capacity, which abruptly becomes the limiting factor for construction. Demolition, being proportional to stock, starts exceeding construction and the housing stock slowly declines. Due to household growth, the inflow of newly zoned capacity and construction will gradually increase over time, but do not keep up with prices and rents, which continue to rise significantly more than in the amended baseline. The structural modification caused sharp changes in dynamic behavior. But it does not yet show opposite movements of prices and construction.



**Figure 8 Simulation results with land use planning**

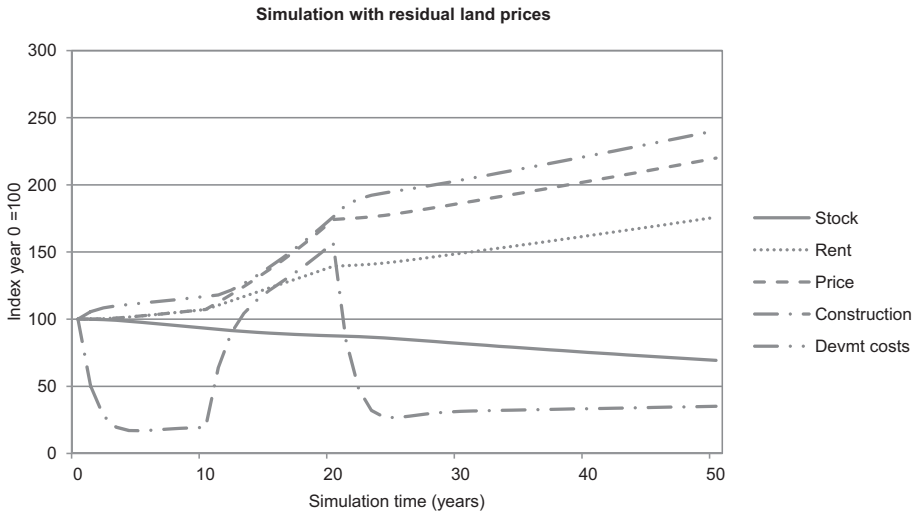


The fourth possible factor is municipal land pricing policy. In the 1990's, many municipalities introduced active land policies and favored residual land pricing over cost reimbursement in order to capture planning gains and use these for other public services (Buitelaar, 2010). Residual land values are by no means unique to the Netherlands, but follow from the willingness to pay for locational advantages where supply is fixed (Di Pasquale & Wheaton, 1996, pp. 35-36). Maximum land prices then equate market prices for real estate minus construction costs for materials and labor (Morley, 2002, pp. 75-77).



**Figure 9** Modified 4QM with residual land prices

In the modified system dynamics model in figure 9, we assume a delayed adaptation of development costs (materials, labor and land prices) to house prices. Development costs are now endogenous and feed back into profit as before. This connects a new reinforcing feedback loop R1 running through stock, rent, price, development cost and construction. This fourth simulation has again radically different behavior from all previous simulations (see figure 10). The stock is continuously decreasing, prices, rents and development rise in synchrony with the demand and interest impulses. Construction follows a distinct pattern. In the first decade without stimuli, development costs adjust to house prices from their initial level. Consequently, profit and construction drops. The stimuli occur in year 10 and cause a sudden upsurge of construction. When the stimuli stop in year 20, construction witnesses a sharp drop again and recovers only marginally in the long run. The gradual rise of prices and rents must be attributed to the declining stock and constant demand from year 20 (demolition is above construction).



**Figure 10 Simulation results with residual land prices**

In figure 10, this model does reveal occasional opposite movements of prices and construction in the first decade and around year 20. Analysis of equations reveals that construction has become dependent on price change rather than price level, in line with the empirical findings of Glaeser et al. (2008). We may have arrived at a dynamic structure based in housing concepts, capable of positively confirming counterintuitive empirical findings. In other words, we built a tentatively plausible dynamic hypothesis of real estate markets, residual land values and observed correlations of prices and construction. Our experiment also tentatively suggests that the other institutional factors do impact house prices and construction, but not in the particular manner we chose as the reference mode of behavior.

This is the author's perception of the quintessence of the added value of system dynamics. This small illustration reveals how system dynamic can contribute to e.g. *'the challenge [...] to identify the balance of market failure versus planning restrictions'* (MacLennan, 2012, p. 13).

That said, in a realistic research project, the model should undergo far more testing and sensitivity analysis, stand in much closer comparison to empirical data, may possibly need further adjustment to fit a particular national context and combine the four single modifications described above. But in this stage, it merely serves as an illustration where system dynamics is effective, how it incorporates institutional feedback and at what type conclusions it may arrive.

### II.3 SYSTEM DYNAMICS IN ISOLATION

Notwithstanding its suitability for tackling certain issues in housing research, system dynamics operates largely in isolation of other social sciences (Repenning, 2003). The isolated position is partially related to historical events in the 1970's around one of the cornerstone projects of system dynamics, namely Urban Dynamics (Forrester, 1969).

A derailed technical debate over validation techniques left the system dynamics community with deeply ingrained notions of antagonism towards statistically based econometric modeling (Alfeld, 1995). This is covered in more detail in section III.2.

Repenning (2003) points at the progress economics and other social sciences have made since then in coping with dynamic complexity. But he also concludes that system dynamics is still entangled in reinforcing processes preventing it to step out of isolation and engage in cooperation with other social sciences.

Another potential cause of isolation can be found in the fundamental paradigms and modus operandi of system dynamics. System dynamicists are in most cases specialists in method but generalists in model content: Forrester covered industrial management (1961), urban growth and decay (1969), economy, resource depletion and sustainability (1971) and more. Vennix (1996) includes housing, commercial fleet and health care topics all in one book. The generalist approach allows to transfer learning from one context to another: similar system structures will behave similarly, regardless whether the system is a housing market, a fishing fleet or a bacterial colony. This follows logically from the perspective of structure driving behavior (or isomorphism), which is a great asset for systematic, generalized knowledge building on behavior of dynamic feedback structures.

But conversely, exactly this methodological specialization prevents system dynamics practitioners from establishing deep rapport with researchers in other social sciences. Repenning (2003) acknowledges this tendency as one of the potential errors in his efforts to apply system dynamics in other social sciences '*failure to ground my work in the language and the literature of the field I was trying to enter*' (2003, p. 320). His conclusion in 2003 bears striking resemblance to the criticisms in the 1970's that Urban Dynamics does not integrate or even mention existing demographic, economic and geographic theories (Gray, 1972, p. 144; Rothenberg, 1974, pp. 19-20; Sagner, 1972, p. 199). The process approach of system dynamics also tends to favor the involvement of policy makers and managers over the participation of other researchers, basically because the former focus more on finding new solutions to real world problems than on methodological debate (Repenning, 2003, p. 320). But again, this does not contribute to integrating system dynamics with other social scientists.

In addition, the methodological specialization may also partially explain why system dynamics works in a particular field (e.g. housing, ecology) are not commonly systematized into position papers or otherwise, with the notable exception of project management (Lyneis & Ford, 2007). System dynamics produced a significant but fragmented knowledge base on housing, real estate and urban development, containing over 150 studies, which was largely unnoticed by the housing research community.

Repenning (2003) draws important lessons from the successes and failures in his cooperation with management scientists in the application of system dynamics. First, he recommends that modeling work should be solidly grounded in the concepts, language and literature of the field of interest. Two more suggestions relate to the communicability of models and modeling insights: large and complex models will deter non-system dynamicists rather than evoke their interest. Furthermore, proper methods should be used for helping the audience of a system dynamics model to develop insight on how the particular structure relates to dynamic behavior. He illustrates how a very simple,

one-stock model helped the aviation disaster research community to venture in new, previously unexplored directions. Smart integration of well-established insight and a simple dynamic model led to this particular success story. His fourth and final recommendation is to focus on solving content problems rather than to engage in methodological debates in modeling techniques.

## II.4 CONCLUSIONS

Taking into account the objective of this thesis and the housing research issues found previously, system dynamics is a suitable complementary (rather than alternative) methodology for the following reasons.

1. It is suitable for handling non-equilibrium situations ranging from trajectories towards equilibrium through moving equilibriums and oscillation (or market cycles) to chaotic behavior. It is therefore able to transcend the a priori equilibrium assumptions found over-restrictive for housing research.
2. With human actors and their decision as fundamental system components, system dynamics is easily capable of handling the endogenous formation of housing preferences to market information, life stages etc. in a structured sense. This contributes to the modeling of realistic housing market processes.
3. The same applies for housing supply. Decisions of the many parties involved in housing development are also easily made endogenous, again for modeling realistic processes. Furthermore, system dynamics has a strong knowledge base in industrial organization and supply chain management. Existing insights may provide a head start for modeling the industrial organization of the housing supply sector.
4. As an innately time based method, system dynamics is capable of handling housing market processes with different time frames. This again helps modeling realistic housing market processes and transcends the somewhat artificial dichotomy of short run and long run processes in economic modeling.
5. System dynamics allows for and even excels at adding additional feedback loops to models, beyond the possibility of analytical solution. This provides ample opportunities for adding institutional feedback like linkages to e.g. land and financial markets, government policies, reinforcing processes in neighborhoods and others.
6. Through its emphasis on mental models, knowledge elicitation and stakeholder participation, system dynamics can operate in environments where data limitations hamper mainstream statistical analysis.

Furthermore, I argue that cooperation between system dynamics and social sciences (housing research in this particular case) is isomorphic to modeling projects in the sense that validation of system dynamics for social sciences is a process of gradual building of confidence. The studied literature suggests the following recommendations for successful cooperation with other social scientists:

1. Research using system dynamics should be thoroughly grounded in the language and literature of the field involved, housing research in this particular case.

2. The use of system dynamics will be more successful when introduced unobtrusively and focused on research problem solving, in order to circumvent fruitless methodological debates.
3. System dynamics will be more acceptable when it first confirms existing insights from other methods and then gradually transcends towards its natural domain of higher order feedback.



# III LITERATURE REVIEW OF SYSTEM DYNAMICS ON HOUSING

## III.1 OVERALL REMARKS AND DESCRIPTIVE STATISTICS

As mentioned in the introduction, a system dynamics knowledge base exists on housing, real estate and urban development. Unfortunately, it is available only in a fragmented way and it is not connected to mainstream housing research.

The third research question of this thesis is focused on mapping this knowledge base in order to provide easier access for future research. In order to answer this question, all relevant publications in the bibliography of the System Dynamics Society (2009) with titles and descriptions including “urban”, “hous\*”, “real estate” were included on the long list. Any other sources known to exist were added, including books, book sections, journal papers, working papers, draft documents and conference contributions from the 2010, 2011, and 2012 system dynamics conference proceedings. New entries were fed back to the System Dynamics Society for updating the bibliography.

In total, we obtained 154 entries, of which 28 journal articles and 73 conference contributions. 44 items are book contributions, of which 33 are directly related to Urban Dynamics, i.e. both volumes of Readings in Urban Dynamics (Mass (1974) and Schroeder, Sweeney, and Alfeld (1975) and Introduction to Urban Dynamics (Alfeld & Graham, 1976). 20 out of 28 journal articles were published before 1981. Only of conference papers and abstracts in proceedings, the period from 1990 onwards contributed a major share (54 out of 73).

After initial superficial reading, those studies were selected for further analysis that a) somehow include a housing or real estate market i.e. aspects of demand, supply, construction etc. focusing on market or government mechanisms and b) present (outcomes) of a quantitative simulation model. The third research question focuses on making a comprehensive catalogue<sup>12</sup> of system dynamics works on housing and therefore, no additional criteria were set for the quality of these works. The chapter therefore encompasses everything from groundbreaking cornerstone studies to only just acceptable conference contributions<sup>13</sup>.

The fourth research question, on the other hand, is concerned with systematizing and integrating these materials in a form supportive of establishing proper connections between system dynamics and housing studies. For this purpose, we classified the materials into four groups on basis of modeling theme, model structures, geography, cross-referencing and use of other influences.

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<sup>12</sup> Although some oversights are highly probable.

<sup>13</sup> System dynamics works not accepted for conferences are not included in the bibliography and therefore logically, also not present in this overview.

The first group is named after the seminal book *Urban Dynamics* (Forrester, 1969). Works in this group either directly relate to *Urban Dynamics* or use very similar model structures. The description of this group in section III.2 focuses especially on *Urban Dynamics* itself and the early 1970's, as this period is very insightful as to the somewhat isolated position of system dynamics. Repenning (2003) described. A second argument is that *Urban Dynamics* still strongly influences system dynamics projects on urban development. The more recent projects in the later *Urban Dynamics Group* are catalogued only briefly without further analysis. The reasons for this will be explained later.

A second group of housing related system dynamics works (see section III.3) is locally based in the Netherlands. In addition to the national context, works of the Dutch group share a strong focus on changing housing policies of the government and other actors like housing associations. The starting point of this group is the housing association model ITS (Vennix, 1996). Many works in this group were carried out in cooperation with the Nijmegen based research group. The pilot projects in chapters IV to VII share these defining characteristics and therefore also belong to the Dutch group.

The third group, described in section III.4 is the most recent and focuses on the worldwide impact of the 2008 credit crisis on housing markets. Studies in this so-called *Recent Real Estate Dynamics Group* focus mostly on issues like real estate market cycles, the role of financial markets and speculation, the effect of government interventions and decision making of actors in the real estate market.

More than both previous groups, the *Recent Real Estate Dynamics Group* refers to and builds its models (partly) on basis of concepts from mainstream housing and real estate research. This explains why the works in this group were subjected to somewhat deeper analysis: they may prove most helpful in building system dynamics model structures rooted in housing theories. The pilot projects in especially chapters V to VII are also based on mainstream housing research concepts and therefore also relate to this group. Finally, all remaining system dynamics studies are catalogued in section III.5. All studies demonstrate some relation to housing, urban development and real estate, but do not connect to *Urban Dynamics*, Dutch housing policy, to the 2008 credit crisis, nor to mainstream housing and real estate literature.

### III.2 URBAN DYNAMICS GROUP

The *Urban Dynamics Group* is described first, as it is the oldest and largest group. This chapter first presents a small summary of the book *Urban Dynamics* (Forrester, 1969) and proceeds to describe the critical reactions it provoked and the defenses taken. The third part of the chapter summarizes and catalogues the more recent works based on *Urban Dynamics*.

#### **Forrester's *Urban Dynamics***

##### *Modeling context*

*Urban Dynamics* is a cornerstone of system dynamics modeling and addresses the causes of urban decay in the 1960's in many U.S. major cities. The dynamic hypothesis underlying the model is that the mix of housing, population and industry creates endogenous



processes of growth, stagnation and decline. Urban areas exist within a “limitless environment” (1969, p. 15). This means that interactions between city and environment do exist, but the urban area does not significantly alter its environment.

The stock and flow structure of the model consists of three subsystems for population, housing and businesses. Within the population, Forrester discerns three categories the managerial-professional class, working class and the underemployed. Residential and industrial structures also have three stages or stocks. Processes like construction, demolition, migration, birth and death influence these stocks. ‘Ageing processes’ play an important part in Urban Dynamics. Premium housing may filter down to become worker or underemployed housing; companies evolve from new enterprises through mature businesses into declining industries.

An intricate network of ratios (like housing densities and jobs to population rates), taxes and attractiveness multipliers (1969, p. 18) link together the main structure and determine immigration of the different social classes, construction, demolition and ageing of residential and industrial structure.

Urban Dynamics itself is a technical book. After a general introduction on urban decay and system dynamics modeling, it rapidly proceeds to describe the more than 100 equations in the model and simulation outcomes from the full model. Alfeld and Graham (1976) gradually build up a simplified but comparable urban model named URBANI explicitly for learning and teaching purposes in “Introduction to Urban Dynamics”. They include the interaction between housing, business and population but abstract from the ageing chains present in the full model.

### *Overall dynamic behavior of the model*

The overall dynamic behavior of the urban dynamics model shows two distinct, remarkably different phases of development. During a first phase of growth, a new, still small city radiates with opportunities and attracts people and businesses from all over the limitless environment. It starts expanding and grows exponentially for several decades until it fills up its land area with business and residential structures and the growth slows down rather abruptly<sup>14</sup>.

Rather than going into stabilization, the city starts to stagnate and deteriorate because the ageing processes take precedence over the growth fostering factors. Former new enterprises develop into declining industry. Premium and worker housing filter down into housing for the underemployed. The city will attract more underemployed people, but without giving them a perspective of socioeconomic improvement any more.

### *Policy programs*

Forrester then proceeds to test common urban programs for improving the urban conditions. He finds that many well-intended interventions fail to make a change for the better and sometimes even worsen the situation. Jobs and training programs for the underemployed and state financial aid to the city have a short-run positive effect, but tend to increase the long-run attractiveness for underemployed, thus reinforcing the effect

<sup>14</sup> Some evidence was documented of Old world cities going through several subsequent phases of growth and stagnation in Eskinasi (2012).

of trapping these groups in a situation without education and employment. The construction of low-cost housing deteriorates the situation faster and deeper than both other programs (1969, p. 65).

Forrester simulates several less common approaches, e.g. to construct new houses for the working class and / or the managerial class. He finds, however, that this does not lead to improvement either, because the overall ratio of housing in the total land area becomes too high. The construction of new industrial activity produces small positive changes, but does not reverse the stagnation process. Demolishing declining industry has mixed merits: it gives more room for new vital businesses, decreases the tax ratio but worsens the job opportunities for the underemployed. Slum housing demolition has comparable effects, but at the expense of a higher out-migration of underemployed groups.

Forrester finally concluded that two main factors cause urban decay: a) an increasing share of old residential and industrial structures and b) a too high share of housing in the total land area, leading to unfavorable ratios of population to jobs. A city can only maintain its socioeconomic vitality by continuously implementing policies focused on encouraging new businesses and discouraging too much housing construction. These policies are applicable in proper locations within the city suffering most from urban decay (1969, p. 105).

### **Criticisms and defense of Urban Dynamics**

Urban Dynamics met “strong emotional opposition” (Forrester, 2007a, p. 349) because of its message that most urban policies followed in the 1960’s and 1970’s were detrimental to the urban economy. Its conclusions were not accepted because of being wrong, but mostly for being politically unacceptable.

A large effort to validate the model stranded (Alfeld, 1995, p. 100) in the typical cross-paradigm confusion between system dynamics and econometrics as described by Meadows (1980). On several occasions, however, model application to urban problems in specific cities and towns led to significant consensus for action and successful implementation of urban policies. It should be noted that these policy projects were successful because they were targeted at very specific policy discourses and finding supporting logic by means of (adapted versions of) the model, rather than to take any given model as a starting point and then comment them for lack of specificity and potential data problems.

A number of criticisms to Urban Dynamics are recurrent. Mass (1974) and Schroeder et al. (1975) address these in Readings in Urban Dynamics, two volumes providing many clarifications of Forrester’s initial texts and many modifications of the original model<sup>15</sup>.

The recurrent criticisms include:

- The lack of use of existing data (Averch & Levine, 1971, p. 158, Babcock, 1972, p. 149, carelessness about proper calibration Kadanoff, 1972 and specific data of particular cities Gray, 1972, p. 143).
- Conclusions follow from Forrester’s assumptions, rather than urban reality (Babcock, 1972, p. 149, Rothenberg, 1974, pp. 19-20).

<sup>15</sup> Most of these modifications do not fundamentally alter the dynamic behavior.

- Forrester does not ground his model in existing economic, demographic and geographic theory (Gray, 1972, p. 144, Rothenberg, 1974, pp. 19-20, Sagner, 1972, p. 199).
- City center to suburb interactions are not present in the model (Babcock, 1972, p. 149, Garn & Wilson, 1972, p. 154, Gray, 1972, p. 143).
- Forrester overestimates the attraction of underemployed groups though housing availability (Babcock, 1972, p. 149 and underestimates the interaction of the city with its wider environment Garn & Wilson, 1972, p. 154).
- Forrester does not clearly define a healthy city and is therefore subjective in evaluating policies (Garn & Wilson, 1972, p. 155, Gray, 1972, p. 143, Jaeckel, 1972, p. 216, Sagner, 1972, p. 199).
- Forrester leaves out some important other policy experiments i.e. rent control and dynamics within the environment (Gray, 1972, p. 141).

Nevertheless, most critics agree that Forrester's model and approach are certainly of importance for research, education and policy making on urban management. This is reflected in statements like the following: "Despite these criticisms of Forrester's conclusions I would argue that his model making is so brilliant and beautiful that his ideas are certainly of examination and further development" (Babcock, 1972, p. 149). "Urban dynamics is an extremely useful educational tool for students of public policy both on the managerial and on the research level" (Belkin, 1972). "The synthesis of all equations (in the model) produces general behavior matching several US cities and some credence is lent to the conclusion that some powerful forces underlying urban conditions reside within the city limits" (Harlow, 1973, p. 126).

### **The later Urban Dynamics Group**

As mentioned before, Urban Dynamics is still very influential in system dynamics thinking on urban issues. This section presents work from 1980 onwards on urban dynamics in chronological order. Interestingly, the use of Urban Dynamic concepts appears to accelerate after 1990 and even more after 2000. Works were included when using (a large part of) the full Urban Dynamics model (Forrester, 1969) or the simplified educational URBAN1 model (Alfeld & Graham, 1976) or concepts closely related to these models.

#### *General applications of the Urban Dynamics model*

Aracil (1980) investigated equilibrium conditions within the URBAN1 model. Braden (1994) describes the development of a basic, four stock Urban Dynamics style model educational purposes in a museum. Suksawang and Srinivas (1995) propose to use the URBAN1 model connected to GIS for teaching graduate students on urban growth with Bangkok as a case study. They do not document a full operational model, nor do they refer to Kuroda and Mark Tsaur (1990), who also use URBAN1 for a Bangkok case study.

Zagonel dos Santos (1996) applies a model similar to Urban Dynamics to the government-planned city of Brasil. He finds that the initial state effort in building the new city continues to attract new migrants for a far longer period, only to stop when job opportunities were in balance with housing and population. The innate dynamics of the

city attracts more than two times the number of inhabitants originally planned for and creates large satellite towns of informal housing.

Feng, Lu, and Wang (2001) present preliminary outcomes of a rudimentary model on urban growth. They connect closely to Urban Dynamics by using identical subsystems (i.e. housing, population and businesses) but do not refer to Forrester (1969). Blanco (2011) applies system dynamics modeling to the issue of growth of informal housing in Latin America. He finds several determinants for the growth of such settlement: increasing demand for low-cost housing, a public system that cannot keep up with demand growth because of cross-subsidization and public policies aggravating overcrowding and using up valuable scarce resources.

#### *City center and suburb interaction*

Sanders and Sanders (2004) also develop a spatial version of Urban Dynamics to include interactions between different residential areas in a city and apply it to Rotterdam. They find that their modifications alter the overall dynamics only slightly. This finding is in line with many other authors, e.g. Mass (1974) and Schroeder et al. (1975). Uchino, Furihata, Tanaka, and Takahashi (2005) follow up on Sanders and Sanders (2004) and elaborate on relative attractiveness within the context of social science in general and spatial urban dynamics specifically.

#### *Peri-urban dynamics and urban sprawl*

Dyner, Berrio, and Bolivar (1989) and Dyner, Munoz, and Quintero (1991) study the dynamics of the periphery of an urban area by means of a small model. They focus on land use change in the rapidly developing urban periphery in Latin America and find system dynamics generally useful for the problem involved yielding plausible simulations. The authors do not include housing market issues in the analysis. Voyer (2004) ventures into the balance between affordable housing and urban sprawl. He finds innovative policy options for attaining both goals.

#### *Urban dynamics and transport interaction*

Kuroda and Mark Tsaour (1990) connect an urban transportation-planning model for Bangkok to URBAN1 in order to find a balance between accessibility and socio-economic development. They conclude from their model that inadequate transportation restricts socioeconomic urban growth. Swanson (2003) extends the urban dynamics template to include commuting transport in a city disaggregated into several districts. He tests several policy experiments for several British towns.

#### *Urban dynamics and policy evaluation*

Jarzynska and Richardson (2006) challenge the original Urban Dynamics model by simulating recent US housing policies for low-income groups. They find that these new policies rather reinforce Forrester's initial findings than disprove the model, but also plead for a shorter-term frame in which both long-term urban growth and short-term needs of lower income households can be balanced. J. Richardson and Elizabeth (2010) compare the recommendations of urban dynamics to the policies followed by the Singapore

government. They find many correspondences even though Singaporean planners most likely were not aware of the Urban Dynamics book.

### *Other urban dynamics studies*

Botman (1981) elaborates a regional planning model for the Eindhoven region, but does not provide any reports on model application in a policy setting. Moffat (1983) constructed a simulation model of urban growth on basis of Marxist theory. Saeed (2010) connects the perspectives of Urban Dynamics and Schumpeter's model of creative destruction. He asserts that we should see the poverty conditions in many developing as the stagnation phase in Urban Dynamics rather than the starting point of growth. Speaking figuratively, he claims that space in such countries might be filled up with unfavorable social and political institutions hampering growth and maintaining stagnation. He demonstrates that in both models, shorter life for infrastructure and capital stock yields better overall performance as this takes off the edge of the ageing processes.

## III.3 DUTCH HOUSING POLICY GROUP

Traditionally, the Netherlands had strongly state influenced spatial planning and housing policies. Botman (1981) can be said to reflect the first post-war episode of housing policy with a strong emphasis on state planning.

From the 1990 onwards, the government started to decentralize and liberalize the housing market to a certain extent, but not without retaining a significant amount of influence (see IV.2, V.2, VI.2 and VII.2). Institutional struggles e.g. between the state and the housing associations over their huge equity, between political parties, academics and economists on the durability of the mortgage interest tax reductions define the next two decades. The 2008-2011 credit and housing market crisis is most likely to increase the pace of further reforms.

The well-documented simulation model ITS focused on the new situation for housing associations, when many state subsidies and loans were canceled out around 1995, thus leaving them with strategic independence from the government, but also with the full financial ownership risk. Vennix (1996) provides a detailed account on its construction for investigating whether housing associations can attain their social goals (i.e. provide housing for lower income groups) while also retaining financial solvability. Together with a consultancy company for housing associations, Vennix found the age structure of the housing stock to be a sensitive variable in regards to this problem. Rouwette (2003) documented several ITS application cases when investigating group model building effectiveness. After several initial successes, however, the model got entangled in annoying dynamics of increasing details and eroding client confidence and was finally discarded as a business risk (Eskinasi & Fokkema, 2006).

Yücel and Pruyt (2011) simulate the dynamics of improving the energy efficiency of the Dutch housing stock and find significant inertia in the system. Radical new policies must be found in order to attain set goals in time.

De Groen (2011) developed an elaborate model on housing migration chains when from 2005 onwards, housing mobility started decreasing. De Groen, Pruyt, and

Bouwmeester (2012) assess the effects of several reforms of the Dutch social housing sector on the housing market behavior of lower income household with a preliminary, relatively disaggregated model. Van Nistelrooij (2009) models the relation between fiscal mortgage support and house process in the Netherlands.

We also documented several studies using qualitative systems thinking for Dutch housing policy problems. Qualitative system thinking shares much of the dynamics and complexity perspective with quantitative system dynamics. It does not use quantitative computer modeling but explains feedback and complexity by means of feedback loops in a more narrative way. Fokkema, Haanemaïjer, De Rooij, and Eskinasi (2005) provide an anthology of housing policy related themes. Jongebreur, Blom, and Van Dieten (2009) developed a causal loop diagram focused on housing satisfaction and intentions to move house.

The pilot projects in chapters IV to VII also count among the Dutch Housing Policy Group.

### III.4 REAL ESTATE DYNAMICS GROUP

As mentioned in the introduction, this group of system dynamics literature connects more to the mainstream real estate economics literature and uses its concepts as model building blocks. This allows to integrate and systematize the contributions of this group in the form of small “concept models” (see G. P. Richardson, 2012) that add up to the modifications of the 4QM in section II.2. They revolve around four dynamically complex aspects of real estate markets. Furthermore, the cross-fertilization of system dynamics and common housing research also brings to the fore several methodological issues for further consideration.

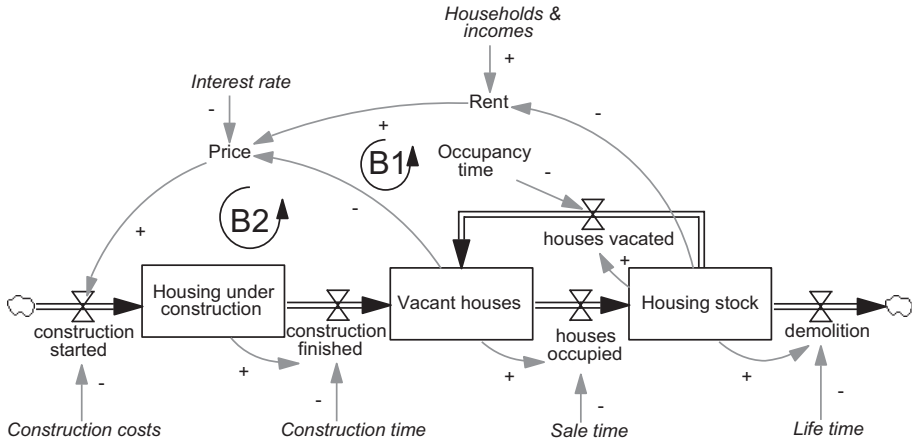
#### **Vacant real estate**

The works of Barlas, Özbas, and Özgün (2007), Atefi, Minooei, and Dargahi (2010) and Mashayekhi, Ghili, and Pourhabib (2009) connect the occurrence of cyclicity in real estate markets with the presence of an intermediary vacant housing stock in the production chain of housing. Even though vacant housing is not contained in the high level 4QM, Di Pasquale and Wheaton (1996, pp. 216-238) demonstrate a strong impact of the vacancy level (or the related variable ‘sale time’) on real estate prices. They also provide a mathematical model for the size of this effect.

The same logic is present in several system dynamics studies: Barlas et al. (2007) investigate the relation of real estate cycles to the ability of developers to properly estimate demand trends and the moves of their competitors. Özbas, Özgün, and Barlas (2008) make a rigorous sensitivity analysis of this model and present findings which variables affect length and amplitude of the cycles. Mashayekhi et al. (2009) demonstrate the differences in cyclicity of housing markets with and without a vacant housing stock. Vacancy structures influencing market dynamics are also present in Hu and Lo (1992) and Eskinasi et al. (2012).

Sterman (2000, pp. 698-707) argues that the tendency of real estate actors to underestimate material delays is an important, if not the main cause of the recurrent nature of real

estate cycles. His position is similar to Wheaton (1999): both supply lags (or material delays) and improper actor understanding of the real estate system (a.k.a. myopic expectations) are necessary for cycles to occur. Figure 11 presents a concept model visualizing these ideas.



**Figure 11 Modified 4QM with vacant housing stock**

The original 4QM in figure 2 strives to balance the housing stock and ‘real’ demand driven by demographic and economic factors. *Real demand loop B1* is generally slow as construction is small in relation to the existing stock and trends in the exogenous variables (incomes, interest rate). Vacant housing, however, strongly affects house prices and construction. With developers underestimating its impact, the *vacant housing loop B2* can start to dominate system behavior by repressing prices and construction. Accumulation of vacant real estate allows price levels below capitalized rents and even below construction costs.

A ‘relative control’ archetype emerges (Wolstenholme, 2003) suggesting a generic solution in finding an absolute rather than a relative target or pivotal variable driving construction. Sterman’s real estate model (2000) has an auxiliary variable ‘vacancy rate’ instead of a stock ‘vacant real estate’. We prefer modeling a stock because of the high impact of vacancies on prices and construction prices (Di Pasquale & Wheaton, 1996; Mashayekhi et al., 2009), success ratios for households (Eskinasi, 2013; Eskinasi et al., 2009) and for reasons of material conservation (see the section on methodological concerns).

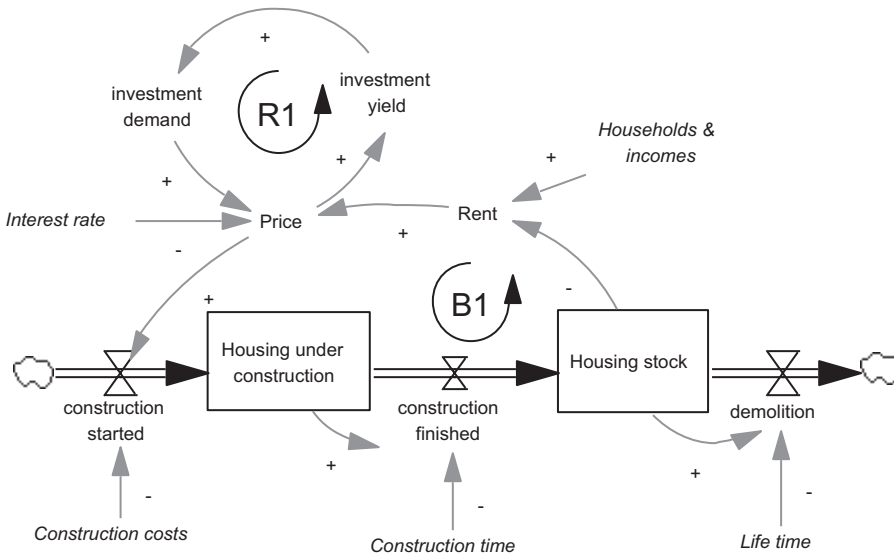
### Reinforcing capital gain or speculation loops

Other system dynamics studies emphasize reinforcing loops based on price increases as an important driver of real estate market cycles. Hu and Lo (1992) found cyclical patterns in the Taiwan housing market and hypothesize, next to common balancing loops, three reinforcing loops running through land and property speculation. Both developers and consumers demonstrate speculative behavior. Speculative supply exist when developers act on price increases, rather than orders from consumers or investors. Chen (2005) adds



external investors that feed speculation when prices rise and add to the bust when selling off speculatively bought properties.

In general, real estate price growth can increase capital investment demand in the property market (in the upper left quadrant of the 4QM, aside from the residentially driven demand for housing services in the upper right quadrant). The effect of rising investment demand on house prices connects a reinforcing feedback loop R1, depicted in figure 12.



**Figure 12 Modified 4QM with investment demand loop**

The configuration with a reinforcing and a balancing loop matches the ‘out of control’ archetype (Wolstenholme, 2003). Balancing loop B1 strives to bring the market into equilibrium. But when price increases attract additional investment yield driven demand, the system may exaggerate its response and over-produce housing. Glaeser et al. (2008) found comparable dynamics when housing markets with high supply elasticity can lead to lower welfare, again because of over-production resulting in price slumps.

### Real estate and the financial market

Several authors also studied the property finance market. Atefi et al. (2010) find that in markets with very low mortgage credit availability, increasing the loan-to-value ratio can support new housing production. Mukerji and Saeed (2011), on the other hand, model dynamics of an (overly) mature financial market. Their causal diagram reveals a ‘success to the successful’ archetype (Senge, 1990; Wolstenholme, 2003) in how households finance home ownership. House price increases make real estate a more attractive investment category than savings. Decreasing interest rates and requirements on mortgage loans allow for higher debts. And the demand created by higher mortgage volumes boost real estate prices. Hwang, Park, and Lee (2009) identify comparable structures within the financial market: increasing returns from residential mortgages attract additional



funding through the sale of mortgage backed securities and other derivatives. The mechanism in both studies is ‘success to the successful’ as booming real estate and financing markets extract funds from other investment classes, whether household savings or stocks and bonds in other economic sectors. The *financial markets loop* R2 connects with the *capital gain loop* R1 into the mentioned archetype. A third modification of the original 4QM would certainly concern the influence of household finance and the mortgage market. An initial attempt on the basis of the studies mentioned is presented in figure 13.

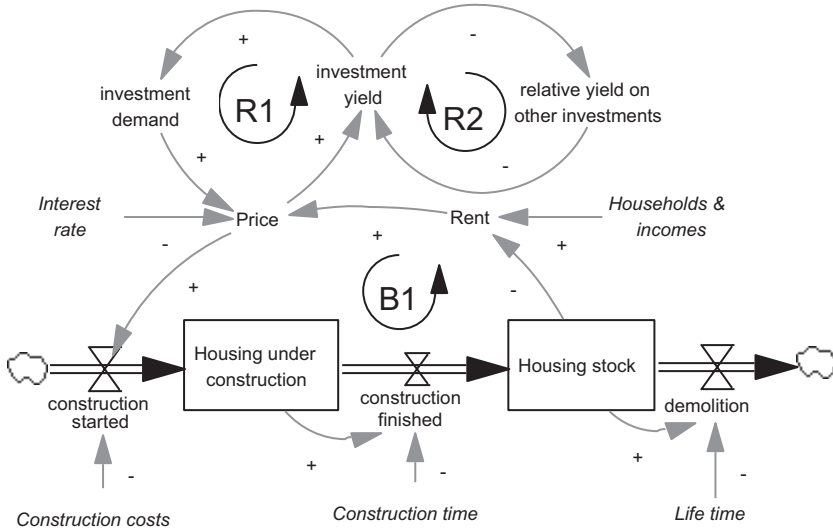
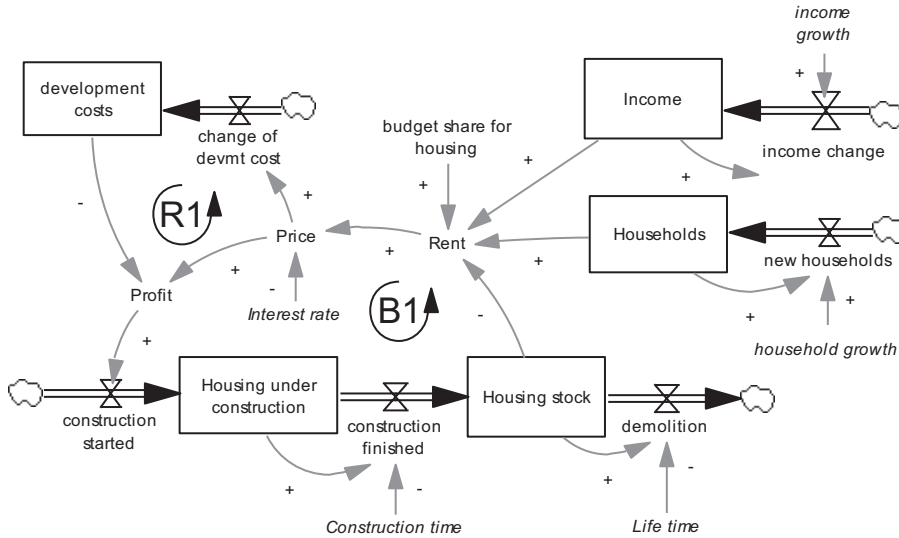


Figure 13 Modified 4QM with financial markets loop

### Government policies & interventions

A final group of studies relates to the effect of government interventions on the housing market. These are relevant as Wheaton (1999) claimed that institutional feedback loops alone may cause market oscillations, notwithstanding rational expectations of actors. Park, Lee, and Hwang (2010) evaluate a controversial package of government measures aimed at increasing the taxation base, preventing speculation and expanding the supply of land for housing. Also Hwang et al. (2009) project proposed policy logic onto their causal diagram. Both works identify several unintended side effects of these measures. Eskinasi et al. (2011) model the dynamic effects of several government interventions (among others land use planning and municipal land policies based on residual land values) in search of the most probable cause for observed counterintuitive trends of construction in relation to house prices. The modification with residually based land prices (see e.g. Buitelaar, 2010) feeds back house prices into development costs. The resulting *residual land values loop* R1 obstructs the response of construction to prices through loops B1 and provides a potential explanation for Di Pasquale’s (1999) conclusion that neither house prices nor construction costs sufficiently explain construction volumes.

This final feature is added here as residual prices are generic (Di Pasquale & Wheaton, 1996) rather than bound to a specific national context.



**Figure 14 Modified 4QM with residual land prices**

Note: this figure is identical to figure 9.

Loops B1 and R1 in figure 14 form the ‘out of control’ (Wolstenholme, 2003) or ‘fixes that fail’ (Senge, 1990) archetype. If low construction is the problem, then house price growth is the fix that will boost construction. However, house price growth also increases development costs through land values and thus worsens the problem of low construction volumes.

### Methodological concerns

Examining the system dynamic works discussed in this paper also identifies two interesting modeling issues. The first aspects regards the integrity of the housing production chain. Most authors (Atefi et al., 2010; Barlas et al., 2007; Eskinasi et al., 2013; Mashayekhi et al., 2009) connect all stocks together into a single production chain (i.e. zoned land, houses under construction, vacant houses, occupied houses etc.). Ho, Wang, and Liu (2010) and Eskinasi et al. (2009) do not connect vacant housing into the housing production chain. Park et al. (2010) focus mainly on price dynamics and have housing production chain variables as auxiliaries. From the viewpoint of material conservation (Sterman, 2000), the first option is preferable.

Second is the occurrence of common economic elasticity variables in system dynamics models (see e.g. Mashayekhi et al., 2009) which possibly conflict with unit consistency requirements. Elasticity expresses overall strength of the correlation between e.g. demand and prices. As system dynamics focuses on relating dynamic behavior to system structure, it could be particularly helpful in finding those structures that demonstrate a given elasticity. In other words: building system dynamics models of such

structural features and measuring the price elasticity in the models' output can help connecting system dynamics and housing & real estate research. Furthermore, micro-economic theories may also contain unit consistent building blocks for system dynamics models (e.g. Eskinasi et al., 2013).

### III.5 ISOLATED STUDIES

Not all system dynamics studies on housing, real estate and urban development build consistently upon each other, as reflected in e.g. Suksawang and Srinivas (1995), Botman (1981) and Feng et al. (2001). This section covers the isolated studies on widely related themes for cataloguing purposes only, without further ambition towards analysis or systematization.

Mosekilde, Rasmussen, Joergensen, Jaller, and Jensen (1985) use a small system dynamics model for venturing into the dynamics of ethnical residential segregation and apply methodologies from chaos theory for analysis of the dynamic patterns. Hongh-Minh and Strohhecker (2002) build a model of internal structure of the UK private housing construction focused on the causes of low performance. They discern several actors as homebuilders, building materials merchants and manufacturers. The model emphasizes production chain aspects and was used for finding different scenarios for improvement. Sehedí (2006) models short stay housing of new immigrants, rather than the dynamics of the 'regular' housing market and does not display any influences from or references to other models.

Kolacek (2006) gives a historic account of rent regulation in the Czech Republic and develops a simple model for calculating new rents on basis of apartment premises, which is a single stock with a proportional growth rate. No supply, demand or other factors are included in the model. Kolacek (2006) refers to a.o. Vennix (1996) but does not borrow any housing related modeling building blocks from the literature.

Ahn and Lee (2010) consider the need for adequate shelter for the South Korean population and determine the driving forces of three main actors: government, suppliers and tenants. From their two-stock model, they conclude that the inflow of sufficient (government) capital is the most important factor for supplying rental housing. They do not connect to an international knowledge base on housing policy nor on system dynamics. Skribans (2010) describes a model developed for forecasting the demand for new apartments in Latvia based on the capacity of the construction industry, price increases and the availability of finance.

### III.6 CONCLUSIONS

Studying existing system dynamics literature on housing indicates the existence of three main groups and a number of unrelated studies. The first group departs from cornerstone project Urban Dynamics, which also played an important role in the antagonism between system dynamics and the housing economics research community. In hindsight, the making of Urban Dynamics did not match later lessons on engaging in fruitful coopera-

tion with other social scientists, in particular in connecting their language and concepts and in the scale of the model itself. That said, Urban Dynamics still inspires system dynamics practitioners and moreover, as will be argued in chapter IV, qualitatively similar patterns may be observed in real world cities.

The Dutch Housing Policy Group is bound to its national context, but has a strong focus on the effect of policy changes in this context. The use of mainstream real estate concepts in system dynamics modeling can only be traced back to 2008 with the advent of the Great Financial Crisis. These works can be systematized into small concept models on four dynamically complex features of real estate and housing markets, acknowledged in mainstream literature.

# IV HAAGLANDEN<sup>16</sup>

## ABSTRACT

This paper describes a group model building project about new housing construction, urban renewal and the impact of both processes on a regional social housing market. A team of seven stakeholders participated in model construction over a one-year period. The paper addresses the modeling process, model analysis and policy experiments. The model yielded several counterintuitive insights, helped the stakeholders to settle a contentious issue and was used in flight simulator workshops with managers and policy makers. By means of questionnaires, we found that most attendants in the project or workshops consider system dynamics modeling as improving communication, insight, alignment and commitment to results.

## IV.1 INTRODUCTION

In his seminal book “Urban Dynamics”, Forrester (1969) delves into the intricate dynamics of urban growth and decay. His main analysis is that after an initial period of growth, aging of housing and businesses in combination with limits to spatial growth pull the socioeconomic structure of a city out of balance. His proposed counterintuitive policy measures clashed with the 1970’s housing and planning paradigms (Forrester, 2007a). The setting of our project however indicates that in the early 2000’s, Dutch urban planners had come to a policy paradigm that is more in line with Forrester’s initial findings. Whereas system dynamics interventions have been said to improve policy making from the 1950s, only recently a research program on effectiveness of modeling has been outlined. Andersen et al. (1997), Andersen et al. (2007), Rouwette et al. (2002), Rouwette and Vennix (2006) elaborate theories and intervention reporting guidelines for assessing group modeling building effectiveness. Our report on the Haaglanden project is structured on the basis of these guidelines. We first describe the context of the intervention. Next we report on the modeling process, involvement of the project group and the resulting model. Finally, we present several reflections on the impact of the project and its quality as a system dynamics venture.

## IV.2 CONTEXT OF THE SYSTEM DYNAMICS INTERVENTION

The modeling project reported here addresses the impact of new construction and transformation of housing on social housing market dynamics. The geographical setting is the Haaglanden region in the densely populated west of the Netherlands. This region

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includes the central city The Hague and its surrounding suburbs and new towns, historic Delft and the horticultural area Westland. Several organizations play a central role in social housing policies in this region. Sociale Verhuurders Haaglanden (SVH) is an association of not-for-profit housing corporations in and around The Hague. Its main task is strategic consulting, representation and lobbying for its members in various decision-making forums. SVH is a small networking organization and the primary client in this project. Its main partner and sometimes opponent is Stadsgewest Haaglanden (SGH), a government office uniting municipalities in Haaglanden. The corresponding author, at that time a consultant at Atrivé, was the facilitator and modeler.

It is necessary to provide clarity about our departure point regarding the style of the intervention. In his analysis of the relation of system dynamics to social theory, Lane (2001) discerns several system dynamics approaches in a two dimensional matrix of social theory. He describes the development of the initial perspective through a broad perspective to the interactive system dynamics practice. The focus of the latter is to create a shared interpretation of a problem through personal involvement of stakeholders. In hindsight, this is the system dynamics perspective of this modeling intervention, more so, because the system dynamics practice of Atrivé stems from Vennix' (1996) work on group modeling building for housing associations. Furthermore, it is necessary to understand that modeling in a consultancy role is by definition linked to a real world client problem and that the driving force for such work is a reinforcing loop of successful system dynamics business and client satisfaction (Eskinasi & Fokkema, 2006). Grütters (2006) points out that in Atrivé's unsuccessful modeling experiences, the plausibility of the model for the client was lost. In summary, these three factors may explain possible biases towards stakeholder assessments in our account: the education of the modeling facilitator within the group model building school, the necessity of client involvement in a consultancy setting and finally the learning effects of negative experiences with losing model plausibility for the client.

### **History of the problem context**

The strategic issue in this project is rooted in the Dutch housing policy. To familiarize the reader with the setting we outline major developments in this field before focusing on the problem addressed in the modeling project.

The first social housing initiatives date back to the 1850's. The 1901 Housing Act gave a legal basis for supporting private, non-profit housing organizations. But only after World War II the government started a large-scale subsidy program for social housing. War damage to the existing stock and the postwar baby boom necessitated an unprecedented green-field construction program, (i.e. construction on previously unoccupied land). In the 1950's and 1960's, construction volume was the main issue and dwelling quality only played a minor role. The 1967 record of an annual output of 125,000 houses is still unbeaten, but to this day a strong focus on green-field development remains. Management of the social housing stock is the responsibility of social housing organizations or corporations. Housing corporations had little influence on construction policy formulation, nor on the housing allocation system, managed by the local authorities. Urban renewal or transformation (i.e. replacing run-down houses within existing cities) focused on incidental slum removal and, especially in the 1960's, on infrastructure improvements and

stimulation of the central business district. In the 1970's, urban renewal policies changed under pressure of the democratization process. Small-scale rehabilitation of 19th century residential areas focused on constructing new social housing for the current inhabitants. This would obviously clash with Forrester's (1969) conclusion that "construction of low-income housing is detrimental or at best neutral to urban vitality" and could have most probably provoked comments as stated in Forrester (2007a, pp. 349-350).

The 1990's offered new challenges and perspectives, when the government started to reduce public spending. Financial support to housing organizations was abolished, object subsidies (i.e. on houses) were reduced and subject subsidies (i.e. rent subsidies to households) were increased. The 1995 Bruterling Act cancelled out all existing loans and subsidies and made housing organizations financially independent from the government. The social housing sector faced three challenges in the 1990's. First, a disturbing new fact was that middle or high-income groups occupied many social dwellings. Low-income groups had to be allocated to more expensive dwellings and rent subsidies rapidly increased. The policy response was to decrease the share of social housing in new construction and to encourage tenants to move up the housing ladder. Second, the housing allocation system underwent major changes in the nineties. In order to provide more transparency, responsibility and freedom of choice for house hunters, a new allocation system was introduced and rapidly gained in popularity. All available dwellings were published in a newspaper or (later on) on internet. Registered house hunters apply for the houses they like best. From these applications, housing corporations select future tenants on the basis of criteria such as age, duration of occupancy or duration of registration. Often, selection procedures distinguish starters from people already living in the region and moving on to another house in the same region ('onmovers'). Starters have not previously occupied a home, whereas onmovers have. People in urgent need, for instance for medical or social reasons or after calamities, get a priority status. A 'forced move' because of urban renewal also entitles applications to a priority status.

Third, the urban renewal program also met with new challenges. Built to relieve the post-war housing shortage, the 1950's large-scale housing estates had gradually developed into unattractive and problematic neighborhoods. The focus on green-field development led to unintended side effects such as selective migration out of the city. Policy makers will now acknowledge that large concentrations of social housing would concentrate poverty and induce urban decay. Their policy objective was to break up large concentrations and construct middle class housing in order to remix the population and improve the economic performance of cities. Speculating from the fact that policy makers now saw large scale social housing as detrimental to urban vitality but did not take follow up by stimulating the growth of new businesses in place, we might conclude that Dutch policy makers have experienced at least some of the processes described in *Urban Dynamics*. Nevertheless, the new urban renewal paradigm demonstrates a shift towards the findings of *Urban Dynamics* as large scale social housing was now seen as a part of the problem rather than the solution.

Building new market housing was also an answer to the increasing shortage of good quality housing, predominantly within the cities (VROM, 2000). New housing construction is however only possible if adequate numbers of social housing are available to provide the necessary working space for urban renewal. Existing housing market

prognosis models confirmed this assumption by predicting a surplus of cheap, old social rental flats. These predictions were however based on the assumption that construction of large volumes of new housing would continue as planned. Reality in the meantime took another course. The 1990's economic boom increased prices of market housing to a level where an average family was no longer capable of purchasing a house. The economic downturn in the early 2000's in combination with long spatial planning procedures decreased green-field construction figures. Contrary to the expectations of some policy makers, pressure on the (social) housing market started to increase, rather than to decrease. Housing policy makers were confronted with a number of choices. Stop urban transformation, risking further deterioration of the housing stock, or proceed as agreed, ignoring declining success ratios of house hunters and risking even deeper stagnation of the social housing market.

### **Starting point for the system dynamics intervention**

This was our clients' complicated situation at the start of the project. SVH and SGH agreed on the necessity of transformation for urban socio-economic vitality. They parted ways when it came to its desired pace in relation to new construction, and on the acceptability of other interventions in the social housing market. SGH is bound by contracts with the national government on new housing construction volume and is eager to improve the housing mix, especially in the central city of The Hague. SGH was not inclined to accept any delays in the transformation program. Their policy of annually transforming 2,000 social dwellings for a ten years' period (2005-2014) was used as the *base run* of our simulation.

The housing corporations and SVH are more sensitive to the decreasing success ratio of their potential clients. This so-called success ratio was the main problem variable. It is defined as the quotient of the annual supply of social houses and the total number of house hunters competing for them, housing corporations have little control over new construction, especially in the market segment and advocate the direct interests of their clients, defined as a high success ratio. SVH therefore favored an alternative policy option, i.e. 1,500 dwellings in the first five years (2005 – 2009) and 2,500 afterwards (2010-2014). SVH also considered changing the housing allocation system and to allow longer outplacement procedures ('stage 1', described later on in this paper) as an option for increasing their clients' success rate. They hoped that this would stop the decline of the success ratio recorded in the period 1998 -2001 and would strengthen its recovery in 2002 and 2003.

During the debate that followed, both parties increasingly emphasized their different viewpoints on the impact of transformation on the social housing market, the extent to which decreases in success ratio were acceptable and how to intervene. The debate became heated to the point that both partners found themselves in outright conflict over the best policy intervention. Table 1 summarizes the main characteristics, viewpoints and policy proposals of both organizations.



**Table 1 Characteristics, viewpoints and policy proposals of parties in Haaglanden**

Actor	SGH	SVH
Represents	Municipal & Regional Authorities	Housing Corporations
Fears	Delay in housing transformation & greenfield construction programs	Decreasing supply of housing due to transformation
Consequences of fears	Increasing urban decay, problems with state on construction subsidy contracts	Decreasing client success ratio
Sensitivity to success ratio	Low-medium	High
Proposed transformation policy	T=2000	T=1500 + STEP (1000;5)
Hope	Keep transformation in pace, positive effects on success ratio come later on.	Slower transformation now leads to higher success ratio, step up when greenfield construction is high.

### IV.3 THE SYSTEM DYNAMICS INTERVENTION

#### Pre-project activities

SVH and SGH could not resolve their problem using traditional consulting or research activities. Consequently Atrivé proposed to develop a simulation model of the contentious issue in a group model building project. The modeling project had two goals: 1. to obtain more insight into the impact of green-field construction and transformation on the success ratio and 2. to learn about the effects of proposed policy interventions (Eskinasi, 2002). The top management and board of SVH supported the modeling project. SGH initially reacted to the project with a mix of curiosity and skepticism. A comparable initial client reaction is also present in the work of Lane et al. (2003).

The director of SVH acted as a gatekeeper (G. P. Richardson & Andersen, 1995). The facilitator and the client organization chose the seven-member project group jointly. The project group consisted of two senior officials (the director of SVH and a high ranking civil servant from SGH), three policy making officials (one from SGH, two from different housing corporations) and a senior housing market researcher from The Hague Urban Development Office. The researcher provided access to many data sources and contributed to a lively debate on facts and figures. He also had strong opinions on the validity of the resulting model. The senior officials participated to a lesser extent in the debate on model structure, figures and content, but dominated the discussion about policy runs in the final stage of the project. The modeling team consisted of two people: the first author in the role of process manager and modeler and one recorder assisting the process. Two different persons fulfilled the role of recorder during the project.

#### Model building meetings

The project started in October 2002 and finished in December 2003. Ten meetings were held, varying in duration from four hours or longer for the first sessions to two hours in the later stages of the project. Most meetings were held in SVH's office. In all meetings

we used a whiteboard to sketch model structure and behavior and we recorded results with a digital camera. The participants invested about 35 hours in the meetings, with some of them occasionally missing out on a session while others spent additional time on data collection. The total time investment of the modeling team is about 220 hours for the facilitator and 80 hours for the recorder. The recorder made agendas and meeting minutes, which formed the basis for the project reports. The results of the different phases of the project were documented in three progress reports and a final report (Eskinasi, 2004). We discerned four separate phases in the project:

- Start: startup and definition of causal relations;
- Model construction: data collection, quantitative modeling and model validation;
- Simulation: comparing the effects of policy options to the base run;
- Evaluation and follow-up: interviews, formulation of conclusions and follow-up activities

During the starting phase, we played the Beer Game as an introduction to system dynamics. In the first meeting we sketched the basic structure of the housing market with the aid of causal loop diagrams. Finally, we carried out the pretest questionnaire for the empirical evaluation (described later on). The report concluding the first phase contained the final causal loop diagram. The model construction phase encompassed translation of the causal loop diagram into a stock & flow model. The project group participated in all meetings by defining and verifying relations and parameters and by analyzing preliminary model results. Most of the actual modeling work was done off-site. This included cross-examination of data sources, literature research, model construction, sensitivity analysis and validation. The modeling phase was also concluded with a progress report. The simulation phase was carried out in three meetings with the project group. We tested different policy options, including SGH's base run and SVH's alternative policy. Additional policy experiments were carried out in order to improve understanding of housing market dynamics and the impact of secondary interventions. In the last meeting the project group formulated its main learning experiences. The progress report of this phase focused on the different policy experiments. The evaluation and follow-up phase included compilation of the final report and several activities after completion of the main project.

Both client organizations brought their simulation experiences to the attention of other urban regions and housing corporations. SVH held two workshops for policy makers of their member housing corporations. The first workshop was held in March 2004 with about 30 attendants. The session started with a slide presentation and demonstration of the model. Participants could then operate a flight simulator version of the model for about 15-30 minutes. This group formed the control group for assessment of the effects of the group model building intervention. SVH organized a second workshop in May 2004 focusing on the long-term strategy with directors and senior managers of the member corporations. During this session, the new housing construction targets proposed by the Ministry of Housing were simulated against the background of possible green-field development locations. Meanwhile, SGH issued its annual housing and construction monitoring report, containing empirical data and an update of existing plans (Haaglanden, 2004b). The report was extended with future scenarios based on the model

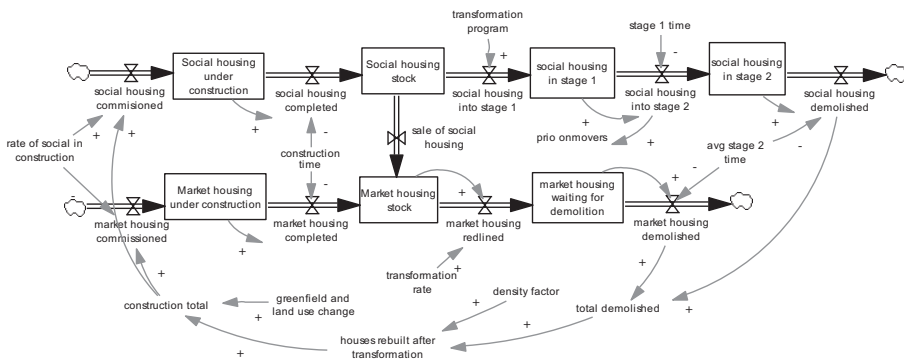
simulations. In November 2004, SVH and SGH invited the Ministry of Housing and the Province of Zuid-Holland for a simulation workshop. They compared four different green-field and transformation scenarios and debated the impact on the social housing market. Finally, Atrivé and AEDES, the housing corporations' branch office, organized a session in February 2005 in which housing strategists worked with the flight simulator version of the model.

#### IV.4 THE RESULTING MODEL

The model consist of four sectors: housing construction and transformation, migration chains and supply, demand and auxiliary variables and policy response. After a description of each model sector we use a causal loop diagram to describe feedback relations. We then address model behavior and validation tests. The final part of this section describes the results of policy experiments. Model equations are available in appendix 3.

##### Housing construction and transformation sector

The first sector (see figure 15), focuses on construction, sale, transformation and demolition of houses. The main structure consists of two production chains, for social rental housing and one for so-called 'market housing'.



**Figure 15** Haaglanden construction and transformation sector

Market houses are for instance owner occupied dwellings or rental apartments owned by commercial investors. The left hand side of both chains depicts the start of the construction process. New houses are commissioned, spend some time in construction and are finally completed and added to the main stocks (social housing stock and market housing stock respectively). An important policy parameter is the rate of social housing in new construction. Its initial value of 30% means that out of 100 new houses 30 will be social and 70 will be market houses. The total volume of new construction originates from three sources. First, the green-field construction program of about 4,000 new houses per year. A second minor source, change of land use, consists of about 800 houses annually, constructed in former industrial or other locations previously not used

for housing. The third source is houses rebuilt after transformation, which closes one of the main feedback loops of the model. After commissioning, the average construction time is 1.5 years. The central part of this sector consists of the social housing stock and market housing stock. A flow from the social into the market housing stock depicts sale of social housing. This is seen as a useful means to improve the housing mix and to provide houses for tenants wanting to buy their rental home. Annually, about 700 houses are sold.

The right hand side of the production chain focuses on transformation of existing housing. ‘Transformation’ is defined as any operation needing moving out the tenants, large-scale reconstruction works and subsequent allocation to new tenants. In most cases this means full demolition and new construction, although high-level renovation is also possible. We ignore smaller repair or renovation works, because these do not impact the social housing market.

With regard to the transformation of social housing, we distinguish two stages. Houses enter stage 1 (social housing in stage 1) when a housing corporation decides to end its exploitation and prepare for transformation. Every year about 2,000 houses, or about 1.3%, are taken out of the social housing stock in this way. Transformation of social housing is one of the crucial policy levers in the model. In stage 1, no more new rental contracts with unlimited duration are given out. In some cases special fixed-term rental contracts are given out to for instance students but in most cases dwellings stay empty. Generally, this encourages other tenants to move out themselves. The average stage-1-time is a policy lever because SVH expected a strong impact on the success ratio; its starting value is set at 1.5 years even though field observations in specific blocks recorded stage-1-times of five years and more. Housing corporations like long stage-1-times, because this leads to less priority housing applicants clogging the allocation system, lowering the success ratio and receiving financial compensation from the association. The downturn of long stage-1-times, mainly perceived by SGH, is postponement of new construction after demolition and a slowing down of the urban revitalization process. The duration of stage 1 was therefore highly relevant to the dispute between SGH and SVH and an important policy lever in the model.

In stage 2, the area is granted special status under Dutch urban renewal legislation. The remaining regular tenants get priority in the housing allocation system, entitlement to financial compensation and move out. Note that longer stage-1-times decrease the number of tenants with priority status, because some of the initial tenants will find a new house by themselves in the meantime. The average stage-2-time is also set at 1.5 years. Its maximum duration is prescribed in legislation. After stage 2, the social houses are physically demolished and new construction can start. As opposed to stage-1-time, the project group did not consider the stage-2-time as a very relevant policy parameter. After all, when stage 2 sets in, the consequences for the success ratio, i.e. the inflow of new priority cases, are out of the hands of any of the organizations involved.

The transformation of market housing follows a different process. A proportion of market housing is redlined and subsequently demolished. Annually only a negligible 0.175% (transformation market housing rate) of market houses is redlined and not deemed relevant to the strategic question of SVH and SGH. It is modeled as a first order material

delay with a stock (market housing waiting for demolition) and again an average time before demolition of 1.5 years.

The total number of houses demolished connects transformation back into the total of new construction as houses rebuilt after transformation total, taking into account the density factor. The initial value of the density factor is 80%, which means that out of 100 demolished houses, 80 houses are rebuilt. In combination with a 30% rate of social housing in new construction, this would result in 24 new social houses and 56 new market houses.

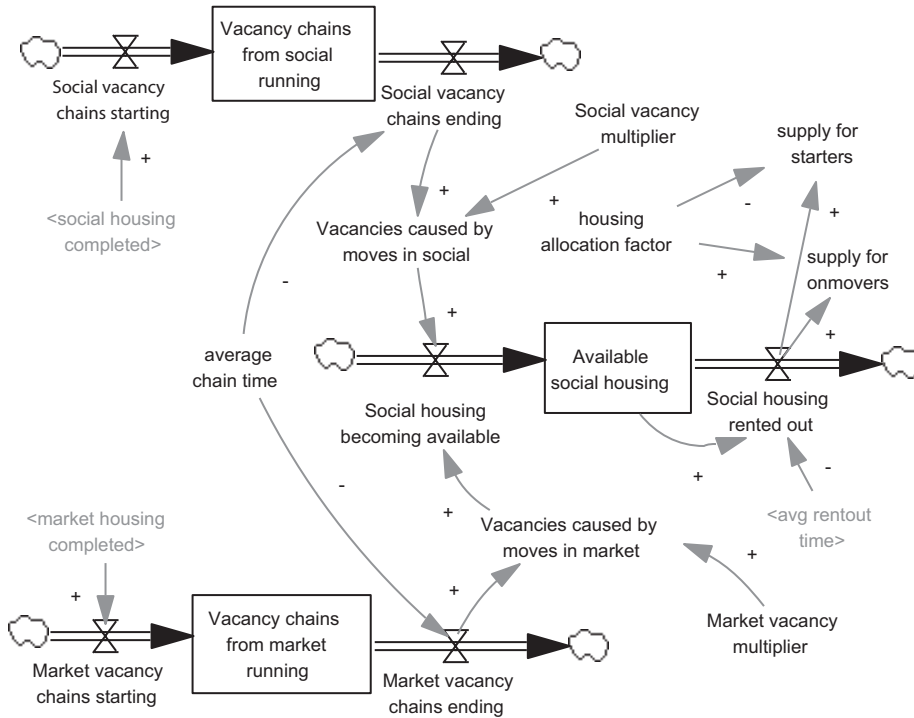
### Supply of social housing sector

The second sector in the model (figure 16) contains the supply side of social housing. Migration or vacancy chains play an important part in this model sector. Vacancy chains start by completion of new houses. The model contains two inflow-stock-outflow structures to capture vacancy chains started by social and market housing respectively. The stocks are labeled ‘vacancy chains from mrkt running’ and ‘vacancy chains from soc hsg running’. The chains run for an estimated time of 1.5 years. This estimate is based on an assumption by the participants in the modeling sessions; no data were found to verify this estimate. Ending vacancy chains of both new social and market housing causes moves within the social and market sector, taking into account the respective migration multipliers<sup>17</sup>. Vacancy chains produce moves by tenants over the complete course of their existence, which is modeled using a continuous delay with avg vacancy chain time as its parameter. Vacancy multipliers show significant volatility over time (Eskinasi, 2004). However, no research was available on the causal relationships determining the multipliers, so we relied on matrix algebra (Teule, 1996) to calculate these from the national housing needs survey and used them as an exogenous time-series input: market to social vacancy multiplier and social to social multiplier.

The social housing becoming available from migration enter into the stock supply of social housing. We chose a stock instead of an auxiliary, because empty flats can accumulate in situations of low demand. Additional available houses come from the housing allocation system’s capability of increasing the share of onmovers leaving social housing (supply from onmovers). This number consists of real onmovers among priority cases and regular onmovers. Other supply sources include houses from people leaving Haaglanden’s social rental sector, people moving out of Haaglanden or the Netherlands altogether. After the average renting out time, the social house is rented out and flows

17 The housing market is mainly a market of secondary properties. The primary supply (new construction) invokes a migration chain that outnumbered the initial supply. Suppose we build 100 new houses and 100 families move in, some of them, let’s say 80, from another dwelling. These vacant dwellings attract another round of families, also leaving homes behind. The chain ends when the final round of available dwellings are occupied by starters or demolished. Thus our construction program causes so-called migration chains, making the number of moves larger than the number of houses built. The migration multiplier is the ratio of housing moves to new construction: if we assume that constructing 100 new houses causes 350 moves in total, the migration multiplier is 3.5. In the model two separate migration multipliers are used, one new social and one for new market housing. Within the social housing sector, construction of market housing on average results in more migration than construction of social housing. In the model we use Teule’s (1996) matrix algebra for calculating migration multipliers from house-moving statistics (e.g. from the longitudinal Housing Needs Survey), assuming that multipliers are stable over time. Recent research however shows that vacancy multipliers are not constant (Eskinasi, 2004). These trends undermine common policy ideas. The market-to-social migration multiplier is declining: market-housing construction has less and less effect on the social market, whereas the social-to-market multiplier increases: new rental housing increasingly attracts people from market housing.

out of the supply stock. The respective housing corporation decides whether houses are best suited for starters or for onmovers. This is reflected by the housing allocation factor, indicating the share of available houses deemed fit for onmovers. This factor is initially 50%, indicating an even division between starters and onmovers.

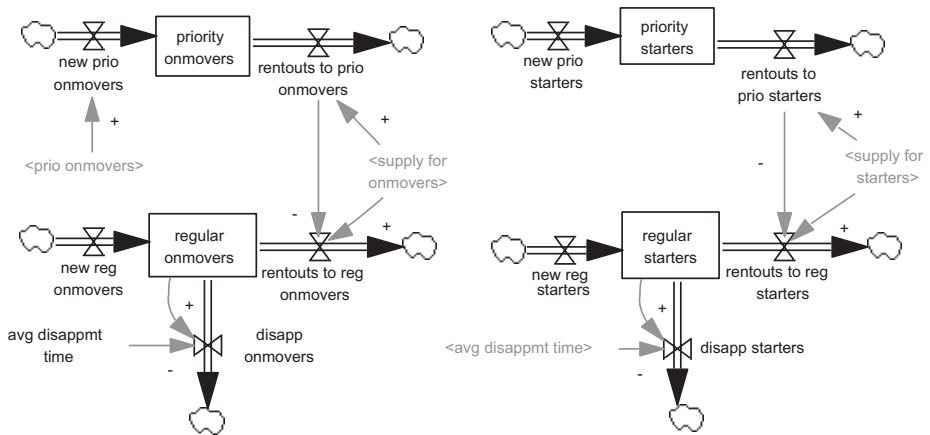


**Figure 16 Haaglanden: supply of social housing sector**

### Demand for social housing sector

The third sector (in figure 17) depicts demand for social housing. The sector consists of four inflow-stock-outflow structures for four categories of house hunters: priority onmovers, regular onmovers, priority starters and regular starters. The current housing allocation is not a queuing system in a strict sense, as people can exert some influence on the waiting time by being more or less selective in choosing a new dwelling. The inflow of three categories of house hunters is driven by external parameters only. Again the project group did not feel confident to formulate a dynamic hypothesis for these inflows and estimated time-series instead<sup>18</sup>. The inflow of priority onmovers is also driven by the demolition of social houses in the first model sector. It takes into account the effect of a longer stage 1-time in the number of transformation priority cases.

<sup>18</sup> The inflow per year for regular onmovers starts at 10,300 and after four years has a constant value of 8,000; inflow of other priority onmovers is constant at 1,500. The number of regular starters is 12,500 at the start of the simulation and constant 9,000 after four years; priority starters are constant at 1,000.



**Figure 17 Haaglanden: demand for social housing sector**

The stocks are depleted by rentouts to the four categories of house hunter flows. In the supply sector, total supply was already split over the starters and onmovers channels. For both channels the distribution logic states that priority cases go first, leaving remaining supply for regular cases. Furthermore, regular onmovers can exit the housing allocation system after an estimated twelve-year so-called “disappointment time”: house hunters will initially enroll in the distribution system and try their chances for some time. In case they succeed, they exit the stock of house hunters as new tenants. In case they do not succeed for a long time (i.e. twelve years), they might try to buy an apartment, try to find rental housing in another urban region, resort to commercial rental dwellings or illegal subletting. In any case, they exit the housing distribution system unsuccessfully and do not use it anymore. The senior researcher estimated the duration and the other project group members accepted this as sufficiently valid. In one of the policy experiments, onmovers could also exit the house hunter stock by buying a (former) social rental dwelling. The regular channel for starters does not have urban renewal priority cases or a homebuyers’ exit.

### Auxiliary variables and policy response sector

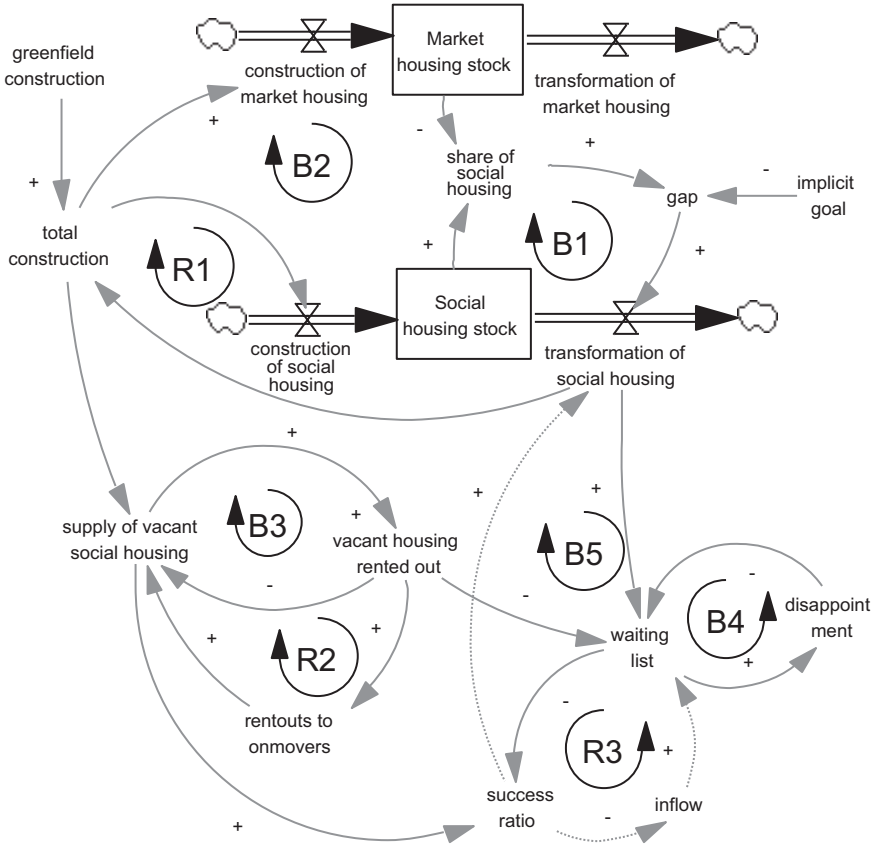
The fourth and final sector contains the rather straightforward definition of several important auxiliary variables, mainly used for graphs and tables. These are common knowledge for Dutch housing policy experts and include:

- Success ratio = (rent-outs to regular onmovers + rent-outs to regular starters) / (regular onmovers + regular starters). The success ratio is the main problem variable in this project and the reciprocal of the average waiting time. The perceived success ratio is a first order delay of the success ratio and will be used in policy experiments. Also specific success ratios for starters and onmovers exist.
- Mutation rate = supply of social houses / social housing stock. The mutation rate is a common auxiliary indicator denoting the dynamics of the housing market. A low mutation rate indicates a stagnant market in which too few houses become available. Too high a mutation rate may raise fears of long term structural vacancies.
- Share of social housing in total stock = social housing stock / (social housing stock + market housing stock). This is an auxiliary indicator for the urban housing mix.



**Feedback loops**

Figure 18 provides an overview of the model feedback structure.



**Figure 18 Haaglanden: feedback structure**

The upper middle part of the figure shows the main housing stocks (market housing stock and social housing stock) and the percentage of social housing of the total number of houses. The clients’ strategy is to reduce the share of social housing to about 30%. This target mainly drives the transformation volume and to a lesser extent green-field construction and sale of social housing. The upper part of the diagram shows the main feedback loops B1 and B2 driving transformation in order to attain the target share of social housing. B1 works by demolishing social houses, B2 by building new market housing as a result of transformation. Since part of the transformation program results in new social housing, a positive loop R1 is also operational. The lower left part of the causal diagram depicts the supply side. Construction and migration multipliers are the main drivers of vacant houses. Available houses being rented out to people on the waiting list decreases both the waiting list and the number of vacant houses (balancing loop B3). The housing



allocation system, however, has a limited capability of increasing the share of onmovers among new tenants. Since some of the onmovers move from one social house to another, a delayed reinforcing loop R2 comes into existence. Finally, the lower right part of figure 18 depicts the demand for social housing. The waiting list is the central variable. Social houses rented out decreases the waiting list. Transformation of social housing increases the waiting list by vacating houses to be demolished, and so does the onmover and starter inflow. A twelve-year disappointment time for house hunters works on the waiting list (balancing loop B4). Waiting list and supply of houses determine the success ratio. In the policy experiments we introduced a reinforcing loop R3 when a decreasing success ratio boosts the starter inflow.

#### IV.5 VALIDATION TESTS

During its development, the model was put through several validation tests described by Forrester and Senge (1980). We describe the outcome of four tests on model structure (structure and parameter verification, the extreme conditions and dimensional consistency test) and three tests on model behavior (the replication of the reference mode, behavior sensitivity test and behavioral anomaly test). Structure and parameter verification were incorporated in the group model building process. The model structure is based on tangible stocks and flows and the project group's knowledge of the housing market. Sufficient statistical data were available on most stocks and flows. Parameters were verified using the same data sources, except for some cases, where the project group made expert guesses consensually. The extreme conditions test was carried out during the simulation phase. Simulation of unrealistically high or low construction programs, transformation programs and housing allocation factor resulted in consistent patterns for mutation and the success ratio. The dimensional consistency test was carried out using the built-in software facility.

Comparing model outcomes to the reference mode of behavior is a behavior reproduction test. Real life data were available from 1998 to 2003. We compared the real against the simulated success ratio (figure 19) and scrutinized its two components, supply of houses (figure 20) and the stock of house hunters (figure 21).

Reference mode behavior test (1)

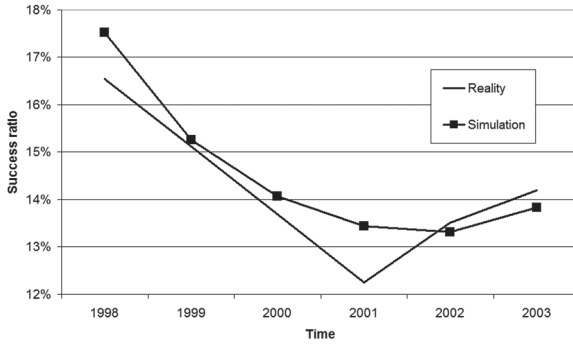


Figure 19 Haaglanden: historical fit for success ratio

Reference mode behavior test (2)

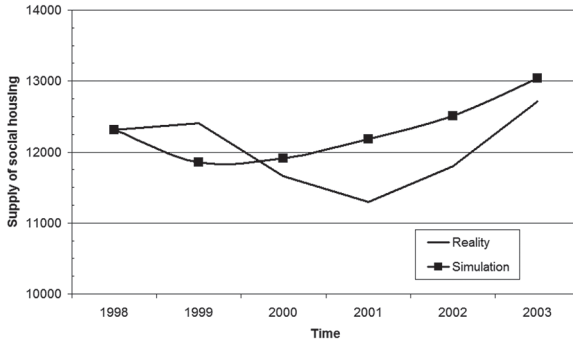


Figure 20 Haaglanden: historical fit for supply of social housing

Reference mode behavior test (3)

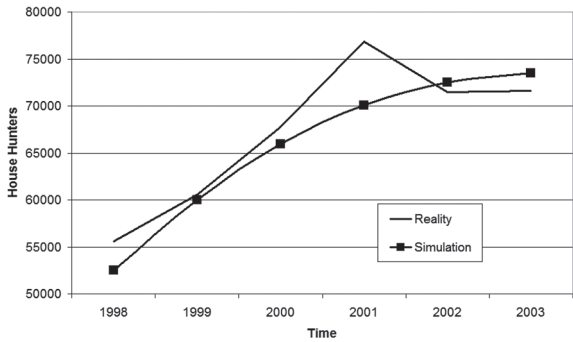


Figure 21 Haaglanden: historical fit for stock of house hunters

The model gets the overall development of the success ratio, albeit that the observed trend is smoothed out and that the simulated level is somewhat higher<sup>19</sup>. Scrutinizing the supply component, we found that the model captures the general movement and figures, but misses the observed increase in 1999 and is not very precise in timing. For the house hunter component, the model gets the development right, but does not capture the 2001 peak.

The project group, however, accepted the symptom generation behavior as valid. Differences might be caused by wrong estimates, but as mentioned before, for some parameters no reliable sources were available whatsoever. Moreover, they related the 2001 peak in house hunters to the introduction of an internet based allocation system, attracting more house hunters (We analyzed this issue in one of the boundary adequacy tests). Differences in supply could be related to the completion of several larger construction projects, so reality had a more discrete character than our simulation model. The project group agreed that such specific events could not possibly be reflected in the model and were thus to be excluded, i.e. placed outside the model boundaries.

Please keep in mind that the SGH project group members were very skeptical at the start whether we could produce a working model of the housing market at all. Now that the model apparently was capable of producing acceptable simulations, they were far more anxious to see the policy experiments rather than linger on further symptom reproduction tests. In the eyes of the project group, the model did exhibit the behavior experienced in the real system. Connecting to our earlier statement on the modeling perspective, we could only interpret this as that we had succeeded in retaining model plausibility (Grütters, 2006) and thus client satisfaction (Eskinasi & Fokkema, 2006). A comparable experience of clients moving from initial skepticism to enthusiasm and model ownership is recorded by Lane et al. (2003). We do not state that further more rigorous validity tests could not have contributed to a better model, but only explain why we reacted as we did, again in hindsight.

The reference mode of behavior of the problem was formulated in dynamic terms as a causal loop diagram in the starting report (see figure 18). But at the start of the simulation project, SGH and SVH were disputing the impact of the base and alternative policy on the housing market. They would easily agree on the causal structure of the problem in the starting phase, but could not come to consensus as how the system would react to both policies. This indicates that they were 'only human' as it has been repeatedly been demonstrated that the human mind is not suited for solving high-order dynamic feedback systems (Forrester, 2007b). And therefore, they needed a consistent quantitative story supported by model output in order to convince themselves and come to some kind of armistice on the necessary policy interventions.

The sensitivity analyses performed on external parameters are described in the final report. Most notably the migration multipliers have a strong impact on the success ratio in the social housing market as does the density factor. The effect of other parameters (e.g. stage-1-time, several other delay times) was very low to negligible. The housing allocation factor provokes a medium sized response, but lower than hoped for.

<sup>19</sup> Based on six data points for each of the three reference modes, analysis of Theil inequality statistics (Stermann, 1984; 2000, p. 875) shows that the majority of error is concentrated in unequal co-variation. The bias and variation component are below 0.30 and 0.04 respectively, indicating that the model captures both the mean and the trend in the data well.

Finally, three boundary adequacy tests focus on loops B1, B5 and R3 in figure 18. All three experiments suggest that the additional loops do not fundamentally alter the dynamics of our simulation. Closing loop B1 in the model means incorporating a 30% target for the share of social housing in the total stock as a driver of the transformation program. It is basically an automatic pilot for one of the time series inputs the client wanted. For the time horizon of our main simulation, we did not register any significant changes in dynamic behavior. In the second experiment, we linked the success ratio to the transformation program via a two-year perception delay (closing loop B5 in figure 18). One of the clients feared that linking transformation input to the success ratio on the market would negatively impact transformation progress. However, working out this loop, we found that its nature is balancing and not reinforcing. Embedding this policy in a feedback loop leads to an overreaction and aggravates deviations in the success ratio in comparison to the Haaglanden data. Increasing the policy information delay increases this effect.

The third and final experiment concerns the peak in the inflow of new starter house hunters observed around 2001 (see figure 21).

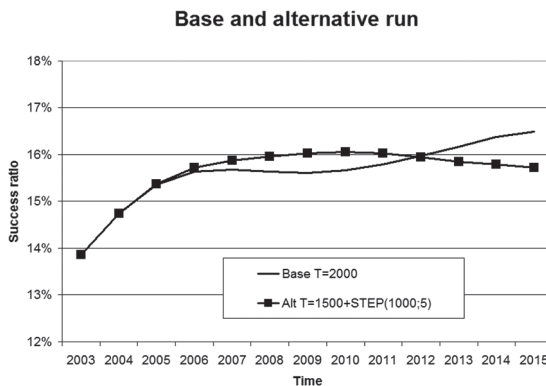
At least two hypotheses may explain this extra inflow. Length of registration is the criteria for starters applying. So if the starters' success ratio decreases, more registration length is needed for getting a rental dwelling. This will encourage other starters to register for the waiting list earlier as well. An alternative hypothesis is that the introduction of internet based housing allocation increased the consumer base, especially among young starters eager to use this new medium. Both hypotheses involve an effect of success ratio on inflow and create reinforcing loop R3 (figure 18). No data were available on the relation between inflow of starters and the success ratio, so we reverted to testing whether observed behavior could be explained by an assumed relationship. The resulting model behavior matches the observed pattern in the data. We conclude that in reality a reinforcing loop between starter inflow and starter success ratio may exist. However, since the modeling team did not feel confident to include this relation in the model, loop R5 is not included in the model used for simulating policy options. Incorporating R5 in the model does not change the conclusions of the policy experiments.

In conclusion, none of the experiments indicates that these structural changes significantly alter model behavior, pointing to well-chosen model boundaries. The purpose of validation of system dynamics models, after all, is the gradual building of confidence of the modeling stakeholders, and the Haaglanden project succeeded in doing so. When the simulation model was run, its output was minutely scrutinized by the project group, most notably the researcher. In this basic behavior anomaly test, no inconsistencies were found and the project group accepted the model as valid for its purpose: to simulate different green-field and transformation policies to assess their impact on the social housing market, in particular the success ratio.

## IV.6 BASE RUN AND POLICY EXPERIMENTS

SGH's new housing policy document (Haaglanden, 2004a) provides the data for the model base run. Simulations start in 1998 and run until 2015. The period up to 2003 is

used as a reference to historic reality, while 2005-2010 serves as the first and 2010-2015 as the second policy interval. Please recall that the clients' main difference of opinion is on the pace of the transformation program: SGH proposed an annual transformation program of 2,000 social dwellings, while SVH favored to transform 1,500 dwellings in the first five years (2005-2010) and 2,500 afterwards (2015-2010). After an initial dip when transformation gets moving, supply starts to increase from the green-field construction program. SVH's alternative policy with lower transformation in period 1 has a small positive effect from about 2005 to 2009, but a significantly larger negative effect in the second period when lower transformation means lower construction, shorter migration chains and less supply. The effect of the 2010 increase to 2,500 materializes only after 2017, because of the delay in the housing production chain. The mutation rate of SVH's alternative lags behind because less transformation means a larger social housing stock. Lower transformation means less urban renewal priority house hunters so that the base run has slightly more house hunters piled up around 2006 – 2009. Both effects combined result in a large difference in success ratio between both policies, as is shown in figure 22.



**Figure 22 Haaglanden: base run & alternative policy**

Transformation has the following effects on the success ratio. First, it increases pressure on the housing market by creating more urban renewal priority house hunters, thus lowering changes for regulars. Second, transformation decreases the social housing stock, lowering the supply of vacant houses by a small amount. In the long run, after the entire transformation pipeline, completion of new houses sets migration chains in motion and increases supply. New construction after transformation, multiplied by the migration multiplier, outnumbers the transformation volume times the urban renewal priority rate. Thus lowering transformation has advantages in the short run, but leads to even larger disadvantages in the long run. The supply side works as a material delay: it postpones and smoothes the impact of transformation and green-field construction. The demand side is basically about accumulation of house hunters. So although postponing construction ultimately results in the same amount of construction output and supply,

the accumulation of house hunters in between sets the success ratio back unrecoverably. Finally, several multipliers influence the overall balance, the most important being the volatile migration multiplier and the transformation priority rate. Combined with the behavior of the production structure, this causes the cost-before-profit behavior signaled by the project group.

The project's final report (Eskinasi, 2004) describes ten simulations made during the main project and focuses on resolving the different opinions on the right pace of housing transformation. Seven out of ten simulations delve into this issue by varying green-field construction and transformation. New green-field construction came out as an important lever. It has a relatively short delay time and a high impact. Due to the migration multiplier, significantly lower green-field development is very detrimental to the success ratio. Different time series of transformation input (the policy standpoints of SGH and SVH) affect the success ratio as described above.

The second policy experiment tested the leverage of the housing allocation system on the success ratio, assumed mainly by SVH. Increased allocation to onmovers was combined with lower green-field development. Compensating low construction volumes by smart housing allocation was not possible to the expected extent. As a result the project group felt that housing allocation was not the right means to boost the success ratio.

A third policy option was directing sale of social houses to house hunters on the waiting list. This enables rapid 'transformation' of the housing stock without any interfering delays. It also directly decreases the accumulation of house hunters and therefore theoretically has a strong leverage on the success ratio: fewer remaining house hunters compete for approximately the same amount of supply. The simulations confirmed this thought. However, the 1990's rapid price increases make it virtually impossible for lower income groups to buy even a former social flat and for middle income groups this is becoming increasingly difficult as well. This option is very difficult to put into practice. The fourth option that was tested was increasing the share of social housing in total construction. Its result is a higher success ratio due to lower accumulation of house hunters. This policy may appear to go directly against the implicit target of decreasing the social stock. Nevertheless it has a range of other favorable outcomes, such as increasing housing quality, lowering concentration of social housing within the central city and to increase its share in the predominantly market housing suburbs.

To sum up, the policy experiments clarified insights on transformation, green-field development and the share of social houses in construction, confirmed participants' expectations on sale of houses and refuted intuitions on the housing allocation system.

## IV.7 EVALUATION OF THE PROJECT

### **Opinion of the project group**

Both participating organizations accepted the model outcomes as valid and the overall conclusions as very insightful. The debate switched from a focus on the 'facts' concerning the impact of transformation on the housing market, to the preferences of and the different interests of both organizations. The system dynamics intervention has 'de-messed'

the problem. In interviews after project completion, the project group reported the following overall conclusions and learning experiences drawn from the simulation project:

- A better understanding of the effect of the several delays in the system. Before the simulation project, the impact of delays was underestimated
- Increased insight into differences between short term and long term effects of housing transformation. The model clearly demonstrated short term and long term effects that differed in magnitude and direction. These effects went against shared beliefs and constituted an important counterintuitive finding.
- The high leverage of new green-field construction, the share of social houses in construction and sale was reconfirmed, albeit that the migration multiplier had a stronger influence than expected and varied over time.
- The leverage of the housing allocation system was far lower than some group members expected or hoped for.
- The differences between long term and short term effects of policy interventions.

### **Some empirical assessments of project effectiveness**

Furthermore, during the project, we carried out some empirical assessments, reported in more detail in Eskinasi and Rouwette (2004). On the basis of the method developed by Rouwette (2003), we assessed whether the modeling intervention impacted the attitude of project group members towards certain policy interventions. Comparing the project group to the participants in the flight simulator workshops, we concluded that only full participation in the project changes a person's attitudes towards the policy measures proposed above. Both the project group and the workshop participants, albeit exposed to very different doses of system dynamics modeling, agree that working with simulation models creates better and faster alignment of mental models than regular meetings.

### **Opinion of the modeling team**

From a content point of view, the model certainly leaves room for further improvement. We did not model the interaction between the market and social housing sector, whereas this is a very important issue explaining the difficulties in the Dutch housing market (Conijn, 2006). Quality improvements within the social sector are not reflected although the housing market balance is distinctly different for old and new social housing. As discussed above, in many cases the project group did not feel confident to formulate loops surrounding the target share of social housing, the transformation program and inflow of the waiting lists. Finding usable data on these relations would have been very difficult. The same applies to the causal relations around the migration multipliers. In these aspects, there is certainly room for further research with system dynamics modeling into the intricacies of the Dutch housing market.

And how did we do as system dynamics modelers? Did we, at least to some degree, meet Forrester's standards for quality of work in the system dynamics field (Forrester, 2007b)? First of all, the project was initiated by two client organizations in dispute over tangible real world policy problems. We did succeed to some degree to provide them with more solid insights into the dynamic behavior of their problem. We delved into the history and details of the problem at hand and developed a relatively compact model showing the causes of the observed difficulty. The model used during the simulations was driven by

external time series, but the boundary adequacy tests indicate that this is not a serious flaw as regards to dynamic behavior during the policy time frame. It may have been the case that the modeling facilitator was not yet skilled enough to translate the ‘time series thinking’ of the project group members into an equivalent loop structure. We did not arrive at a high leverage policy which fundamentally alters the dynamic behavior, basically because our clients were mainly concerned on settling their dispute. They agreed that the system dynamics modeling intervention succeeded in this aspect and that it provided them with highly relevant learning experiences about the dynamic behavior of the Haaglanden social housing market.

## IV.8 CONCLUSIONS

The Haaglanden group model building project has produced several interesting and tangible results. First of all, its context indicates a shift in the basic ideas of urban renewal policy in the Netherlands. Whereas in the 1970’s urban renewal was focused on technical improvement of the housing stock, the 1990-2000 programs emphasize balancing of the urban population and housing mix in order to improve urban socio-economic vitality, a central issue in Urban Dynamics (Forrester, 1969). Second, the group model building intervention has helped the client organizations in settling a highly contentious issue, i.e. the best pace of transformation of social housing. In the interviews after the project, participants mention several new insights into the behavior of the housing market, such as the impact of delays, the accumulation on the waiting list and the effectiveness of several alternative policy options. Third, we found that all participants see system dynamics modeling as a better means of decision making than regular meetings, but that only with people deeply involved, group model building has a significant impact on the attitude towards policy options. Finally, we summarized several possible improvements and questions for further research and reflected on our results in the perspective of Foresters (2007b) standards for good quality system dynamics modeling. The modeling project helped our client organizations to improve understanding of the matter at hand and to solve their policy conflict. The project has been useful in that respect.



# V HOUDINI<sup>20</sup>

## V.1 INTRODUCTION

This chapter describes the work on progress on Houdini, a system dynamics model used for explaining regional divergence and the impact of institutional features on the development of house prices and construction. Houdini has its foundations in the four quadrant model of Di Pasquale and Wheaton (1996) (further: 4QM). The modifications of the 4QM described in chapter II.2 (rent regulation, fiscal mortgage support, land use planning and residual land prices) were first applied in Houdini.

Houdini is based on the extensive critical literature advocating reforms of the Dutch housing market and inherited concepts from existing economic models of the housing market (Donders et al., 2010; Romijn & Besseling, 2008; Van Ewijk, Koning, Lever, & De Mooij, 2006). Houdini was reviewed by a well-established expert panel, consisting of representatives of universities, ministries and national research and policy analysis institutes. This chapter reports Houdini's structure, validation, base run, policy experiments and follow up activities.

## V.2 CONTEXT OF THE SYSTEM DYNAMICS MODELING PROJECT

### **History of the problem context**

From the Reconstruction Period after World War II onwards, Dutch housing policy was led by government policies rather than by market principles. Eskinasi et al. (2009) tell the tale of different *state* housing policy approaches from post war mass housing provision through the 1970s new towns and urban rehabilitation for low income groups to the 1990s and early 2000s, when housing policies started to pay lip service to market principles. Housing associations were privatized to a certain extent, consumer demand became more important for new construction and socioeconomic revitalization became a prime objective of urban renewal. But more fundamental reforms of the housing market were postponed: rent regulation, mortgage interest tax reductions and spatial planning were still in place.

The 1990s witnessed decreasing mortgage interest rates, growing incomes and improved availability of mortgage credits for households. Average house prices increased from under € 100.000 in 1995 to nearly € 250.000 in 2007. Measuring house prices in multiples of median incomes, in 2007, 100.000-inhabitant Eindhoven out-priced New York and Amsterdam was the 13th most expensive worldwide (Romijn & Besseling, 2008, p. 27). Households and the state budget were increasingly at risk from high mortgages and interest fluctuations, rent regulation discouraged commercial investors to build

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<sup>20</sup> This chapter is based on: Eskinasi, M., Rouwette, E., & Vennix, J. (2011). *Houdini: a system dynamics model for housing market reforms*. Paper presented at the 29th International System Dynamics Conference, Washington DC. And: Eskinasi, M. (2011). *Houdini: een systeemdynamische modellering van regionale woningmarkten. Achtergrondstudies* (pp. 56). Den Haag: Planbureau voor de Leefomgeving.

rental housing and tenants to move from cheap apartments, thus obstructing housing market dynamics. It was estimated that the state and the housing association directly and indirectly subsidize housing with € 29 billion annually (Don, 2008, p. 3).

The balancing feedback loop of the 4QM, however, should make high prices boost new construction. Dutch construction statistics, however, show ever *decreasing* construction volumes from 1990 onwards. The spatial planning system was seen a probable culprit (Besseling et al., 2008).

The Balkenende IV coalition government (2006-2010) with Christian democrats -advocating homeowners' interests- and social democrats -reluctant to ease rent regulation- made a compromise to once more postpone fundamental housing market reforms. This moratorium spurred an unprecedented stream of economic studies, mostly very critical of the state housing and planning policy, demonstrating many negative effects and calling for fundamental reforms, (e.g. Conijn, 2006; Don, 2008; Hof, Koopmans, & Teulings, 2006) and others.

The Ministry of Housing, the traditional stronghold of the planners' interventionist paradigm was forced into the defense before the new conservative Rutte I government dismantled it in 2010. The new government set out to decentralize housing and spatial planning to provinces and municipalities and to tighten the fiscal and legal leashes for housing associations.

### V.3 THE SYSTEM DYNAMICS MODELING PROJECT

The development of Houdini started in 2008 as a private project out of interest for the substantive matter and caught the interest of a leading academic for its prospects of generating insights into transition paths towards a more stable housing market. At this stage, only limited time could be invested in Houdini, but as much literature was available<sup>21</sup>, a simple prototype was built and producing plausible first results near the end of 2009.

Houdini was brought to the attention of PBL Netherlands Environmental Assessment Agency. Its staff was working on a large scale demographic style housing market model on the municipal level. The prospect of using (parts of) Houdini for this large model made PBL hire the modeler. As PBL is concerned mainly with regional housing markets, it was decided to translate Houdini into a regional model.

The prototype saw many improvements and finally evolved into the first fully documented and validated version of Houdini (Eskinasi, 2011a). Three runs were made on basis of regional housing market data. Region A represents the national average, region B is the densely populated northern part of the Randstad around Amsterdam, and Utrecht, region C is the declining far southeast of Limburg. Furthermore, different policy experiments were carried out, focusing on reducing rent regulation, mortgage tax deduction and interventions in the spatial planning system and comparing differences for the three regions. Feedback between (adjacent) regional housing markets was missing in the first generation of Houdini.

21 Most notably modeling studies of the Economic Assessment Agency on the rental (Romijn & Besseling, 2008) and owner occupied (Van Ewijk et al., 2006) sectors, a household behavioral model (Ras, Eggink, Van Gameren, & Ooms, 2006), an anthology of housing market critiques (Don, 2008) and the 4QM (Di Pasquale & Wheaton, 1996).

An expert panel was formed to provide guidance to the modeling project. It consisted of two leading housing academics, housing experts from CPB, SCP<sup>22</sup> and the Economic Research Institute of the Construction Industry (EIB), policy makers from the (former) Ministry of Housing and expert staff from PBL. A first plenary session was held in June 2010, when work on the first version was in full swing. Later on, the modeler regularly contacted members of the expert panel for advice and feedback.

The shift in purpose of the model should be noted: the initial purpose was to model the problematic housing market behavior on the national level. At that time, CPB only just published their own national housing market model (Donders et al., 2010), based on the integration of two separate studies of the owner occupied (Van Ewijk et al., 2006) and the rental sector (Romijn & Besseling, 2008). Only with PBL hiring the Houdini modeler, the regional aspect was added to the modeling purpose. Possibly, this saved Houdini from a competing model issue with the CPB housing market model (Donders et al., 2010; Eskinasi & Fokkema, 2006), but necessitates future fundamental rethinking of the model's focus as regional interactions need to be added. Several small study models were made for this purpose, but the start of the middle incomes and mortgages modeling projects drew away attention from further development of spatial versions of Houdini.

#### V.4 THE RESULTING MODEL

##### **Overview of the model and general aspects**

Houdini is based on the 4QM and is the initial source of the institutional features added to the 4QM in illustrations 1 and 2 in section II.2, i.e. stock and flow structures for population and incomes (in order to attain unit consistency), rent regulation, fiscal mortgage support, land use planning and residual land pricing. Furthermore, Houdini has a double housing production chain for owner-occupied and rental housing respectively. This structure is somewhat comparable to Haaglanden (see figure 15), but adds the rent and price variables of the 4QM. The rent axis in the 4QM is defined here in terms of *user costs*: the real economic costs for using real estate, the standard approach in the national and international housing economic literature (e.g. Di Pasquale & Wheaton, 1996; Poterba, 1984). User cost theory takes into account three components: maintenance and other costs, financing costs and housing appreciation. Di Pasquale and Wheaton (1996, pp. 247-255) discern three variants how households take appreciation into consideration. With exogenous expectations, home owners do not base price expectations on housing market trends, but on e.g. inflation or general GDP growth. Rational price expectations, the standard in mainstream economics, allows households to correctly forecast future time trajectories of a market after an exogenous shock occurred<sup>23</sup>. Adaptive or myopic expectations, finally assume that households take into account *historic* price increases

22 CPB Netherlands Bureau for Economic Policy Analysis deals with economic aspects of many policy fields, mostly on the national level. PBL Netherlands Environmental Assessment Agency deals with environmental issues, land use, agriculture and food quality, water management, regional development, regional economies and housing markets. SCP is the Netherlands Institute for Social Research, taking mostly the household viewpoint. All three agencies therefore work on housing market models and studies but sometimes have different viewpoints and opinions.

23 They are not expected to correctly forecast the occurrence of the actual exogenous shocks, as is suggested in some criticisms of rational expectations.

for current decision making. Adaptive expectations are a precondition for the occurrence of real estate cycles (Wheaton, 1999) and introduce the reinforcing loop of speculative incentive in figure 12. The exact specification of the appreciation component proved a great opportunity for debate with the mainstream housing economists from the CPB.

Moreover, Houdini models the peculiar interplay of prices between the owner-occupied sector (with prices stimulated by fiscal mortgage support) and especially the social rental sector with rent regulation. Houdini also adds a dynamic structure for household tenure choice and fiscal feedback.

Finally, houses are heterogeneous as to size, quality, amenities and location. Housing economic literature defines the housing stock in terms of abstract housing services or quality units. Larger or better houses (housing structures or housing units) then provide more housing services than smaller ones. Economists criticize planners for over-emphasizing housing units and demographic prognosis and underestimating demand for housing quality based on income growth (Eichholtz & Lindenthal, 2008, p. 80) and the negative welfare effects of all government interventions.

### **Main model structure**

Figure 23 shows the production chain of the Houdini model, with details removed for clarity's sake. Loops B1 and B2 represent the main balancing loop of the 4QM for the owner occupied and rental sector respectively. Likewise, R1 and R2 constitute the residual land prices loops for both sectors. Furthermore, a flow variable is added representing the sale of rental housing into owner occupation.

The interconnection of owner occupied and rental housing through housing prices generates interesting dynamics. The price dynamics of the owner occupied sector (influenced by exogenous demand and interest rates) transfer to the rental sector. When sold, rental dwellings will collect the same free-market, per-unit prices as owner-occupied housing (taking into account of course differences in size, quality etc.). On the other hand, the investment value of rental housing is based roughly on capitalized regulated rents<sup>24</sup>. Owner-occupied prices are stimulated by fiscal mortgage support, but rental investment values controlled by rent regulations are far lower than the free-market values (Conijn & Schilder, 2009). The difference between (stimulated) market value and rental investment value is the so-called value gap, which depresses rental construction and stimulates sale of rental housing. Balancing loop B3 will strive to equalize out price differences through the sale of rental housing, but as long as fiscal mortgage support artificially lowers the effective discount factor in the owner occupied sector only, the system is not capable of attaining equilibrium.

<sup>24</sup> A fixed capitalization rate was used here, based on Donders et al. (2010)

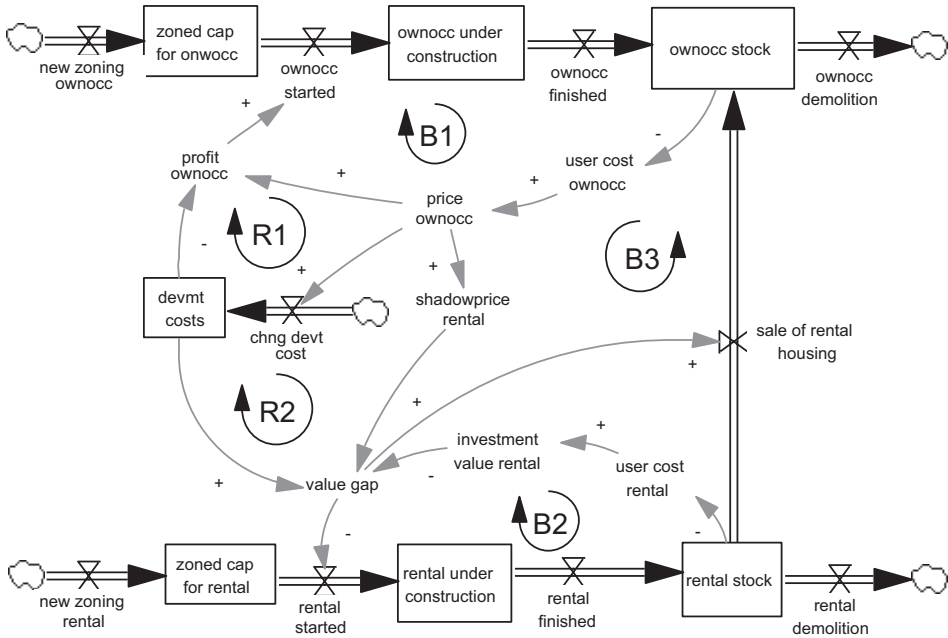


Figure 23 Houdini: price interaction between rental and owner occupied sector

Figure 24 shows the additional feedback loops governing the dynamics of tenure choice, subsidies and fiscal pressure on household incomes. Tenure choice is operationalized here as the fraction of households choosing owner-occupation. The income distribution of owner-occupation, however, is very skewed as fiscal mortgage support is most advantageous for higher income groups and rental housing allowances are limited to lower income groups. Rent regulation applies for all income groups in rental housing and works as an additional, implicit subsidy financed through the lowered investment yields of housing associations (Conijn, 2008; Conijn & Schilder, 2009).

But on the overall level, both instruments add up to the total fiscal pressure on incomes: housing subsidies and tax benefits influence peoples' decisions on tenure. Balancing loop B4 represents households' considerations on the affordability of owner-occupied housing. Loop B5 is dormant, as rent regulation prevents increased demand for rental housing to propagate into higher user costs. Likewise, rent regulation prevents the state expenditure on direct rental housing to spiral out of control through loop R3, which is actually being used as an argument to preserve rent regulation.. Loop B6 shows how fiscal mortgage support (i.e. 'subsidy' for owner occupied housing) increases income taxes and – in theory- lowers tenure choice probability. Due to progressive income taxes, however, higher income households benefit more from fiscal mortgage support.

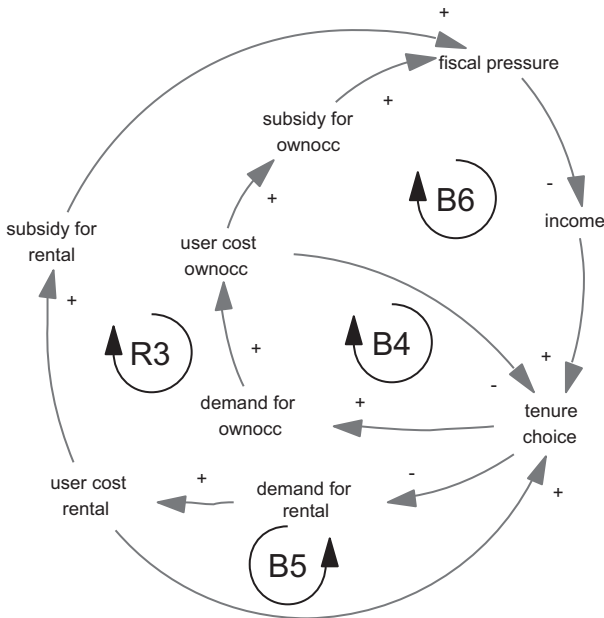


Figure 24 Houdini: fiscal and tenure choice dynamics

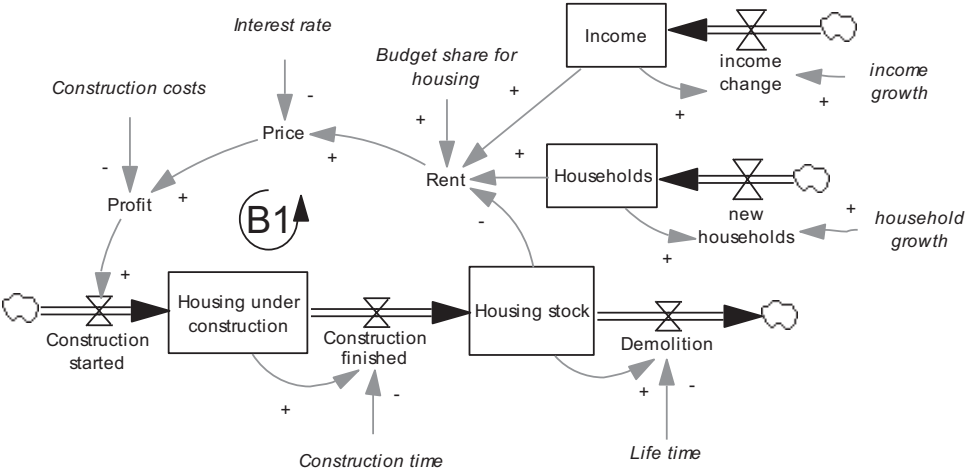
### Modeling details

On the demand side, Houdini takes into account the possibility of population decline. The household growth rate (see figure 25, right hand side) is a linear function of time, with its parameters estimated on the basis of a demographic prognosis. Its slope is negative, so population growth decreases and at a given moment, even population decline will occur. The three regions in Eskinasi (2011a) were chosen in order to display large variation in population growth: region C was already declining in 2010, whereas region B would continue grow for nearly a century. In average region A, population growth decays to near zero at the end of the simulation period, i.e. 50 years. Income growth takes historical figures and future scenarios as exogenous input.

The dynamics of the tenure choice variable in figure 24 is the subject of interesting debate. The first version of Houdini used a statistical estimate (Ras et al., 2006) where tenure choice depends in household incomes, a regional (constant) factor and the ratio of user costs in both sectors<sup>25</sup>. This solution gave tenure choice a strong endogenous character, but also caused unit consistency flaws and debates with the CPB economists participating in the project. They proposed a unit consistent solution adhering to micro-economic foundations with a fixed budget share for housing and a fixed tenure preference, based on a nested Cobb-Douglas utility function with budget constraints. This solution was based, however, on a model with abstract housing services rather than concrete heterogeneous housing units. This left Houdini with still unresolved tension

<sup>25</sup> Several other variables used in the regression were not used in Houdini, like ethnicity, education level etc.

between the planners' and the economists' paradigm. Linking one house (or housing unit) to one household is a fundamental cornerstone of housing planners' thinking. Vennix (1996, p. 220 - 221) also encountered this issue. Economists, however, criticize exactly this point of the planners' doctrine: it is not flexible enough to accommodate changes in demand for housing quality. Housing researchers, on the other hand, point at the fact that also such common utility functions are still too stylized to represent real housing market processes (Maclennan, 2012) and that these underestimate the impact of macro-context factors restricting household choices in the prevalent dynamic life-course approach (Clark, 2012). Such debates on the nature of housing choice is a proper example of a so-called messy problem, where different stakeholders (or disciplines) hold very different perspectives on a particular notion (Vennix, 1996, p. 13). In any case, the first version of Houdini had not yet reached a fully satisfactory modeling solution on the issue of tenure choice and housing quality when attention moved towards the middle income project in chapter VI.



**Figure 25 Houdini: household and income dynamics in the 4QM**

The second illustration in section II.2 demonstrated a simple model modification for integrating land use planning (see figure 7) as an extension of the housing production chain. Houdini features a comparable structure with zoned capacity stocks for owner-occupied and rental housing respectively (see figure 23). The inflow to these stocks is governed by household growth: land use planning agencies also use the demographic forecasts on which the exogenous parameters for household growth is based. They estimate the future number of households at a given time horizon (e.g. 15 years ahead), determine the expected housing shortage and allocate sufficient annual slices of zoned capacity. Distribution of capacity over sectors is based on the tenure choice variable discussed above. Just like the real-world system, this structure disregards the influence of income growth and interest rates in housing demand, as Eichholtz and Lindenthal (2008) argue. Houdini also features the mechanism of residual land prices (see figure 23, loops R1 and R2). As argued in section II.2, residual land prices make development costs adjust



dynamically to market prices for housing. Brick and mortar construction costs grew only moderately (Besseling et al., 2008) from the 1970s onwards, so land prices absorb the remaining share of house price increases. Rouwendal and Vermeulen (2007) demonstrated empirically that in the Netherlands, housing construction hardly reacts to prices on the short and medium run, due to the complexities of land use planning and residual land pricing. Buitelaar (2010) explains how Dutch municipalities started to pursue active land policies based on residual prices. This enabled them to recover investment costs made and to capture part of the very lucrative profits made in greenfield development. It is therefore plausible to assume that the residual land price structure (see figure 9) applies for the Netherlands<sup>26</sup>.

Furthermore, a high level of market concentration characterizes the Dutch development and construction industry (Buitelaar & Pouls, 2009): a small number of large firms dominates the market and owns most land to be zoned for residential development, especially in the densely populated Randstad. This so-called Cournot oligopoly (Varian, 1992) allows developers to capture a higher profit rate, determined by market concentration and price elasticity of demand. In Houdini, this aspect of the Dutch construction market is integrated into the relation between profits and construction output (see figure 23).

Figure 24 shows the feedback between fiscal mortgage support and rental housing allowances to the average household income level. Lowering public expenditure may harm demand for housing, but can be (fully or partially) compensated by decreasing taxes, so-called ‘back funneling’. The first version of Houdini also contains several other taxation mechanisms for policy experiments, e.g. taxing deregulated rents<sup>27</sup> or sale of rental housing. Finally, Houdini has several outcome ratios like house prices, user costs to income, housing shortage (households minus stock) and the percentage of housing subsidies to national income.

## V.5 VALIDATION TESTS

Several validation tests were carried out with the model (Forrester & Senge, 1980). Boundary adequacy tests were not yet carried out in this stage, but may be based on comments received from the expert panel. Structure and parameter verification were based on existing housing literature and statistical sources. Dimensional consistency was safeguarded with the modeling software and is correct. As mentioned before, the demand equations were most problematic in this respect.

As for behavior reproduction, the simulation was tested against statistical data over 1995-2000 with Theil’s inequality statistics (Stermann, 1984). Figure 26 shows the reference mode of behavior and simulation results for housing prices and new construction. The model is quite precise as to housing stock development at a 1% RMSPE error and has acceptable statistics for price development<sup>28</sup>. Housing supply is notably difficult to model

<sup>26</sup> Initially, the modeler also assumed that oversupply of zoned land would put downward pressure on the development cost: with surplus supply, land would become cheaper. Land market experts questioned this loop because most land is already owned by developers.

<sup>27</sup> Such a measure was actually implemented early 2013, much to the dissent of housing associations.

<sup>28</sup> RMSPE  $\approx$  5% &  $U_c \approx 0,85$  (Eskinas, 2011a, p. 62).



(Di Pasquale, 1999) and leaves room for improvement here as well<sup>29</sup>: Houdini misses the upswing of construction from 2004 onwards, swings further down until 2009, when actual construction declined due to the credit crunch. The upswing of actual construction is strongest in the rental sector from 2006, when housing associations intensified their efforts. This is not yet conceptually reflected in the model.

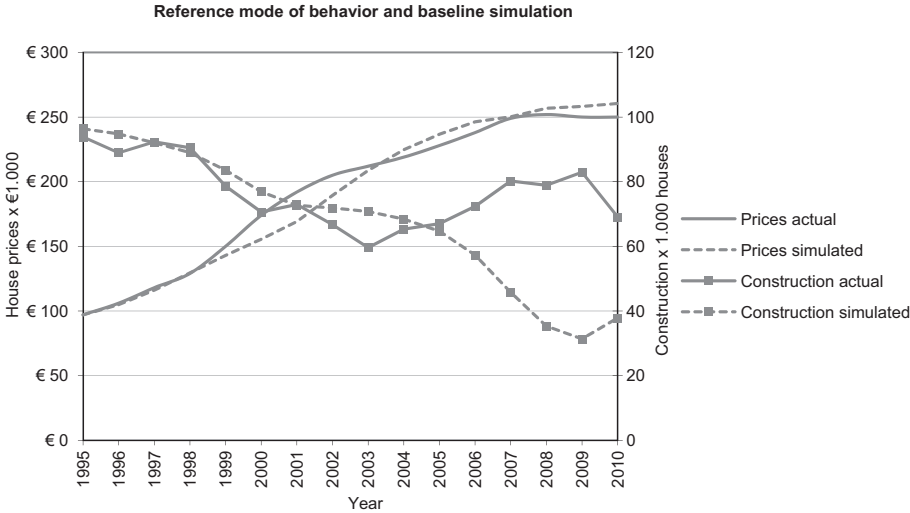


Figure 26 Houdini: reference mode & historical fit

Several parameter sensitivity analyses were run using software facilities. The sensitivity of the model to capital market interest rate reflects well documented responses of real housing markets: increasing interest rates decrease house prices and make construction collapse. Also varying household income growth yields recognizable responses.

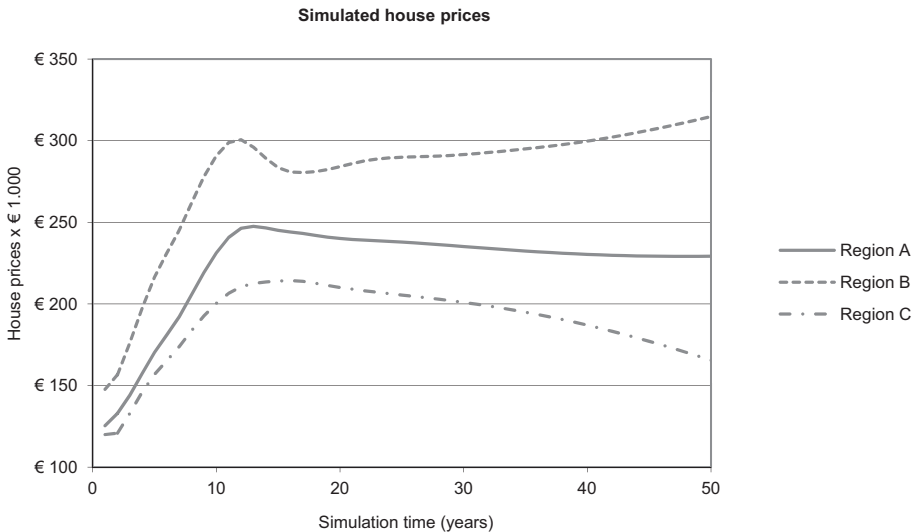
The response of the model to price and especially income elasticity of demand is difficult to interpret. This confirms the unit consistency test in the sense that the demand section is pointed out as a conceptually weak point in the model. Sensitivity analysis with the time offset of the planning system, albeit far-fetched at first sight, yields a proper system dynamics counterintuitive insight: a longer offset has the planning system anticipate earlier on future population decline. Fewer houses are built when demand is still growing so shortages and prices increase. In the regulated situation, this tempers demand so much that the quality fit of demand and supply improves. A short time offset causes the opposite effect in that the planning system produces more in the first years, leading to over supply when population declines. This results somewhat resembles the findings of Glaeser et al. (2008) that ample supply elasticity can also be detrimental to overall welfare through overproduction of housing.

29 RSMPE  $\approx$  13% &  $U_c \approx 0,85$  for owner occupied and RSMPE  $\approx$  25% &  $U_c \approx 0,95$  for rental (Eskinas, 2011a, p. 62).

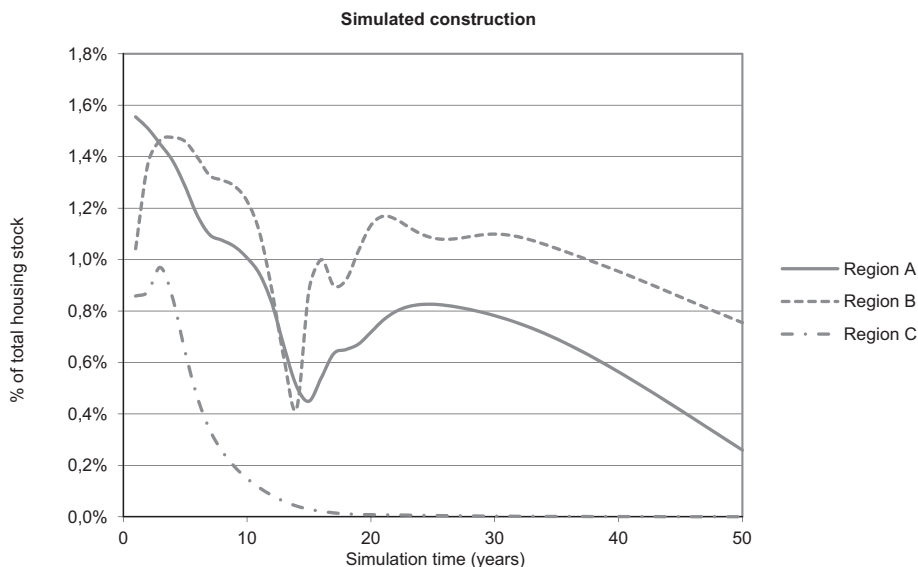
## V.6 BASE RUN AND POLICY EXPERIMENTS

The base runs in figure 27 and figure 28 show the long run effect of unchanged housing policies on the three regions. Starting year 0 equals 1995 and the simulation runs for 50 years. Region A represents the national average, region B is the densely populated northern part of the Randstad around Amsterdam, and Utrecht, region C is the declining far southeast of Limburg. B has a higher and C a lower income growth ratio than average A. In Region A, population growth slows down and reaches 0 near year 50. Region B keeps growing throughout the entire simulation horizon, but the population of region C declines from year 15 already.

The 1990s saw significant decreases in mortgage interest rates, with very limited regional differentiation. For the long term, a fixed assumption of interest level was made of 3% in real terms. The simulation shows the recognizable rapid growth of prices in all three regions. Differences in income growth, demography and starting situation of the housing stock (prices, ratio of rental) explain different growth curves. A bit of speculative incentive sneaks into households' decision making and price increases are stimulated. But economic growth slows down (income growth decreases and interest rate climbs) and house price growth levels off quite suddenly. Development costs used to lag to house price development, but now rapidly catch up, decimating profitability and construction. When the system recovers from this external shock (interest rates and income growth stabilize, demography slows down), it is effectively exhibiting zero real growth in house prices in region A, returning growth in B and accelerating decline in C. This closely matches the reference mode of behavior as described above. Construction recovers in A and B, but not in C.



**Figure 27 Houdini: base line simulation of house prices for three regions**



**Figure 28 Houdini: base line simulation of construction for three regions**

Policy experiments were carried out from year 20, focusing on the mortgage interest tax reduction and rent regulation. Rent deregulation is simulated by allowing higher rent increases. Causally speaking, the hindrances to balancing loop B2 are gradually lifted. Rents and asset prices rise, but shifts the balance in the tenure choice loops towards owner occupied housing. Rents will grow until market rents are reached when investors have a certain return level on the asset price of rental dwellings. Because growing region B has relatively high house prices, it takes a longer time to reach market rents than in average region A. Likewise, declining region C with lower prices reaches market rents earlier. Higher rents lead to a shift in tenure choice towards owner occupied housing, increasing both price and construction levels in it.

Decreasing the mortgage tax reduction from an average 25% to 15% in year 20 leads to somewhat lower prices. In causal terms, lower mortgage tax reductions increase the effective interest rate. Construction responds dramatically in the short term and shrinks 40% relative to the baseline simulations. Because the growth of the housing stock stops and demand continues to grow, the initial price loss is compensated to some extent in the medium term. On the longer term, the market prices stabilize only just under the level of the baseline. Region B and C respond similarly, albeit with construction in declining region C coming to a complete halt by year 15.

Combining both experiments shows that the effect more or less add up. Higher rents shift demand to owner occupied housing. Reducing mortgage tax reductions decreases house prices and construction of owner occupied housing even more. The transition time of regulated rents to market rents, however, is shortened: lower house prices lower market rents as well.

## V.7 FOLLOW UP ACTIVITIES AND REACTIONS TO HOUDINI

The modeling report was shared with the members of the expert panel and several meetings were held to obtain their feedback of the model structure and model outcomes. The first meeting of the expert panel in June 2010 yielded suggestions as to the relevance of housing quality, the necessity of regional interactions, modeling simplicity and the importance of a well-chosen base line simulation.

Within PBL, Houdini was received positively, but no very targeted feedback was provided. This may be caused by the lack of a sufficiently specific purpose for Houdini. One surveyor, generally critical of large scale modeling, however, found the system dynamics approach in comparison more attractive as it incorporates behavioral responses of actors and support what-if policy experiments.

Simulation of future house prices nevertheless caused some nervousness. A draft article containing price graphs for a professional magazine was postponed awaiting further support of well-established academics because of potential fuzz with national and local policy makers. The same attitude towards the price graphs was found with the CPB housing economists in the expert panel. Their model would only show the deviation of policy experiments from the base path.

Moreover, the CPB housing economists contributed to a strong but constructive debate on the underlying principles of Houdini. First, they criticized the lack of economic rigor on the demand side: Houdini has no explicit bookkeeping of expenditure on housing. As mentioned before, the demand equations were weak as it comes to meaningful units. The CPB experts suggested using a behavioral system of housing consumers consisting of a budget constraint and maximization of utility. These suggestions provided a clear framework for modeling demand with straightforward equations in comprehensible units and will be implemented in a next model version.

The adaptive price expectations were most controversial. Notwithstanding some empirical support for adaptive price expectations in the housing market, (e.g. Case & Shiller, 1989; Glaeser, 2013; Hamilton & Schwab, 1985), rational expectations are axiomatic in mainstream economics. And with CPB mainstream economists as partners in the modeling project, this issue was a hurdle to take in building confidence in the model (Forrester & Senge, 1980). On the other hand, straying from axiomatic perfect competition in reference to the structure of the Dutch supply side (with planning system and oligopoly) provoked questions of clarification rather than an axiomatic debate. Overall, CPB is supportive of Houdini, in particular with regard to the regional differences and interactions and explicit modeling of the planning system.

Houdini was put to the test in a project on long term spatial scenarios for the Netherlands. A land use transport interaction model, TIGRIS XL (Zondag & De Jong, 2011) provides the main quantitative framework. It is a large scale model of employment, transport, housing and other land use. It does not explicitly model house prices. Both Houdini and TIGRIS used inputs from several demographic and economic scenarios. Both Houdini and TIGRIS simulated new housing construction. A sufficient fit between both models in terms of Theil statistics then allowed the house price output of Houdini to be accepted for the project. Furthermore, data collected for Houdini contributed to the final project report (Hilbers et al., 2011).

## V.8 EVALUATION OF THE PROJECT

### **Opinion of the expert panel and the modeler**

Houdini 1.0 is only the starting point, so no final conclusions can be formulated at this point. The impact of Houdini 1.0 is limited, because its purpose is not well defined: it started as a ‘hobby project’ with a regional dimension added only later.

Houdini does not yet satisfactorily reproduce the reference mode of behavior, especially the total construction volume. This points at possible flaws in the boundary adequacy of Houdini. It is plausible to assume that Houdini still lacks proper representation of the factors driving construction by housing associations.

On the other hand, experimenting with Houdini demonstrates the agility of system dynamics in comparison with large-scale demographic modeling. Furthermore, in hindsight, Houdini provided PBL with a starting point for modeling institutional features of Dutch housing and real estate markets and proved an important preliminary model for the Middle Incomes simulation described in chapter VI.

## V.9 CONCLUSION AND DISCUSSION

Upon their first encounter in the early seventies, urban dynamics and housing economics clashed and thereafter developed in isolation of one another. Nevertheless, stock, flows, feedback loops and real world policy problems are innate to both fields. At least one implicit system dynamics model, the 4QM, exists within housing or real estate economics. Only since 2007, references to it are found in system dynamics literature. It may be useful to explore other implicit system dynamics models in urban, real estate and housing economics and related sciences (geography, urban sociology, planning) and to model them using formal system dynamics methodology. Notwithstanding the inspirational sparks of Urban Dynamics, a closer connection between system dynamics and the substantive sciences may be to the benefit of both fields.

Houdini is a housing market model based on both system dynamics and housing economics. Its development indicates that a moderately experienced system dynamics modeler with a background in the substantive field can construct a targeted and working housing market model in a limited amount of time, at least in comparison with other modeling approaches.

Notwithstanding a significant wish list for a major revision, Houdini 1.0 is a functional model with a first practical application in the long term spatial scenario project finished. Houdini has provided the PBL staff with great learning opportunities about the presence of system dynamics in other approaches, on modeling institutional features of the housing market, on the type of criticism to be expected for this type of modeling. Later on, Houdini proved a suitable preliminary model for other projects. As to the learning aspect of system dynamics modeling, Houdini demonstrated more than sufficient performance.



# VI MIDDLE INCOMES<sup>30</sup>

## VI.1 INTRODUCTION

Traditionally, Dutch housing associations have provided rental housing for a large share of the population and account for 40% of the total housing stock. Recently, however, due to European competition regulations and lobby pressures from commercial real estate investors, the so-called state support regulation (SSR) stipulates that 90% of the allocated social rental dwellings should be assigned to lower income groups. The SSR further restricted the position of middle income groups on the housing market, with their housing market opportunities already diminished by inflated prices for owner occupied housing and an underdeveloped private rental sector. Introduction of the SSR also coincided with the impact of the credit crisis on the Dutch housing market.

The timing of the introduction of the SSR complicates proper impact analysis of the SSR. Empirical data would always encompass both effects. The PBL Netherlands Environmental Assessment Agency therefore resorted to building a system dynamics simulation for assessing the isolated impact of the SSR on housing market success ratios for different income groups.

## VI.2 CONTEXT OF THE SYSTEM DYNAMICS INTERVENTION

The modeling project reported here addressed the impact of the SSR on the position of middle income groups within the wider framework of the entire housing market. The model itself is embedded in a mixed methodology research project with additional policy and housing literature study, regular data analysis and interview with stakeholders.

The project was started when the Housing Section of the Ministry of the Interior requested PBL Netherlands Environmental Assessment Agency to carry out an impact analysis of the SSR. A project group consisting of policy officials, researchers, academics, policy advisors, PBL management and research staff provided guidance to the project. The research staff of PBL carried out the research activities with regular consultations from one academic. The project ran from October 2011 to October 2012 provided input to other PBL studies on the effect of demographic change on the housing and land use (De Groot et al., 2013) and parented several articles in professional magazines (Eskinasi & De Groot, 2013; Van Middelkoop, De Groot, Verwest, & Eskinasi, 2013). The final report (Eskinasi et al., 2012) was discussed in Parliament.

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30 This chapter is based on two policy reports of PBL the Netherlands Environmental Assessment Agency and two papers presented at the ENHR 25th International conference, Tarragona, Spain, i.e: De Groot, C., & Eskinasi, M. (2013). *Increased homeownership in an ageing society: the traces of elderly homeowners in declining and tensed housing markets in the Netherlands*. Eskinasi, M., De Groot, C., Van Middelkoop, M., Verwest, F., & Conijn, J. B. S. (2013). *Simulating success ratios for middle income households with system dynamics*.

### History of the problem context

Housing associations play an important role in Dutch housing, owning approximately 2,25 million dwellings, or 31% of the total housing stock and 70% of all rental dwellings (CBS, 2013). From the 1950's, initially private housing associations had become important instruments in state housing policies. Social housing in the Netherlands traditionally had a mass provision character, rather than being limited to the most disadvantaged groups in society. The 1990's constitute a watershed in the traditional approach. Future subsidies and outstanding loans were canceled out in 1995 ("Bruterling"), leaving housing associations on more distance from the state and at full financial risk for managing the large social rental housing stock. Some minor state support instruments continued to exist: through a state guarantee structure (WSW) housing associations had access to cheap finance from a bank for government agencies (BNG), the state supervising organization CFV may allocate direct financial support for distressed projects or entire housing associations and furthermore, some municipalities had continued to provide housing associations with cheap land for social housing construction (Eskinasi et al., 2012, p. 29). Social rents are still subject to state regulation, but housing associations also play a role in subsidizing rental housing. The Bruterling coincided with an unprecedented housing boom throughout the 1990, when house prices doubled in 10 years. The equity of housing associations grew significantly, but rent levels only increased about 18%. State regulation did not allow high rent increases, but housing associations also contributed by keeping rents structurally below the state given maximum. The equity of housing associations is in mortmain, so they lack incentives to strive for a market yield on equity invested. The resulting yield compression largely eliminated competition in the rental sector. In this situation of near-monopoly, waiting lists continued to exist, as especially new middle income households could not afford owner occupied housing and the favorable rents discouraged higher income tenants to move out of social rental housing.

Commercial investors in rental housing, mostly backed by pension fund capital, protested against the apparent lack of level playing field and started lobbying in the national government and the European Union. After years of lobbying and debate, the European Commission approved the so-called State Support Regulation proposed by the Dutch government in December 2009. This regulation defined social housing (i.e. dwellings owned by housing associations with monthly rents below €647 as a service of general economic interest (SGEI) and its accompanying state support arrangements (mentioned above). The target group of state supported social rental housing was limited to households with annual incomes below € 33.600 (2011 price level), about 42% of the population<sup>31</sup>. It was stipulated that 90% of all available social dwellings must be allocated to households with incomes below the said €33.600. No formal restrictions apply for the allocation of the remaining 10%, this is left to the competence of housing associations.

The approaching introduction of the SSR spurred a hot debate, particularly on the effects for the lower middle income groups (€ 33.600 to roughly € 43.000; 13% of all households). These groups were said to face severe affordability and mortgage availability problems for entry to the owner occupied housing sector, the former caused by the steep price increases in the 1990's and the latter by the response of the banking sector to

31 Of which, for many different reasons, a certain share already lives in owner occupied or commercial rental housing.



the 2008 credit crisis. It was feared that the SSR would not only restrict their entry to the social housing sector, but also discourage propensity to move house and so depress housing market dynamics even more, on top of the unfolding effects of the credit crisis (Atrivé & OpMaat, 2011; Kromhout, Smeulders, & Scheele-Goedhart, 2010; RLI, 2011). Many parties therefore advocated to extend the entry to the social housing market also to middle income groups.

The narrative of most reports, however, was to depart *ex ante* from the difficulties of middle income groups, illustrate this departure point with descriptive analysis and then to call for changes or even abolition of the SSR. But no fundamental impact analysis was made, comparing housing market effects *ceteris paribus* of scenarios with and without the SSR. Several factors would highly complicate such an impact analysis. First, the SSR was introduced only recently so only very limited data would be available. Second, its introduction coincided with the most strenuous effects of the 2008 credit crisis on the Dutch housing market, so that available data, if any, would contain influences of both factors. Finally, the latest comprehensive survey data set on housing preferences dated from 2008 (predating the crisis), with a new survey only available in April 2013.

The PBL research staff therefore proposed to develop a simulation model using data of the 2008 survey. This simulation would allow for proper impact analysis, but not for prognosis of the actual course of events or even deep and detailed insight into the dynamics of the period 2010-2015. This was consistently communicated to all parties involved throughout the entire project in order to properly manage expectations about the model validity.

Furthermore, judging from previous housing studies, the PBL research staff expected large regional variance in the effects of the SSR, with the public debate mostly voicing common perceptions of the housing market in congested Randstad regions. As one housing market researcher was also a seasoned system dynamics modeler, it was decided to use system dynamics for the modeling parts of the research project.

### VI.3 THE SYSTEM DYNAMICS MODELING PROJECT

#### **Pre-project activities**

Pre-project activities consisted of regular consultations with the Housing Section of the Ministry of the Interior. In these consultations, it was discussed and agreed that PBL would make an impact analysis of the SSR. The management team of PBL discussed and approved the project proposal. A policy official of the Ministry and the responsible manager of PBL acted as gatekeepers for staffing the project group and the research team.

#### **Research activities**

The research project followed a mixed methodology approach. A discourse analysis of the history of the SSR revealed several blind spots in the public debate and identified implicit hypotheses on the effect of the SSR and mitigating policy measures for simulation. Review of academic literature on housing preferences, housing economics provided theoretical cornerstones for the simulation model. Regional interviews and document

analysis indicated the large regional variation in effects and formed a reality check for simulation results. Statistical data analysis enriched the regional interviews and provided input for the simulation model.

The research team met weekly to discuss project management and to share preliminary insights and conclusions. The modeler monthly consulted one of the academics in the project group to discuss modeling aspects and to review simulation results for validation. The total time expenditure for PBL staff amounted to ca. 2.000 working hours, of which approximately 500 were invested in the construction of the simulation model.

In order to assess the magnitude of the regional variation, the research team selected six widely different regions. The region around Amsterdam is the most tensed housing market in the country, rural but stable Friesland and declining Zeeuws-Vlaanderen are the other opposites. Most interesting were three intermediary regions: Eindhoven, Rotterdam and Arnhem-Nijmegen, as we had no strong intuitions on the effect of the SSR in these regions.

#### VI.4 THE RESULTING MODEL

The simulation model is solidly grounded in theories on housing market economics household behavior in relation to residential mobility. The simulation itself was built in Powersim Studio 9 SR1. Input data were generated in SPSS from the housing survey. Interfacing with the simulation model was done in Microsoft Excel.

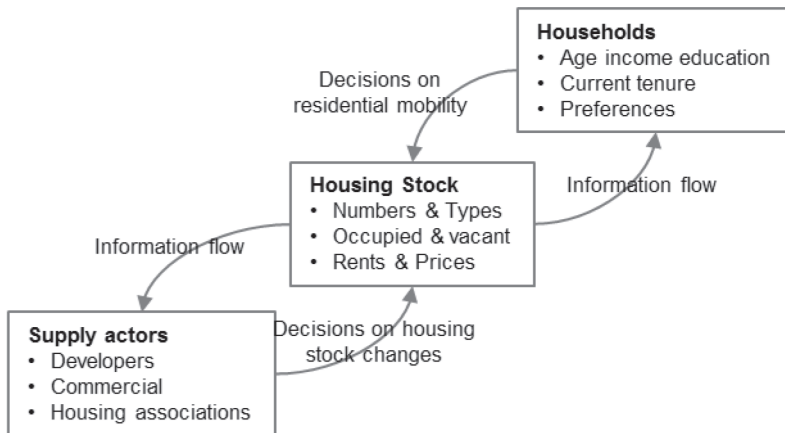
##### **Overall model structure**

The overall feedback structure of the model (see figure 29) connects to the worldview of system dynamics. Decisions of actors influence the housing stock or market. Actors, however, base their decisions on information about prices, rents, availability. Households base their decision to move not only on socio-economic and demographic variables, but also on market information about prices and availability. Developers base decisions to buy land, and start construction on price trends, local circumstances etcetera. Housing associations constantly balance financial and social goals through rent level selling, sale of housing and new construction on basis of needs perceived, i.e. market information. The model gains its dynamic complexity from this constant feedback.

The actual simulation model also draws conceptually from the four quadrant model of Di Pasquale and Wheaton (1996), which connects three partial markets (housing services market, housing property market and construction market) into a balancing or equilibrium-seeking feedback loop. It also inherited several modifications of the 4QM from housing market model Houdini (Eskinasi, 2011b) (see also chapter V).

On the demand side, households exert demand both on basis of semi-static household properties, but also of market information. On the supply side, two main types of actors exist in the model. Developers strive to maximize profits upon sale of newly constructed housing. Landlords (housing associations and commercial investors) let dwellings, order new construction and sometimes demolition, sell existing rental housing and set rent levels. The commercial rental sector is open to external capital, so these actors are driven by return on investment. The Dutch social rental sector is a closed system. Housing

associations strive to fulfil social objectives within the bounds of financial stability. In the model, their social objectives consist of construction, rent setting and sale of dwellings. The interest coverage ratio (ICR) is the main financial variable. A low ICR signifies financial problems, stimulates rent increases and sale and decreases construction. Higher ICR's exert converse influences.



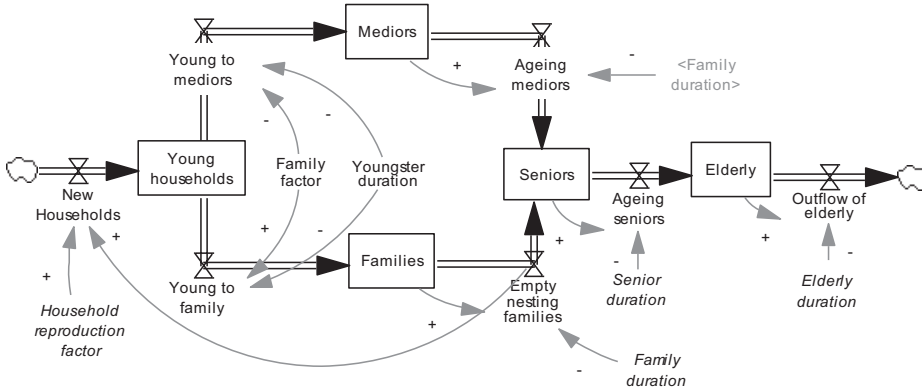
**Figure 29 Middle incomes: overall feedback structure**

### Household sector

The household sector of the model is based on the dynamic life-course approach (Clark, 2012) where both macro and micro factors influence the housing decisions (Van Ham, 2012). In system dynamics terms, the main structure is an ageing chain, where households evolve through five stages or stock variables: young households in the formation phase (up to 30 years), the family phase (30-54 years) and a parallel category for households without children, the senior phase (55-74) and the elderly phase (75+). Figure 30 shows the main structure of this model sector. Intermediary flow rates are based on duration of the distinct phases. Family households moving to the senior or empty-nest phase produce new young households, thus creating a feedback loop. This model sector was calibrated to fit the 2011 national and regional demographic housing forecast PEARL (De Jong et al., 2005).

The households are categorized into two dimensions: education level and current tenure. We discern three education levels and assume it constant from household formation onwards. Education level is relevant as a strong predictor for the income career of a household. Households with higher education have larger probability of attaining a high income mid- and end-career and when pensioned. Groups with lower education tend to have lower incomes throughout their full life cycle. This is relevant as the targeted middle income group is very heterogeneous as to age, education level and income dynamics. Households are labeled by current tenure or housing type. The model discerns four types of rental housing, three types of owner occupied (based on rent and price levels

respectively) and a remaining tenure category for households not having a home yet. The disaggregation by current tenure form is required for simulating residential mobility, and filtering and limiting entry of moving households to certain tenure types allows to simulate effects of the SSR.



**Figure 30 Middle incomes: simplified household sector**

By means of probability tables, the simulated household evolution (by household stage and education level) yields the development of households by stage, education and income.

### Demand and matching sector

The purpose of this model sector is to translate household dynamics to demand in the housing market by means of using mobility and housing preferences and by applying affordability and institutional restrictions.

In this sector, a central variable is the stock of actively house hunting households. The household type and tenure specific average occupancy time (based on the 2009 housing survey) determines the inflow of households into this stock. The stock has two outflows for successful and unsuccessful house hunters. Unsuccessful households exit after a constant disappointment time. Successful house hunters exit upon finding a new house matching their preferences, taking into account financial and institutional restrictions. The structure here is similar to the Haaglanden model (Eskinasi et al., 2009). Dividing the number of successful house hunters by the stock of searching house hunters yields the average search time, the central indicator for chances of different income groups on the housing market. Figure 31 illustrates the overall structure of this model segment.

The mentioned institutional and financial restrictions include an array of factors like income development, budget shares for housing, maximal loan to income ratios, age limits for mortgages, barriers in allocation systems for social rental housing and the relative price-quality levels of current and available houses, influencing substitution<sup>32</sup>

<sup>32</sup> Assuming a substitution elasticity of 1.

from the given housing preference pattern in the 2009 housing survey. For determining housing budgets, the model takes into account all components of the user cost approach (Conijn, 1995; Donders et al., 2010; Renes et al., 2006), including the effects of mortgage debt on the income. Moreover, households moving from one house to another and elderly households flowing out of the housing market vacate houses which are added to the available housing stock.

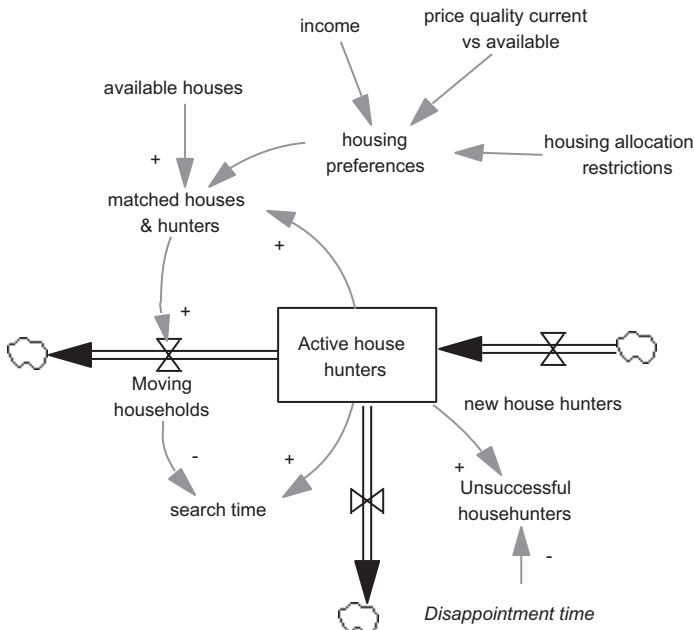


Figure 31 Middle incomes: simplified demand and supply matching

### Housing stock sector

The housing stock sector registers the changes to the housing stock. Its main structure is a short production chain with houses under construction, vacant and occupied houses and it is disaggregated by tenure type and ownership: both housing associations and commercial investors can own houses in the rental tenure forms. Changes to the housing stock reflect sale of houses, transfers between owners and rental tenure types, construction and demolition. The supply side actors control these flows.

Houses move between occupied and vacant state on basis of the mutation and absorption rates<sup>33</sup>, both of which are linked to the house moves of households in the demand and matching sector.

The model registers the dynamics of house prices and rents (or user costs for owner occupied housing) by means of so-called co-flow structures (Sterman, 2000). In accordance with Di Pasquale and Wheaton (1996), the absorption rate of the owner occupied

<sup>33</sup> The mutation rate controls transfer from occupied to vacant, the absorption rate the transfer from vacant to occupied.



is the gross yield on rental housing, defined as the ratio of rents to prices. Their rent policy focuses a maximizing rents within legal bounds. They hold fixed preferences for new construction and sale of rental houses, but react to the actual gross yield and the absorption rate. Unlike housing associations, commercial investors are open to the capital market and can attract external equity. This allows them to react to gross yield rather than to solvency or interest coverage.

The equity of housing association is earmarked for social rental housing. They can attract external finance, but must always balance their net cash flows with interest payments. The interest coverage ratio is the main financial criteria for decision making. Safe interest coverage ratio's entice housing association to set lower rent increases, to sell less and to build more new houses. A simplified diagram of housing associations' finance is presented in figure 32.

It should be noted that all activities of these actors influence the overall balance on the housing market and indirectly the actions of households (see figure 29).

### **Auxiliary sector**

Next to the sectors described above, the model contains many auxiliary variables for connecting to starting data and for making different aggregations for graphing purposes.

## **VI.5 VALIDATION**

As the model is relatively complex, several approaches are needed to validate its working and outcomes. Forrester and Senge (1980), Coyle and Exelby (1999), Vennix (1996) and many other authors cover techniques for validating system dynamics models. First, the model is based in common real estate and housing literature, so that structure validation was made more or less implicitly during model construction.

On the technical side, issues like unit consistency are safeguarded in the software. Model structures and outcomes were rigorously scrutinized by the academic members of the project group. Their statistics of inequality (Sterman, 1984) were also calculated for several variables<sup>35</sup>.

But most important, the regional interviews and data analysis pointed in the same direction as the simulation results. In other words, this contributed to behavior testing of the model. This factor significantly solidified the conclusions drawn.

Furthermore, all project team members, involved academics and managers of PBL consistently communicated the scope of the model: its purpose is to make an impact analysis of the SSR, three mitigating policies and regionally different housing market and population variables. It was strongly emphasized that the model outcomes could not

35 The fit of simulation outcomes to empirical data and existing forecast through the Theil statistics of inequality (Sterman, 1984) was done for nine higher-level model variables, i.e. the total housing stock, the total populations in number of households, four household subgroups available in the demographic forecasts, total new construction, new construction and sale by housing associations. Table a1 presents the Theil statistics for these variables. Note that variables with high errors (RMPSE) have only few data points  $n$ . Not much value was attributed to the Theil statistics for several reasons. First of all, other validation techniques had already convinced the project team. Second, there are sufficient data points only for comparing the demographic dynamics with other forecasts and finally, the model was consistently communicated not to forecast events, so that a historical fit would seem relatively useless.

be interpreted as a detailed prognosis of the actual course of events with the financial crisis unfolding. This disclaimer was well-received by the policy officials and no discussions on the scope or validity occurred yet. This indicates that the model was accepted as valid for its specific purpose, namely an impact analysis of the measures mentioned above.

The cross-validation of model output, interviews and statistical analysis and the proper framing of the model purpose strongly increased confidence in the model.

## VI.6 BASE RUN AND POLICY ALTERNATIVES

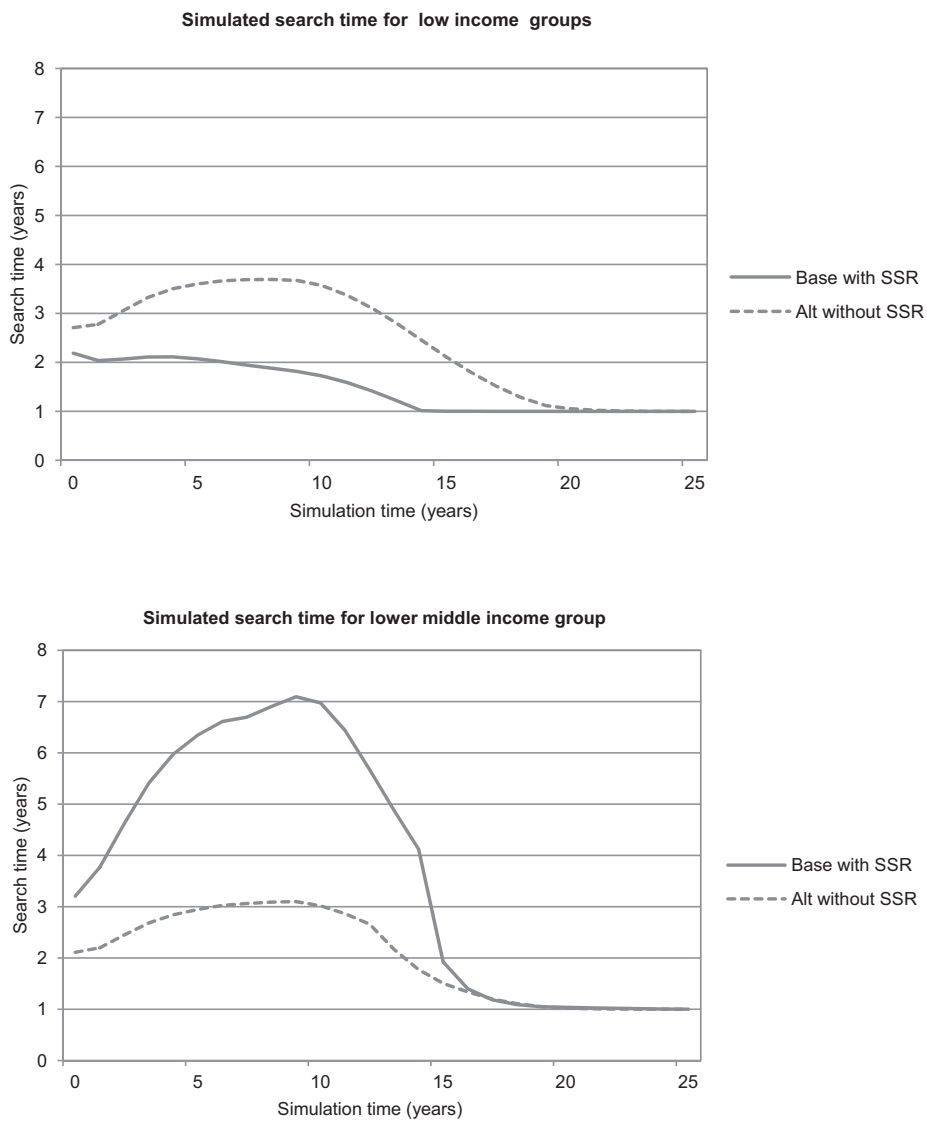
After model testing and validation, we simulated the baseline (with SSR) and alternative (without SSR) policies to see the effects of the SSR on the average search time for lower, middle and higher income groups. But to our initial surprise, average search times tended to decrease strikingly in both runs. Upon further scrutiny, we concluded that the outflow of elderly households must be the main cause: the postwar generation is strong in numbers and has a significant higher level of home ownership than prewar generations. Within 15 to 20 years, this outflowing postwar generation will vacate large numbers of owner occupied single-family houses, resulting in continuous downward pressure on house prices to the benefit of middle and even lower income groups (De Groot & Eskinasi, 2013; De Groot et al., 2013). These findings are similar to e.g. Mankiw and Weil (1988) and Myers and Ryu (2008).

**Table A** Theil inequality statistics for nine main variables

	Households	Housing stock	Total construction	Construction by HA's	Sale by HA's
n	24	24	4	3	3
r <sup>2</sup> =	0,9970	0,9960	0,8513	-0,1075	-1,0000
MSE=	2,63E+09	3,64E+09	8,46E+07	1,13E+06	2,25E+06
RMSPE=	0,63%	0,77%	13,23%	0,19%	10,23%
U <sub>m</sub> =	0,65	0,56	0,02	0,02	0,07
U <sub>s</sub> =	0,13	0,23	0,82	0,23	0,05
U <sub>c</sub> =	0,22	0,21	0,16	0,75	0,87

	Households	Young households	Families & mediors	Seniors	Elderly
n	24	24	24	24	24
r <sup>2</sup> =	0,9970	-0,6196	0,9705	0,9834	0,9966
MSE=	2,63E+09	1,49E+09	1,48E+10	2,51E+10	2,35E+09
RMSPE=	0,63%	3,66%	3,76%	6,3%	5,20%
U <sub>m</sub> =	0,65	0,24	0,89	0,93	0,10
U <sub>s</sub> =	0,13	0,04	0,07	0,01	0,77
U <sub>c</sub> =	0,22	0,72	0,04	0,06	0,12





**Figure 33 Middle incomes: main simulation results for (a) lower incomes and (b) lower middle incomes**

Simulation results on the short term effect of the SSR confirmed initial fears (see figure 33). Especially house hunters from the lower middle income groups just above the € 33.600 income limit suffered most from the SSR. Income groups between € 38.000 and € 43.00 were also impacted. Higher income groups witnessed smaller changes in search times due to indirect crowding effects in the owner occupied sector. Lower income house hunters, on the other hand, were found to profit significantly from the SSR<sup>36</sup>. Even though in hindsight, this is a logical effect, it had not been signaled let alone emphasized in the public debate, which had been biased towards the effects for middle income groups. Figure 33 presents the development of average search times for the two main focus groups under the baseline and alternative scenario's.

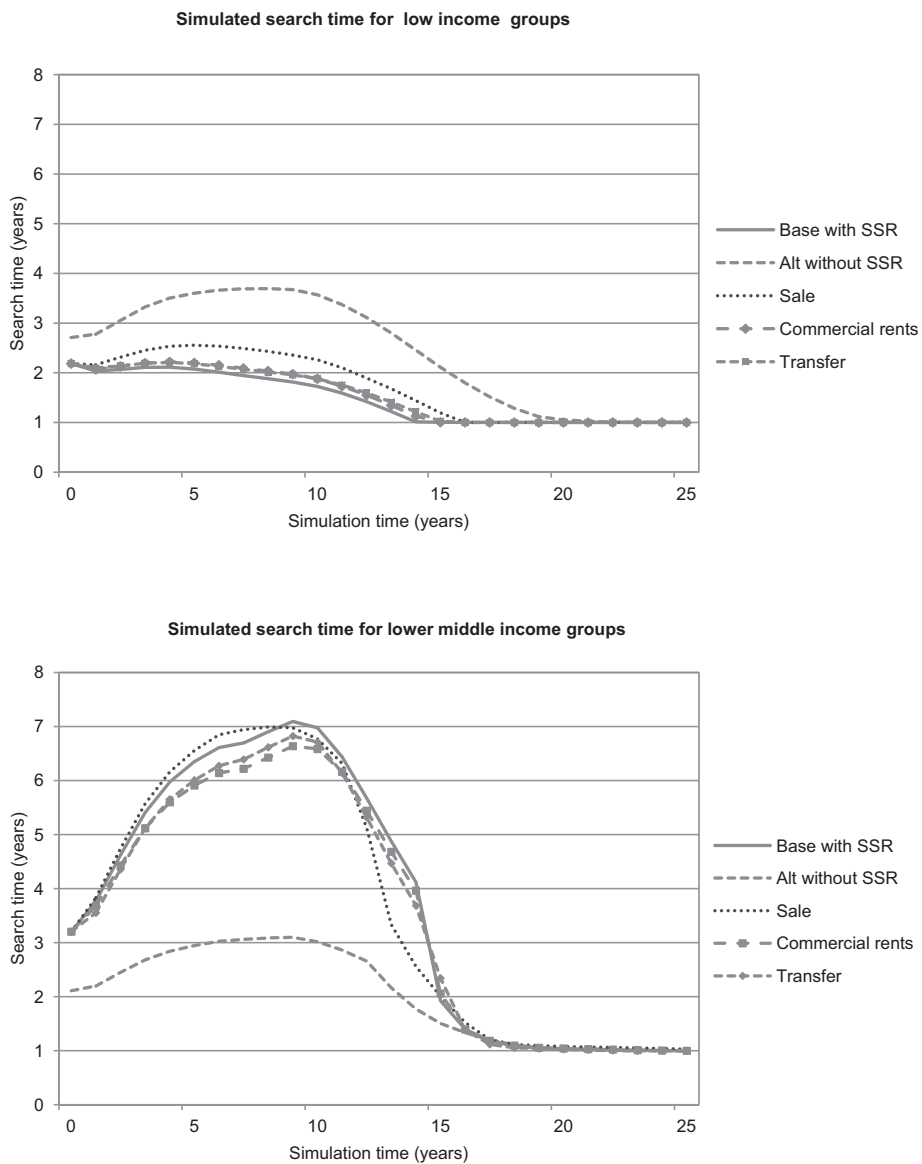
### Mitigating policies

Furthermore, three mitigating policies were simulated, based on existing policy lines and the public debate on the SSR. Some parties advocated selling former social rental houses or increasing the rents of suitable houses in order to transfer them to the commercial rental sector<sup>37</sup>. These parties argued that middle income groups should not have subsidized housing and that these measures would increase the availability of houses for them. The alleged effects, however, did not materialize in the simulation (see figure 34). In the first five to ten simulation years, owner occupied and commercial rental housing are financially still out of reach for house hunting middle income families. Income increases in the longer run would improve affordability, but then the effects of the measures would not differ significantly from the overall relaxation of the housing market due to the outflow of elderly households. Furthermore, the measures have negative impact on the lower income groups for obvious reasons: suitable vacant houses would be moved away from them.

A third mitigating policy consists of transferring some of the social rental houses into a portfolio exempt of the SSR, for which housing associations do not have state support. As opposed to transferring them to the commercial segment, it is not necessary neither to increase rents into the commercial segment, nor to wait until vacancy. The simulation indicates modest positive effects for middle incomes and modest negative effects for lower income groups, as this measure allows for competition between these group in a part of the social housing market.

36 The graphs suggest that the negative effect for lower middle incomes is much larger than the positive effect for low income groups. This applies on a per household basis. There are, however, many more house hunting low incomes than house hunting middle incomes. Measuring in total search years over the entire market, the simulation with SSR is slightly more favorable.

37 Houses with monthly rents over € 634,- (2011 price level) are considered commercial rental housing.



**Figure 34 Middle incomes: effect of mitigating policies for (a) low and (b) lower middle income groups**

### Regional simulations

There is, however, significant regional variations in housing markets. In order to simulate regional variance of the impact of the SSR, we took a selective sample of six regions, ranging from the highly tensed housing market around Amsterdam, through the urbanized regions Arnhem-Nijmegen, Eindhoven, Rotterdam, to rural but stable Friesland and declining Zeeuws-Vlaanderen. Intuitively, we expected the SSR to increase tension in Amsterdam and probably also in Eindhoven, which was labeled as a region of scarcity in one change of rent regulation legislation. For Friesland and Zeeuws-Vlaanderen, we expected virtually no complications as houses are much cheaper and people are generally oriented more towards home ownership in these regions. We had no strong intuitions for Arnhem-Nijmegen (not a scarcity area) and Rotterdam (low house prices, ageing economic structure and selective outmigration). We double checked our simulation results with interviews and analysis of data and policy documents for these regions.

Amsterdam came out as the most tensed region, as expected. Immigration of groups with higher education plays a significant role: these groups enter as low incomes, make a career and pass through the middle income segment upward. Even though the SSR certainly adds to the tension, its impact is relatively small in regards to the overall pressure. The effect of ageing was much smaller in Amsterdam, but the mitigating policies worked relatively well because of the higher upward mobility of the well educated population.

In all other urbanized regions, intraregional differences in pressures dominated the outcome of the interviews and literature study. In most cases, no complications for middle incomes were found in the central cities, but pressure and effects of the SSR concentrated in the suburbs, where the housing stock is generally more in line with the preferences of middle income groups. Opposed to our intuition, Arnhem-Nijmegen demonstrated the second most tensed housing market with a relatively large sensitivity to the SSR. The mitigating policies showed mixed results: In Arnhem-Nijmegen, sale had better performance as house prices are somewhat lower. In Eindhoven, the effect of sale was smaller, later and more concurrent with the demographic effect. The simulation for Rotterdam showed a faster relaxation of the housing market than generally expected.

The results for Friesland and Zeeuws-Vlaanderen matched our expectations: very low pressure on the housing markets, no problems for middle incomes whatsoever and consequently, no additional complications through the SSR.

## VI.7 FOLLOW-UP ACTIVITIES

The final report was published in October 2012 and sent to Parliament. On several occasions, MPs questioned the Minister of Housing about the effects of the SSR on basis of the report. Some of the most striking findings were published in professional magazines: the expected future impact on the housing market when the baby boom generation will start leaving the market around 2020 (Eskinasi & De Groot, 2013) and the fact that real complications of the SSR are most probably confined to the most tensed housing markets in the Northern Randstad only (Van Middelkoop et al., 2013). Furthermore, the analysis of baby boom outflow was also published in De Groot et al. (2013) and on basis of the dynamic theory, more detailed data analysis was published in De Groot and

Eskinasi (2013). Findings were also presented on several national conferences. Near the end of 2013, the Ministry requested additional simulations based on motions voted for in Parliament.

## VI.8 EVALUATION OF THE PROJECT

### **Opinion of the project group and research team**

The project group accepted the model outcomes as valid and relevant to the discussions on the SSR, even though at that time, other housing market issues were dominating the public opinion. On basis of the study, the Ministry of the Interior felt confident to oppose changes to the SSR proposed by some MPs but encouraged municipalities and housing associations to use the possibility of the third mitigating policy<sup>38</sup>.

The academic project group member most closely involved in model construction and validation changed his perception of system dynamics from initial skepticism towards a sufficiently positive attitude to request system dynamics modeling assistance for a follow-up project (see also chapter VII).

The management of PBL found the conclusions on the regionally diverging impact of the outflow of elderly relevant for policy and further research. The dynamic theory of outflow of elderly was elaborated further in De Groot and Eskinasi (2013) and De Groot et al. (2013).

Members of the research team valued the close-knit cooperation between the modeling and the other parts of the research project. It was noted that at project inception more emphasis was on the modeling, but when results started to emerge, the relative weight of the regional case studies increased. They felt confident that this PBL research project was more comprehensive than all previous studies on the SSR. Even though they were not very deeply involved in the model itself, they perceived it as reliable because it produces an internally consistent story and because its outcomes matched findings of the other parts of the research projects.

### **Opinion of the modeling team**

In the opinion of the modeling team, in casu the system dynamics modeler, the middle income model increased the current level of modeling skill and experiences. The model incorporates experiences and building blocks from previous modeling projects but also includes several extensions. It is consistent with common housing theories, provide answers to a complicated question in a setting where other approaches might not have succeeded due to data limitations. The model completely avoids driving external time series.

The modeler suggests that the current model size is close to the limits a single modeler can reasonably handle in the given work setting. The model does take a significant set of startup values and has a certain amount of disaggregation i.e. in the housing stock,

<sup>38</sup> Even if it should be admitted that the Ministry was reluctant a priori to change the SSR, though mostly because of the burdening procedures with the EU and not because of any assessment of impact on the housing market.

educational levels of households. The array size of eight at most, however, did not escalate into the problematic dynamics experienced with ITS (Eskinasi & Fokkema, 2006). In the light of Forrester (2007b) standards, the model clearly demonstrates why expected stagnation of residential mobility does not occur and why neither the proposed changes to the SSR nor the mitigating policies have high leverage on market dynamics. Moreover, the model outcomes suggest that factors that do matter (i.e. the nascent rising outflow of elderly ) are not yet on the retina of policy makers and that current policies miss a crucial point. On the other hand, no high leverage policies were found that mitigate detrimental effects of the outflow. Overall and taking into account that the elderly outflow finding still reverberates among policy makers, the modeler considers middle incomes to be a relatively successful system dynamics project.

## VI.9 CONCLUSIONS

The simulation project on the middle incomes has demonstrated that nationwide measures can have largely different effects in different regional housing markets. On the one hand, it confirmed that the SSR can be problematic for middle incomes in the short run. On the other hand, the project has helped to put the effects into perspective. First, the positive effect for lower incomes had been underemphasized in the public debate. Second, the outflow of the baby boom generation becomes very dominant in the long run and overpowers the impact of the SSR. Even though the outflow of baby boomers is present in international literature, the current policy debate in the Netherlands is focused on adapting existing and building suitable houses for elderly people, but disregards the outflow effect as yet. Third, the simulation unveiled the large regional variance in the impact of the SSR and the mitigating policies.

The use of the system dynamics methodology enabled the research team to develop a relatively complex model for impact analysis of a particular measure in a rather short time frame. Furthermore, it allowed to isolate the impact of the SSR from external effects like the credit crisis, but nevertheless to put the SSR into a comprehensive picture of all interactions on the housing market. Cross-validation of conclusions and proper communication of the scope and limitation of the model contributed to successful landing of the conclusions at the Ministry of the Interior. Building the simulation required significant system dynamics skill and experience, but is still worth the effort.

# VII MORTGAGE MODEL<sup>39</sup>

## VII.1 INTRODUCTION

In addition to the strong role of housing associations in the rental sector, the Dutch state has been supporting home owners for decades. Fiscal facilities allow deducting mortgage interest from the taxable household income base and to exempt home related equity from equity taxes, both equity invested in the home as special savings schemes for mortgage debt service. The 1990's witnessed decreasing mortgage interest rates and abundant capital for mortgage financing. Housing prices boomed, new mortgage schemes maximized interest deductions and the total mortgage debt grew from ca. € 295 billion in 2000 to over € 650 billion in 2010. The financial crisis in 2008, however, necessitated banks and the government to finally face and manage the risk of this mountain of mortgage debt. The Amsterdam School of Real Estate developed a system dynamics model of the mortgage growth in cooperation with a system dynamics modeler of PBL Netherlands Environmental Assessment Agency. The model demonstrates that it is virtually impossible to decrease the mortgage debt significantly over the next ten to fifteen years.

## VII.2 CONTEXT OF THE SYSTEM DYNAMICS INTERVENTION

The system dynamics project was carried out in 2012 and 2013, when the financial crisis had necessitated the Dutch government to introduce austerity policies and to restrict the widely criticized mortgage tax reduction. From January 1<sup>st</sup>, 2013, households taking out a new mortgage are entitled to fiscal support only when the mortgage is annuity based. The system dynamics project set out to explore the possibilities of reducing the total mortgage debt by means of further policy interventions.

### **History of the problem context**

Historically, the Netherlands has a long tradition of allowing mortgage interest payments to be deducted from household taxable incomes. It is, however, only since the 1990's that this fiscal mortgage support has become a determinant factor in housing market dynamics.

The 1990's witnessed a shift in state housing policy. In order to reduce financial pressure on the state budget, financial arrangements with housing associations were drastically reduced (see also IV.2). Furthermore, agreements between the state and lower authorities on new housing construction increasingly emphasized owner occupied construction. Household and income growth had stimulated demand and the main policy paradigm was to build better and more expensive housing in order to stimulate vacancy chains. More affluent households should move into owner occupation and thus vacate the abun-

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<sup>39</sup> This chapter is based on Schilder, F., Conijn, J. B. S., & Eskinasi, M. (2012). *De Nederlandse hypotheekschuld in 2025: de (on)mogelijkheid om de stijging van de hypotheekschuld te beperken*. Amsterdam: Amsterdam School of Real Estate.

dant social rental housing for less affluent groups and young households. Between 1995 and 2012, the owner occupied stock grew from around 3 million houses to nearly 4.4 million houses, whereas the total rental stock decreases from 3.2 million to slightly under 3 million.

Global economic growth led to decreasing mortgage interest rates. Housing prices boomed and banks developed many new mortgage saving schemes in order to maximize the fiscal support and extend interest payments. In most cases, households took out interest-only loans with a linked savings schemes, based on cash savings and/or stock investments. Interest payments could then be deducted for the full amount and duration of the loan, and the tax-exempt savings scheme would amortize the loan fully and at once at the end. The financial engineering minimized the monthly costs of mortgages for households or, in other words, maximized mortgage loan volumes and interest deductions. This supported further price growth (Staten-Generaal, 2012), so it is reasonable to assume the presence of a financial accelerator in house prices (see also Anundsen & Jansen, 2013).

Both price and volume growth led to a rapid increase of the total amount of mortgage debt from approximately € 330 billion in 2001 to nearly €630 billion in 2011 (DNB, 2012), provoking concerns from the National Bank, international organizations and the national government about stability of the national economy and the government budget. After years of debate on reforms and incremental measures, the government decided in 2012 to restrict fiscal support for new mortgages to annuity based schemes only.

Meanwhile, the housing market started to suffer the impacts of the Great Financial Crisis of 2008 onwards: construction and house sales plummeted and prices decreased by about 20%. With decreasing housing prices, more and more households faced negative equity (Van Middelkoop, 2010), especially younger households who bought homes at the price peak financed with the more risky types of loans, in those regions struck most by prices decreases from 2008 onwards. There is an unequal distribution of LTV ratios between age groups: older home owners generally bought for still low prices, have more and initially low self-amortizing mortgages on low and have been amortizing for a longer period, saw increasing house prices. Newer home owners bought for much higher prices, have initially high mortgages with increasing interest-only components, did not yet built up much savings or investments and face decreasing house prices.

### VII.3 THE SYSTEM DYNAMICS MODELING PROJECT

#### **Pre-project activities**

Before the start of the mortgage model project, several authors had made empirical analyses of the problem of negative home equity. Schilder and Conijn (2012b) estimate that approximately half a million families had negative home equity in 2011. They also found that negative equity is concentrated with younger age groups and more recent home purchases. Van Middelkoop (2010) adds a regional perspective and demonstrates also significant geographical concentration around new town Almere and in the region near Rotterdam. The absence of reliable data on the amount of equity in savings schemes, however, complicated analysis. Estimates widely varied from € 30 billion to € 220 billion.



Discussions between researchers and officials of the Dutch National Bank on the underlying assumptions led to the start of the mortgage modeling project. The purpose was to simulate the future trends of the total mortgage volume and to test the impact of different factors and policy measures.

### **The modeling project**

A small team of housing researchers carried out the mortgage modeling project: the authors of one of the estimates of the total equity in savings schemes (Schilder and Conijn (2012b)) and a system dynamics modeler in their network. A preliminary model was built, tested and fine-tuned in a relatively short period. After model validation and calibration, several scenarios were reported in Schilder et al. (2012) and Schilder and Conijn (2012a).

## **VII.4 THE RESULTING MODEL**

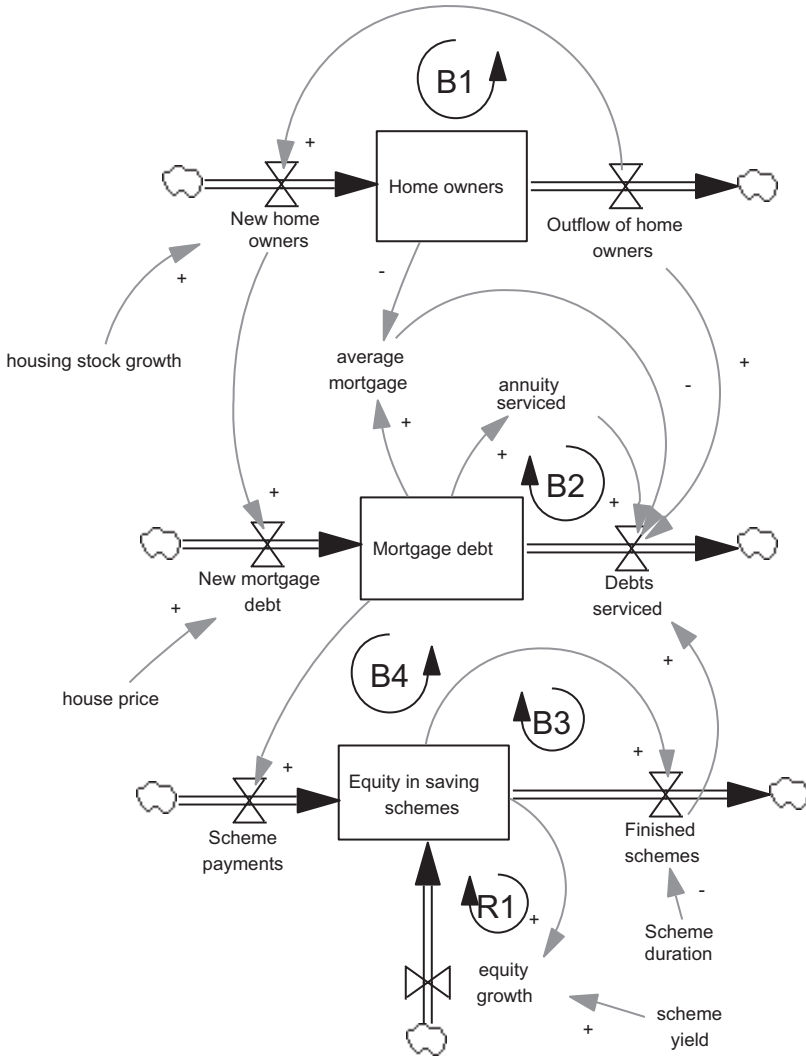
### **Overall structure**

The overall model structure consists of three main stock variables: home owners, total outstanding mortgage debt and the total amount of equity in the said saving schemes. Development of the owner occupied stock and of house prices is modeled in stock variables as well, but these are governed by exogenous time series and are not part of the feedback structure. The model is basically an ageing chain of home owners with mortgage debt and equity in savings schemes as its co-flows.

Figure 35 clarifies that the model has no complicated feedback structure. Exogenous housing stock growth drives the ageing chain of home owners, the inflows of mortgage debt depends on inflow of new home owners and house prices. Saving schemes dynamics are closely linked to mortgage debt and have a fixed duration. In fact, the only reinforcing loop in the model is the savings scheme equity growth loop R1 with the savings scheme interest or yield as a parameter. The overall dynamics of the model are dominated by the inertia and the history of the stocks.

### **Home owners according to age groups**

The full model adds more detail to the simplified structure in figure 35. First of all, the stock of home owners is disaggregated into five-year age groups. Inflow and outflow rates are age specific. Home owners move through the ageing chain on basis of simple first order material delays. Furthermore, residential dynamics are added for home owners moving from one house to another within the owner occupied sector, again based on age specific move rates. When moving to better and larger houses, home owners take out additional mortgages. The co-flows for mortgage debt and saving scheme equity are also disaggregated by age groups.



**Figure 35 Mortgages: simplified model structure**

**Mortgage debt by age group and type**

The model discerns three main types of mortgages: self-amortizing or annuity mortgages, interest-only mortgages with a linked saving scheme and pure interest-only mortgages without saving schemes. For type 1, a part of the mortgage payments is used to amortize during the mortgage duration. The outstanding mortgage debt decreases gradually and so do interest and the entitlement to fiscal support. Type 2 consists of payments for the interest-only mortgages and for the saving scheme. Only at the end of the duration, the mortgage debt is amortized in one go by the saving scheme, which is properly dimensioned for this purpose. This type of mortgage maximizes tax deductions

and profits from the savings interest on the scheme. Some schemes are cash based and guarantee 100% accumulation, other schemes are stock investment based, offer higher yields but also the risk of building up not enough capital, leaving the home owners with a partially uncovered interest-only loan. Type 3 are true interest-only loans without saving schemes.

The stock of mortgage debt is disaggregated by age group and mortgage type. The distribution of mortgage debt over types for new and moving home owners is given exogenously. This parameter was used for simulating different policy scenarios. Another parameter models credit rationing for new home owners.

### **Equity in savings/ investment scheme**

The third stock is only relevant to the second type of mortgages. It registers the accumulation of equity in the savings scheme through periodical payments and interest accrument. It forms a first order material delay with a fixed duration. Standard system dynamics material delays with average duration did not yield optimal results, so a discrete conveyor-belt delay was used in the final model. When savings schemes finish, they automatically amortize the connected mortgage.

### **Initial values and parameters**

Initial values of the stocks were taken from the 2002 housing survey. Parameters for e.g. residential mobility rates are based on a time series of four subsequent housing surveys i.e. 2002, 2006, 2009 and 2012.

## **VII.5 VALIDATION**

The reference mode of behavior for the model is the development of total mortgage debt in the Netherlands (see figure 36). Different sources for total mortgage debt give somewhat different values<sup>40</sup>. The error level between these sources is about 4%.

Furthermore, the number of house sales was available as a second reference mode of behavior. The project team succeeded in calibrating the model to closely match both reference modes of behavior (see figure 37 and figure 38). Theil statistics for both reference variables have errors on the 3% level, i.e. lower than the error level between empirical sources for mortgage debt<sup>41</sup>.

40 The statistical office CBS and EMF/DNB have full time series for 2001 – 2011, housing survey only four years. Theil statistics between CBS and EMF/DNB are: RMPSE = 3,8%,  $U_m = 0,70$ ,  $U_s = 0,18$ ,  $U_c = 0,12$ .

41 Theil statistics for mortgage debt: RMPSE = 3,0%,  $U_m = 0,04$ ,  $U_s = 0,80$ ,  $U_c = 0,16$ ; Theil statistics for house sales: RMPSE = 3,2%,  $U_m = 0,13$ ,  $U_s = 0,10$ ,  $U_c = 0,76$

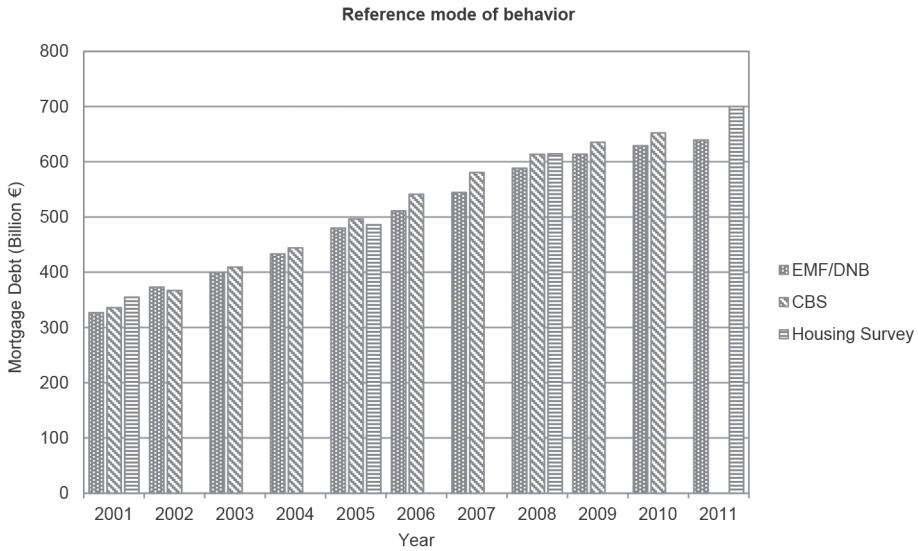


Figure 36 Mortgages: reference mode of behavior from three sources

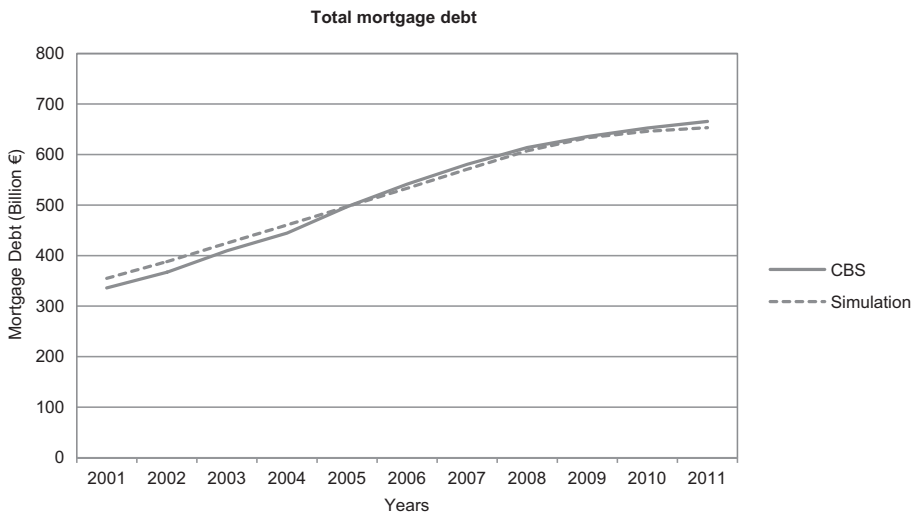
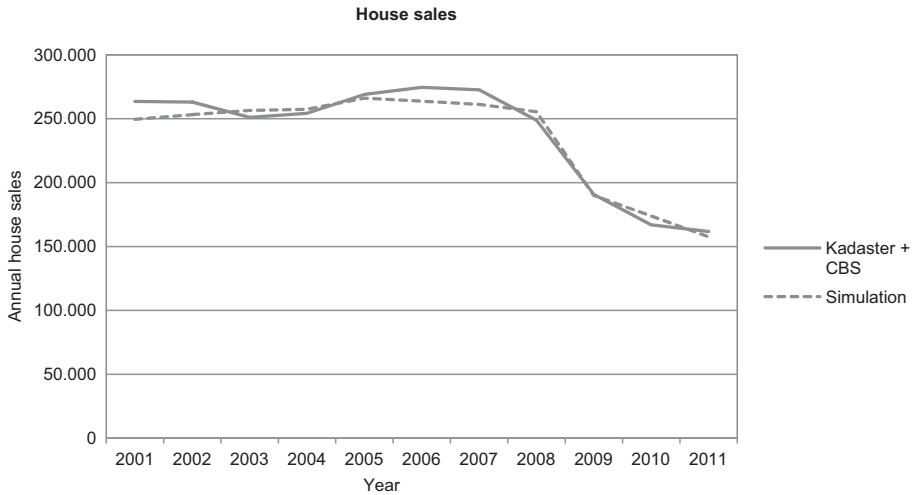


Figure 37 Mortgages: total debt RMoB and simulation



**Figure 38 Mortgages: house sales RMoB and simulation**

The model structure presented in section VII.4 was accepted by the project team as an adequate representation of the real world system, based on their expert knowledge of the housing market. Additional structure and behavior tests (Forrester & Senge, 1980) (mostly sensitivity tests) and model improvements were carried out during the development of the model. Dimensional consistency was enforced in the software. After finding that calibration had made the model closely reproduce the historical data, the project group accepted the model as valid for simulating future trends and patterns and for assessing the impact of policy alternatives.

## VII.6 BASE RUN AND POLICY ALTERNATIVES

Two reports (Schilder & Conijn, 2012a; Schilder et al., 2012) cover an extensive range of sensitivity analysis and policy scenarios with the mortgage model. These lead to grim conclusions: none of the sometimes rather drastic scenarios succeeds in stabilizing the total mortgage debt at the level of 2013. A going-concern scenario with annually 50.000 new owner occupied houses, prices recovering from the financial crisis and no policy interventions on mortgages demonstrates that the total mortgage debt will increase even further from around € 650 billion in 2010 to nearly € 950 billion in 2025. A scenario with significantly lower new construction (30.000 houses annually) reduces the total debt to € 875 billion in 2025. Simulation of actually taken policy measures (all new mortgages as of 2013 must be of type 1) still shows an increase to € 800 billion in 2025. Even scenarios combining all negative external influences (low construction, continued price slumps, policies banning new type 2 and type 3 mortgages) demonstrate 6% to 8% autonomous

growth. The average autonomous growth over 30 different scenarios, however, amounts to 24% with a 9% standard deviation<sup>42</sup>.

The main driver of this autonomous growth is a strong cohort effect. New home owners finance at current, relatively high prices with relatively many type 2 and type 3 mortgages (in the going concern scenarios). Old home owners leaving the housing market, on the other hand, have mortgages for the far lower house prices of the early 1990's and before. Amortizing type 1 mortgages are more frequent among old home owners, simply because their mortgages predate the financial innovations in the 1990s.

The overall dynamics of the mortgage debt are therefore driven by exchanging old low amortizing mortgages for high new, interest-only mortgages (with or without savings scheme). The difference in price levels between the early 1990's and 2010 is predominant: even with obligatory type 1 mortgages for all new cases, total mortgage debt continues to grow. Replacement of old low with new high mortgages is the main driver for this behavior.

Sensitivity analysis reveals that the total mortgage debt relates positively to the level of new housing construction. In the general perception of economic theory, more supply should lead to lower prices. The model, however, clearly demonstrates that the volume effect is the dominant driver for total mortgage debt. Mortgage debt also correlates positively with house price growth and negatively with the yield on saving schemes. The response over the 30 scenarios for these three variables is almost linear.

**Table 2 Mortgages: sensitivity analysis**

Variable	Linear estimate	Correlation
Construction (relative) C	$M = 0,093 C + 0,9003$	$r^2 = 0,9563$
Price growth G	$M = 2,283 G + 0,9508$	$r^2 = 0,97$
Saving scheme yield Y	$M = -0,6699 Y + 1,0135$	$r^2 = 0,9814$

Table 2 shows the results of the sensitivity analysis. Dependent variable M represents the final level of mortgage debt (in 2025) divided by the same indicator in the base run. Price growth and savings scheme yield represent absolute values used in the sensitivity analysis. Construction is relative to the construction level in the base variant. All signs of parameters are plausible. More construction and price growth lead to higher mortgage volumes. Higher savings scheme yields lead to more redemptions during the simulation time horizon and thus to somewhat lower mortgage volumes.

## VII.7 EVALUATION OF THE PROJECT

### Opinion of the research team

The mortgage modeling project helped the research team, consisting mostly of housing economists, to gain a better understanding of system dynamics modeling and its potential merits. They particularly valued the rapid construction of a model producing

<sup>42</sup> Autonomous growth ranges from said 6% to 37%.

plausible results. Fine-tuning and calibrating took relatively little time, contributed to accurate reproduction of historical trends and helped to produce a report on the subject in time. The housing economists in the project team therefore felt confident that both forecasted trends and the policy scenarios were also sufficiently plausible.

Moreover, the model provides opportunity for further analysis of cohort effects in mortgage volumes. The model itself, consisting of a Powersim project with a linked excel worksheet for data entry, allows for easy simulation of additional scenarios.

Overall, the project helped the researchers in gaining a positive attitude towards well-conducted and compact system dynamics simulation in housing research works.

## VII.8 CONCLUSIONS

The mortgage modeling project solidified existing concerns on the dynamics of the total mortgage volume in the Netherlands. The system dynamics model is comprehensible, reproduces historic trends. It also indicates that no plausible scenarios or policy interventions will significantly reduce the mortgage volume in a short period of time. Findings were presented to government officials and were well-received.

Working with system dynamics (and a system dynamics modeler specialized in housing issues) led to a plausible, practical and useful model built in a relatively short period of time. The project contributed to a more positive attitude towards system dynamics among the participating housing economists.





# VIII CONCLUSIONS, DISCUSSION AND QUESTIONS FOR FURTHER RESEARCH

## VIII.1 REVIEW AND MAIN RESEARCH CONCLUSIONS

This section reviews the research purpose and questions for this work. It connects the work done and the research questions into main, overall conclusions. The subsequent sections provide more detail on the findings on a) modeling housing problems with system dynamics and b) using the relatively unknown system dynamics method in cooperation with housing researchers.

As to the research purpose, we set out to systematize the intuitively sensed connection between housing research and system dynamics. We defined six research questions revolving around three central aspects of this purpose, namely a) the fit between the nature of contemporary research issues and the system dynamics method, b) improving the accessibility of cumulative system dynamics knowledge on housing and real estate and finally c), the results of pilot projects, both in terms of housing content and cooperation with housing researchers.

The first research question focused on identifying suitable housing research issues for the application of system dynamics.

1. Which contemporary research issues in housing studies are particularly fit for tackling with system dynamics?

Many contemporary housing research issues were found to revolve around complexity. Complexities include the nature of housing itself, behavioral and institutional traits of the housing market, interactions with government policies and other markets, data gaps, problems with analytical solution of nonlinear feedback systems and more. System dynamics was then identified as a suitable method for tackling research challenges revolving around modeling realistic market processes, institutional and behavioral feedback loops and those hampered by data problems. The ease of adding institutional and behavioral feedback loops (e.g. land use planning, zoning, fiscal arrangements, housing subsidies, behavior of households, market actors and other parties based on market information) to system dynamics models allows transcending certain limitations stemming from potential differences between theoretical notions (e.g. long term equilibrium assumptions) and short term, out of equilibrium or dynamically complex policy issues.

Then, in question 2, we considered that the causes for system dynamics not being commonly used might provide crucial insights for attaining the research purpose.

2. What factors have contributed to the lack of systematic cooperation between housing research and system dynamics up to the present? What practices and recommendations are present in existing literature for improving cooperation?

We had to conclude that system dynamics operates in isolation of most other social sciences, with the notable exception of management sciences like project management and supply chain management. The isolated position was attributed to several causes. First of all, due to the methodological specialization, most system dynamicists tend to cover many subjects rather than to delve deeply into one or some. This is very helpful for building system dynamics knowledge on dynamic behavior of archetypical feedback structures. From the viewpoint of the involved social sciences, however, system dynamicists may appear to lack proper understanding of the content involved and the other methods being fruitfully applied already.

The second cause is historical, but closely related: the first encounters between system dynamics and housing research stranded in hostile method debates over Urban Dynamics, one of the cornerstone projects of system dynamics. System dynamics and housing research developed mostly separately since then.

Nevertheless, the system dynamics community also reports positive experiences in cooperation with other social scientists, when a) closely connecting to concepts and literature of the field of interest b) staying away from futile method debate and focusing on problem solving instead and c) building compact models comprehensible for social scientist that help them improve *their* structure-behavior intuitions (rather than focusing on system dynamics practitioners as a reference).

Given this state of affairs, exploratory research was found most suitable for discovering possible common grounds between housing research and system dynamics. The scope of work was delimited in two main tasks: a) a literature review of existing system dynamics experiences on housing, real estate and urban dynamics and b) experimentation with system dynamics in housing policy research. The strong point of exploratory research is its focus on discovery and the generation of (new) theories at the expense of its conclusions and insights being mostly tentative and not of a confirmatory nature.

Research question 3 presented a very basic but necessary step in connecting housing and system dynamics, namely the cataloguing of the fragmented system dynamics knowledge base on housing.

3. What is the accumulated knowledge of system dynamics on housing related issues up to now?

The literature review of over 150 works revealed the existence of three groups and a number of isolated efforts, mostly conference papers. First is the Urban Dynamics Group that connects to and extends upon the homonymous cornerstone project. The second group is locally based in the Netherlands, with a strong focus on changing policies in this particular national context. The third group was labeled Recent Real Estate Dynamics with focus on the causes and effects of the 2008 financial crisis and with stronger connections to mainstream real estate and housing research than both other groups.

Furthermore, the basic catalogue of works needs systematic integration and connection to housing research issues as formulated in research question 4.

4. How can it be systematized and integrated into a form that is supportive of the research purpose of this study?

The analysis of the Urban Dynamics Group, the Dutch Housing Policy groups and the isolated efforts is descriptive and brief. Deeper analysis of the third group yielded several archetypical real estate system structures on the basis of a mainstream economic model with embryonic system dynamics properties. These include vacant real estate, investment yield driven behavior, the link with financial markets and the interplay between real estate and land markets through residual land prices.

The four pilot projects represent the empirical part of this thesis. They were included in the research setup in order to experiment with housing modeling and with cooperation with housing researchers. These aspects are reflected in questions 5 and 6.

5. What system dynamics models can be built in close connection to mainstream housing research? What is their added value to the existing knowledge base of both system dynamics and housing research regarding content?
6. What lessons can be learnt from the model building experiences in research question 5 about fruitful cooperation between system dynamicists and housing researchers?

The pilot project Haaglanden is a typical Group Model Building project. It helped its participants to improve understanding of the regional housing market. Desk research project Houdini laid out many of the institutional feedback structures present in the illustration in the introduction, provoked great debates with mainstream housing economists and is ancestral to the third and fourth model. The Middle Incomes project is a relatively successful attempt at tackling a complex impact analysis of policy changes. It is also relatively successful in embedding system dynamics in a mixed method research project and in building confidence of housing researchers in system dynamics. The same is true of the fourth and final project, focused on the dynamics of the ever growing national mortgage debt in the Netherlands.

The insights from the pilot projects, both on content and cooperation with housing researchers, are dealt with in more detail in the two following sections. They are tentative as further confirmatory research should follow and, most probably, they are partial due to limitations in scope of any thesis and possible biases in the selection of theme and method. Therefore, also follow-up exploratory research is necessary into the possible omissions in this work.

The first set of insights is content-based and focused on housing system dynamics modeling. Section VIII.2 recapitulates the findings of this thesis in the form of building blocks for housing system dynamics models, dynamic insights and policy implications. It also presents questions for further research, encompassing both further exploratory and confirmatory research issues.

The second set of insights is process-based and is labeled 'insights on embedded system dynamics'. Section VIII.3 presents the tentative findings and conclusions of this thesis on the process of connecting system dynamics with other social sciences, not per se housing research.

## VIII.2 INSIGHT FOR HOUSING SYSTEM DYNAMICS MODELING

### **Building blocks for system dynamics models of housing problems**

The purpose of this section is to recapitulate the building blocks for system dynamics models grounded in the language and ideas of housing research. As such, they are more recognizable and acceptable for housing researchers. Some building blocks do not contain higher order feedback, but provide an entry point for housing researchers and a starting point for adding e.g. institutional and behavioral structures. Other blocks contain archetypical system structures with two or more main feedback loops and yet another set provides extensions and modifications for approximating these archetypes to real world housing systems.

The building blocks were implicitly formulated in the illustrations in chapter II, in the literature review of the recent real estate dynamics group (see III.4) and in the pilot projects in chapters IV to VII.

#### *Embryonic system dynamic modeling building blocks*

We found that the 4QM of di Pasquale and Wheaton is an embryonic system dynamics model containing a single balancing feedback loop. The 4QM as specified by the authors needs several improvements from the viewpoint of proper system dynamics practice.

The rent and construction functions contain variables with ‘exotic’ units from the system dynamics point of view. The rent function is easily re-specified with a simple micro-economic demand function. The construction function is easily (but admittedly somewhat artificially) re-specified by using a lookup table function on the basis of profit, i.e. house prices minus construction costs. Finally, the addition of a first order material delay in the construction supply chain makes the model more realistic. Figure 25 presents the modified 4Q in system dynamics notation.

#### *Archetypical housing system structures*

*Residual land prices* add the first additional feedback loop to the 4QM. Development costs i.e. the sum of land price and construction costs will dynamically follow the market price of housing with a certain delay time. As in the basic 4QM, they feed into profits, determining the annual construction volume. The additional feedback loop is of a reinforcing nature. The main balancing loop and the residual reinforcing loop constitute the ‘out of control archetype’ of the core set of Wolstenholme. It is depicted in figure 9. Section II.2 demonstrates that this structure is better capable of generating some particular traits of the response of construction and house prices in the Netherlands than other commonly criticized policy instruments. Construction now reacts to price increases rather than price levels, in line with findings from mainstream empirical research.

*Vacant housing* can be added as an intermediate stock between housing under construction and the main housing stock. A flow variable must be added from the main housing stock back to vacant housing. Sale or letting time and occupancy time variables govern these flows. Vacant housing has a significant direct impact on housing prices, constituting a second balancing loop in the model. The ‘relative control’ archetype emerges: the dominance over house price dynamics can shift between normal residential demand and

supply to vacant housing, allowing for significantly more volatility. The model structure is found in figure 11.

The influence of *capital gain* and *financial markets* can be modeled by adding one or two reinforcing loops to the price variable. The first loop (in figure 12) represents yield compression, as investors value potential price increases and bid lower capitalization factors. The second loop (in figure 13) represents capital transfers from other economic sectors (e.g. through mortgage backed securities) when residential real estate is more profitable. On the macro-economic level, *housing subsidies* can feed back to incomes through a fiscal pressure loop (see figure 24) of balancing nature.

### ***Extensions and modifications of the supply chain***

The housing supply chain can be extended with several stages during production or demolition, if necessary for the particular problem. *Housing transformation* can be modeled as feedback from demolition to construction (see figure 15).

*Land use planning* can be modeled as an additional stage of the housing supply chain. This will require specification of a zoning equation (e.g. on basis of demographic forecasts or otherwise) and modification of the construction equation allowing for the influence of accumulated zoned land (see figure 7).

A tentative modeling of the *behavior of commercial developers* for the owner occupied sector must include newly started construction as output on basis of price and construction costs information, vacancy levels and other endogenous variables.

*Landlord behavior* could include construction, acquisition, sale and rent setting policies (see e.g. figure 32). Different types of landlords (i.e. social, private, institutional) may respond differently to market impulses and solvency.

### ***Extensions and modifications for vacancies and housing allocation***

A *waiting list stock* with appropriate in- and outflows allows modeling waiting list and housing allocation dynamics. The inflow represents new house-hunters. Outflows represent successful and unsuccessful exits. Housing allocation logic can be used to govern the successful outflow (see figure 17 and figure 31). *Vacancy chains* can be modeled explicitly (as in figure 16) or by connecting moving households to vacant housing (see chapter VI).

### ***Extensions and modifications for life course and demand dynamics***

Adding simple stocks with single inflows and growth factor for population and income allows for better representation of demand side dynamics (see figure 25). The dynamic life course approach can be implemented by means of a modified ageing chain (see figure 30). Housing preferences and substitution can be modeled dynamically e.g. by modifying static preferences on basis of endogenous variables in the model (see chapter VI).

### ***Extension and modifications for tenure, subsidies, mortgages etc.***

Different tenure forms (e.g. rental and owner occupied housing) can be modeled by doubling, multiplying or disaggregating the housing supply chain and adding possible interactions between them (e.g. sale of rental housing into owner occupation)

(see chapters IV to VII). Co-flow structures can be used for keeping track of characteristics like value, user cost etc. (see chapter VII).

Mortgage dynamics can be modeled as a co-flow to the number of owner occupiers, taking into account price and mortgage levels, financial and institutional restrictions etc. (see chapter VII).

Rent regulation is easily implemented by limiting the volatility of the rent variable, either statically (see section II.2) or dynamically (in chapter V). Fiscal mortgage support is best modeled as a subsidy on the 'rent' or 'user cost' variable in owner occupied housing (see illustration 2 and chapter V).

### *Identified building blocks not elaborated yet*

Several building blocks were identified in the pilot projects, but not yet elaborated sufficiently:

- Co-flow structures for housing units and housing services (quality units).
- Interregional interactions, interactions with labor markets, transport etc.

Other issues were signaled in the contemporary research issues, but not yet elaborated in the pilot projects at all:

- Reinforcing neighborhood change processes on basis of social parameters.
- Industrial organization and supply chain dynamics within the housing development and building sector.

### **Tentative dynamic insights and policy implications**

The pilot projects yielded the following findings in terms of dynamic insights and policy implications.

In relation to the need to integrate *real housing market processes and institutional feedback*, two projects (Haaglanden and Middle Incomes) indicate that the policy makers involved tend to overestimate the influence of rental housing allocation systems on secondary housing supply (i.e. stemming from vacancies in the existing stock). Both projects document actors' hopes that housing allocation has reinforcing effects through vacancy chains. These effects did not materialize in neither simulation. The actors involved in the Haaglanden project reported learning on this aspect. The Middle Incomes simulation clearly demonstrates the trade-off effect between income groups when housing allocation rules change. The Ministry of Housing communicated this finding in a policy and political frame.

In relation to the housing research issue of *demand and behavior dynamics*, the projects indicate on the other hand that generational population dynamics are quite a dominant influence on housing market dynamics. Another important finding of Middle Incomes is that the outflow of the large baby boom cohort may become a paramount factor in housing supply and house prices. Even though other studies (e.g. Mankiw & Weil, 1988; Myers & Ryu, 2008) pointed at this effect, it has not yet made it into housing policy consciousness, possibly because standard demographics forecasts overemphasize age group distributions (i.e. stock variables) and tend to overlook flow variables like the outflow of elderly people. Houdini demonstrated that (regionally different) demographic development is a strong and sensitive determinant of house price dynamics, ranging from

sustained price growth to rather steep price decline when the declining population starts allowing for structural vacancy in the existing housing stock. This finding is comparable to Gyourko and Glaeser (2005).

The results from Houdini and Middle Incomes also point out that the generic housing market structure displays widely varying time trajectories of important variables like prices, construction and supply. In real world terms, this suggests that regional differences in population and housing stock composition matter more than expected.

The actors involved in the Haaglanden project reported learning on the impact of delays in the housing construction supply line. Previously, they had underestimated the time delay over which new greenfield construction of mostly owner occupied housing affects the vacancy rates in the existing social rental housing stock. Due to this underestimation, they had gotten into conflict over short-term overreacting policies when the effect was not yet manifesting itself. This is comparable to the finding that actors inside the system underestimate delays (Sterman, 2000) and to Wheaton (1999) stating that market cyclicity can depend on such supply delays.

The Mortgage Model demonstrates tenacious dynamics of mortgage debt. Sensitivity analysis with the construction level indicates that the volume effect of new mortgages is by far dominant over the price effect of larger housing supply. The combination of strong price dynamics, generational effects and regional difference can lead to highly skewed distributions of mortgage debts, risks and housing wealth over age groups and regions.

### **Questions for further research on housing system dynamics**

Insights based on some literature and a limited number of pilot projects inevitably lead to questions for further research.

First of all, the set of modeling building blocks was distilled only from the literature base and the pilot projects. It is plausible to assume that also alternative modeling solutions exist, next to those presented here. In order to do so, more projects must be carried out, not only to tackle single policy issues, but also reflect, extend and improve the set of modeling building blocks.

Second, the archetypical system structures and the extensions still lack rigorous simulation. They should undergo sensitivity and deep uncertainty analysis and other possible advanced simulation techniques. Deeper archetype analysis taking into account intended and unintended consequences, problem and solution links can help build intuition for high-leverage policies, but should be followed up by quantitative simulation. The literature provides sufficient guidance for such rigorous simulations (e.g. Özbas et al., 2008; Wheaton, 1999 and the advanced simulation and analysis techniques in section II.2).

Third, a much deeper connection must be established between outcomes of system dynamics simulations and empirical findings of housing research. First of all, these empirical findings are necessary for establishing reference modes of behavior, for parameterizing models and for parameter verification tests. It is necessary to contemplate the proper use of the rich basis of elasticity estimates from common housing research for system dynamics. Elasticity represents the overall statistical correlation strength between economic variables. System dynamics is focused on finding structures generating such correlations. It is therefore arguably more natural to measure the elasticity of system dynamics simulation outcomes ex-post than to use elasticity as a model



parameter. The former approach may be helpful in demonstrating congruence between system dynamics models and empirical findings and thus in integrating different strands of research. The latter approach is suspected to lead to unit consistency problems and methodological discussions.

Fourth, the tentative dynamic insights above emphasize the importance of regional differences. In that light, it is necessary to work on truly regional housing market models with regional interactions. The Houdini project also signaled this, but no sufficient progress was made to draw even very tentative conclusions. More research is therefore necessary. Most probably, such modeling efforts will closely connect with land use and transport interaction models, integrate insights and modeling molecules from Urban Dynamics and make use of the system dynamics literature on spatial modeling, GIS and spatial archetypes. There is sufficient material in the system dynamics knowledge base on these themes for further literature research as done in chapter II.

And finally, more research is needed on the exact niches of system dynamics and other complexity based modeling and simulation techniques. For practical and historical reasons, this thesis focuses mostly on applying system dynamics on suitable housing research issues. The comparison of system dynamics to other methods is still superficial. Additional research is needed here, focusing on both the theoretical notions underlying different methodologies and their application on real world housing issues.

### VIII.3 INSIGHTS ON EMBEDDED SYSTEM DYNAMICS

The purpose of this set of insights is to make explicit the findings of this thesis on improving the application of system dynamics in housing research or *pars pro toto*, social science in general. The insights are formulated in the form of a proposition, a definition and a dynamic hypothesis. They are further illustrated with thesis findings and comparisons to the well-documented Group Model Building approach for further clarification.

#### **A basic proposition**

The basic proposition underlying ‘embedded system dynamics’ can be formulated as follows:

*The process of acceptance of system dynamics in social science is isomorphic to the validation process of system dynamics modeling projects.*

System dynamics departs from the stance that models are ultimately imperfect representations of imperfect human mental models of real world systems. There is no such thing as absolute validity of models, but only through the gradual building of confidence can a model be found to be useful at best for a given, well defined problem.

If the problem is the limited application of system dynamics in social science, then isomorphism between individual system dynamics projects and the wider application of system dynamics in social science may apply. Hence it is proposed that wider acceptance requires the gradual building of confidence of social scientists in system dynamics,



which can only be gained through intensive cooperation. In the end, cooperation is the structure that drives confidence and acceptance behavior.

Another famous and fundamental system dynamics aphorism can be restated as 'all methods are wrong, but some methods are useful'. Repenning (2003) pointed out that focusing on understanding complex social phenomena is more helpful than targeting methodological audiences. System dynamics is not useful for short-term prediction, econometric estimates are not useful for understanding dynamic complexity and GIS are unusable for analyzing policy discourses. Focusing on research problems implies that much more care should be taken in identifying which method is suitable for a particular aspect of the problem.

That said, it is also necessary to acknowledge that many system dynamics concepts are shared with other methodologies: stock, flows, feedback, delays, endogenous perspectives, none of these are the exclusive territory of system dynamics. Proper consideration of this fact may constitute another opportunity for establishing rapport with social scientists.

### **A definition of embedded system dynamics**

From these considerations a definition of embedded system dynamics can be proposed.

*Embedded system dynamics focuses strongly on solving social research issues by means of a mixed method approach, where system dynamics and other approaches are highly complementary and equivalent in emphasis.*

Embedded system dynamics is somewhat orthogonal to the methodological specialization commonly found among system dynamics practitioners. It requires the participation of researchers equally well versed in other methodologies. In order to maintain the proper focus on social system content, it is desirable that output of the different methodological approaches is equivalent in the contribution to the research conclusions. Partial results from e.g. literature analysis, statistical data analysis, interviews and modeling should be cross-examined and the main conclusions be supported from all parts, not only through the model simulation results.

Embedded system dynamics requires that the system dynamics model is properly grounded in the theories and empirical findings of the respective field of application, based on the judgment of other experts involved. In other words, embedded system dynamics needs other social researchers to participate in building the conceptual models, in structure, parameter and behavioral validations.

The purpose of mixing of methodologies in embedded system dynamics is to create opportunities for deep involvement of other researchers in the construction and validation of the system dynamics model, for only deep involvement in Group Model Building was demonstrated effective in changing attitudes towards a particular subject (Eskinasi & Rouwette, 2004; Rouwette, 2003).

It is proposed here that deep involvement of social scientists is crucial for changing their attitudes towards system dynamics from ignorant, indifferent or skeptical to positive. Equivalent application and combination of different contributions into a closely-knit and cross-confirmed network of conclusions will foster the sense of ownership. Most

probably, it will take a longer time frame than one research problem in order to allow them to internalize system dynamics to such an extent that they are capable of properly identifying in which case system dynamics can be usefully and successfully applied. This is relevant as will be demonstrated in the dynamic hypothesis below.

The close availability of other methods may prove helpful in preventing the weaknesses of system dynamics to escalate. Suppose that system dynamics has helped build intuition on e.g. the outflow of elderly households and that it is necessary to determine differences between regions. A team comprising mostly of system dynamics practitioners might be tempted to disaggregate the model and run into the failure dynamics encountered with the ITS model (documented in III.3). A mixed method team, on the other hand, might decide to do statistical analysis of the most important variables revealed by the system dynamics model.

Embedded system dynamics put special requirements on system dynamics practitioners. First, they must withstand the temptations of methodological specialization implicitly recommended by the community. It is essential that they are sufficiently skilled in system dynamics to build the relatively small models other social scientists can absorb (Repenning, 2003). Furthermore, they must be on par with their colleagues as regards content: they must deeply understand what research issues matter and where they can make system dynamics excel. Most likely, they will have to specialize in one or a limited number of subjects at most, more so, because the other social scientists will have to accept them as adding value in their projects in the first place.

Embedded system dynamics is participative in a certain sense and related to Group Model Building. The participative element is however less visible than in classical GMB. Arguably, sessions enumerating and linking variables into causal loop diagrams may be more problematic in working with social scientists than with policy actors, as it is more likely that these sessions will provoke the methodological debates many system dynamics authors warned against. Probably, it is better to work with concept models, demonstrate that existing knowledge is incorporated in them and to engage in common validation and simulation experiments.

Experiences in the projects indicate that proper communication of scope, purpose and limitation of system dynamics models is crucial for embedding system dynamics in social science. Computer modeling is a vast subject in general and implicit expectations and perceptions of modeling scope, purpose and limitations are a potential source of derailing methodological discussion. The scope and purpose of the four projects presented in chapters IV to VII already display significant variety and the processes of building confidence in the models (or validation) correlate to these differences.

Haaglanden followed the well documented and proven group model building approach. It adds to the evidence that GMB can successfully help policy makers to improve their understanding of complex systems they are dealing with. The scope of the project was to resolve their policy conflict by means of modeling. The model therefore reflects their mental model of the real world system, even if it could theoretically be criticized for the presence of driving time series or missing some of the dynamics in the historical data. In essence, however, the model gained instant validity when it helped them discover that their policy conflict was about different aspects of the dynamic behavior of the same structure. Once they understood that, tension was resolved and the project could

be safely and successfully concluded. The most important purpose here was the learning of the involved policy makers and all validation issues should be seen in this respect. Haaglanden is classic GMB and not embedded system dynamics because it did not apply a mixed method approach. All research activities were centered on system dynamics modeling, whereas the Middle Incomes project also dedicated significant research time to the policy discourse analysis, theory building, regular data analysis and the regional case studies encompassing literature study, data analysis and interviews.

The scope of the Middle Incomes project was different. It set out to make an impact analysis in a politicized setting, hampered by a lack of reliable data and with strong interference of the economic dynamics at that moment. Purpose, scope and limitations of the model were clearly, consistently and repeatedly communicated. The model was for impact analysis on basis of older data and should by no means be interpreted as a forecast of actual events. Validation of the Middle Incomes model is therefore more reliant on the strong theoretical basis of the model structure, on the cross-confirmation of its outcomes with the interviews and statistical analysis, on the consistent story it tells and on the fact that it helps to put the debated regulation into a wider picture. These factors contributed most to the acceptance of the model for its purpose than comparisons with the difficult empirical data situation.

In the Mortgage model, emphasis was more on statistical validity, on calibration and forecasting the future trend. The structure of the model is relatively simple and relies more on time delays and the associated inertia than on complex feedback structures. Furthermore, much more suitable data was available for statistical testing, parameter estimation etc. It is useful to accent that this actually allowed a more data driven approach than in the Middle Incomes project. This explains the differences in emphasis between both projects. That said, the Mortgage model does provide a consistent story why the total amount of mortgage debt is likely to increase even more and why most policy scenarios do not have significant impact. In that sense, the Mortgage Model has the strong narrative commonly associated with properly conducted system dynamics modeling.

The projects with most impact (i.e. attention of government officials, policy impact and positive attention from other social scientists) had embedded system dynamics characteristics: Middle Incomes and Mortgage Model.

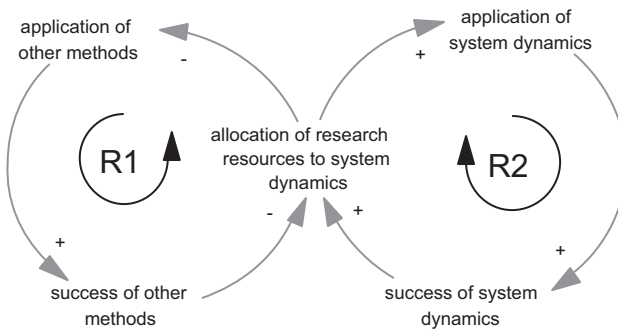
In this regard, Houdini is somewhat less successful. It lacks deep participation and thus support of other researchers, it maneuvers on the brink of a competing model issue with the CPB model, has no direct policy outlet and its boundary adequacy is still questionable. On the other hand, it has laid important foundations for the modeling of institutional features (land use planning, residual land prices, rent regulation, fiscal mortgage support, fiscal feedback, developer and housing association behavior), demographic dynamics and regional variety found in other models, most notably Middle Incomes. A large-scale land use and transport interaction model inherited Houdini's residual land pricing features successfully. It is probably most just to consider Houdini as a preliminary model for Middle Incomes and the set of modeling building blocks above and as such, it has been successful as a learning tool.

In summary, most elements for embedded system dynamics are natural for system dynamics. Isomorphism helps to understand that gradual building of confidence applies

both in single projects as in long-term cooperation with social scientists. Experiences in system dynamics literature show that one must establish rapport to content and content people, deeply involve them and allow them to internalize in order to gain acceptance and confidence. Proper communication of modeling scope, purpose and limitations may be even more crucial in working with social scientists than with policy makers. Methodological debates and overwhelmingly complex models on the other hand will be detrimental to this purpose.

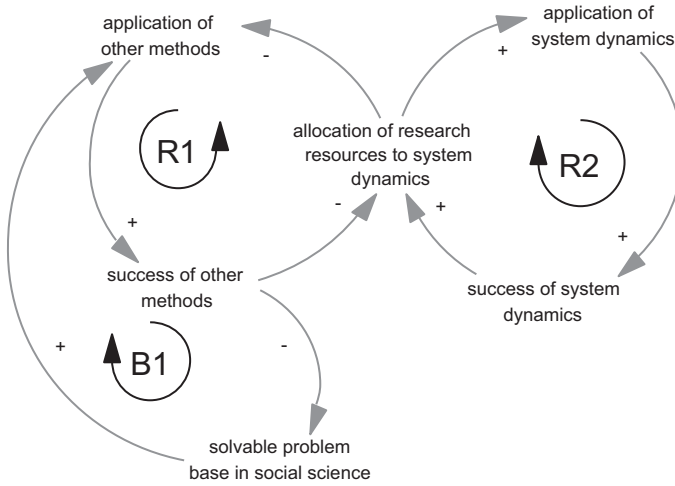
#### VIII.4 EPILOGUE: A DYNAMIC HYPOTHESIS FOR EMBEDDED SYSTEM DYNAMICS

This chapter is concluded with a dynamic hypothesis for embedded system dynamics, inspired by Repenning (2003). The first sketch in figure 39 represents the current state of affairs, where other methods are granted research resources because they are more successful than system dynamics (loop R1). A success-to-the-successful archetype emerges with R2 keeping system dynamics depleted of resources, so that no successes ensue.

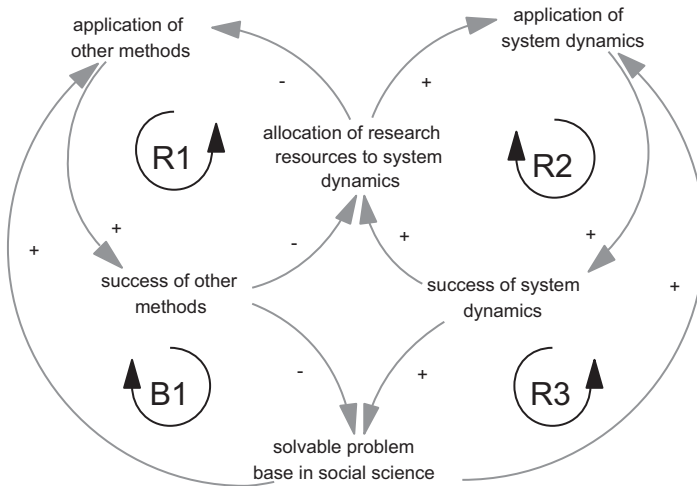


**Figure 39 Epilogue: Success to other successful methods**

In the second stage (see figure 40), the stock of problems solvable by these other methods is gradually depleting and begins to limit growth. Authors complain about aimless plateaus (Forrester, 2007b), stalled agendas and lack of real progress (MacLennan, 2012), indicating that the balancing loop B1 is now dominating system behavior. Note that R1 and B1 combine into an underachievement archetype (Wolstenholme, 2003). Vice versa, however, system dynamics may be running out of relevant solvable problems for its lack of connection to other social sciences.



**Figure 40 Epilogue: Other methods run out of solvable research problems**



**Figure 41 Epilogue: Demonstrate system dynamics helps solve previously unsolvable problems**

In figure 41, an initial success of system dynamics proves that more research issues are resolvable. In other words, proper command of system dynamics will allow research teams to venture into new, previously inaccessible directions. But only when that leads to the discovery of new solvable problems is loop R3 connected. Embedded system dynamics is instrumental to loop R3 because the required content specialization is indispensable for mapping out and discovering the very system dynamics niche in every branch of social science.



# APPENDICES, LISTS AND REFERENCES

## APPENDIX 1 COMMONLY USED VARIABLES IN MODEL REPORTS

### *Main stock and flow variables, model parameters*

- A: available or vacant house.
- B: housing preference, budget share for housing.
- C: construction. Mostly the stock of houses under construction. Commonly related flow variables are C started, C completed. Factors and parameters related to construction are mostly lower case c.
- D: demolition. When used as stock variable the stock of houses awaiting demolition. Common flow variables are D redlined (designated for demolition), D demolished (actually demolished). Factors and parameters related to demolition are mostly lower case d.
- F: taxes, fiscal pressures.
- H: households. H generally designates the main stock variable. Many models have a flow variable H growth.
- i: interest rate, discount factors.
- K: construction costs, development costs. In simulations with residual land prices, K mostly includes both actual construction costs (labor and materials) plus the residual or Ricardian land price.
- L: loans, mortgage volume.
- M: mutation rates, housing vacancy turnover.
- N: saving schemes equity in mortgage model.
- P: house price. Vacant possession values for both owner occupied and rental houses to be sold, tenanted investment value when let.
- R: rent, user cost.
- S: housing stock.
- T: tenure choice.
- t: simulation time; dt simulation time step.
- Greek lower case tau  $\tau$ : delay and adaptation times, mostly connected to flow variables.
- U: success ratio, search time.
- W: households on waiting list, active house hunters.
- X: transfer of houses between categories, e.g. sale, liberalization etc.
- Y: household incomes.
- Z: zoned capacity, used in land use planning simulations.

### *Dimensions, subscripts*

- age: age groups.
- edu: education level.
- exo: exogenous time series.
- i: indexed variables, mostly with starting value = 100 or 100%.

- inc: income groups.
- group: used as shorthand for combination of age group, household stage, income and education levels.
- seg: housing market segment: social rental vs. market in Haaglanden, rental vs. owner occupied in Houdini, eight types in Middle incomes.
- stage: different household stages in Middle Incomes.
- own: ownership categories, like ha for housing associations, ownocc for owner occupation, inv for commercial investors and dev for developers.

## APPENDIX 2 MODEL AND SIMULATION REPORT FOR THE MODEL IN II.2

### *Experimental setup*

The experimental setup consists mainly of simulation runs with subsequent changes to the model structure. The model documented in table 3 is in stable equilibrium. Subsequently, the following simulation runs were carried out:

1. Baseline simulation with 1% household and income growth and an interest rate decreasing from 5% in year 10 to 4% in year 20.
2. Model modification for rent regulation.
3. Model modification for fiscal mortgage support.
4. Model modification for zoning.
5. Model modification for residual land prices.

No optimization experiments were carried out.

### *Model reporting*

**Table 3 Demonstration model: PMRR-compliant model report**

Formulations and comments	Units
$H_t = H_0 + \int_0^t H_{\text{growth}} \cdot dt; H_0 = 10^6$	Households
$H_{\text{growth},t} = H_t \cdot h$	Households / year; 1 / year
The total population $H_t$ measured in households portrays exponential growth with a constant growth rate $h$ .	
$Y_t = Y_0 + \int_0^t Y_{\text{growth},t} \cdot dt; Y_0 = 30 \cdot 10^3$	€ / (household * year)
$Y_{\text{growth},t} = Y_t \cdot y$	€ / (household * year <sup>2</sup> )
The income per household $Y$ also growth exponentially with growth rate $y$ .	



Formulations and comments	Units
$B_t = Y_t \cdot b; b = 1/3$	€ / (household * year)
Households spend a fixed share b of their income on housing.	
$S_t = S_0 + \int_0^t (C_{\text{completed},t} - D_{\text{demolished},t}) \cdot dt; S_0 = 10^6$	Houses
$D_{\text{demolition},t} = \frac{S_t}{\tau_{\text{life}}}; \tau_{\text{life}} = 100$	Houses/ year; year
The actual housing stock $S_t$ integrates completed construction and demolition. Demolition is proportional to the housing stock, assuming a life time $\tau_{\text{life}}$ of 100 years.	
$R_t = \frac{H_t \cdot B_t}{S_t}$	€ / (house * year)
$P_t = \frac{R_t}{i}; i = 0.05$	€ / house; 1/year
The market rent level $R_t$ is total demand $H \cdot B$ divided by the housing stock $S$ . Rent $R$ capitalized into house prices $P$ through discount rate $i$ .	
$\Pi_t = P_t - K; K = 150 \cdot 10^3$	€/house
Profits per house $\Pi$ equal house prices minus construction costs $K$ .	
$C_{\text{started},t} = f(\Pi_t)$	House/year
Profits $\Pi$ determine the volume of newly started construction $C$ by means of a manually determined function $f$ .	
$C_t = C_0 + \int_0^t (C_{\text{started},t} - C_{\text{completed},t}) \cdot dt; C_0 = 20 \cdot 10^3$	Houses
The stock of houses under construction $C_t$ integrates new construction starts and completed construction	
$P_i = \frac{P_t}{P_0}; R_i = \frac{R_t}{R_0}; S_i = \frac{S_t}{S_0}; C_i = \frac{C_t}{C_0}$	dimensionless
Index variables in graphs show only relative values with initial value = 1.	

### Simulation reporting

All simulations were conducted in Powersim Studio 9 Expert SR1 32 bit build 9.11.5227.6 on a Fujitsu Esprimo desktop computer with an Intel Core i5 CPU at 3.2GHz and 4GB RAM under Windows 7 64 bit. The simulation horizon was set at 100 year, using 1<sup>st</sup> order Euler fixed step with time step  $dt=1$ . All simulations finished within one second, including outputting the index variables to Microsoft Excel 2010 Professional Plus build 14.0.6129.5000 (32-bits) for graph formatting.

The parameter and model structure changes in Table 4 define the consecutive simulation runs mentioned in the experiment setup.

**Table 4 Demonstration model: PSRR-compliant simulation report**

<b>Baseline simulation</b>	
Parameter changes from table 3: $0 < t < 10 \Rightarrow h = y = 0; i = 0.05$ $10 \leq t < 20 \Rightarrow h = y = 0.01; i = 0.05 - 0.005 \cdot (t - 10)$ $t > 20 \Rightarrow h = y = 0; i = 0.04$	
The baseline is simulated with 1% household and income growth from year 10 to year 20. In the same period, the interest rate decreased from 5% to 4%.	
<b>Rent regulation simulation</b>	
Parameter changes as in baseline	
$R_t = \min \left( \frac{H_t \cdot B_t}{S_t}; r_{\text{ceiling}} \right); r_{\text{ceiling}} = 10 \cdot 10^3$	€/ (house * year)
The rent level $R_t$ is regulated not to exceed its initial value.	
<b>Fiscal mortgage support simulation</b>	
Parameter changes as in baseline	
$R_t = \frac{H_t \cdot B_t}{S_t} \cdot (1 + r_{\text{mortgage},t}); t \geq 10 \rightarrow r_{\text{mortgage},t} = 0.2$	€/ (house * year)
From year 10 onwards, rents are being subsidized 20%.	
<b>Zoning simulation</b>	
Parameter changes as in baseline.	
$Z_t = Z_0 + \int (Z_{\text{new},t} - C_{\text{started},t}) \cdot dt; Z_0 = 100 \cdot 10^3$	houses
$Z_{\text{new},t} = H_{t+10} \cdot h = h \cdot H_0 e^{h \cdot \tau_{\text{forecast}}}; \tau_{\text{forecast}} = 10$	Houses/year
The stock of land zoned for housing construction $Z_t$ integrates newly zoned land $Z_{\text{new},t}$ and construction started $C_{\text{started},t}$ . The planning system strives to add new zoned land in proportion to future household growth.	
<b>Residual land prices simulation</b>	
Parameter changes as in baseline.	
$K_t = K_0 + \int_0^t \frac{P_{t-dt} - K_{t-dt}}{\tau_{\text{residual}}} \cdot dt; K_0 = 150 \cdot 10^3; \tau_{\text{residual}} = 2$	€/house
Due to residual land pricing policies, total development costs $K_t$ adapt in $\tau_{\text{residual}}$ years to house prices $P_t$ .	

## APPENDIX 3 MODEL AND SIMULATION REPORT FOR HAAGLANDEN MODEL

### Experimental setup

The experiment setup for Haaglanden was mostly based on running different time series for urban transformation and greenfield development. Two other simulations includes increased sales of social housing and a higher rate of social housing after construction. The simulations made with the project group did not include structural modifications to the model.

### Model reporting

**Table 5 Haaglanden: PMMR-compliant model report**

Formulations and comments	Units
<i>Sector 1 Housing production and transformation</i>	
$S_{s,t} = S_{s,t} + \int_0^t (C_{\text{completed},s,t} - D_{\text{redline},s,t}) \cdot dt \pm \int_0^t X_{s,t} \cdot dt; S_{s,0} = \{228500, 146500\}$	Houses
The stock S of houses of a certain type s (social rental or market) at any moment of time t is calculated from the number of houses completed C completed, the number of houses redlined for demolition D redline and the sale of social houses X. The initial number of houses was taken from Haaglanden (2004b).	
$C_{\text{completed},s,t} = \frac{C_{s,t}}{\tau_{\text{construction}}}; X_{s,t} = 700; \tau_{\text{construction}} = 1,5$	Houses/year; year
The number of houses annually completed is equal to the stock of houses under construction $C_{s,t}$ divided by the construction time $\tau_{\text{construction}}$ of 1,5 years. Furthermore, annually, a fixed number of social rental houses $X_{s,t}$ is being sold and transferred to the market housing stock.	
$C_{s,t} = C_{s,0} + \int (C_{\text{started},s,t} - C_{\text{completed},s,t}) \cdot dt; C_{s,0} = \{4600, 860\}$	Houses
The stock of houses under construction $C_{s,t}$ forms a production chain with a material delay. It integrates new construction starts $C_{\text{started},s,t}$ and completed construction $C_{\text{completed},s,t}$ . Starting values were calculated from Haaglanden (2004b).	
$C_{\text{started},\text{social},t} = C_{\text{started},\text{total},t} \cdot c_{\text{social}}; C_{\text{started},\text{market},t} = C_{\text{started},\text{total},t} - C_{\text{started},\text{social},t}$	Houses/ year
$C_{\text{started},\text{total},t} = C_{\text{rebuild},t} + C_{\text{exo},t}; C_{\text{exo},t} = \{\text{timeseries}\}$	Houses/year
The total volume of construction started is the sum of houses rebuilt after transformation plus an exogenous component. The latter consists of greenfield development and the change of land use.	
$c_s = \{0.7; 0.3\}$	Dimensionless
Factor $c_s$ determines the share of market (70%) and social rental (30%) housing in new construction.	

$D_{\text{market},t} = D_{\text{market},0} + \int_0^t D_{\text{redline,market},t} \cdot dt - \int_0^t D_{\text{demolished,market},t} \cdot dt$	Houses
<p>Demolition of market houses is a first order material delay. It integrates redlined houses and demolished houses over time.</p>	
$D1_{\text{social},t} = D1_{\text{social},0} + \int_0^t D_{\text{redline,social},t} \cdot dt - \int_0^t D_{\text{stage2,social},t} \cdot dt$	Houses
$D2_{\text{social},t} = D2_{\text{social},0} + \int_0^t D_{\text{stage2,social},t} \cdot dt - \int_0^t D_{\text{demolished,social},t} \cdot dt$	Houses
<p>Demolition of social houses is a second order material delay, with two stages with different legal status and possibilities for housing associations.</p>	
$D_{\text{redline,social},t} = \{\text{timeseries}\}$ $D_{\text{redline,market},t} = S_{\text{market},t} \cdot d_{\text{redline,market}}$ $D_{\text{demolished,s,t}} = D_{s,t} \cdot \tau_{\text{demolition}}$ $d_{\text{redline,market}} = 1.75 \cdot 10^{-3}; \tau_{\text{demolition}} = 1.5$	Houses/ year; 1/year; year
<p>Entry into the demolition stage of the housing production chain is exogenous for social housing. Annually a small fraction of market housing <math>d_{\text{redline,market}}</math> is redlined for demolition. The final outflow <math>D_{\text{demolished}}</math> takes into account an average demolition time <math>\tau_{\text{demolition}}</math> of 1.5 years.</p>	
$D_{\text{stage2,social},t} = D1_{\text{social},t} / \tau_{\text{stage1}}; \tau_{\text{stage1}} = 1.5$	Houses/year; year
<p>The two-stages material delay for demolition of social houses has an intermediate flow with another 1.5 year stage 1 delay time <math>\tau_{\text{stage1}}</math>.</p>	
$C_{\text{rebuild,s,t}} = D_{\text{demolished,s,t}} \cdot c_s \cdot c_{\text{density}}; c_{\text{density}} = 0.8$	Houses/year; dimensionless
<p>New houses <math>C_{\text{rebuild}}</math> are built after demolition. Density factor <math>c_{\text{density}}</math> sets the proportion of new construction after transformation to demolished houses. Construction of new houses after transformation feeds back into the construction stage of the production chain.</p>	
<p><i>Sector 2: Demand for social housing, waiting lists and housing allocation</i></p>	
$W_{\text{pri},t} = W_{\text{pri},t=0} + \left( \int_0^t W_{\text{in,pri},t} - \int_0^t W_{\text{disap,pri},t} - \alpha \left( \int_0^t A_{\text{pri},t} - \int_0^t X_{\text{pri},t} \right) \right) \cdot dt$	households
<p>The general equation for households on the waiting lists integrates new inflows, outflow of disappointed house-hunters, housing allocations and transfer of housing for the four distinct house-hunter groups, i.e starters and onmovers, each with and without priority. Factor <math>\alpha</math> links houses to household in a 1-to-1 ratio. Startup values for all four types were taken from Haaglanden (2004b).</p>	

$W_{in,regular,t} = \{\text{timeseries}\}; W_{in,prioritystarters,t} = 1000$	Households /year
The inflow of both types regular house-hunters is an external time series given in table 6. The inflow of priority starters is a fixed number.	
$W_{disap,regular,t} = W_{regular,t} / \tau_{disap}; \tau_{disap} = 10$	Households / year; year
Regular house-hunters get disappointed after 10 years and leave the waiting list. Priority house-hunters do not get disappointed.	
$A_{pri,t} = a_{pri} \cdot A_t / \tau_{rentout}; \tau_{rentout} = 1; a_{onmovers} = 0.5$	Houses/ year; year; dimensionless
The total number of houses allocated for starters and onmovers respectively follows from the total number of available houses, a rentout time variable and the housing allocation factor a. The latter determines the share of houses allocated to onmovers.	
$A_{regular,t} = A_{pri,t} - W_{priority,t} / \alpha$	Houses / year
Priority house hunters precede over regular house-hunters, for starters and onmovers respectively.	
$W_{in,priorityonmovers,t} = w_{priorityonmovers} + \alpha \cdot \delta \cdot D_{demolished,s,t}$	Households/ year
The inflow of new priority onmovers consists of a fixed component w for social and medical cases and a dynamic component related to the number of social houses demolished. Transformation priority rate $\delta$ determines how many households must be granted priority, depending on the duration of stage 1.	
$A_{social,t} = A_{social,t=0} + \left( \int_0^t Q_{end,seg,t} \cdot q_{seg,t} - \int_0^t A_{starters,t} - \int_0^t A_{priorityonmovers,t} - (1-\beta) \cdot \int_0^t A_{regularonmovers,t} \right) \cdot dt$	Houses
The general equation for the available social housing stock integrates inflow from ending vacancy chains and new rent-outs to house-hunters. Note that a certain proportion beta of regular house-hunters leaves a social dwelling that must be added to the stock of available social houses. The ending vacancy chains take into account the multipliers q.	
$Q_{seg,t} = Q_{seg,t=0} + \int_0^t C_{completed,seg,t} \cdot dt - Q_{seg,t} / \tau_{chain}; \tau_{chain} = 1.5$	Houses; years
Vacancy chains Q are modeled as a first order material delay. Newly completed houses in both segments start vacancy chains that run for $\tau_{chain}$ years.	
<i>Sector 3: auxiliary variables</i>	
$M_{seg,t} = A_{seg,t} / S_{seg,t}$	1/year
The mutation rate M is the proportion of available houses to the total stock.	
$U_{grp,t} = A_t / W_{grp,t}$	1/year
The success ratio U is the proportion of available houses to the number of households on the waiting list.	

**Table 6 Haaglanden: exogenous time series and non-linear relations**

	year											
Exogenous time series	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020
greenfield construction	4600	4750	5500	4000	4000	4000	4000	4000	4000	3000	2000	1000
change of land use	0	400	800	800	800	800	800	800	800	0	0	0
total exogenous construction	4600	5150	6300	4800	4800	4800	4800	4800	4800	3000	2000	1000
transformation of social housing	450	1400	1200	1300	1950	1950	1950	1950	1950	1500	1000	500
new regular starters	12500	13300	9500	9000	9000	9000	9000	9000	9000	9000	9000	9000
new regular onmovers	10300	7600	8800	8000	8000	8000	8000	8000	8000	8000	8000	8000
market to social migration multiplier	1,53	1,03	1,03	1,03	1,03	1,03	1,03	1,03	1,03	1,03	1,03	1,03
social to social migration multiplier	2,24	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97	1,97
<b>Non-linear relations</b>												
Stage 1 time (year)	0	1	2	3	4	5	6	7	8	9	10	(indep)
Transformation priority rate	100%	80%	73%	67%	60%	55%	50%	45%	41%	38%	33%	(dep)

### *Simulation reporting*

The simulations for Haaglanden were run on a 2002 laptop computer with more or less standard specifications running under Windows. The simulation was built in Ithink 7.0.

## APPENDIX 4 MODEL AND SIMULATION REPORT FOR HOUDINI MODEL

### *Experimental setup*

The experiment setup for Houdini was based on running the simulation model with parameter sets for three regions. One set represented the national average, one set the economic focal area Northern Randstad and the final set reflects the declining area in the far south of Limburg.

Furthermore, several policy experiments were carried out with rent deregulation, lower fiscal mortgage support, less restrictive land use planning and different adaptation times in residual prices. Full details are provided in Eskinasi (2011a).

### Model reporting

**Table 7 Houdini: PMRR-compliant model report**

Formulations and comments	Units
<i>Section 1: Demand side</i>	
$\dot{i}_{av,t} = \dot{i}_{av,0} + \int_0^t \frac{(\dot{i}_{ex,t-dt} - \dot{i}_{av,t-dt})}{\tau_i} \cdot dt; \dot{i}_{ex,t} = \{\text{timeseries}\}; \dot{i}_{av,0} = \dot{i}_{ex,0}$	%/year
Interest rate $\dot{i}_{ex}$ reflects the relatively volatile capital market mortgage interest rate. As most Dutch mortgage have periodic fixed interest rates, the model works with a materially delayed or smoothed interest rate $\dot{i}_{av}$ with a delay time $\tau_i$ of 5 years. $\dot{i}_{ex}$ is based on an exogenous time series (see Eskinasi, 2011a).	
$H_t = H_0 + \int_0^t H_t \cdot h_{growth,t} \cdot dt; h_{growth,t} = h_0 - h_1 \cdot t$	Households
The stock of households H grows annually with a certain proportion. The households growth rate is not constant but decreases over time as the population ages and starts to decline in the future. The growth rate, determined by constant $h_0$ and time coefficient $h_1$ , was calculated from the CBS household forecast.	
$Y_t = Y_0(1 + y^t) - \frac{F_t}{H_t}$	€ / (household* year)
$Y_t$ is the development of consumable incomes over time, based on starting value $Y_0$ income growth rate $y_t$ (taken from CBS data). The fiscal pressure per household $F_t/H_t$ is subtracted dynamically (with proper corrections).	
$T_t = \text{probit}(b_0 + b_r + b_1 \ln \frac{R_{0,t}}{R_{r,t}} + b_2 \ln Y_t)$	dimensionless
Tenure choice $T_t$ is the fraction of households preferring owner occupied housing. Both the income level Y and the ratio of user costs in the rental $R_r$ resp. owner occupied sector $R_0$ determine its value. The statistical probit equation was taken from Ras et al. (2006), $b_0$ : constant; $b_r$ regional constant, $b_1$ coefficient for relative user costs, $b_2$ coefficient for income.	
<i>Sector 2: Housing production chain</i>	
$S_{seg,t} = S_{seg,0} + \int_0^t (C_{seg,completed,t} - D_{seg,demolished,t} \pm X_{sale,t}) \cdot dt$	Houses
The main housing stock variable integrates new completed houses, demolition and transfer of houses between segments (owner occupied and rental).	
$D_{seg,demolition,t} = S_{seg,t} \cdot d_{seg}$	Houses / year

Annual demolition is modeled as a fixed proportion of the stock	
$C_{seg,t} = C_{seg,0} + \int_0^t (C_{seg,started,t} - C_{seg,finished,t}) \cdot dt; C_{seg,finished,t} = C_{seg,t} / \tau_{construction}$	Houses
The stock of housing under construction integrates new construction starts and finished construction. Construction takes an average period of $\tau_{construction}$ .	
$Z_{seg,t} = Z_{seg,0} + \int_0^t (Z_{seg,new,t} - C_{seg,started,t}) \cdot dt$	House
The stock of zoned capacity for housing integrates newly zoned land and started construction.	
$Z_{seg,new,t} = T_t (H_{t+\tau_{forecast}} - S_t) / \tau_{forecast}; \tau_{forecast} = 15$	Houses/ year
Zoning strives to minimize the housing shortage $\tau_{forecast}$ years ahead by adding annual slices of zoned capacity. Distribution over segments is on basis of tenure choice.	
<i>Sector 3. User cost, price dynamics and interactions</i>	
$R_{ownocc,t} = \frac{H_t \cdot T_t \cdot B_t}{S_{ownocc,t}} \cdot (1 + r_{subs,ownocc})$	€/(house*year)
User costs for the owner occupied sector is derived here on basis of the Cobb-Douglass equation, taking into account tenure choice and the fiscal subsidy on owner occupied housing. Note: this equation is in the unresolved part of Houdini.	
$R_{rental,t} = \min \left( \frac{H_t \cdot (1 - T_t) \cdot B_t}{S_{rental,t}} \cdot (1 + r_{subs,rental}); R_{regulated,t} \right)$	€/(house*year)
User costs in the rental sector follows the same form, but also take into account the maximal regulated rents. Note: this equation is in the unresolved part of Houdini.	
$P_{ownocc,t} = \frac{R_{ownocc,t}}{i_{ownocc,t}}; i_{ownocc,t} = i_c + i_{mortgage,t} + i_{spec} \cdot \frac{(P_{ownocc,t-dt} - P_{ownocc,t-\tau_{spec}})}{\tau_{spec}}$	€/house; 1/ year
Prices derive from rents divided by the discount factor $i$ . Discount factor $I$ includes a constant cost component, a mortgage interest rate and a component for slight influences of adaptive price expectations. The first components were found in literature, the third was calibrated to historical prices. Note: this equation provoked most debate with the housing economists.	
$P_{rental,investment,t} = \frac{R_{rental,t}}{i_{rental}}; i_{rental} = i_c + i_l$	€/house
The investment value of a rental house is based on capitalized, regulated rents. The discount factor $i$ includes a cost and a financing component.	



$P_{\text{rental,shadow},t} = P_{\text{ownocc},t} \cdot p_{\text{quality}}$	€/house
The sale value of rental dwellings, however, is proportional to the value of owner occupied housing, taking into account the relative quality.	
$P_{\text{gap,rental},t} = P_{\text{rental,shadow},t} - P_{\text{rental,investment},t}$	€/house
The value gap represents the difference between shadow price and investment value.	
$K_t = K_0 + \int_0^t \frac{P_{t-dt} - K_{t-dt}}{\tau_{\text{residual}}} \cdot dt$	€/house
Total development costs follow the principle of residual land prices as in appendix 2.	
$\Pi_t = P_{\text{ownocc},t} - K_t$	€/house
Development profits are market prices minus development costs.	
$C_{\text{ownocc,started},t} = f(\Pi_t); C_{\text{rental,started},t} = f(\Pi_t, P_{\text{gap,rental},t})$	House/year
Construction starts are based on profits. For the rental sector, also the value gap is taken into account	
$X_{\text{rental},t} = f(P_{\text{gap,rental},t})$	Houses/year
Sales of rental housing into owner occupation are driven by the value gap.	
<i>Sector 4. Fiscal feedback</i>	
$F_t = R_{\text{ownocc},t} \cdot H_t \cdot T_t \cdot r_{\text{subs,ownocc}} + R_{\text{rental},t} \cdot H_t \cdot (1 - T_t) \cdot r_{\text{subs,rental}}$	€/ year
The total amount of subsidies includes fiscal mortgage support and rental housing allowances. These feed back into net incomes. For potential policy experiments, additional taxes can be introduced, e.g. on rental housing or on property sales by housing associations.	

### Simulation reporting

All simulations were conducted in Powersim Studio 9 Expert SR1 32 bit build 9.11.5227.6 on a Fujitsu Esprimo desktop computer with an Intel Core i5 CPU at 3.2GHz and 4GB RAM under Windows 7 64 bit. The simulation horizon was set at 100 year, using 1<sup>st</sup> order Euler fixed step with time step  $dt=1$ . All simulations finished within one second, including outputting the index variables to Microsoft Excel 2010 Professional Plus build 14.0.6129.5000 (32-bits) for graph formatting.

Table 8 presents the main exogenous parameters for Houdini. The main startup values are given in table 9 and some historical time series and nationwide simulation parameters in table 10.

**Table 8 Exogenous regional parameters for Houdini**

Exogenous parameters for Houdini			National	Decline	Randstad
$h_0$	Intercept for household growth		1,0285%	0,5300%	0,7900%
$h_1$	Coefficient for household growth		-0,0215%	-0,0340%	-0,0085%
$b_r$	Regional factor in tenure equation		0	0,083	-0,402
y	Income growth	years 0 - 4	0,69%	0,43%	1,62%
		years 5 - 9	0,88%	-0,57%	0,66%
		years 10 -14	2,24%	0,24%	2,72%
		From year 15	1,30%	0,40%	1,80%

**Table 9 Startup values for Houdini**

Startup values			National	Decline	Randstad
Housing stock	% owner occupied		48,4%	45,7%	31,3%
	Shortage		4,8%	2,0%	10,5%
Demand	incomes	pp2005	€ 27.700	€ 26.800	€ 27.000
	Tenure choice		46,5%	56,4%	37,2%
User cost	Owner occupied	pp2005	€ 7.125	€ 6.925	€ 8.400
	Rental	pp2005	€ 4.100	€ 4.300	€ 4.100
Investment value	Owner occupied	pp2005	€ 125.400	€ 121.500	€ 147.700
	Rental	pp2005	€ 71.800	€ 75.750	€ 71.800

**Table 10 Historical time series and simulation parameters**

Variable		Historical			Simulation
		Yr 0-4	Yr 5-9	Yr 10-14	From yr15
$i_{\text{mortgage}}$	Mortgage interest rate	3,78%	2,44%	2,75%	3,00%
$dR_{\text{regulated}}$	Maximal annual rent increases	1,66%	0,14%	0,54%	0,50%

### Policy experiments

The following policy experiments were carried out in Houdini:

- The rent deregulation simulations allow for a significantly higher maximal annual rent increase of 3,0%, instead of 0,5%.
- Decreasing the fiscal mortgage support is modeled as a single step from 25% to 15% in simulation year 20.
- Additional policy experiments with different supply responses are presented in Eskinasi (2011a).

## APPENDIX 5 MODEL AND SIMULATION REPORT FOR MIDDLE INCOMES MODEL

### Experimental setup

The main experimental setup for Middle Incomes encompassed base line and alternative simulations with and without the SSR in place. The model simulates both policies on different regional datasets, representing both the national average and six, selectively picked, widely varying regional housing markets. Where relevant, three mitigating policies were simulated as well.

### Model reporting

**Table 11 Middle incomes: PMRR-compliant model report**

Household sector	
$H_{t,young,edu,seg} = H_{0,young,edu,seg} + \int_0^t \left( H_{t,new,young,edu,seg} - \frac{H_{t,young,seg}}{\tau_{young}} + H_{move,t,young,edu,seg} \right) dt$ $H_{move,t,young,edu,seg} = \sum_{to} W_{success,t,group,from,to} - \sum_{from} W_{success,t,group,from,to}$	Households
<p>The stock of young households in each housing market segment integrates the inflow of new households, the flow of young households into the family and medior stage plus the movement of young households between housing market segments. The flow into the two next stages is governed by a fixed duration <math>\tau_{young}</math>. The movement of households between segments is based on cross-summation over the flow of successfully exiting house-hunters <math>W</math> in each household type, education level and current and previous housing market segment.</p>	
$H_{t,med,edu,seg} = H_{0,med,edu,seg} + \int_0^t \left( \frac{(1-h_{fam})H_{t,young,edu,seg}}{\tau_{young}} - \frac{H_{t,med,edu,seg}}{\tau_{fam}} + H_{move,t,med,edu,seg} \right) dt$ $H_{move,t,med,edu,seg} = \sum_{to} W_{success,t,group,from,to} - \sum_{from} W_{success,t,group,from,to}$	Households
<p>The equation for mediors is similar to that for youngsters. One share of young households (<math>h_{fam}</math>) flows to the family stage, the rest (<math>1-h_{fam}</math>) to mediors. Mediors exit to seniors after the same stage duration as families.</p>	
$H_{t,fam,seg} = H_{0,fam,seg} + \int_0^t \left( \frac{h_{fam} \cdot H_{t,young,seg}}{\tau_{young}} - \frac{H_{t,fam,seg}}{\tau_{fam}} + H_{move,t,fam,edu,seg} \right) dt$ $H_{move,t,fam,edu,seg} = \sum_{to} W_{success,t,group,from,to} - \sum_{from} W_{success,t,group,from,to}$	Households
<p>The family equation is similar to the medior equation.</p>	

$H_{t,young,new,edu,seg} = \frac{H_{t,fam,edu,seg}}{\tau_{fam}} \cdot \frac{h_{children}}{h_{young,size}} \times h_{edu,edu}$	Households
<p>New young households are created when families exit the family stage. The number of children per family <math>h_{children}</math> and the average young household size <math>h_{young,size}</math> relate both flow volumes together. The education matrix <math>h_{edu,edu}</math> determines distribution of young households over education levels on basis of the education level of the parents.</p>	
$H_{t,sen,edu,seg} = H_{0,sen,edu,seg} + \int_0^t \left( \frac{H_{t,fam,edu,seg} + H_{t,med,edu,seg}}{\tau_{fam}} - \frac{H_{t,sen,edu,seg}}{\tau_{sen}} + H_{move,t,sen,edu,seg} \right) dt$ $H_{move,t,sen,edu,seg} = \sum_{success,t,group,from,to}^{to} W_{success,t,group,from,to} - \sum_{success,t,group,from,to}^{from} W_{success,t,group,from,to}$	
<p>The equation for senior households has the familiar form. Both families and mediors flow into the senior stage. Outflow to the elderly is again determined by a fixed duration and the common migration component is also present.</p>	
$H_{t,eld,edu,seg} = H_{0,eld,edu,seg} + \int_0^t \left( \frac{H_{t,sen,edu,seg}}{\tau_{eld}} - \frac{H_{t,eld,edu,seg}}{\tau_{eld}} + H_{move,t,eld,edu,seg} \right) dt$ $H_{move,t,eld,edu,move} = \sum_{success,t,group,from,to}^{to} W_{success,t,group,from,to} - \sum_{success,t,group,from,to}^{from} W_{success,t,group,from,to}$	Households
<p>The equation for elderly households is similar to the equation for elderly.</p>	
$H_{t,stage,edu,inc} = H_{t,stage,edu} \times h_{t,stage,edu,inc}$	households
<p>A fixed stage and education specific matrix based on the Housing survey distributes households over income groups.</p>	
<p><b>Housing stock sector</b></p>	
$S_{t,seg,own} = S_{0,seg,own} + \int_0^t \left( A_{absorb,t,seg,own} - M_{t,seg,own} - D_{t,seg,own} \pm X_{t,seg,own} \right) \cdot dt$	houses
<p>The occupied housing stock S integrates housing turnover (vacant houses being reoccupied A absorb and occupied houses becoming available M), demolition and transfers of occupied houses between owners (e.g. housing associations and other investors).</p>	
$A_{t,seg,own} = A_{0,seg,own} + \int_0^t \left( \frac{M_{t,seg,own} - A_{absorb,t,seg,own}}{C_{t,finished,seg,own} \pm X_{t,seg,own}} \right) \cdot dt$	houses
<p>The stock of vacant houses A integrates housing turnover (vacant houses being reoccupied A absorb and occupied houses becoming available M), finished new construction C and transfers of houses between categories upon vacancy (i.e. sale into owner occupation, transfer between rental sectors etc.).</p>	
$X_{t,seg,ha} = X_{goal,seg,ha} \quad C_{t,seg,own} = C_{0,seg,own} + \int_0^t \left( C_{start,seg,own} - \frac{C_{t,seg,own}}{\tau_{construction}} \right) \cdot dt$	houses
<p>The stock of houses under construction integrates new construction starts and finished construction. Finished construction is based on a fixed construction time <math>\tau_{construction}</math>.</p>	

$C_{t,start,seg,ha} = f\left(ICR_t, a_{t,seg}\right) \cdot c_{goal,seg,ha} \cdot \left(S_{t,seg,ha} + A_{t,seg,ha}\right)$	Houses/year
Construction starts by housing associations are based on a goal percentage $c$ of their total housing stock (occupied $S$ and vacant $A$ ) and influences of interest coverage ratio and absorption rate in each segment.	
$C_{t,start,inv} = f\left(i_{t,seg,inv}, a_{t,seg}\right) \cdot c_{goal,seg,inv} \cdot \left(S_{t,seg,inv} + A_{t,seg,inv}\right)$	Houses/ year
Construction starts by commercial investors are based on a goal percentage $c$ of their total housing stock (occupied $S$ and vacant $A$ ) and influences of the absorption ratio $a$ and the gross yield $i$ in each segment.	
$C_{t,start,seg,dev} = f\left(\Pi_{t,seg,dev}, a_{t,seg}\right) \cdot c_{goal,seg,dev} \cdot \left(S_{t,seg,own} + A_{t,seg,own}\right)$	Houses/ year
Construction starts of owner occupied houses by developers are based on a goal percentage $c$ of the total owner-occupied housing stock (occupied $S$ and vacant $A$ ) and influences of development profit $\Pi$ and the absorption ratio $a$ .	
$\Pi_{seg,t} = P_{seg,t} - K_{seg,t}$	Eur/house
Development profit equals market prices minus development costs	
$K_t = K_0 + \int_0^t \frac{P_{t-dt} - K_{t-dt}}{\tau_{residual}} \cdot dt$	Eur/ house
Development costs gradually adapt to market prices because of residual land prices.	
$X_{t,sale,seg,ha} = f\left(ICR_t, a_{t,seg}\right) \cdot x_{goal,seg,ha} \cdot A_{t,seg,ha}$	Houses/ year
Sale of rental houses into owner occupation by housing associations is based on a goal percentage $x$ of their vacant houses $A$ and the influences of the ICR and the absorption ratio $a$ .	
$X_{t,sale,seg,inv} = f\left(i_{t,seg,inv}, a_{t,seg}\right) \cdot x_{goal,seg,inv} \cdot A_{t,seg,inv}$	Houses/year
Likewise, the sale of rental houses into owner occupation by commercial investors is based on a goal percentage $x$ of their vacant houses $A$ and the influences of the gross yield $i$ and the absorption ratio $a$ .	
$A_{absorp,t,seg,own} = w_{density} \sum_{from,to} W_{succes,t,group,from,to}$	Houses/year
The annual volume of absorbed vacant housing is a cross-summation of the successful house-hunters by new segment of residency. Factor $w_{density}$ brings into account the average housing density per household, in this model per definition one house per household. For definitions of variable $W$ , see the sector for house hunters and housing allocation.	
$M_{t,seg,own} = \left( \sum_{success,t,group,from,to}^{from} W + \sum_{\tau_{eld}}^{seg} \frac{H_{eld,t,edu,seg}}{\tau_{eld}} \right) \cdot w_{density}$	
Likewise, the annual volume of houses becoming available (or mutations) is a cross-summation of successful house-hunters by previous segment of residency. Furthermore, houses become available when elderly households leave the housing market due to death or moves to retirement homes.	

$a_{t,seg} = \frac{A_{absorp,t,seg}}{A_{t,seg}}$	%/year
The absorption ratio $a$ is the quotient of annual housing absorption and the total vacant housing stock $A$ . In the owner occupied sector, its reciprocal is the sale time. The absorption ratio $a$ is used in many places as an influence of housing market pressure on e.g. construction, sales, prices, occupancy duration of current home owners, etc.	
$m_{t,seg} = \frac{M_{t,seg}}{S_{t,seg} + A_{t,seg}}$	%/year
Likewise, mutation rate $m$ is the quotient of housing becoming available and the total housing stock $S+A$ .	
<b>Rents, user costs and housing prices sector</b>	
In the middle income model, co-flow structures exist for the bookkeeping of these properties of the housing stock. These structures also discern between occupied and vacant houses $R_S, R_A$ and $P_A, P_S$ respectively. The flows are linked to the flow of the housing stocks $S$ and $A$ . Appropriate corrections are made for transfers, demolition, construction. Furthermore, rents in the occupied housing stock are subject to annual rent increases. For vacant rental houses, rents can be adapted to market (or policy-given) level in one step. Finally, house prices are subject to market influences related to sale time (or absorption ratio). Such additional corrections are labeled $R'_A, R'_S, P'_A$ and $P'_S$ .	
$P_{S,t,seg,own} = P_{S,0,seg,own} + \int_0^t \left( \frac{P_{A,t,seg,own}}{\tau_{abs}} - P_{M,t,seg,own} - P_{D,t,seg,own} \pm P_{X,t,seg,own} \right) \cdot dt$ $+ \int_0^t P'_{S,t,seg,own} \cdot dt$	
$R_{S,t,seg,own} = R_{S,0,seg,own} + \int_0^t \left( \frac{R_{A,t,seg,own}}{\tau_{abs}} - R_{M,t,seg,own} - R_{D,t,seg,own} \pm R_{X,t,seg,own} \right) \cdot dt$ $+ \int_0^t R'_{S,t,seg,own} \cdot dt$	
$P_{A,t,seg,own} = P_{A,0,seg,own} + \int_0^t \left( P_{A,t,seg,own} - \frac{P_{Amt,seg,own}}{\tau_{abs}} + P_{C,t,finished,seg,own} \pm P_{X,t,seg,own} \right) \cdot dt$ $+ \int_0^t P'_{A,t,seg,own} \cdot dt$	
$R_{A,t,seg,own} = R_{A,0,seg,own} + \int_0^t \left( M_{A,t,seg,own} - \frac{R_{Amt,seg,own}}{\tau_{abs}} + R_{C,t,finished,seg,own} \pm R_{X,t,seg,own} \right) \cdot dt$ $+ \int_0^t R'_{A,t,seg,own} \cdot dt$	

$R_{A,t,seg,own} = \frac{R_{t,seg,own}}{S_{t,seg,own} + A_{t,seg,own}} \cdot A_{t,seg,own}; \text{etc}$	Eur/ (house*year)
For these variables, the averages per housing market segment are used in the co-flow equations. Averages per segment are taken over the full stock i.e. occupied plus vacant housing.	
$P'_{S,t,seg,own} = P_{S,t,seg,own} \cdot f(a_{t,ownocc}); P'_{A,t,seg,own} = P_{A,t,seg,own} \cdot f(a_{t,ownocc})$	Eur/ (house*year)
Housing prices are under influence of the absorption rate in the total owner occupied sector. The influence function is estimated on basis of sale time and price development data, see note 34 (page 97) to chapter VI.	
$R'_{S,annual,t,seg,own} = R_{S,t,seg,own} \cdot r_{t,seg,own}$	Eur/ (house*year)
Annual rent increases in the occupied rental stock $R'_s$ are an annual percentage $r$ of the existing rent $R_s$ .	
$r_{t,seg,ha} = r_{t,seg,max} \cdot f(ICR_t); r_{t,seg,inv} = r_{t,seg,max}$	%year
Housing associations generally do not maximize rent increases, only if a low ICR urges them to do so. Commercial investors generally maximize rent increases to the legal maximum.	
$R_{S,harmon,t,seg,own} = P_{t,seg,own} \cdot i_{t,harmon,seg,own} - \frac{R_{t,seg,own}}{S_{t,seg,own} - A_{t,seg,own}}$	Eur/ (house*year)
Upon signing a new rental contract, rents are being harmonized to a new level, reflecting the desired gross yield level.	
$i_{t,harmon,seg,ha} = i_{required,seg,ha} \cdot f(ICR_t); i_{t,harmon,seg,inv} = i_{required,seg,inv}$	%year
The new gross yield upon rental contract signing $i$ is based on the required rate of return. This requirement is higher for commercial investors than for housing associations (due to state support aspects). Furthermore, housing associations take into account their interest coverage ratio. 'Poorer' housing associations will ask higher harmonized rents.	
<b>House hunters and housing allocation sector</b>	
$W_{t,group} = W_{0,group} + \int_0^t (W_{new,t,group} - W_{success,t,group} - W_{disapp,t,group}) \cdot dt$	Households
The stock of house hunting households $W$ integrates entries of new house-hunters, exiting disappointed house-hunters and those that succeed in finding a new house. The stock is disaggregated into household types, education, income and current housing market segment (indicated by the common index 'group' for shorter notation).	
$W_{disapp,t,group} = \frac{W_{t,group}}{\tau_{disapp}}$	
The outflow of disappointed (unsuccessful) house-hunters is governed by a fixed 'disappointment time'.	
$W_{new,t,group} = \frac{H_{t,group}}{\tau_{residency,group}} \cdot f(a_t)$	
The inflow of new house-hunters is governed by the average residency duration for each group and housing market segment. The inflow of new house-hunting home owners is furthermore influenced by the absorption rate in the owner occupied sector.	

$T_{t,group,seg} = W_{t,group} \cdot t_{base,group,seg} \cdot f(J_t)$	
The distribution of house hunters over preferred types of new housing T is dynamic throughout the duration of house-hunting. It is based upon a fixed base preference matrix t (from the Housing Survey) and takes additional influences from J, a vector of influences of substitution, financial and institutional restrictions.	
$W_{success,t,group} = f(W_{t,group}, A_{t,seg,own}, e_{ssr})$	
The number of successful house-hunters is determined by the number of active house-hunters W, the available housing stock A and a vector e of state support parameters (i.e. the 90% allocation criterion, the income and the rent level limits).	
<b>Housing association financial sector</b>	
$L_{t,ha} = L_{0,ha} \int_0^t (L_{mut,t,ha} + L_{transfer,t,ha}) \cdot dt$	EUR
The main equation for housing association debt volumes L integrates debt mutations (for normal operation an investment) and debt transfers reflect housing between the two operational regimes of the housing association (i.e. social and non-SGEI), used only in policy experiments.	
$L_{mut,t,ha} = L_{t,ha} \cdot i + F_t - K_{am,t,ha} - K_{si,t,ha}$	EUR/year
The increase in housing associations debt equates the total negative cash flow (positive cash flow decreases debts). Cash flows include interest payments $L_t \cdot i$ , due taxes F, cash flow from active management $K_{am}$ (sales, construction etc.) and cash flows from standing investments $K_{si}$ .	
$K_{am,t,ha} = \left( X_{sale,t,seg,ha} \cdot (1 - k_{sale}) + \frac{C_{t,seg,ha}}{\tau_{construction}} \right) \cdot P_{t,seg,ha} + D_{t,seg,ha} \cdot d_{transformation}$	Eur/year
Active management cash flows include sale proceedings, construction, demolition and transformation costs.	
$K_{si,t,ha} = (R_{t,seg,ha} - k_{oper}) \cdot S_{t,seg,ha}$	Eur/year
Cash flows from standing investments are rental proceedings minus operational costs (management, maintenance, social expenditure).	
$ICR_t = \frac{K_{si,t,ha}}{L_{t,ha} \cdot i}$	dimensionless
The interest coverage ratio is the quotient of standing investment cash flows and interest payments.	

**Simulation reporting**

All simulations were conducted in Powersim Studio 9 Expert SR1 32 bit build 9.11.5227.6 on a Fujitsu Esprimo desktop computer with an Intel Core i5 CPU at 3.2GHz and 4GB RAM under Windows 7 64 bit. The simulation horizon was set at 25 year, using 1<sup>st</sup> order Euler fixed step with time step dt=0,1. All simulations finished within one second, including outputting the index variables to Microsoft Excel 2010 Professional Plus build 14.0.6129.5000 (32-bits) for graph formatting.



Startup data and model parameters are too large to be reproduced here, but are available on request.

### *Policy experiments*

In the baseline policy run, the state support regulation criteria for housing allocation apply. The criteria do not apply in the alternative policy run. The criteria are:

- 90% of vacant social rental housing of housing associations is reserved for lower income groups.
- This applies to social rental housing up to the third segment (monthly rents of maximally € 634,-)
- This applies to households with maximal annual incomes of approximately € 34.000,-.

The three mitigating policies are:

- Transferring 20% of suitable houses above the given rent criteria into the commercial rental sector.
- Doubling the sales efforts of housing associations
- Transfer of 10% of suitable housing into the non-SGEI management sphere of housing associations.

## APPENDIX 6 MODEL AND SIMULATION REPORT FOR MORTGAGE MODEL

### *Experimental setup*

The experiment setup for the mortgage model contains many different runs. Part of these runs are sensitivity analysis of variables like construction volume, price growth and the yield on savings schemes. Other experiments include variations of the mix of allowable mortgage types, one of which closely reflects the actual government policy to accept only new self-amortizing mortgages for fiscal mortgage support as of 2013.

### *Model reporting*

**Table 12 Mortgage: PMRR-compliant model report**

$H_{age,t} = H_{age,0} + \int_0^t (H_{age,entry,t} - H_{age,exit,t}) \cdot dt + \int_0^t (H_{age-\tau_{ageing},ageing} - H_{age,ageing}) \cdot dt$	Households
The stocks of home owners by age groups integrates entry and exit of new home owners plus the effects of ageing.	
$S_t = S_0 + \int_0^t C_t \cdot dt; C_t = \{\text{timeseries}\}$	Houses
The stock of owner occupied houses simply integrates an external time series of net increases of the stock.	

$H_{age,entry,t} = h_{age,entry} \cdot (C_t + \sum_0^{age} H_{age,exit,t}); h_{age,entry} = \{\text{distribution}\}$	Households / year
<p>Entry of new home owners is equal to the net growth of the housing stock plus the sum of exiting home owners. Distribution over age groups is governed by an exogenous distribution table.</p>	
$H_{age,exit,t} = H_{age,t} \cdot h_{age,exit} \cdot h_{age,exit} = \{\text{distribution}\}$	Households / year
<p>The number of exiting home owners is proportional to the number of owners in an age group. The fraction of exiting home owners is external, fixed and age specific.</p>	
$H_{age,ageing,t} = H_{age,t} / \tau_{ageing}; \tau_{ageing} = 5$	Household/ years
<p>Annually, a fraction of the owners in an age group ages into the next age bracket. Tau ageing defines the resolution of age groups. It is set at 5 years.</p>	
$L_{age,type,t} = L_{age,type,0} + \int_0^t (L_{age,type,new,t} + L_{age,type,add,t} - L_{age,type,amort,t}) \cdot dt + \int_0^t H_{age,ageing,t} \cdot \bar{L}_{age,t} \cdot dt$	
<p style="text-align: right;">Euro</p>	
<p>The total, age and type specific amount of mortgage debt integrates inflows, outflows and ageing effects. Inflows include mortgages of new owners and additional mortgages of moving home owners. The outflow equals the amount of amortization. The ageing effect provides for proper age group bookkeeping and transfers a proportional amount of mortgage debt with ageing home owners into an older age group.</p>	
$P_t = P_0 + \int_0^t P_t \cdot p_t \cdot dt; p_t = \{\text{timeseries}\}$	Euro/ house
<p>The price of owner occupied homes simply follows an exogenous time series of annual price growth rates.</p>	
$L_{age,type,new,t} = \left[ (H_{age,entry,t} \cdot P_t \cdot p_{entry}) \times l_{type,new,t} \right]$	Eur/ year
<p>The inflow of mortgage debt of new home owners is proportional to the number of new home owners, the actual average house price level and a factor p expressing the relative average price for new home owners, as they may buy cheaper houses. Factor l distributes mortgage debt of new home owners over mortgage types 1, 2 and 3. It is a time series in order to allow policy measures influencing the mortgage type mix.</p>	
$L_{age,type,add,t} = \left[ (m_{age} \cdot H_{age,t} \cdot (P_t \cdot p_{move} - \bar{L}_{age,t})) \times l_{age,type,t} \right]$	Eur/ year
<p>The inflow of additional mortgage debt taken out by moving home owners take several component. First, the number of moving households per age group, defined by the total number H times a mutation rate m. Second, the average amount of additional mortgage debt, i.e. the difference between current house prices P*p for moving owners minus their existing mortgage loan L. Third, the distribution of additional mortgage debt over mortgage types 1,2 and 3.</p>	

$L_{\text{age,type,amort},t} = H_{\text{age,exit},t} \cdot \bar{L}_{\text{age,type},t} + \begin{bmatrix} L_{\text{age,type1},t} \cdot l_{\text{age}} \\ N_{\text{age},t} \cdot n_{\text{age,xpire}} \\ 0 \end{bmatrix}$	Eur/ year
<p>The annual volume of amortization consists of a) amortization by exiting home owners (e.g. by emigration, move to rental or death) and b) type-specific amortization component: fixed annual proportional payments for type 1 mortgages, lump sum payments when saving schemes expire for type 2 and no additional amortization for type 3. Both annual amortization of type 1 and final amortization through saving scheme expiration were implemented as age specific, fixed proportions of the mortgage debt and the accumulated saving scheme equity, respectively.</p>	
$N_{\text{age},t} = N_{\text{age},0} + \int_0^t (N_{\text{age,deposit},t} + N_{\text{age},t} \cdot i - N_{\text{age},t} \cdot n_{\text{age,xpire}}) \cdot dt + \int_0^t H_{\text{age,ageing},t} \cdot \bar{N}_{\text{age},t} \cdot dt$	
Euro	
<p>The total volume of equity in saving schemes integrates annual deposits, yield on the equity collected and the annual volume of expiring saving schemes. Furthermore, it takes into account ageing of home owners for correct generational bookkeeping.</p>	
$N_{\text{age,deposit},t} = L_{\text{age,type2},t} \cdot n_{\text{deposit}}$	Eur/ year
<p>Annual deposits into the saving scheme are implemented as a fixed proportion of the related mortgage loan volume.</p>	
<p>In addition to the dynamic structure above, the model implements several totals, averages, data input and other auxiliary variables.</p>	

### Simulation reporting

All simulations were conducted in Powersim Studio 9 Expert SR1 32 bit build 9.11.5227.6 on a Fujitsu Esprimo desktop computer with an Intel Core i5 CPU at 3.2GHz and 4GB RAM under Windows 7 64 bit. The simulation horizon was set at 100 year, using 1<sup>st</sup> order Euler fixed step with time step dt=1. All simulations finished within one second, including outputting the index variables to Microsoft Excel 2010 Professional Plus build 14.0.6129.5000 (32-bits) for graph formatting.

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The purpose of this PhD thesis is to contribute to a systematic connection between housing policy research and system dynamics. Housing policy research recognizes many complexities of housing markets and housing policy, e.g. in the nature of housing itself, in the time frames of different housing market processes, the interplay between housing, demographic development and the macro economy and the many institutional aspects of markets and government policies. System dynamics is a computer simulation based methodology for exactly such complex, dynamic social systems as housing markets. But despite the apparent fit, there is yet no systematic cooperation between both disciplines.

This thesis therefore aims at laying some groundwork for more systematic application of system dynamics in housing policy research. It identifies issues in housing policy research centered around dynamic complexity, which are suitable for system dynamics. The thesis presents a comprehensive overview of existing system dynamics literature of housing, urban development and related themes. A main part of the thesis consists of four case studies, where system dynamics was applied on policy issues in close cooperation with housing researchers. These case studies cover many themes like the interplay between greenfield construction and urban renewal, the dynamic effect of zoning and residual land markets on housing prices and construction, the impact of changes in eligibility regulations for social housing for different income groups and the dynamics of the Dutch mortgage market. The thesis conclusions encompass a set of over twenty modeling building blocks for housing market simulation and recommendations on proper embedding of system dynamics modeling in contemporary housing research.

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