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An Agent-Based Market Analysis of Urban Housing Balance in The Netherlands

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Abstract: The Dutch housing market comprises three sectors: social-rented, private-rented, and owner-occupied. The contemporary market is marked by a shortage of supply and a large subsidised social sector. Waiting lists for social housing are growing, whereas households with incomes above the limit do not or cannot leave the social sector. Government policy and market regulations change frequently, not least for political reasons. In view of commonly recognised problems in the housing market, this article considers the 'internal demand' of those households that are dissatisfied with their current residence. We examine the effects of regulatory policy by means of an exploratory agent-based simulation. The results provide perspectives on how internal demand is impacted by regulations in a housing market that is suffering from a shortage, and allow decision makers to weigh the pros and cons of policy measures.

Keywords: residential housing; simulation; policy analysis; agent-based modelling

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1. Introduction

The Dutch residential market is experiencing a profound housing shortage at the time of writing—an imbalance which is expected to grow in the medium term. The market comprises three sectors: social-rented (managed directly or indirectly by municipal governments), private-rented (regulated by a combination of municipal and national government), and owner-occupied (affected by the mortgage market) [1].

This article studies holistically the Dutch housing market and its tri-sector peculiarities. In particular, we examine the effects of government policy by means of an exploratory, agent-based simulation. The goal is to provide a path to greater transparency into the pros and cons of current and contemplated policy measures.

Among the contemporary problematic issues is the difficulty faced by younger people in entering the housing market. Regulations for the social housing sector and for mortgages have resulted in a situation where first-time home buyers ('starters') with a middle income in the market are both ineligible for social housing and unable to purchase a property [2]. Combined with the limited supply in private renting, this situation leaves a starter with very few options.

Starters who are eligible for social housing experience that the social-rented market has growing waiting lists in every major urban area [3]. We use the term *external demand* to refer to those wishing to enter the housing market, notably starters. On the other hand, occupying social housing are families with children living in one-bedroom flats, some waiting for their turn for a larger houses; others who are affected are who had their turn but are now ineligible for larger social housing because they earn above the maximum income to qualify, but who are also unable to afford to rent privately or to purchase a property [4]. We use the term *internal demand* to refer to those who have a home currently but are dissatisfied with it. On the other hand, at the same time, there are 'empty nesters'—parents whose children have moved out, who keep living in social houses that are big enough to support a family with children [5].

Internal demand is of particular interest because it reveals a sort of inefficiency in the housing market, were citizens' satisfaction could be increased without the need to build more houses. This is especially so as the speed at which houses can be built is limited, and house building is currently an environmental, economic, and social justice question in The Netherlands and other (European) countries. There are important political ramifications [6]. Moreover, internal demand is intertwined with contemporary questions about public housing policy, intergenerational differences, the ageing population, housing for refugees and asylum seekers, and equity [7].

The shortage of supply causes imbalance: some households will not have a home to own or will pay more for the few available dwellings than they would otherwise; some households under-pay and others over-pay; some households lack space while others have space to spare. The specific question we investigate is the following: *How is internal demand impacted by regulations in a housing market that is suffering from a shortage?* This question gains importance because of contemporary economic, social, and political debates in The Netherlands.

We address this question by developing an agent-based model (ABM) of the Dutch housing market—in particular, the city of Amsterdam. ABM is an appealing investigative methodology as it allows one to explore and estimate the effect of policy changes [8]. The simulation model intends to achieve three purposes: 1. Achieve a conceptual contrast with economical models through the use of a different modelling technique. 2. Investigate the effects of regulations on specific household groups. 3. Provide a flexible approach in which policy changes and new policies can be easily studied. Our modelling methodology emphasises a descriptive and data-initialised model, capturing as many of the realistic processes of the contemporary housing market as possible. This paper thus provides an ABM of the contemporary Dutch residential housing market, including the significant social housing sector.

Results from the simulation indicate that the following topics are interesting for further exploration: policy levers around tenant selection in the social sector, single versus double waiting time accumulation, the income limit, and demand restraint. Further, we identify the opportunity for more narrowly scoped ABMs to study specific policy questions.

The remainder of the article is structured as follows. Section 2 introduces the market to be studied. Section 3 provides a review of related work in light of the chosen methodology. Section 4 presents the agent-based model. Section 5 reports simulation results from the ABM on the question of interest. Section 6 concludes with a discussion of limitations and future work.

The subsequent appendices provide details about the market under study (Appendix A), full details of the model (Appendix B), and further experimental results (Appendix C).

2. Background and Context

This section provides the context of the Dutch housing market, together with an analysis from the academic literature and popular media addressing apparent problems. The following Section 3 will survey the relevant scholarly literature.

Since legislation and the market situation changes frequently—especially compared to the frequency at which household occupants move—we take January 2021 as our reference date. We use the term 'house' to refer to any of the stock of residential housing—whether this is a house, a flat, or a studio.

As introduced above, the market comprises three sectors: social-rented, private-rented, and owner-occupied. Under Dutch law, the social sector consists of all houses rented out at a price under the 'liberalisation' limit. Conversely, the private sector contains all houses rented out above the liberalisation limit. The owner-occupied sector consists of all houses that are occupied by the owner of the house. From 2013 to 2022, open market houses were a bull market, marked over-pricing occurring in 2020–2021. The bull market was finally tempered by rising interest rates in the second half of 2022.

We briefly describe each of the three sectors, reserving additional details to Appendix A. First, the social sector consist of all houses that, at the start of their contracts, were rented out under the liberalisation limit (set at around EUR 750 monthly), approximately 30% of the total. This is high rate—the highest rate in Europe—means that the social sector must be included in any model. Most of the social sector is organised by housing corporations. The goal of the social sector is to house the lowest-income households—hence the liberalisation limit. Rents in the social sector are bound by a ceiling depending on the quality of a house. The 'Huurcommissie' calculates a score using various properties of a house, and relates every score to a maximum rent [9]. Whereas the other sectors use a free market to match renters and landlords or buyers and sellers, the social sector generally uses a regulated, regionally centralised system to match houses and households.

Second, the housing that is rented privately comprises approximately 15% of the total [10]. While the private sector consists only of houses rented out above the liberalisation limit, not every house is allowed to be rented out at such a price. Similarly to how the Huurcommissie decides the maximum price of houses in the social sector, in limited cases, it can also enforce this for privately rented houses.

Third, the final of the three sectors, the owner-occupied sector, comprises approximately 55% of the total. The houses in the this sector can easily transition to a rental market when the owner decides to rent out the house. Similarly, a house in the rental sector can be sold to the occupant or a new owner who will occupy the house to move to this sector. Some municipal governments—especially in larger cities—have started to require owners to occupy their homes to prevent investors from buying new houses and renting them out [11].

The Dutch housing market described here suffers from contemporary problems. We give three examples of problems commonly perceived in the market. First, for starters with a middle income, the regulations for the social rental housing sector and for mortgages have resulted in a situation where these households are both ineligible for social housing and unable to purchase a property [2]. Combined with the limited supply in the private sector, this situation leaves a starter with very few options. In this paper, problems are approached with the egalitarian goal of satisfying as many households as possible in the existing system.

Second, satisfying all households' preferences is not possible, due to scarcity of supply, but also due to opposing preferences. We describe the problems arising from two such cases. Firstly, there are those who live in too small a home and those living in a larger home than they need. Secondly, there are those who pay too much rent and those who pay too little rent.

For the first case, the 'opposition' is between expanding households where children are born, and households where all children have left ('Lege nesters', *empty nesters*) [12]. The expanding families are searching for a larger home, while the empty nesters occupy these larger homes. For the second case, the 'opposition' is between households that have increased their income but stay in the social sector, 'Goedkope Scheefwoners' (*cheap-skewed renters*), and households that are—partly due to a limited capacity in the social sector—paying too much rent 'Dure Scheefwoners' (*expensive-skewed renters*) [13]. The opposition is in the fact that the expensive-skewed renters could potentially have entered the social sector if the cheap-skewed renters had left the social sector.

Third, Ref. [14] reviews the government policy in the Dutch housing market and concludes that the current policy creates social inequality. Further, the author concludes: "Many citizens, and more specifically low-middle income groups and young households, do not understand the current policy choices which leads to an increasing distrust in government and to instability in society". The social inequity is found to be increasing: [10] studies the rise in buy-to-let and its affect on—in particular—starters in the housing market.

3. Literature Review

Having introduced the market to be studied, we now survey the relevant literature. This section reviews previous work related to modelling the housing market, focusing on the systematic working of housing markets and the behaviour of actors that interact in the market. The broad variety of approaches in the literature include case studies [15], policy analysis [8], and agent-based models [16]. The majority of the literature considers the open market of private-rented and owner-occupied sectors. For succinctness, we refer to just 'buyers' and 'sellers', also including renters and landlords.

3.1. Considerations in Housing Market Modelling

We begin with buyer and seller searching strategies. The first step for a transaction in the housing market is that a buyer or seller looks for a partner(s) to negotiate with, i.e., a seller or buyer, respectively. The searching strategy for buyers is defined by a buyer reaching out to sellers. For example, a buyer anticipating more favourable market conditions might delay their search. The searching strategy for sellers can include when to sell, but also how long a seller waits for higher bids or at what price a seller advertises. Research on these strategies considers both a theoretical optimal strategy and real strategies applied in the housing market.

The authors of [17] compare two selling strategies (the stopping and number rule) under different market conditions using a theoretical simulation. They conclude that neither strategy dominates the other and that, rather than choosing one over the other, an adapting strategy would be most effective. The authors of [18] create a simulation to experiment with varying combinations of buyer and seller strategies. Their work highlights the importance of the interaction between different agent strategies.

Intertwined with searching strategies is the 'system' by which buyers and sellers find each other, which can be a deciding factor in the market. The authors of [19] provide an overview of matching models used to model this process for housing markets. The system is dependent on the spread of information and the speed of processes such as negotiation or requesting a mortgage. The authors of [19] also connect the matching progress to the role of the listing price, i.e., the price at which the seller places the property on the market.

The strategy of a seller is also dependent on the role of the seller. The authors of [20] considered the effects of the time on the market upon the selling behaviours of both private sellers and real estate agents. This was carried out by applying an estimation model on a dataset of a popular real estate marketing platform in Russia. They concluded that real estate agents are more impatient sellers than private sellers.

The *listing price* is the amount of money a home is advertised at—the asking price to purchase or rent the house. The authors of [21] compare two seller strategies that use the listing price differently. The listing price is the amount of money a home is advertised with. The first uses the listing price as a ceiling, while the other uses the 'best-offer-over' method, where the listing price functions more as a signalling device or a floor. They analysed 50,000 transactions in Rotterdam, The Netherlands, and found no clear difference in transaction price between the strategies.

The different usage of listing prices is a specific point of interest in the housing market, as the listing price can have very different meanings in different circumstances [19]. The listing price can communicate the following messages:

- I am willing to sell my home for at least X.
- I am willing to sell my home for more than X.
- I am willing to sell my home for X, but am willing to lower my price.

The listing price is especially interesting because the changing role is not explicit, but rather a gradually changing use of the same value.

The authors of [22] recognised a different role of the listing price during booms or busts and try to explain this behaviour with an econometric model. They conclude with the conjecture that a boom causes a change in the methods sellers use to price their houses which lasts beyond the initial boom. Earlier research of [23] and [24] conclude that the way the listing price changes the expected time before a sale depends on the market conditions.

Not only the market conditions change the role of the listing price. The authors of [15] observed a difference between the theoretically optimal and actual selling strategy for setting listing prices in Norway. The authors showed that the actual selling strategy was beneficial to estate agents, to the detriment of the seller they represent.

A third aspect of the housing market is the decisions of households. In particular, the amount of buyers and sellers on the market is dependent on the decision of households to sell or buy. Modelling this decision process can give more insight into how households react to changing market conditions.

The authors of [25,26] created agent-based models that consider the decision-making process of households in greater detail. The life events of a households provide a change in needs, while the household's perception of the market informs them whether it is worth searching for alternative housing.

An interesting modelling choice is made by [27], who models households with an cultural component. This cultural component informs where a household wants to live. If there is no location that satisfies the cultural need of a household, they either leave the city or change their own cultural component depending on their economical situation. We note the idea that the state of the housing market can impose changes on a household.

After a household has decided to move and found a seller from which to buy a home, the buyer and seller proceed to negotiate a final transaction price. To understand this negotiation process, Ref. [28] investigated the influence of various factors on the outcome of the negotiation process for historical transactions. The authors found no evidence that first-time buyers have worse bargaining outcomes compared to repeat buyers.

The authors of [29] concluded that real estate agents may make agreements between buyers and sellers more difficult instead of easier. They also suggest that the cost of a real estate agent is paid by both buyer and seller and not only by the party making the formal payment. Finally, they highlight that a real estate agent should be considered as a (third) negotiation party, with its own self-interests, rather than part of one side of the negotiation.

3.2. Agent-Based Models for Housing Markets

The majority of research on the housing market is either social–anthropological [30] or economic [31] in nature, and carried out at a *macro level*. Econometric models analyse the relationships between housing prices and market fundamentals. These models can analyse specific policies, as long as those policies can be described in terms of the economic variables; however, econometric models cannot accommodate individual-level behaviour and results. Because of this, these models struggle to predict emergent patterns caused by policy [16,26,32] (compare the point of [33]).

This paper adopts agent-based modelling [34,35] with the rationale that the ABM methodology allows a focus on the choices of and effect on individual households within the regulations—renters, buyers, and sellers—and the emergent city- and national-level effects. The choice of ABM as a methodology is recommended by [8], who highlight the influence of regulations in both the rental and home-ownership sectors on tenure choice. Additionally, ABM allows one to explore and estimate the effect of policy changes, and the use of ABM allows unexpected interactions between regulations to emerge [36].

We are not the first to recognise ABM as a proven choice for studying housing markets. Existing studies have a wide range of foci—from reproducing historic events [26] to comparing buyer and seller strategies [18]. However, to our knowledge, there are no models which include the Dutch social sector.

An important precedent for ABM is the model of the home-ownership sector in England, UK, presented in [16]. The authors show that a simplified model of the housing market can replicate key behaviours observed in the real market. Their model provides effective ways to model income and home-owner behaviour when income changes. However, from a spatial perspective, Ref. [16] assume that buyers that cannot buy a home leave the local market to some alternative municipality. However, if this alternative does not exist, such as in a scarce market, these buyers would not leave the market and keep providing pressure on the market. The second reason that the model of [16] cannot be used for our research question is that it does not consider the rental sector.

The authors of [37] focused on the choices of individual households. They included renovation and emigration as additional choices for a household. The agents in their model proactively and reactively gather imperfect information about the market and take into account how a residential location affects their (daily) budget.

The authors of [25] created a model that focuses on the decision of households to enter the market if they expect to be able find a better home. The households also take into account the expected sale price. This results in a dynamic model in which households react to the state of the market.

In response to a financial crisis, Ref. [26] created an extensive model of the Washington, D.C., housing market. Their design reproduces historical data based on rich micro datasets; as an example, the number of households is matched to census data. Notably, they model both home-ownership and renting.

The authors of [38] created a model of the Danish housing market and studied the effect of income and interest shocks. The households vary their characteristics mainly with age. Most notably, the households change their preferences with age, but do not explicitly change their needs.

The authors of [18] set up agents with different strategies to research how strategies affect each other. In this model, agents are only a buyer or a seller, not both, and no new agents enter over the simulation time.

The authors of [39] created a model that combines the purchasing, renting, and investing sectors into one model. The first part simulates the demographics and provides triggers for households to look for a different home. The second part models the process of matching between offering agents and the agents that received triggers. While there is both a rental and buying sector, they both use the same system.

The authors of [40] study the effects of government fiscal policy instruments on regulating the housing market by means of a data-driven ABM, presenting a case study of the Korean market.

A number of other works model aspects of the housing market or urban housing development using ABM (e.g., [41]). To our knowledge, none address the case of a Dutch municipality setting with all three of social-rented, private-rented, and owner-occupied dwellings. Section 2 summarised the unique features of this market.

The closest are [42], who look at negotiation in Dutch property purchases using ABM, and [32], who look at the peer-to-peer rental market in Amsterdam, again using ABM.

Our work is different from both of these. The authors of [42] present a short, non-archival paper about bidding strategies. The market considered in that work is simple, and notably does not include social housing, and the simulation briefly reported is highly stylized. That work is focused on buyer's bidding strategy in the private owner-occupied sector. We focus on the dynamics of the market across all sectors.

The authors of [32] look at the Amsterdam housing market but with a firm emphasis on the 'Airbnb effect' and policies to counteract it. They are not interested in the dynamics of the three sectors of the market, they do not consider housing shortages per se, their treatment of the social housing sector is superficial, and their time frame is shorter. By contrast, we do not consider tourists and short-term Airbnb-like rentals. A comparison of our work with that paper is thus not meaningful.

3.3. Simulating Households Over Time

The initial population of households for the housing market can be generated with the known data of the current population. However, as simulating the housing market for the purpose of this paper requires a medium–long time span, it becomes necessary to also simulate the future population. In The Netherlands, future households are predicted yearly by the Dutch statistics agency (Centraal Bureau Statistiek, CBS). The CBS method for prediction is in itself a simulation model [43]. The CBS model does not model households but rather people, in terms of their position in a household and 'Burgerlijke Staat' as their state.

The possible household positions are the following:

- Child living with parents.
- Single-person household.
- Living with a partner without a child living at home.
- Living with a partner with a child living at home.
- Parent in single-parent household.
- Other members of a private household.
- Member of institutional household.

The 'Burgerlijke Staat' can be one of four states: never married, married, widowed, or divorced. (In this system, registered partnership and marriage are treated the same).

To model the state of a person in the next simulation step, transitions between states are utilised. For every possible transition, the frequency is estimated from measured data in combination with assumptions. The frequency is further separated by age, gender, and the current simulation year. The assumption is made that the transitions are only dependent on the factors of age, gender, and the state of a person. Besides the transitions between the different states, births, deaths, and migration are modelled to have persons enter and exit the simulation. Births are based on the female population present in the simulation.

4. Model Design

Having introduced the system to be studied, and having surveyed related work, especially in ABM, in this section, we next describe the methodology and the data collected and overview the ABM constructed. The following section employs the ABM in simulation.

4.1. Methodology

Since the focus of the main research question is on the demand caused by individual households, the methodology is agent-based modelling [34], as indicated in Section 3. This choice is made because, in order to investigate the internal demand in a housing market—caused by the mismatch between a households needs (or wants) and the properties of the house they current inhabit—it is necessary to use a methodology that can model individual households and houses. Further, the methodology needs to be able to differentiate between different motivations for internal demand to give better insight into possible solutions or causes. ABM fills these need through its focus on individual agent behaviour.

Section 2 described the working of the Dutch housing market. We aim to create a descriptive model [44], using the available documents, data sources, and interviews with real estate agents.

Our approach to construct the ABM has two parts. The first part of the modelling process fills in the technical parts of the model, finding out which rules form the systems in the housing market. The second part of the modelling process fills in the data-initialised and social–logical parts of the model.

A challenge is that data about the points of interest in the housing market are often (publicly) unavailable, disconnected, or possibly non-existent. Additionally, the data that do exist is are often private information divided over many parties. Due to these factors, the choice was made to make a model that is restricted by the available data. For this reason, some less central aspects of the system were excluded: see Section 4.2 below, Section 6, and Appendix B.

As we explain below, household agents form the core of the ABM. The model description follows the ODD (overview, design concepts, details) protocol [45]. The model was implemented using NetLogo [46], and is available at DOI doi.org/10.4121/21757244.

We retrieved datasets from the CBS, the municipality of Amsterdam, the Dutch citizen financial advice agency (Nationaal Instituut voor Budgetvoorlichting, Nibud), and Nul20, a platform for information about housing policy and urban development in the Amsterdam metropolitan area. Additional data originally published in 'Maandstatistiek van de bevolking' were requested from the CBS and can be found in [47].

For the initialisation of households, the most recent available CBS datasets were used. For the generation of the initial incomes of households, the dataset retrieved from CBS (www.cbs.nl/nl-nl/visualisaties/inkomensverdeling (accessed on 2 September 2021)) was fitted to a Gaussian distribution following [16]. (The choice of a Gaussian distribution for households' income, though following the literature, is recognised as an approximation. Typically, this distribution is log-normal, except for very high incomes. It would be interesting to see whether the ABM could also incorporate these very high incomes. However, the particular behaviour of such households needs to be taken into account in the model.)The data were separated between households with one or two money-earners. For the transitions of households, data from the five most recent years, for which all points of interest were available, were used. Since there is no centralised public dataset for the supply of houses that includes the desired features, the data for houses were selected to be the most recent data available about the housing supply in Amsterdam (data.amsterdam.nl (accessed on 2 September 2021)). For the calculation of the maximum mortgage, data as per 2021 were retrieved from [48].

Lastly, we retrieved qualitative data from the Dutch central government (Rijksoverheid), 'Woningnet Regio Amsterdam' (the central allocation system for the social sector in Metropolitan Amsterdam), and Dutch legal documents. Specific (legal) sources used are reported in [47].

4.2. High-Level Conceptual Design

We built an ABM to capture the salient processes in the Dutch housing system. Thus, the observed system is decomposed into separate components and structured to show the relationship between them. The result of this process is shown in Figure 1.

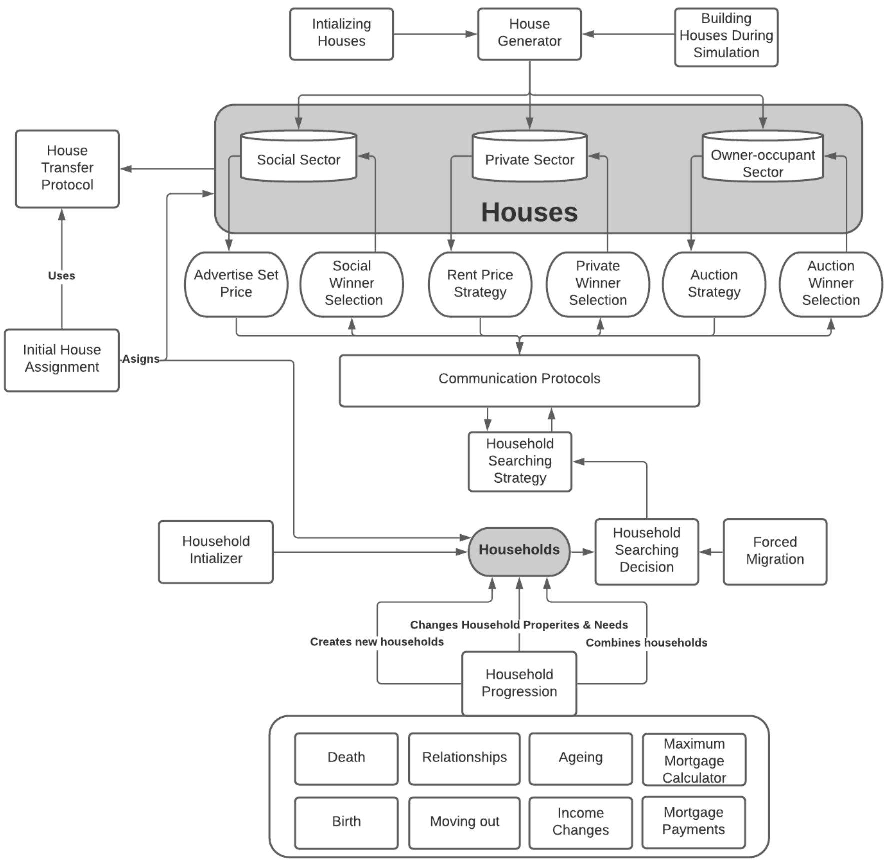

Figure 1. High-level overview of component interaction.

First, the agents that act in the model are identified. On the one hand there are households, which are groups of people that live together and search for houses collectively. On the other hand, there are the suppliers of houses: the housing corporations, landlords, real estate agents, and owner-occupants looking to sell. These agents can be abstracted to a strategy that is used to sell a particular house; in this way the 'house' becomes an agent. This abstraction retains the ability for these groups to use the fact they own a large share of the supply in their strategy.

Households have two interactions. They decide whether they search for a different house when conditions change, and they apply to houses for rent and bid on houses for sale. Houses also have two interactions. They set and advertise a (sale of rent) price, and select a winner when bids or applications have arrived.

Second, the systems representing the environment are considered. Grouped together as 'Household Progression' are the systems that represent the change households experience over time. These systems simulate the life of persons through birth, ageing, and death—the financial situation is simulated through income changes and mortgages; the composition of households is simulated through children moving out to create their own households and relationships, which either combines two households who start a relationship or splits a household because a relationship ends.

The other environmental systems are forced migration—simulating migration that forces households to move, such as being evicted—and the system to simulate new houses being built during the simulation.

Third, the systems to initialise the agents and the support processes are added. The 'House Transfer Protocol' decides how houses are transferred from (n)one household to another; the 'Communication Protocols' ensure agents understand each other's messages, and that they only have knowledge of information the other agent willingly exposes; and the 'House Generator' creates new houses when needed.

Some factors have been considered but intentionally excluded from the model. Firstly, the periodical changes of systems are excluded—most notably, the mortgage calculation and possible mortgage options offered by banks. Their decision-making process is too complex to predict. Secondly, systems related to money are excluded: this comprises savings, interest, houses needing repairs, and eviction. Our research question does not need the prices in the model to representative of the real future, as the goal is to measure motivations; while households are motivated to move by high rents, and in reality savings and eviction are influential, these factors are excluded to reduce complexity. Finally, the model is designed under the assumption that the composition of the housing market does not change (during the simulation), as the focus is not on construction policies. We discuss limitations and extensions of the model at the end of the paper.

A full description of the model in ODD format is provided in Appendix B.

4.3. Verification

We perform a set of actions to check whether the NetLogo software implementation of the ABM design is correctly implemented. First, the NetLogo program has been verified by reviewing the code, varying the parameters, and running the simulation during the implementation process. Second, the program checks for incorrect states or attributes of households multiple times in each simulation step. A check function was introduced that checks whether the state of the household is correct with its attributes and whether all attributes are set to a valid value. The benefit of this function is that every run that it completes has not violated these constraints, even if the code can reach an invalid state in other scenarios. Third, the outputs of the model were reviewed by Dutch real estate agents. It was not the intent that the model mimics historical market developments, or predicts the future, but the professionals agreed that the outputs were reasonable in their opinion.

5. Simulation Results and Discussion

We undertake a set of simulation experiments to explore different settings and simulated policies. The experiments fall under three categories: first those that pertain to policies set by corporations and the government; such policies can be changed by the policy maker relatively easily. Second, experiments exploring the different behaviours of households;

such behaviour changes might be hard to incentivise in practice, but simulation can explore the consequences without having to consider how the behaviour could happen. Third, experiments exploring changes in the environment; these changes can only result from a large or time-consuming process, but can be of great importance.

The ABM is run 100 times with a simulated time period of 75 years. As there was no sufficiently detailed national dataset of houses in The Netherlands, and the social market functions differently per region, the model uses Amsterdam as a basis for its default settings. Table 1 summarises all input variables, their default values, and—if applicable—the motivation for the value.

Table 1. Default values for input variables.

Variable	Value	Remark
seed	0	Setting seed to 0 generates random seeds
plot?	disabled	Disabling plots improves performance
maximum_simultaneous-_reactions_social_market	8	Simulates the 2 reactions per week as 8 reactions per month.
maximum_simultaneous-_reactions_lottery_social_market	8	
supply_lottery	10%	
maximum_income_social-_rental_market	40,024	The maximum income for the social market is set to 40,024 according to current Dutch law [49].
mortgage_length	360 months	
mortgage_type	annuity	
mortgage_interest	0.0210	
population_size	1000	A compromise between population size and simulation length
housing_supply	951	
free_housing_supply%	18	Based on the reported composition for Amsterdam in [50].
private_housing_supply%	51	
home_ownership-_housing_supply%	31	
Size1/2%	31.29	Calculated using 'Woningvoorraad naar stadsdelen en aantal kamers per woning, 1 januari 2021'
Size3%	34.35	
Size4%	23.69	
Size5%	10.67	
social_rent_432.51%	21.22	Calculated using 'Corporatiebezit naar huurklassen en stadsdelen. 1 januari 2020'
social_rent_432.51_to_619.01%	53.37	
social_rent_619.01_to_663.40%	11.16	
social_rent_663.40_to_737.14%	14.25	
house_worth_to_221000	12.21	Calculated using 'Woning voorrraad naar stadsdelen en waarde van de woning, 1 janurari 2020 (procenten)'
house_worth_221000_to_310000	22.18	
house_worth_310000_to_385000	22.48	
house_worth_385000_to_511000	22.48	
house_worth_511000_plus	20.65	
new_houses_monthly	0.84	Follows the plans reported in the construction goal in [51], scaled down with the house supply in the simulation
new_houses_type	flat	
social_leave	disabled	Other values for these variables are used to introduce variations
old_large_house_leavers	disabled	
spouse_waiting_time	'always'	
building_waiting_time	'while_searching'	
migration	0.00	
migration_type	percentage of households	
shocked%	20%	These values are set according to the defaults in [16], from which the income shock system originates.
shock_size	20%	

Before discussing the experiments, the default configuration of the simulation is investigated with a sensitivity analysis.

5.1. Sensitivity Analysis

To have a better understanding of the effect of the input variables on the model outcomes, we perform a global sensitivity analysis using the Sobol method [52]. For Sobol, for each input variable of interest, a range of values needs to be provided (see Table 2). For values that require a boolean or string, a uniform distribution is mapped to the possible options.

Sobol assumes independent variables for its analysis, but the input settings for the sizes of houses and the sizes of the three sectors are represented as percentages. These variables need to add up to 100% and thus are dependent variables. Instead, it is possible to represent a set of dependent variables through a single independent value. The ability to see the the impact of each separate variable is lost; instead, only the impact of the set of variables together is known.

Table 2. Overview of the input variables analysed; for each value range, a data type is indicated.

Variable	**Range**	**Type**
seed	[100,000, 200,000]	Integer
maximum_simultaneous_reactions_social_market	[1, 16]	Integer
maximum_simultaneous_reactions_lottery_social_market	[1, 16]	Integer
supply_lottery	[0, 100]	Float
maximum_income_social_rental_market	[35,000, 45,000]	Float
social_leave	[True, False]	Boolean
old_large_house_leavers	[True, False]	Boolean
spouse_waiting_time	[always, never, divorce]	String
building_waiting_time	[while_searching, always]	String
new_houses_monthly	[0, 2]	Float
housing_sector_combinations	[0, 5150]	Integer
size_combinations	[0, 176,850]	Integer

Due to the large amount of output variables, the results are summarised in Table 3; the full results are provided in [47]. Mostly notable is the fact that the distribution of houses across sectors is often the most influential factor. While this is an interesting factor, its dominance makes the analysis of the lesser factors difficult. For the number of households, the interaction of the seed and the division of the market sector is most influential; the importance of the seed suggests that there is no connection between the inputs and the number of households. The large confidence intervals temper strong conclusions from the analysis.

Table 3. Overview of the output variables measured.

Variable (NoH = Number of Houses)	**Major Contributor ($ST > 0.4$)**	**Minor Contributor ($ST > 0.25$)**
NoH wanting to move out	new_houses_monthly	housing_sector_combinations
NoH motivated by divorce	housing_sector_combinations	new_houses_monthly
NoH motivated by too small homes	size_combinations	housing_sector_combinations
NoH motivated by social_leave	social_leave x housing_sector_combinations	
NoH motivated by old_large_house_leavers	old_large_house_leavers	
NoH motivated by high_rent	housing_sector_combinations	
Avg. age private sector	old_large_house_leavers housing_sector_combinations	
Avg. age social sector	housing_sector_combinations	
Avg. age owner-occupied sector	housing_sector_combinations	
Avg. age homeless	housing_sector_combinations new_houses_monthly	
Avg. rent private sector	old_large_house_leavers	size_combinations
Avg. mortgage size owner-occupied sector	housing_sector_combinations	
Avg. % of income spent in private sector	housing_sector_combinations	old_large_house_leavers
Avg. % of income spent in social sector	housing_sector_combinations social_leave	

Table 3. *Cont.*

Variable (NoH = Number of Houses)	Major Contributor (ST > 0.4)	Minor Contributor (ST > 0.25)
Avg. % of income spent in owner-occupied sector	housing_sector_combinations	
Number of Households	seed housing_sector_combinations	
Avg. waiting time of searching households		old_large_house_leavers building_waiting_time housing_sector_combinations
Avg. waiting time of successful renters	housing_sector_combinations	new_houses_monthly
Avg. waiting time all households	building_waiting_time	
Avg. waiting time low-income households	housing_sector_combinations	building_waiting_time
Highest waiting time	old_large_house_leavers	housing_sector_combinations

In the measurement for the average waiting times of all households, it is notable that the building_waiting_time input fundamentally changes how waiting time is accrued: this makes other factors less significant relatively easily. For policy changes, we therefore have to consider that it may not be possible to simultaneously—or with the same metrics—evaluate them.

5.2. Experiment 1: Changing Policy

Since regulation and policies are created and used by centralised organisations—principally national and local governments—policies are comparatively easy to change. However, decision makers request insight into the implications of contemplated changes on the housing market and citizens.

Four different policies present in the Dutch housing market are explored: 1. The size of the supply that is handed out using lotteries instead of selection; 2. The option for couples to posses two independent waiting times; 3. The number of reactions each person can use in a week; 4. The maximum income limit in the social sector. For conciseness, additional figures are provided in Appendix C.

5.2.1. Lotteries for Social Housing

In Amsterdam, social sector houses are assigned with two methods: lottery and selection. The selection prioritises the households with the longest waiting time while the lottery randomly selects from all eligible households that applied. As these systems are used side by side in practice, the question of how the simulation changes when a different amount of the supply is dedicated to the lottery is investigated.

For a higher degree of lotteries, Figure 2B shows that the social sector is younger. Conversely, Figure 2A,C shows that the 'homeless' and private rental households are older on average. Figure 3A,B show that, with a higher degree of lotteries, households with a lower waiting times are successful, and the average waiting time is higher.

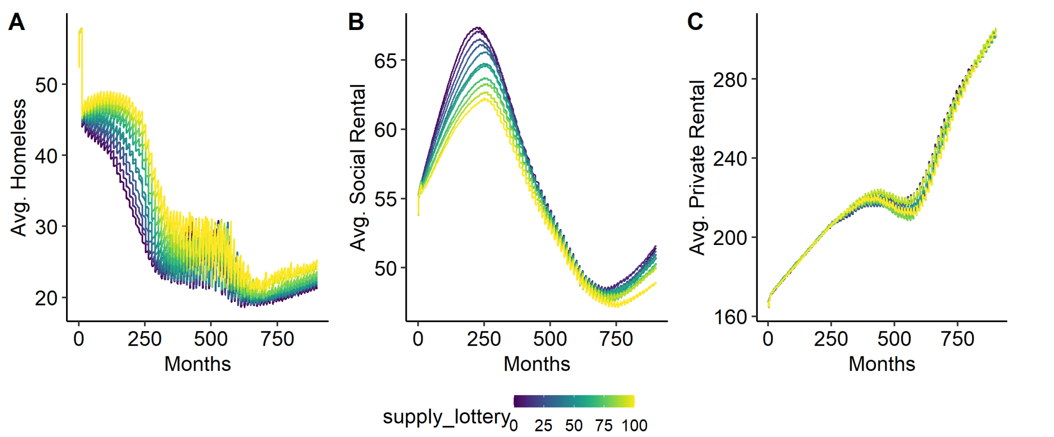

Figure 2. Age of households (**A**) who are 'homeless', (**B**) in the social sector, or (**C**) living with parents.

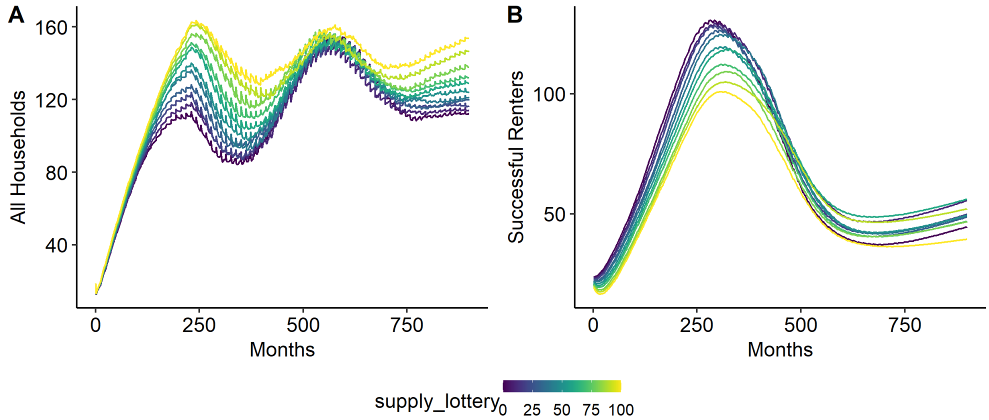

Figure 3. Average waiting time for (**A**) all households, and (**B**) all successful renters.

5.2.2. Divorce and Secondary Waiting Times

In the social market in The Netherlands, any person can be signed up twice: one time as registrant and one time as co-registrant. A co-registrant does not build up any time, but it does allow one to search for a home for both the registrant and the co-registrant. This results in a couple having two separate waiting times by both independently signing up and being each others co-registrant, potentially giving an advantage over a single-person household.

The benefit of this system is that, should these partners divorce or split, the partner that was a co-registrant does not have to start building their waiting time from zero. To investigate the potential impact of this benefit for couples, an experiment with alternative systems for the waiting time of the co-registrant is created.

Consider Figure 4. Firstly, one can see the variation effect on households with the motivation 'relationship ended' in Figure 4B. If the second waiting time is dedicated to divorce, then the fewest households are searching with this motivation; if the second waiting time is not used, then the most households are in this category. The differences seen in Figure 4A in waiting times are higher for divorce, because the waiting times function differently in each variation—some waiting times are reset less often in the 'divorce' variant.

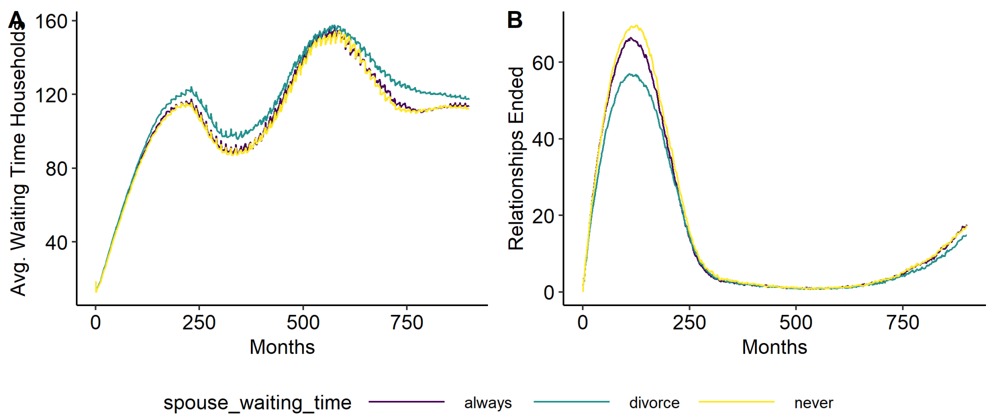

Figure 4. After a relationship ended, the (**A**) average waiting time, and (**B**) number of households unable to find a home.

5.2.3. Maximum Number of Reactions

The social market assigns houses using selection rules to assign a house to households appropriately. A limitation to this system, however, is that a house will be assigned only to one of the households that reacted to the house. This means that the household that theoretically would be the best fit for the house might not have reacted to it. Altering the number of maximum reactions a household can make leads to it being more or less likely that the best-fitting household is able to react to the house, changing how efficiently the houses are utilised.

Slight differences are seen in total number of searching households in Figure 5B, where the scenario with 12 monthly reactions is slightly more favourable. It should, however, also be considered that a larger amount of reactions can be impractical due to households not being required to accept a house and needing time to inspect it.

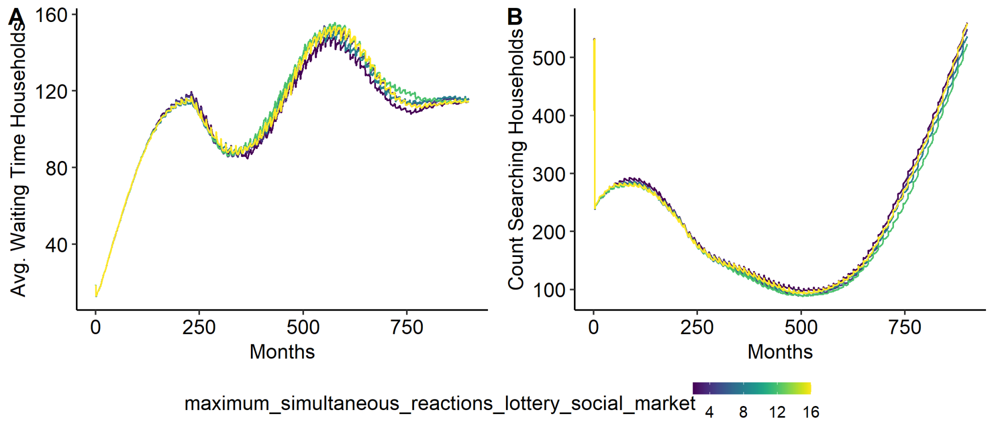

Figure 5. (**A**) average waiting time of households, and (**B**) number of households looking for a home.

5.2.4. Increased Income Limit for Social Housing

In The Netherlands, households with middle incomes have a hard time purchasing a house; for this problem, increasing the income limit of social housing is proposed as a solution. This experiment changes the income limit to investigate the effects.

Most clear are the results in Figure 6; the group of 'homeless' households is slightly younger, while the social sector is slightly older.

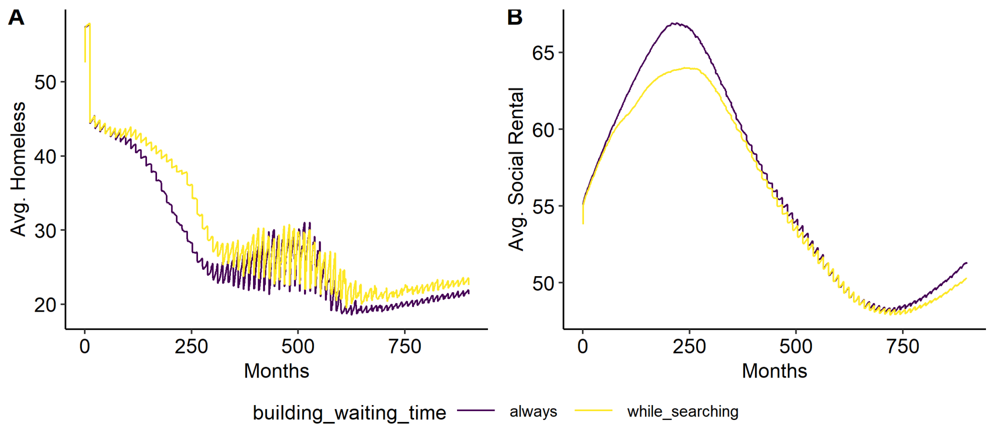

Figure 6. (**A**) average age of households without a home or living with parents, and (**B**) average age of households socially renting.

5.3. Experiment 2: Changing Behaviour

Having studied policy changes, in the second set of experiments, we study how the simulation outcomes change if behaviour is modelled differently. We look at two concepts: (1) a different way for households to accumulate waiting time; (2) a willingness to help other households. Creating a bottom–up change in behaviour may be more difficult in reality than changing top–down policies, as the choice of every individual household matters. Nevertheless, it is valuable to consider whether the change in behaviour is effective before considering how the behaviour could be changed.

5.3.1. Waiting Time for Social Housing

As a default, the assumption is made that households are always signed up for the social sector, as this is the optimal strategy if the sign-up fee is disregarded. If a household is signed up, then the household passively builds up waiting time, regardless of their circumstance. The only way for the waiting time to be reset is if the waiting time is used, or the registration lapses. In this experiment, we investigated what happens if, instead, households can only build up waiting time while they are actively searching in any market. This prevents households that are currently happy in their home from building up waiting time pre-emptively, and can—to a certain extent—model households in the social sector that do not sign up again after receiving a social house.

Figure 7A shows a clear decrease in the waiting time present in the simulation as the time in which waiting time can be built up is limited. Figure 7B shows that younger households obtain access to the social sector.

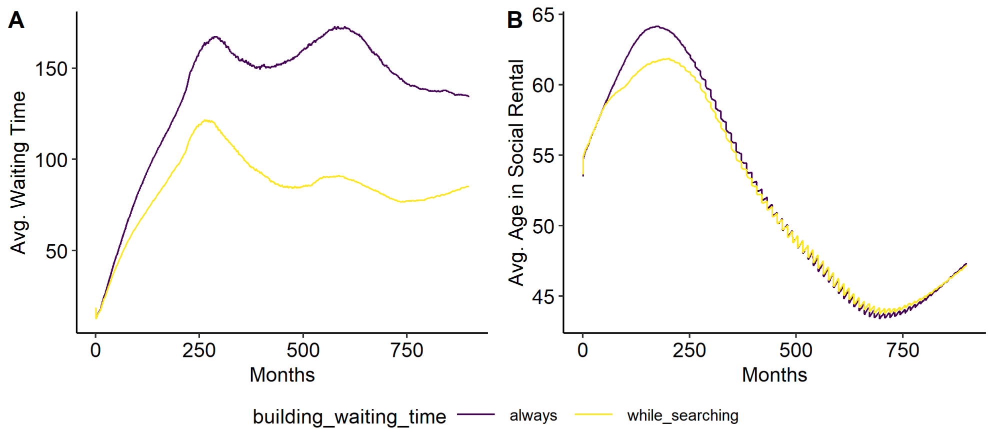

Figure 7. (**A**) average waiting time of households, and (**B**) average age of households socially renting.

5.3.2. Willing Social Market Leavers

In the Dutch housing market, there are two common occurrences which lead to inefficient or unintended usage of houses. First, the cheap-skewed renters, which are households that live in the social sector but now earn above the maximum income to enter the market. They are not part of the target group of social housing, but still use a resource for this group. Secondly, empty nesters, who are parents whose children have moved out but who still inhabit a large house that could house a family instead. These households could be incentivised to search for more fitting homes. In this experiment, we investigated what would happen if all these households would be successfully nudged to start searching.

The first observation, as shown in Figure 8A, is that an increase in rent occurs for both variations where older households try to free family homes. Figure 8B also shows a longer waiting time for households which are able to enter the social sector for these variations. For the variation (true, false)—where only households intentionally leave the social sector—the waiting times in Figure 8B are decreased compared to the baseline.

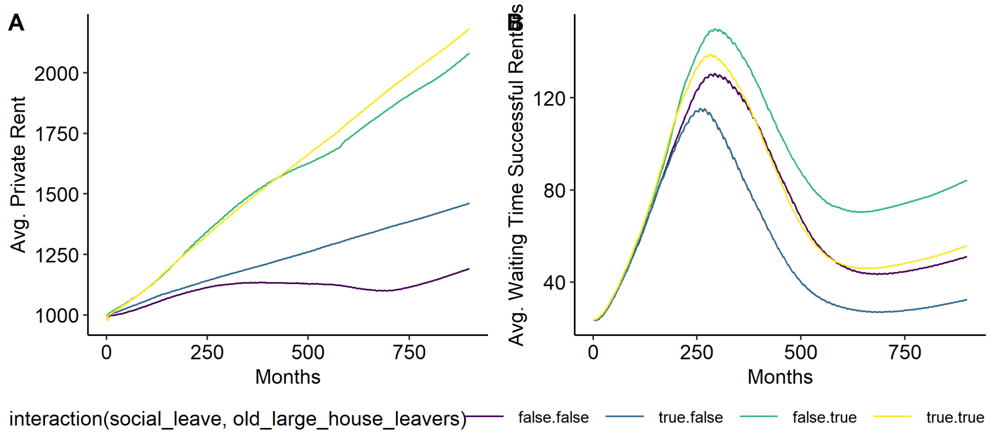

Figure 8. The (**A**) average private rent, and (**B**) average waiting time for renters successfully entering the social sector.

5.4. Experiment 3: Changing Environment

The final set of experiments study variations in the environment, in order to understand their impacts. The simple migration mechanism is considered first to examine how influential its inclusion can be. Then, different supplies of houses are considered: the sizes of houses and the size of market sectors are varied.

5.4.1. Migration

In this experiment, the impact of migration is tested: households that leave due to, moving out of the city for a new job, for example. We note that migration was previously excluded from the sensitivity analysis due to its large impact on run time.

While motivations to move are decreased by increased migration rates, the total number of searching households increased, as seen in Figure 9. The additional figures in Appendix C show differences in the motivations for agents' searching, reported in (Figure A7e).

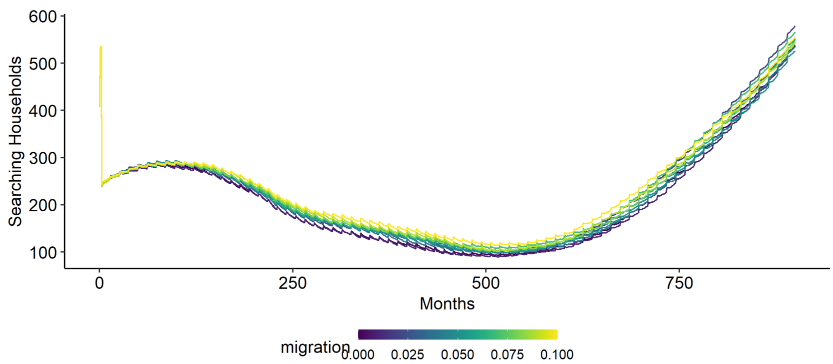

Figure 9. Number of households searching for a home.

5.4.2. Varying Size Compositions

Recall that the default composition for houses in the system is the composition in Amsterdam (Table 1). As the composition does not change over time, we investigated whether a different composition of houses can decrease the desire to move in the market. In this experiment, the size compositions are altered, as a tuple of percentages (Size 1/2%, Size 3%, Size 4%, Size 5%).

Figure 10 shows that fewer households with larger houses are searching for new homes. The compositions (0, 0, 0, 100) and (10, 20, 30, 40) have similar performances. The full maximum size house composition (0, 0, 0, 100) actually prevents more people from moving out but has no problems regarding the size of houses. In contrast, the (10, 20, 30, 40) composition has fewer problems when relationships end or when people want to move out (compare [53]); but in return, there is a problem with too-small houses. Additionally, Figure 10 shows a much lower private renting ratefor the (0,0,0,100) composition.

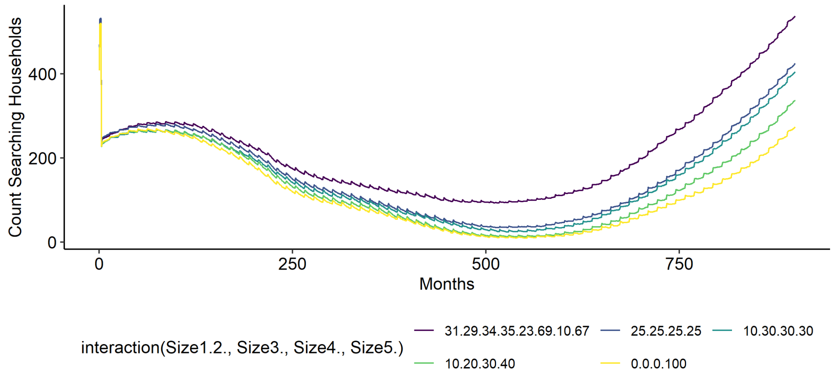

Figure 10. Number of households searching for a home and average monthly rent paid in the private sector.

5.4.3. Varying Market Compositions

The default composition for houses in the system uses the composition in Amsterdam. As the composition does not change over time, we investigated whether a different composition of houses can decrease the desire to move in the market. In this experiment, the market compositions are altered.

Figure 11A shows that, for both variations with an increased owner-occupied sector, there are more searching households. Figure 11B shows that, for private rentals, a larger private sector (and smaller owner-occupied sector) has the lowest private rental rate. Notably, in the latter sub-figure, one can see an apparent temporal reversal in the role of sector composition. This is interesting for future study.

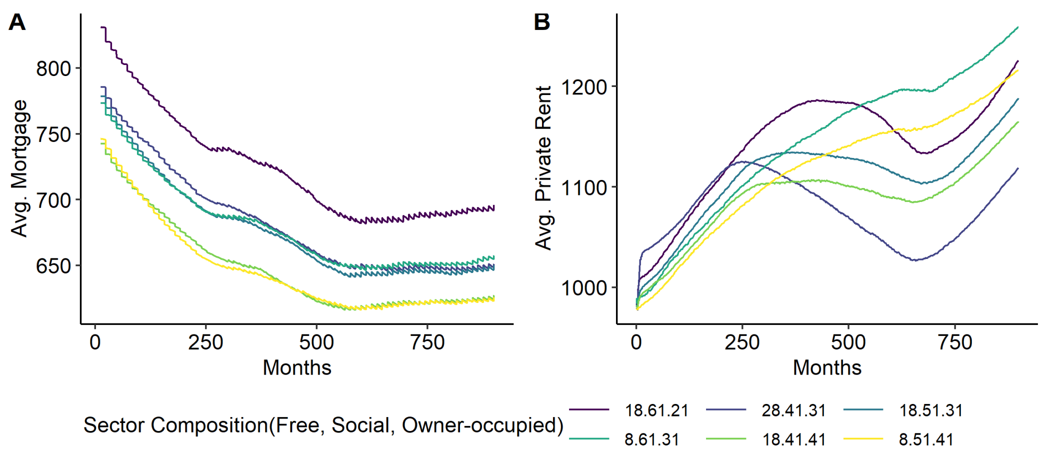

Figure 11. (**A**) Average monthly mortgage payment, and (**B**) average monthly rent paid in the private sector.

5.5. Discussion

Summarising this section, the experiments indicate that the ABM is effective in considering the effect of different scenarios on the demand of households. The clearest results are seen in Section 5.2.2—the secondary waiting time is influential in the success of divorcees finding a different home—and in Section 5.3.2, which suggests that empty nesters leaving large homes have a bigger negative effect through an increased demand. This is in comparison with the positive effect they have on utilisation due to families using their large homes. Furthermore, the results on selection versus lottery in Section 5.2.1 are interesting—that lotteries favour starters to the detriment of those families who have been waiting longer for social housing. The results for the income limit for social housing in Section 5.2.4 are also interesting; this adjustment helps older starters and older (non-starter) households, to the detriment of poorer or younger households. Other results have less significant outcomes, in line with the exploratory nature of this work.

5.5.1. Limitations

The significance of the conclusions from the other scenarios is lower, due to the current scale of the simulation. The ABM reported in this paper is detailed, and includes modelling of (medium/long-term) population growth and the addition of new housing stock. Increasing the scale and time span can be achieved by abstracting some market details. Indeed, to further investigate cyclic demand–supply behaviours and long-term consequences, an alternative model design can be considered in which the number of houses is defined in relation to the size of the population as a cyclic function. This would allow for the stronger control of an expected supply of houses over a simulation course.

A second limitation with the implemented model is the disentangling of specific causes of internal demand. Here, there are two points to note. First, because only one motivation can be reported at any given moment, the experiments cannot show that a *specific* demand has reduced since households may have a different kind of demand preventing the targeted demand from being reported. Second, because the motivations are aggregated, the detail at the household level is lost. This manifests with no measured difference between a small group of households experiencing problems over a long period of time and a large group of households experiencing problems for a short period. To resolve this issue, the temporal extent of motivations also needs to be measured. It may also be useful to expand motivations to measure the reasons households are unable to find a home in addition to why they are unhappy with their current home.

We note that the primary research question is largely unaffected by these points, as the specific cause of demand does not change the total demand. Further, the ABM methodology is successful in flexibly examining policy changes and new policies. Only some policy changes cannot be covered by existing household behaviour, such as the different styles of secondary waiting times allowing for different long-term strategic behaviours. Researching this particular aspect is better served by algorithmic or game-theoretic approaches, which can explore which strategies are effective.

In all three experimental sets, a trend is seen in the number of households—the number of households rapidly increases after roughly 45 years. This coincides with the moment in which the number of houses temporarily exceeds the number of households. The cause of this phenomenon is partly the way in which relationships function. (When relationships are ended, one partner might maintain custody of all children, while the other one becomes independent. The split-off partner might then form a new relationship and choose to have more children in this relationship. Additionally, relationships can form between two households with many children, which might end, leaving another person without children.) An option to mitigate this is to introduce gender as a factor in the analysis; here, the number of children accounted for might depend on how many children a woman has had before. This can contribute to the number of children born independently of a current relationship. We also note that, in the model, the lack of a house does not prevent childbirth; this might not be the case—and could be more restricting—in real life.

Finally in terms of the limitations of the current model, there are two (smaller) design limitations which became apparent during the experimentation. First, the simple market mechanisms for the private rental and owner-occupied sector are not flexible enough to function well during, e.g., an abundance of houses. Second, childbirth is only dependent on the age of the household and number of children currently living at home. When all children are moved out, this can cause children to be born that are not born in reality, especially as the model considers that children look for their own home early in adulthood.

5.5.2. Validation

For the kind of ABM that this paper develops, as [34] points out: "The real outcome of the model is not the experimental results so much as an increased insight and knowledge and that outcome can be validated through several different methods". Part of the knowledge pertains to the model design and the pointers to follow-on the ABMs discussed above. Part of the knowledge applies to the real Dutch housing market. Here, we can say that policy makers have a broad simulation tool. For examining specific policy questions, further modelling and experiments with more narrowly scoped ABMs are recommended; we discuss these opportunities in the next section.

We remark that validation via historical replay is difficult due to the lack of data; it is more likely to be the case for more narrowly scoped models. Moreover, the ABM developed thus far is a long-term, forward-looking simulation. In this regard, there is not an obvious path to compare with the market in, for instance, 2050.

6. Conclusions and Future Work

In the context of the Dutch housing market, this paper argues that the interaction between choices of households and regulations in the social-rented, private-rented, and owner-occupied sectors shapes the choices of households. The goal is to provide a path to greater transparency into the pros and cons of current and contemplated policy measures. The specific question we investigate is the following: how is internal demand impacted by regulations in a housing market that is suffering from a shortage? The behavioural interaction between households motivates the approach of developing an agent-based model. With it, we examined the effects of regulatory policy by means of exploratory simulations. To our knowledge, this is the first ABM that captures the important social rental sector of the Dutch market.

The simulation results find that, in the social sector, selection may be preferable over lottery due to the bias of the latter towards households that already own a home. These households leave a home which then, in turn, can satisfy a different household. This first satisfies a part of internal demand, and then creates a new opportunity to fulfil other demand. What is important to consider here is the impact on specific parts of the housing market. For example, lottery is preferable for younger households without a home. It is important that, when considering internal demand, those who are not yet part of the housing market are still considered; policies should not only prioritise those who are already part of the sector. Policies that focus only on 'fixing' internal demand might end up shuffling people in the sector instead of allowing new entrants into the sector.

The metric of 'secondary waiting time' can be effective in helping split households to find a home, but has unclear effects on other households. This metric focusses on a specific type of internal demand. An open question is the impact of households using the secondary waiting time in a strategic manner to gain an advantage; the benefit of secondary waiting time for divorcees might not weigh up against the downside of its strategic use by (other) households. Here, the focus is on a specific type of internal demand, and we note also the 'gap' between what the rules allow and what households might—in principle—do, as strategic exploitation of secondary waiting time requires intentionally and effort.

Increasing the income limit for the social sector is found to favour older households. We note that such a 'solution' to the housing shortage, namely increasing income limits, does not address root causes: it does not address any internal demand or systematic issues (as all data points between scenarios converge over time) but rather temporarily shifts the burden onto younger households. Perhaps more promising, and more direct, specific policies for older households, namely encouraging them to move from larger houses or apartments to smaller ones, have been introduced in Amsterdam at the time of writing.

Market policies that encourage a change to behaviours—designed to increase housing stock utilisation—can instead spur demand. An example is the just-cited policy of downsizing for older households. With respect to behaviour changes, further study is warranted, as experiments could measure households' motivations more carefully; triangulation with household survey and panel data is a promising direction.

Since an ABM is a deliberate abstraction of reality, it should be noted that the presented model does not intend to predict the fiscal future of the housing market. While rich in descriptive detail, the developed model is somewhat limited by its smaller scale and shorter simulation time span than originally envisioned, together with some design limitations that have been found. In this regard, there is a case for a less detailed—but not overly simplified—model if the whole system is to be simulated [44,54]. Such a more narrowly scoped model or models might also result in more significant outcomes. Nevertheless, the experiments reported here have led to some interesting suggestions for the original research question and multiple directions for future work.

First, it is recommended that alternative designs for the way the population is simulated are considered, in order to improve the scaling of the execution time with an increased simulation time span. This will allow experiments to consider the effects over multiple generations. With this, the measurement of motivations can be expanded to measure multiple motivations and to consider the length of time that households hold these motivations.

Second, the composition of the housing sector neglected the small 'senior housing' part of the social rental sector. A recent government policy is to build more homes that are dedicated to older couples or singles. Further, one can allow the relative size and distribution of house sizes to change over time; indeed, the three sectors can be expected to expand at decoupled rates.

Third, some policies can be examined with a restricted model that encompasses only the social sector. A narrower, social-only ABM with a greater degree of abstraction would allow us to study the consequences of agents needing time to inspect houses (and possibly refusing a house after an inspection)—a salient factor to correctly understand the practical limitations of an assignment system. Additionally, agent preferences and the existence of multiple separate regions in the social sector could be considered. Likewise, a narrower, private-only ABM could examine the shift to temporary rental agreements in the private sector [55].

Fourth, a contemporary debated political question is where and how many new houses to construct, to address the fundamental imbalance of greater medium-term demand than housing supply. The results in Section 5.4.2 suggest that larger houses reduce demand, as expanding families do not need to move. Building larger houses, however, requires more space, resulting in a smaller total supply. This can be investigated in two steps: the trade-off between house size and the amount of houses—which can consider both monetary cost and spacial cost—followed by using the trade-off to setup different scenarios for either a model or simply to compare the results to the known demand.

Fifth, the consequences of couples being able to utilise two separate waiting times can be explored further through the view of optimal strategic behaviour. A related point is that different regions use different selection rules to select winners. The (strategic) consequences of these different policies are ripe for study [56].

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Details about the Dutch Housing Market

The appendices provide details about the market under study (this Appendix A), full details of the model (Appendix B), and further experimental results (Appendix C).

Further to Section 2, this appendix provides more details about the three sectors of the Dutch housing market.

Appendix A.1. Social Rental Sector

Appendix A.1.1. Selection

The system for allocating houses to households can have different forms; the most common method is through the use of 'waiting time'. In the 'waiting time' systems, people sign up for a regional system and start gaining points every month that they are signed up. The requirements to be signed up are being above 18 and being allowed to live in The Netherlands. A small fee has to be paid yearly to each regional system by the person who is signed up.

Houses are published on the system and people can apply to be selected for up to a maximum of two houses simultaneously. Not every person can apply to every house: 'passend toewijzen' [57] limits which rentals can be matched to which incomes, and the corporations further impose additional restraints depending on the intended usage of the house, such as allowing only youth, seniors, or families to apply. The person with the most points (the longest waiting time) is selected first to inspect and either reject or accept the house. If a person rejects it, then the next applicant in the ranking is selected.

An exception exists in this system: Households can be given priority, which means they are ranked above all other applicants. If households with priority reject a house three times, then they lose their priority.

The other common variant, besides the waiting time system, is a lottery, which utilises the same restrictions for who can apply; here, a random application is selected from all eligible applicants. These two systems often exist side by side. The lottery can then provide houses for households with a shorter waiting time, who may be more willing to accept a less suitable house.

The lottery also limits persons to two applications simultaneously, separately from the applications to the non-lottery houses. However, in this system, a household exists as a registrant, their dependents, and a potential co-registrant. A person can be both registrant and co-registrant, which means that two partners can both be signed up as registrant, become co-registrant to each other, and in this way exist as two separate entities in the system. Effectively, they can double their maximum amount of applications, and accumulate two separate waiting times.

There are two ways a registrant can lose their accumulated points: either by accepting a house or by ending their registration. In the aforementioned case of partners, only the registrant loses their accumulated points; the co-registrant does not.

Appendix A.1.2. Cheap-Skewed Renters

Households in the social sector might increase their income above the maximum income that a household is allowed to have if they want to enter the social sector; they can then be considered cheap-skewed renters. A 'too high' income, however, is not a legal reason for a landlord to end a rent agreement [58]. What is different for these households with a higher income is that their rent can be increased more than their lower-income counterparts [59]. The increased rent, however, may never exceed the maximum rent decided by the 'Huurcommissie' [60]. It should be noted that the maximum rent for a house can be higher than the liberalisation limit. This faster rent increase may motivate households to leave the social sector if the cost becomes comparable to the private or owner-occupied sector.

Appendix A.2. Private Rental Sector

Rent Increases

The initial rent in the private sector can be set freely by the landlord, rent increases, however, are more regulated. The law restricts general rent increases to be limited to once every 12 months for existing contracts.

There are two mutually exclusive ways to increase rents. The first option is by including a rent increase clause in the contract; this can take many forms, e.g., a yearly percentage increase or matching market rents every five years.

The second option is by proposing a rent increase to the renter. If they do not accept this increase, then the case can be brought before a judge who can decide whether the rent increase is justified. If the judge does think the rent increase is justified, then the renter has one month to either accept the rent increase or end the rental contract [61].

Traditionally, rental contracts in The Netherlands have been of unlimited length, with the methods of ending a rental contract from the side of the landlord being limited to cases such as the aforementioned disagreement on a rent increase. Additionally, the cancellation period starts at 3 months and can increase up to 6 months depending on how long a household has lived in the home [58].

There has, however, been a increase in the prevalence of temporary contracts in the Dutch housing market, as noted by [55].

Appendix A.3. Owner-Occupied Sector

Appendix A.3.1. Mortgages

Households buy houses in this sector through a combination of savings and mortgages. The mortgages are strictly regulated and this regulation is one of the ways the national government influences this sector. Many different forms of mortgages have existed over the years; but, currently, only two forms can benefit from mortgage interest deductions—annuity and linear mortgages [62].

The linear mortgage divides the mortgage payment equally over each month and adds the interest, resulting in a decreasing monthly payment. The annuity has a constant monthly payment from which the percentage of that monthly payment paid for interest decreases when the leftover mortgage decreases. Because of mortgage interest deductions, the effective cost of annuity mortgages increases each month, but they benefit more from the mortgage interest deduction compared to linear mortgages.

How large the maximum mortgage for a household can be depends on the income(s) of the household, whether they are state pension beneficiaries, and the interest on the mortgage. The exact calculation for a mortgage is redesigned yearly through the advice of the '*Stichting Nationaal Instituut voor Budgetvoorlichting*' [63]. Banks giving out mortgages can deviate from this calculation if they provide a good reason.

Appendix A.3.2. Auction and Negotiation

The buying and selling process for houses is regulated based on what is in a transaction agreement, e.g., the seller's liability for undisclosed known defects, but not on the process of coming to an agreement.

Nevertheless, most transactions are organised by real estate agents. The largest association of real estate agents in The Netherlands is the '*De Nederlandse Cooperatieve Vereniging van Makelaars en Taxateurs in onroerende goederen*' (The Dutch Cooperative Association of Real Estate Agents and Valuers). This organisation claimed a market share of 69% in 2020 [64,65]. This organisation has guidelines that shape the process of agreeing to a transaction.

The first process they use is direct negotiation, the only restriction being that they are not allowed to play out multiple bidders against each other. Concretely, this means they should not communicate the bid of one bidder to another, and only have back-and-forth negotiation with one bidder at a time. They can still communicate that a bidder would need to bid higher to continue negotiations. These rules also do not stop new bidders from inspecting or bidding on the house.

The second process is used to expedite the process when there is larger amount of (serious) bidders. It is essentially a blind, single-bid auction, called 'bieden bij inschrijving', where all potential buyers can bring out a bid and the seller chooses the winner. The winner is not necessarily the highest bidder, but the bidder with the most favourable conditions for the seller. The information revealed in this auction is limited to the bid of the winner.

The understanding of these processes has been achieved partly through an interview with an anonymous real estate agent in November 2020. This real estate agent also stated that, in their experience, this auction is currently more common than it was twenty years ago.

Appendix B. Details of the Agent-Based Model

Further to Section 4, this appendix provides all details of the ABM design in line with the ODD protocol [45].

Appendix B.1. Purpose and Patterns

The main purpose of the model is to create a description of the Dutch housing market, especially the Dutch social sector, as there is no prior work that simulates it. Since this goal alone is not clear enough to asses what the model needs to contain, we additionally try to understand how regulations in the housing market affect the demand of individual households. This is encapsulated in the research question articulated in Section 1: how is internal demand impacted by regulations in a housing market that is suffering from a shortage?

Due to the uniqueness of the Dutch social sector, the relative slow speed of housing markets, and the often-changing laws related to housing, there are no data available to base a pattern on that can be used to determine the correctness of the model outcomes. Nevertheless, we still have expectations for a housing market during a shortage: growing waiting lists, 'homeless' households, growing rents, growing housing prices, and an imperfect match between homes and households.

We aim to create a descriptive model, using the available documents, data sources, and interviews with real estate agents.

Appendix B.2. Entities, State Variables, and Scales

The model includes the following entities: persons, households, houses in the private rental, social, rental, or home-ownership sector, and the observer. The households and houses are the key components of a housing market, while the observer represents the environment in Netlogo. The choice to model all three market sectors was made due to the motivation of a household to leave a sector being dependent on the costs in another sector. Persons are an abstract entity in the system and are always part of a household, but are able to leave a household to create an independent household.

A single collective exists in the model—a relationship that is forming but where both partners have a house that is not large enough for the combined household. This collective has no state variables, as it is a connection between two households. This will be further explored in the relationship sub-model in the sub-model section. The state variables for the observer, houses, persons, and households are recorded in Tables A1–A4, respectively.

Table A1. State variables of the observer.

State Variable	Variable Type and Units	Meaning
months	integer, dynamic, months	The number of months simulated since the start of the simulation.
new_houses_progress	float, dynamic	If the number of houses to be built is not a natural number, this variable stores the remainder as progress to the next house to be built.
migration_progress	float, dynamic	If the number of households to be migrated is not a natural number, this variable stores the remainder as progress to the next household to be migrated.

Table A2. State variables of houses.

State Variable	Variable Type and Units	Meaning
status	string, dynamic, 'occupied' or 'empty'	Whether a house is currently occupied by a household.
house_size	integer, static, [2,5]	The size of a house—as a living room plus a number of bedrooms.
quality	float, static, [0,1]	The quality of a house.
		Additionally, for owner-occupied houses:
status	string, dynamic, 'occupied', 'for_sale' or 'preparing_sale'	Indicates whether a house is occupied, for sale, or empty but not yet for sale.
sale_prices	list of integers, dynamic	The prices that the house has been sold at in the past.
offers	A set of offers made by households, dynamic	A set of offers made by households.
		Additionally, for private rental houses:
rent	integer, dynamic	The current rent of the house.
		Additionally, for social rental houses:
assignment_type	string, static, 'selection' or 'lottery'	Whether the winner of the house is chosen through lottery or selection rules.
rent	integer, static	The rent of the house.

Table A3. State variables of persons.

State Variable	Variable Type and Units	Meaning
age	integer, dynamic	The age of a person.
birth_month	integer, static	The month a person is born in and after which they become older.
waiting_time	integer, dynamic	The waiting time a person has accumulated for the social sector.

Table A4. State variables of households.

State Variable	Variable Type and Units	Meaning
adults	list of persons, dynamic	Represents the adults present in a household.
children	list of persons, dynamic	Represents the children present in a household.
household_type	string, dynamic, 'single' 'unmarried_pair' 'married_pair' 'single_parent' or 'forming_relationship'	An indicator of the composition of the household, whether a pair is married and whether the household is in the process of being formed.
mortgage	float, dynamic	The outstanding balance of a mortgage.
mortgage_time_left	integer, dynamic, months	The amount of months until a mortgage is repaid.
income	float, dynamic, euros	The yearly (standardised) income of a household.
searching_reason	string, dynamic	The reason a household is searching for a different house, if applicable.
house	house, dynamic	The house a household currently inhabits.

Housing corporations are excluded as an explicit entity but are instead encoded in the behaviour of houses in the social rental sector. Similarly, landlords are encoded in the behaviour of houses in the private rental sector. Real-estate agents are excluded to simplify the model, but their influence can be seen in the behaviour of houses in the owner-occupied sector.

Spatial factors are not modelled, but the model assumes that each household present in the simulation has no housing options besides those modelled. The 'space' modelled is the entire housing market of interest for the households present. This assumption is necessary to measure the motivations of households that are searching—to claim that a household cannot find a large enough house, all possible houses must have been considered.

We weighed up whether explicit spatial interactions among agents would aid the study of our main research question. As noted in Section 3.2, some prior works, such as [16], have taken this approach. In the context of our main research question, spatial factors are secondary in the decision-making of households. That is, we are less interested in which district a household moves to than we are in the characteristics of the household, the house, the process, and the behaviour of the market.

The model runs at 1-month time steps, while the housing market functions every day; by choosing a larger time step, less processing time is need to run a longer simulation; meanwhile, most processes in the model follow the 1-month time step, and income shocks happen every 12 months. Auctions for owner-occupied houses take 2 months to complete. Ideally, the simulation length would be infinite, or at the very least it should consider multiple generations to see cyclic behaviours, but the simulation length of the implementation is limited by the population growth which exponentially increases the run-time.

Appendix B.3. Process Overview and Scheduling

In order to model the housing market, processes are included to model the environmental changes (migration and the addition of new houses), the housing sectors (advertising, reactions, and selection of winners, the increase in waiting times, mortgage payments), and the changing needs of households (childbirth, deaths, income changes, relationship forming and breaking, the evaluation involved in a search, and children moving out). Finally, the process of households searching for houses is the main matter that makes these components interact.

The schedule in each tick is as follows:

1. The environment adds new houses and forces households to migrate.
2. Households evaluate whether they want to start searching for a new house.
3. Households searching evaluate whether they want to stop searching for a new house.
4. Houses execute the 'advertise' sub-model.
5. Households react to advertisements.
6. Houses select winners using the 'selection' sub-model:
   (a) Owner-occupied houses select winners and are occupied by the winner.
   (b) Social rental houses select winners and are occupied by the winner.
   (c) Private rental houses select winners and are occupied by the winner in the order of the ascending rents.

   Households that win a house update their house state variable; owner-occupied houses that are won update their `sale_prices` state variable. Any house that is left sets its state to 'empty'; private rental houses also update their rent state variable.
7. The 'relationship' sub-model is executed:
   (a) Relationships are ended, splitting households into two households.
   (b) Relationships are started in a random order, combining two households into one.
8. Every 12 months, households update their income state variable through the 'income shock' sub-model.

9. Households execute the 'population' sub-model, updating all but the house and income state variables:
   (a) Add 1 month to all waiting times of adults.
   (b) Update the age of children and adults if it is their birth month.
   (c) Check whether a child is born in the household.
   (d) Households check whether their household_type has to change.
   (e) Check whether children or adults decease; if all adults are deceased the household, including surviving children under or at 18, are removed, then update the status if a house was occupied.
   (f) Households check whether their household_type has to change.
   (g) Children above or at 18 form their own households, but are still considered a child of the current household until they find a house to move to.
   (h) Households pay their monthly mortgage and update their mortgage and mortgage-time-left state variables.

The addition of new houses and migration is carried out first so that the new houses and released houses and households can act in the same step. Households evaluate whether they want to search for a new house and then evaluate whether the original reason they started searching remains relevant. Households decide whether to search before the searching process begins so they can start searching in the step in which they made this decision. As households first evaluate whether they want to start searching and then whether their reason for searching is still relevant, households that lose their original searching motivation use one month to reevaluate their searching goals.

Advertising is the first step of the searching process; houses communicate to households. This is followed by households searching and applying to the houses and then houses selecting winners. No other processes are present between these three steps to ensure that every application made is relevant, and that no house or households has changed to make the advertisement or offer fall through, e.g., a household could have a change in income, making them ineligible for the social sector or unable to afford a bid made. The order in which houses advertise or households react is not important, as advertisements and reactions are always considered as a group and never in a specific order.

Selecting the winners of houses is order-dependent, as any winner selected is unable to win a different home. The assumption is made that households have some influence on the order in which houses are allocated. It is assumed that households meet the following characteristics:

- Prefer to own a house, since, in a shortage, houses generally increase in value.
- Prefer the social sector over the private sector, as the social sector is systemically cheaper.
- Prefer cheaper private sector houses over more expensive ones.

This results in all owner-occupied houses selecting winners first in a random order, then all social sector houses in a random order and finally the private sectors houses in order of ascending rents. The random order of social sector and owner-occupied houses is chosen to simulate that the houses are allocated in some order and that households have to accept or reject a house before knowing their result for other allocations. Rather than assuming that every households accepts each house the random order is used to consider a random valid allocation with low computational costs. The ascending order of rents for private houses is to simulate that cheaper private rental houses compete with each other through their rent, meaning that a more expensive house may have no interested parties because they found cheaper alternatives.

The tail end of the tick processes the changing composition and needs of households; this block could be carried out at the start of the tick, but by placing it at the tail end, it becomes possible to use the first tick to finalise the initialisation. The block cannot be placed between the searching process and the evaluation to search, as this would mean households are searching even though they no would longer feel that they need to search.

Relationships are first ended and then started because the original data do not measure relationships that are shorter than a month. Relationships are handled before the population sub-model, as changes in relationships change the chances of childbirth and death. The income shock is carried out after the relationships to ensure the shock is only applied to households that will exist in the next tick; it is carried out before the population sub-model so that the income shock does not affect children who have turned 18. For these children, their income has been newly generated; a change in this income would not be experienced as a shock but as a different starting income. This is carried out yearly to simulate a change in jobs and wages over a lifetime.

The order in the population sub-model is important for sub-steps 9b–9e; the ages of persons in a household influence whether a child is born or whether someone dies. Childbirth is dependent on the amount of people present in the household, but both the order of births and that of deaths are equal.

Appendix B.4. Design Concepts

Appendix B.4.1. Basic Principles

The basic principle of the created model is to describe the functioning of the Dutch housing market in an abstract manner. This model is based on the laws and regulations that form this market. The benefit of creating a model to describe the market is that, while creating a program that implements this model, the modeller is forced to ask questions to make the program complete. The agent behaviour focuses on households trying to optimise outcomes for themselves, as we lack a good understanding of agent behaviour, especially for the social sector. As there is a focus on the motivation of households to search, we aspire to model both the complete population and the complete housing market; there are no households not reporting their motivation and there no alternatives for households we do not consider.

Appendix B.4.2. Emergence

The emergent results of the model are the motivations for moving which are present in the simulation model, the average of age of households in various sectors, the average waiting time of all households, and the average waiting time of households successfully renting a social rental house.

All model factors influence the emergence of these results; the competition for the limited supply of houses is due to the changing needs, which decide which households inhabit which house at any given moment.

The number of households in the simulation is caused by the life events of childbirth, death, and relationships forming or ending. The probabilities are (largely) independent of the availability of houses. A small exception exists for relationships that are delayed in their forming due to neither partner having a large enough house, but the variability caused by this interaction is minimal.

The motivations for moving are the most important result, as they show the situations in which someone is unable to find a house. The other values are important depending on which variation in policy is being studied.

Appendix B.4.3. Adaption

Owner-occupied houses and private rental houses have an adaptive behaviour to set their auction price and rent price, respectively. Owner-occupied houses set their listing price to be equal to the mean latest sale-price of ten owner-occupied houses that have the most similar qualities. This design tries to model the idea that the price of a house is dependent on the (recent) sales of similar houses.

Private rental houses set their rent equal to the mean rent of all private houses times 1.2; additionally, for every month in which nobody is renting the house, the rent drops by 25 (but never below its minimum rent). This design models a slow Dutch auction; here, every month, the price is decreased until someone accepts. The mean rent is used as a basis because rent contracts in The Netherlands do not have a determined end. This way, houses that have been rented a long time ago can quickly catch up. The multiplication by 1.2 and the monthly decrease of 25 have been manually calibrated, and do not work for all circumstances.

Households firstly adaptively decide whether they want to search for a different home. Households decide to search for a different home if they are 'homeless', living with their parents, paying too much, or living in too small a home. Additionally, there are variants in which households decide to search if they are cheap-skewed renters in the social sector or when the household is an empty nester. The objective measures for these statements will be discussed in the subsection objectives below. If the condition that originally triggered the searching process is no longer true the searching process is ended.

Secondly, households adaptively decide which houses to apply to or bid on. Households apply to as many social houses that fit their needs and that they are allowed to apply to. If there are any owner-occupied houses which a household considers itself to have a chance of winning, they will bid their maximum mortgage on these houses. If there are no owner-occupied houses of interest, the household will bid on all private rental houses that are affordable and large enough. Objective measures for these decisions are explained in the following subsection. Only the reactions to owner-occupied homes change a state variable—the offers made on that house. In addition to other requirements, a empty nester only reacts to houses with a size of 2.

Finally, houses select winners adaptively; social rental houses select using the selection rules. They filter households with incomes fitting for the rent of the house and then select the household with the highest waiting time; or, if their assignment type is lottery, they select randomly. Private rental houses select the household with the highest income, while owner-occupied houses select the households with the highest bid. If a winner is selected, then the house associated with a household is changed and the house itself becomes occupied; meanwhile, any house previously inhabited by a household instead changes its status to empty.

Appendix B.4.4. Objectives

The implicit objective of private rental houses is to optimise the total rent paid; the objective of owner-occupied houses is to sell for as much money as possible in a short time span.

The objective of households is to satisfy their needs, and they have a preference for higher quality. Households desire to have a home that is affordable; this is when the monthly housing cost is smaller than half of the monthly income, calculated with $rent/mortgage < income/24$. The choice for half the monthly income is made arbitrarily, as the exact limit for a household depends on their other expenses, which are not included in the model. Households also desire a large enough home; the size of home which a household wants is calculated with $min(2 + (\frac{number\ of\ children}{2}), 5)$. It is assumed that the parents/adults in the household share one bedroom; one room is counted as a living room; then, a maximum of two children share a bedroom (based on the number of rooms for houses advertised for large or small families); finally, a household desires to live in the largest possible house.

A household can consider itself a cheap-skewed renter if they occupy a social rental house and have an income higher than the maximum income allowed for entering the social rental sector. A household can consider itself an empty nester if the oldest adult is older than 65, it contains no children, and the size of the house they inhabit is larger than 2.

Social sector houses follow the rules for the social sector in reality and they implicitly carry the various motivations that created this real system.

Appendix B.4.5. Learning

Learning is not implemented.

Appendix B.4.6. Prediction

Private rental and owner-occupied houses act under the assumption that a shortage will remain, and only increase their prices. (This prediction, however, can be incorrect, as discussed in Section 6). Similarly, households assume that the shortage will last, and that—therefore—owning a home is always preferable to renting a home. Households consider that they have a chance to win an auction for an owner-occupied home if their maximum mortgage is larger than 90% of the list_price. Private rental houses assume that the household with the highest current income will be most likely to be able to pay the rent in the future. The motivation being that it takes more setbacks for a high-income household to be unable to pay rent than a low-income household.

Appendix B.4.7. Sensing

Households and houses have perfect knowledge of their own state variables. Households know the quality, size, rent, or list price and auction date of all houses that advertise themselves. These values are known because the house advertises them to promote itself.

Private rental houses know the income of all households that apply, which is motivated by the landlord posing income requirements in reality. Private rental houses know the average rent being paid in the market due to their knowledge about the general state of the rental market.

Social rental houses know the income and waiting time of all households that apply. Both these values must be reported to the social sector to sign up.

Owner-occupied houses know the bids made by households (which is part of their own state-variable offers). They also know the transaction price of all other houses, due to public information in The Netherlands.

Appendix B.4.8. Interaction

Households compete for the limited supply of houses. Houses advertise and share the previously mentioned values to households, while households apply and share previously mentioned values to houses. Two households may work together as a collective to search for a house if they want to form a relationship.

Appendix B.4.9. Stochasticity

First, the model is initialised randomly in such a way that the composition of households, the income of households, the size, quality, sale prices, and rent of houses, the starting waiting time of households, and initial assignment of houses to households, are all stochastic (section initialisation, below). The initialisation is set randomly to avoid bias of any particular starting setup, and because the information on the real situation is not sufficient to exactly replicate either the existing households or housing supply. For the generation of new houses, the quality is random, but the value and rent are dependent on the existing houses. The sector a new house belongs to is also generated randomly, such that, over time, the size of the sectors stays (relatively) stable. For new households, only the income is random.

The life events of death, child birth, and relationship forming and ending are simplified, the probability of such an event happening to a households is known. A random number is generated between 0.0 and 1.0; if the probability is higher then the generated value, the event happens. In the forming of a relationship, a partner household is chosen based upon a known distribution of age differences between partners; randomness is used to select the difference. Social rental and owner-occupied houses select winners in a random order, as a single household may win multiple houses but be forced to accept a house before knowing its result for other auctions/applications.

The households experiencing income shocks are chosen randomly.

Appendix B.4.10. Collectives

Two households in the process of forming a relationship may use a composite of their states to search for a house.

Appendix B.5. Initialisation

Various data sources were used to create distributions for the initialisation of the model. The creation of these distributions is discussed in [47].

The houses are generated using the 'house generation' sub-model, with some alterations. Instead of a house having a probability to set an attribute to a certain value, a percentage of the whole population (of a sector) is assigned that value. Firstly, a percentage of all houses is assigned to each housing sector. Within in each sector, the values for size are set. As we only have information for the house sizes of the whole market, we ensure each sector has a similar distribution of sizes.

For social rental houses, rents are assigned for the whole group; they are ordered by quality, so that higher-quality houses have a higher rent. Finally, all houses are assigned an initial worth. The houses are ordered on quality so that the initial house price is related to the quality. Even though only owner-occupied houses use these data, the distribution is only known for all houses; thus, the assignment is carried out over all houses. Input parameters decide the amount of houses generated, the percentages of houses that have a certain size, social rent, sector, and house value.

Next, households are generated; the number of households is decided by an input variable. For each household, a known distribution is used to decide its household_type, the number of children, and the age of the reference adult. If the household_type indicates a two-parent family, a second adult is generated with the distribution of age differences for relationships. The waiting time for each adult is initialised randomly between 0 and 30 months. The choice was made to start the simulation with small differences in waiting time to simulate a situation where the waiting time has just been introduced; the intention was to let the simulation with time arrive in a situation where the waiting time has been implemented for longer. The limited length of the simulation prevents this.

Households start with no searching reason, no mortgage, and no mortgage length. An income is generated from a known distribution depending on whether the household has one or two adults using the income sub-model.

A known distribution of the ages of children is used to generate an amount of ages equal to the amount of children; starting from the oldest age, an age is assigned to each child. The child chosen from the households are either at least 16 years older than the youngest child; alternatively, none exist in the oldest household. This age difference is used to ensure that, realistically, the child could have been born in this household, as pregnancies before 16 are rare.

The birth months of each adult and child are randomly set to a value between 0 and 11. A uniform distribution of birth months is assumed.

Finally, private rental and then social houses are assigned to households. The data contained in chapter 3.1 of "Ruimte voor wonen Kernpublicatie Woon 2018" [66] are used to assign households to the rental sectors; if there are not enough households in a group, the house is not assigned. The houses in the private and social sector are sorted by descending size first and descending rent second. The houses are assigned to households in the following order:

- Two-parent families (unmarried or married pairs with children).
- Single-parent families.
- Pairs without children aged between 35 and 65 years.
- Single-person households aged between 35 and 65 years.
- Pairs without children aged above 65 years.
- Single persons aged above 65 years.
- Pairs without children aged below 35 years.
- Single-person households aged below 35 years.

First, families are assigned to the largest houses, as they have a motivation to have these larger houses. Then, households aged between 35 and 65 years are assigned to the next largest houses; they are in the age group where they have the most financial means and are most likely to still consider having children. Then, houses are assigned to households aged above 65 years as they have had the most time to obtain a larger houses. Finally, younger households with the least means are assigned to the smallest houses. Pairs are assigned before singles as they have more financial means. For social rental houses, the rules surrounding 'passend toewijzen' [57] are used to assign houses. The rent of private rental houses is set to be 35% of the monthly income of the household.

Owner-occupied houses and any houses not yet assigned are allocated through the normal means at the start of the simulation. At the start of the simulation, the auction date for owner-occupied houses is the first tick instead of two months later. For this reason, we previously placed the changing of needs at the tail end of the tick.

Appendix B.6. Input Data

The model does not use input data to represent time-varying processes.

Appendix B.7. Sub-Models

Appendix B.7.1. House Generation

When a new house needs to be generated, the input percentages for sizes and sectors are used as a probability.

For social rental houses, the quality is randomly set between 0.0 and 1.0. The `assignment_type` is set according to the input probability a house is assigned with a lottery. The input percentages for rents in the social sector are used as probabilities to generate the initial rent. The initial status is set 'empty'.

For owner-occupied houses, the quality is set randomly between 0.0 and 1.0 and the starting value in `sale_prices` is set to the average latest sale price of all owner-occupied houses with a quality at most 0.1 larger or smaller then the quality of the generated house; if there are none, then the average of all owner-occupied houses is used. The initial status is set to 'preparing_sale'.

For private rental houses, the quality is randomly set between 0.5 and 1.0; to simulate that, a house needs to exceed a certain quality to be allowed to be a private rental house. The initial rent is set to 1.2 times the mean rent of occupied houses; the same existing houses set their rent. The initial status is set 'empty'.

Appendix B.7.2. Relationships

Relationships are both formed and ended; depending on the age and type of a household, the probability that a relationship ends or starts is known. How these data have been calculated is described in [47].

For all households in a relationship, a value between 0.0 and 1.0 is generated; if it is lower than the probability of splitting, then the households are split. A partner is randomly selected to leave the household, except in the variant where the waiting time is dedicated to divorce, in which case the second adult always leaves.

This partner creates a new household with a searching reason that indicates they are searching because their relationship has ended ('split'). They set their size to be 1 and they generate a new income.

The household that is left by the partner removes the partner, and generates a new income. The household keeps all children. New incomes are generated to simulate an adjustment to the new situation affecting job opportunities, and because relationships have a higher combined income, that needs to be adjusted down when a partner leaves.

For all households not in a relationship, a value between 0.0 and 1.0 is generated; if it is lower than half, as any relationships forming affects two persons, the probability of forming a relationship is formed. The household that forms a relationship uses the distribution of known age differences for relationships to find a partner. If the exact difference in age cannot be found, the closest match is used.

If neither partner has a house, only one partner has a house, or both partners have a house and one of these houses is big enough to house the combined households, the households combine. The incomes are summed and the adults and children of one household are appended to the other. Finally, another value between 0.0 and 1.0 generated to see whether the relationships is a married pair or an unmarried pair depending on the input parameter that sets the percentage of households that marry.

If both partners have a house, but neither house is big enough (see section objectives), a collective household is formed to search for a house. This collective functions as a normal household for the advertising sub-model and reacts to advertisements instead of the households. Any household that belongs to a relationship collective does not participate in reacting and advertising. The population sub-model, however, only applies to the component households and not the collective household. When this collective wins a large enough house, the households combine, as previously described.

Collectives already know whether a relationship will be unmarried or married, and collectives also roll for a chance to split; in this case, the collective is removed and both households resume participating in searching and advertising.

Appendix B.7.3. Income

Incomes are generated using a gamma distribution. For the generation of incomes for a single person, the calculation is:

$$(\text{random-gamma } 2.4055239\ 0.14532885) * 1000 + 13000 \tag{A1}$$

For the income of a pair, the calculation is:

$$(\text{random-gamma } 3.2113136\ 0.13220595) * 1000 + 13000 \tag{A2}$$

These distributions have been created by fitting a gamma distribution with R to the data retrieved from the CBS: www.cbs.nl/nl-nl/visualisaties/inkomensverdeling (accessed on 2 September 2021).

Appendix B.7.4. Income Shock

Ideally, incomes would follow a change over the lifetime of a household, but no system or data were found to facilitate this. Instead, the system for income shocks of [16] is followed. One input parameter decides how large a part of the population is affected by an income shock, while another decides how large this shock is. Half of the affected group experiences the income shock upwards, that is:

$$income = income * (1 + 0.01 * shock\_size) \tag{A3}$$

While the other half experiences the income shock downward, that is:

$$income = income * (1 - 0.01 * shock\_size) \tag{A4}$$

Appendix B.7.5. Advertise

Private rental houses with the status ‘empty’ communicate their rent, size, and quality to all households. Social rental houses with the status ‘empty’ communicate their rent, size, quality, maximum income for households, and assignment type to all households with less income than the maximum income.

Owner-occupied houses with the ‘preparing_sale’ status remove any old communication, set their auction_date to be in 2 months time, and change their status to ‘for_sale’.

After this, owner-occupied houses with the ‘for_sale’ status communicate their list_price, size, quality, and auction_date to all households.

Appendix B.7.6. Population

The population sub-model handles the monthly changes of individual households. Firstly, it increases the waiting times of adults by 1. If the variant 'while_searching' is active, this is only carried out if households are searching for a house. Secondly, the age of a child or adult is increased if it is their birth month. Then, for each combination of household_type, age, and size, the probability that a child is born is known. The origin of this probability is described in [47]. A value between 0.0 and 1.0 is randomly generated; if it is lower than the probability, a child is born; that is, a person of age 0 with the current month as the birth month is appended to the children state variable.

Households now update their household_type, as a single household may have become a single-parent household, and this can influence the following step.

For each combination of age and household_type, the probability that a person deceases is known. The origin of this probability is described in [47]. A value between 0.0 and 1.0 is randomly generated for each child (under or at 18) and adults; if it is lower than the probability, the adult or child is removed from the adults or children state variable. If all adults are deceased, the household is removed, including children (under or at 18). The status of the house that was occupied is updated to either 'empty' or 'preparing_sale', depending on the sector.

Again, the household_type is checked, as the removal of children may make a single-parent household a single-person household, or the removal of an adult may make a married or unmarried pair a single-person or single-parent household.

Children that are 18 form their own household; they generate an income, are of household_type single, have no children, the adults role is filled by themselves, they have no mortgage or mortgage time left, a waiting time of 0, no house, and their searching_reason is 'moving out'. Children living with their parents are still part of the children state variable of their parents until they find a house, at which point they remove themselves from it.

Finally, households pay their monthly mortgage, updating their mortgage by subtracting the monthly mutation calculated using the mortgage sub-model and decrease their mortgage time left by 1.

Appendix B.7.7. Mortgage

The mortgage sub-model provides three functionalities: it can calculate the maximum mortgage a household can have, the monthly payment, and the monthly decrease in the outstanding mortgage balance.

The calculation for the maximum mortgage is:

$$\begin{aligned} monthly\_interest &= \frac{mortgage\_interest}{12} \\ power &= (monthly\_interest + 1)^{mortgage\_length} \\ maximum\ mortgage &= \frac{income * fin/12}{(monthly\_interest * power)/(power - 1)} \end{aligned}$$

where mortgage_interest is a parameter of the simulation indicating the yearly interest on mortgages and mortgage_length is a parameter indicating the length of the mortgage in months. fin is the financing norm for the household; in the simulation, this norm is only decided by the income of a household. The values used are displayed in Table A5 and originate from [48]. These values have been retrieved from the 'welAOW' category for a yearly interest of 2.1%.

For annuity mortgages, the monthly payment and mutation are calculated as:

$$monthly\_interest = \frac{mortgage\_interest}{12}$$
$$mortgage\_payment = \frac{mortgage * monthly\_interest}{1 - (1 + monthly\_interest)^{-mortgage\_time\_left}}$$
$$mortgage\_mutation = mortgage\_payment - mortgage * monthly\_interest$$

For linear mortgages, the monthly payment and mutation are calculated as:

$$monthly\_interest = \frac{mortgage\_interest}{12}$$
$$mortgage\_payment = \frac{mortgage}{mortgage\_time\_left} + mortgage * monthly\_interest$$
$$mortgage\_mutation = \frac{mortgage}{mortgage\_time\_left}$$

where $mortgage\_time\_left$ is a state variable of households indicating how many months are left until the mortgage is repaid.

Table A5. Financing norms for yearly incomes.

Income	Financing Norm
income <= 22,500	0.195
income <= 23,000	0.205
income <= 24,000	0.215
income <= 24,500	0.22
income <= 25,000	0.225
income <= 26,000	0.23
income <= 27,000	0.235
income <= 28,000	0.24
income <= 29,000	0.245
income <= 32,000	0.25
income <= 41,000	0.255
income <= 43,000	0.26
income <= 44,000	0.265
income <= 45,000	0.27
income <= 46,000	0.275
income <= 47,000	0.285
income <= 50,000	0.29
income <= 63,000	0.295
income <= 67,000	0.30
income <= 70,000	0.305
income <= 73,000	0.31
income <= 77,000	0.315
income <= 83,000	0.32
income > 83,000	0.325

Appendix B.7.8. Selection

Private rental houses selects the household that reacted to their advertisement with the highest income as winner. If applicable, the previous house owned by this household has its status set to 'preparing_sale' or 'empty'; the house that is won is assigned to the household and has its status set to 'occupied'. If a private rental house does not have a winner, it lowers its rent by 25 but not below the minimum rent.

If the current month is the auction date set by an owner-occupied house, it selects the household with the highest bid as winner, but this household pays only the bid of the second-highest bidder (if there is one). This, combined with the fact that households do not know others' bids, results in blind second-price auction. The idea is that households with greater means are more likely to win, but they are able to approximate what other households would bid and pay just enough to win. If applicable, the previous house owned by this household has its status set to 'preparing_sale' or 'empty'; the house that is won is assigned to the household and has its status set to 'occupied', and sets it latest sale_prices to be equal to the bid of the second-highest bidder. The wining household sets its mortgage to the bid of the second-highest bidder, and sets it mortgage time left to be equal to the mortgage length.

Social rental houses that have the `assignment_type` lottery filter out applicants that have an income above the maximum income parameter. Then, it randomly selects a winner from all filtered applicants.

Social rental houses that have the `assignment_type` selection filter out applicants based on the 'passend inkomen'. First, they remove households with an income higher than the maximum income.

If the rent of the social house is below or equal to 633.25, it filters:

- Single-person households with an income $\leq$ 23.725 younger than 65 years.
- Single-person households with an income $\leq$ 23.650.
- Households with two persons with an income $\leq$ 32.200 with the oldest adult younger than 65 years.
- Households with two persons with an income $\leq$ 32.075.
- Households with three or more persons with an income $\leq$ 32.200.

If the rent of the social house is above 633.25 and below or equal to 678.66, it filters:

- Single-person households with an income $>$ 23.725.
- Single-person households with an income $>$ 23.650 with the oldest adult than 65 years.
- Households with two persons with an income $>$ 32.200.
- Households with two or more persons with an income $\leq$ 32.075 with the oldest adult older than 65 years.
- Households with three or more persons with an income $\leq$ 32.200.

If the rent of the social house is above 678.66, it filters:

- Single-person households with an income $>$ 23.725.
- Single-person households with an income $>$ 23.650 older than 65 years.
- Households with two persons with an income $>$ 32.200.
- Households with two persons with an income $>$ 32.075 with the oldest adult older than 65 years.

If the filtered group instead comprises all applicants with an income under the maximum, then these are considered. From the filtered group, the household with (maximum) highest waiting time is chosen. In the variant where the secondary waiting time is reserved for divorce, the household with the highest waiting time for the first adult is chosen. The winning household sets the waiting time that made them win to 0. In the variant where the secondary waiting time cannot be used, both waiting times are reset to 0. Finally, the house is assigned to the household, its status is set to 'occupied', and the previously inhabited house has its status changed to 'empty' or 'preparing_sale'.

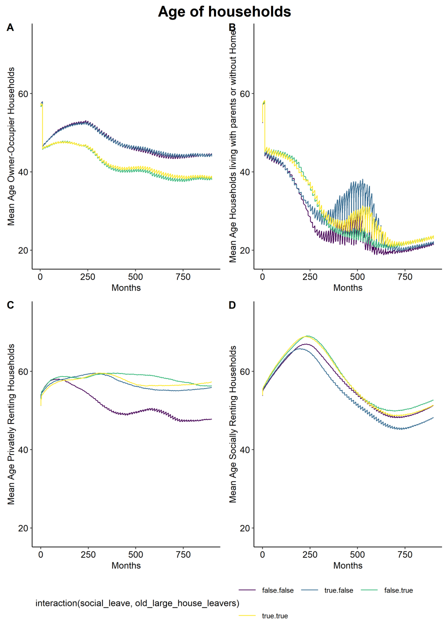
If a household previously occupied a private rental home, then the private rental home that has it is status changed to 'empty' sets its rent to be equal to the mean rent of the occupied private rental houses, times 1.2.

Appendix C. Analysis Results

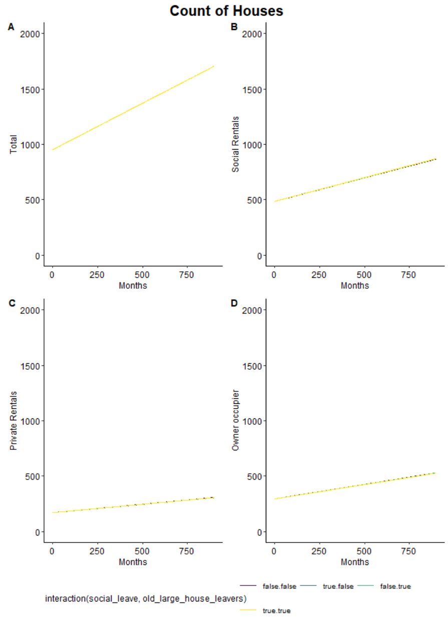
Further to Section 5, this appendix provides additional graphs from the simulation runs. A discussion of these results is found in [47].

Appendix C.1. Changing Policy

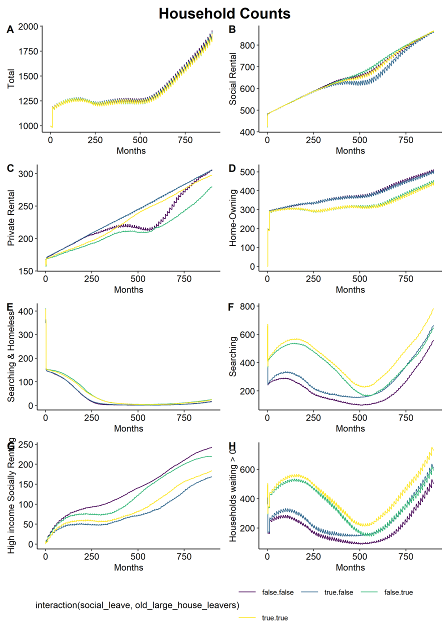
Appendix C.1.1. Lotteries for Social Housing



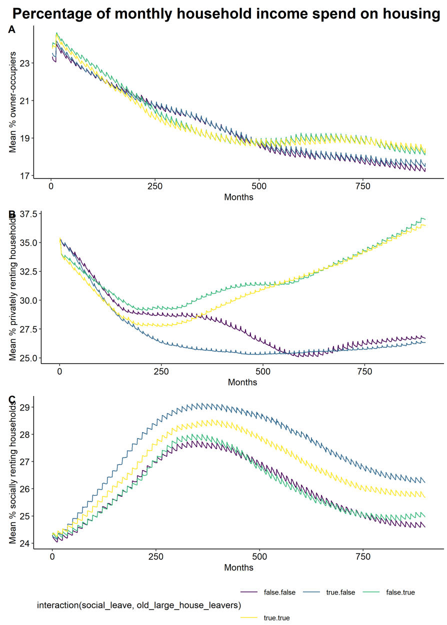
(**a**) Age of households in housing sectors.



(**b**) Count of houses in housing sectors.

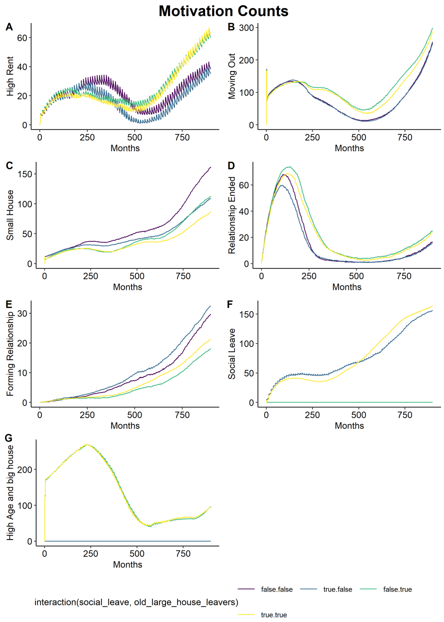


(**c**) Count of households.

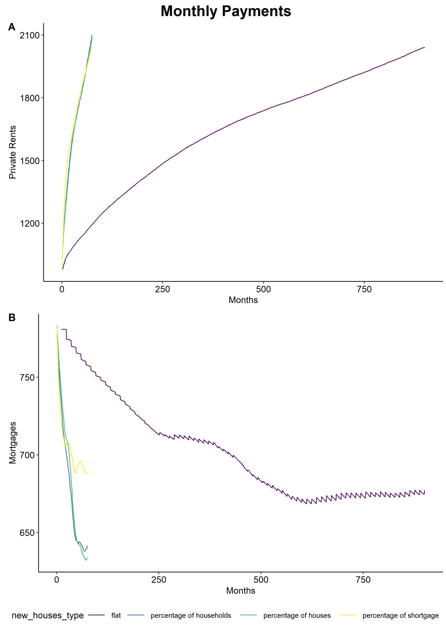


(**d**) Percentage of monthly household income spent on housing.

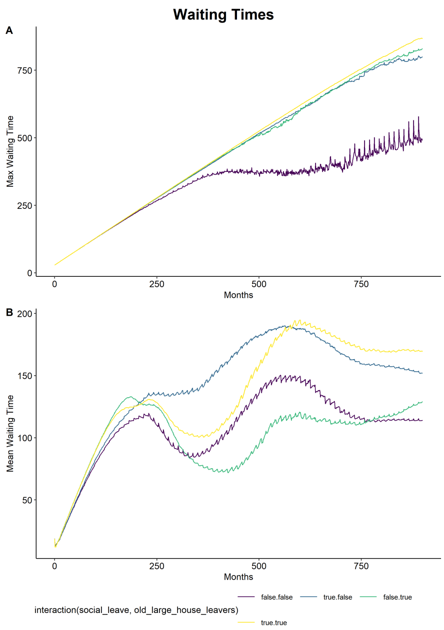
Figure A1. *Cont*.



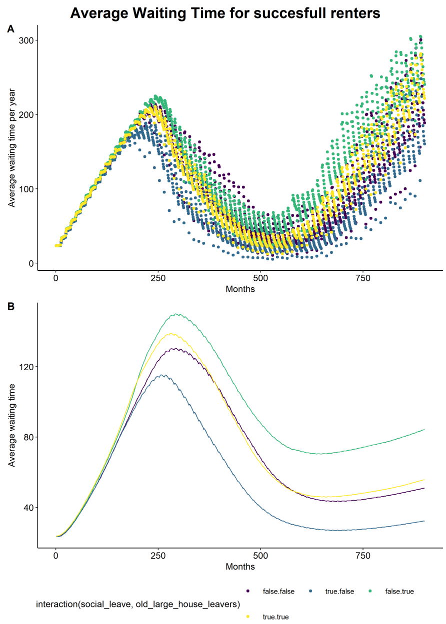
(**e**) Count of household motivations to move.



(**f**) Monthly payments for private rents and mortgages.



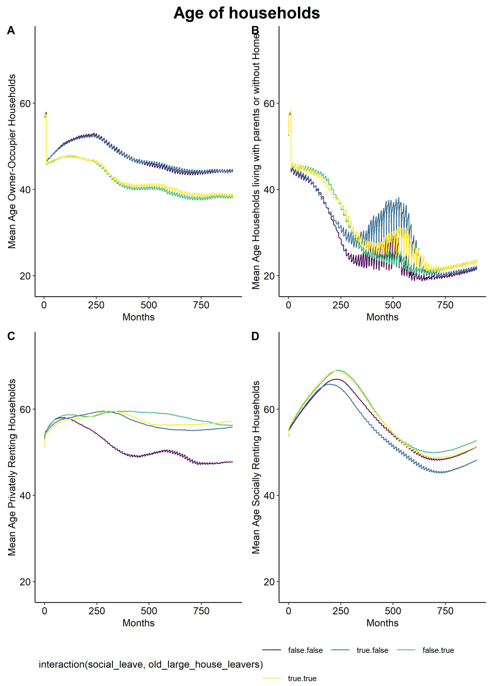
(**g**) Waiting times of households.



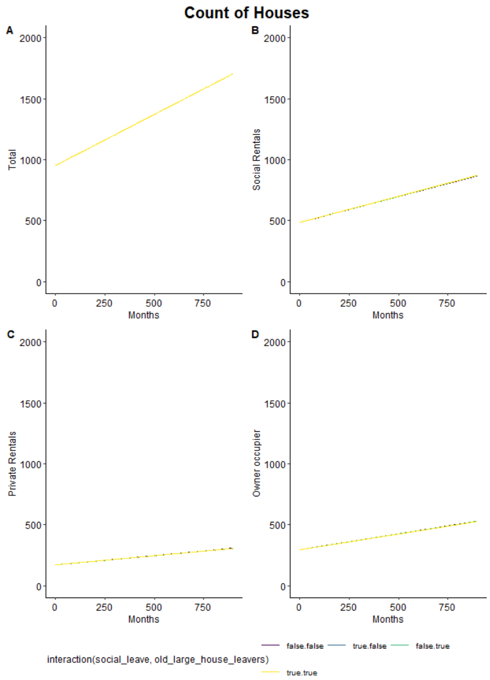
(**h**) Waiting times for households that successfully rent a social house.

Figure A1. Lotteries for social housing.

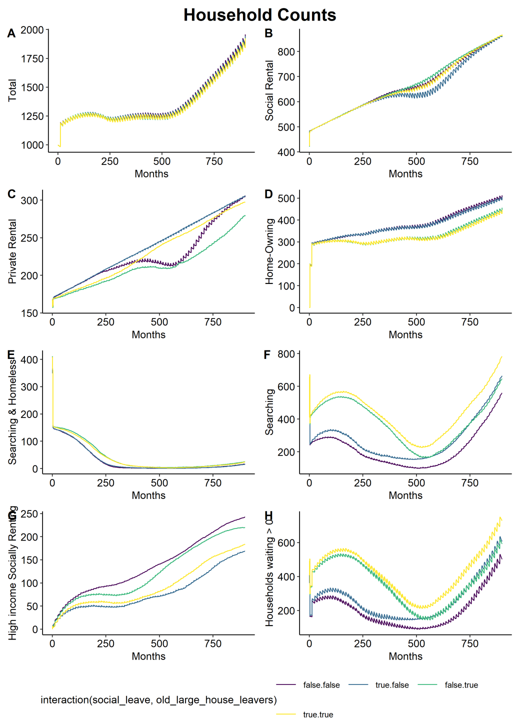
Appendix C.1.2. Divorce and Secondary Waiting Times



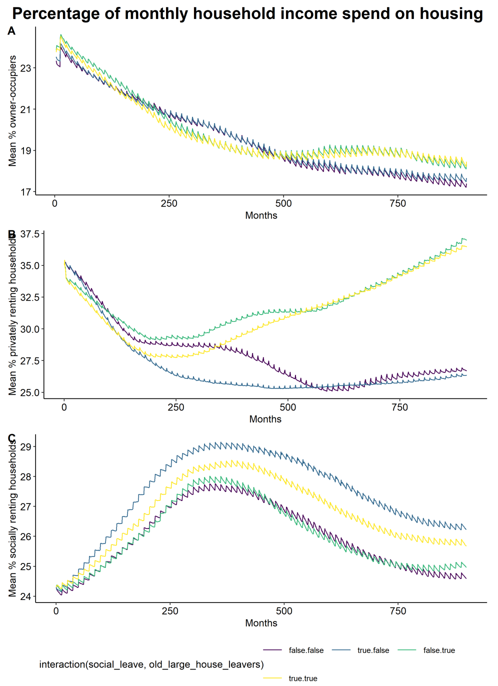
(**a**) Age of households in housing sectors.



(**b**) Count of houses in housing sectors.

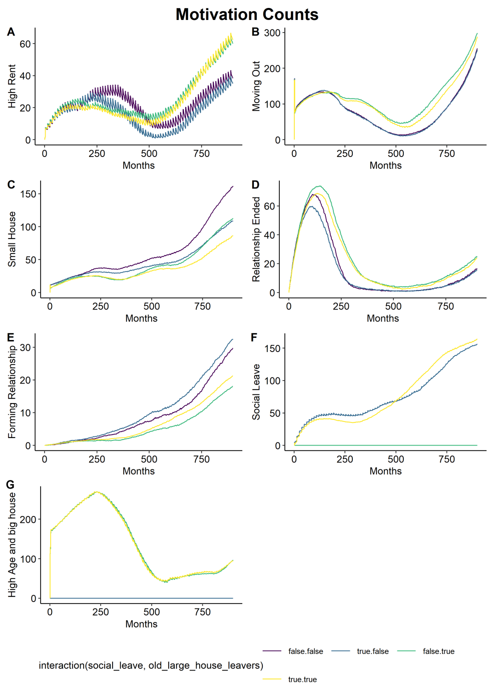


(**c**) Count of households.

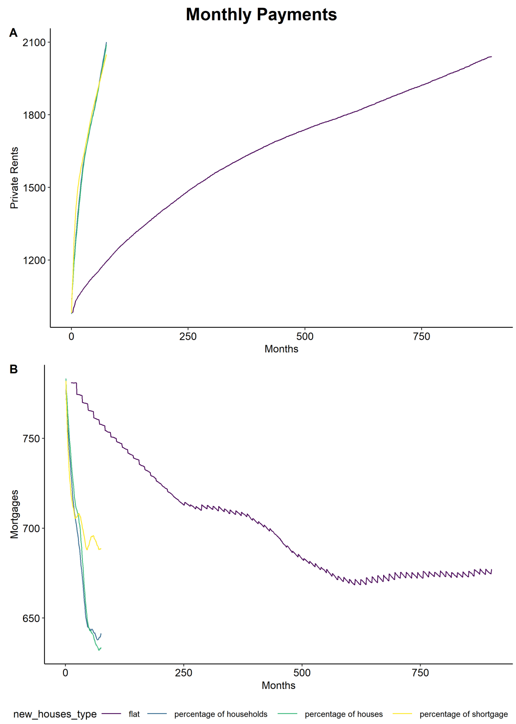


(**d**) Percentage of monthly household income spent on housing.

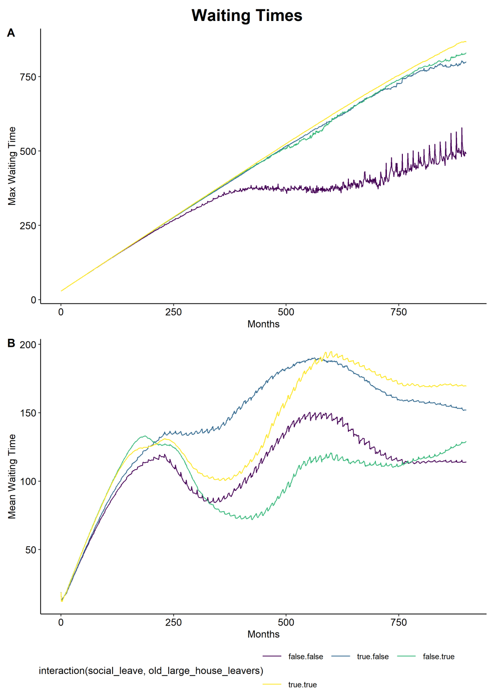
Figure A2. *Cont.*



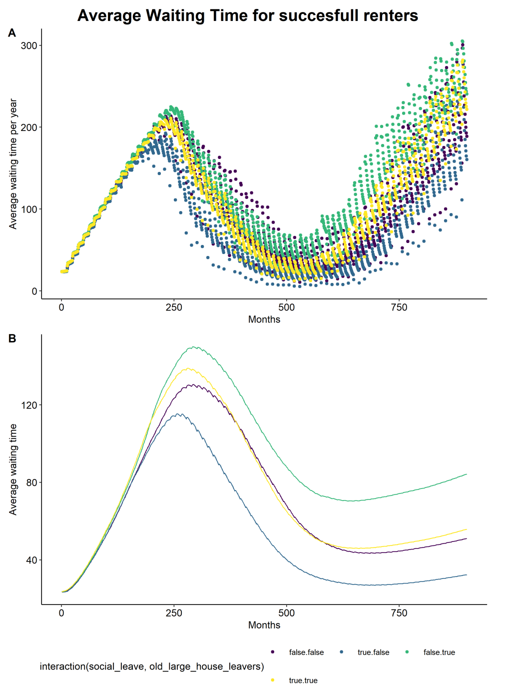
(**e**) Count of household motivations to move.



(**f**) Monthly payments for private rents and mortgages.



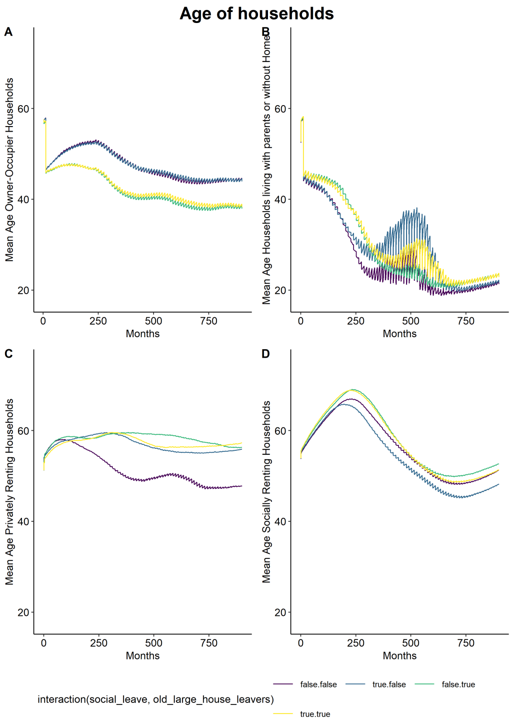
(**g**) Waiting times of households.



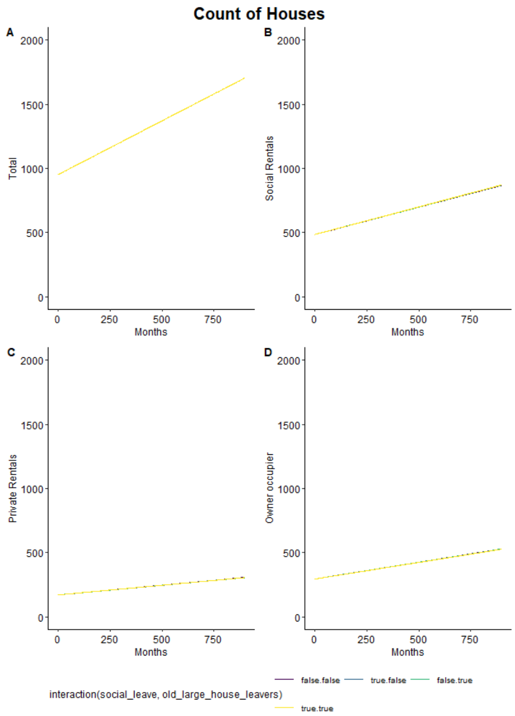
(**h**) Waiting times for households that successfully rent a social house.

Figure A2. Divorce and secondary waiting times.

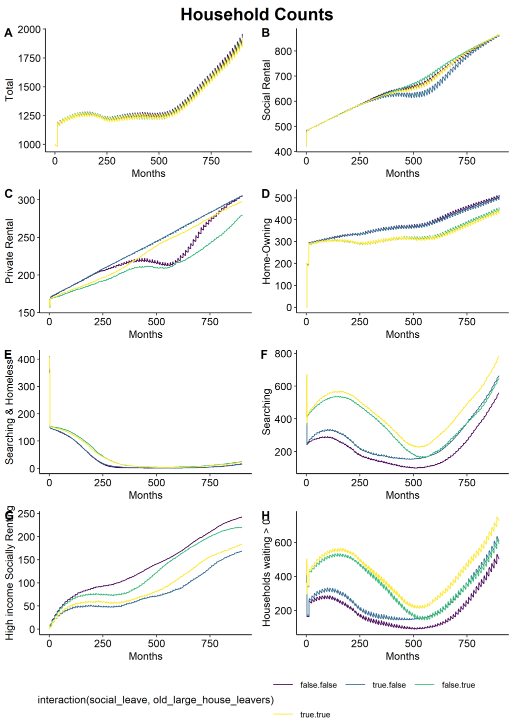
Appendix C.1.3. Maximum Number of Reactions



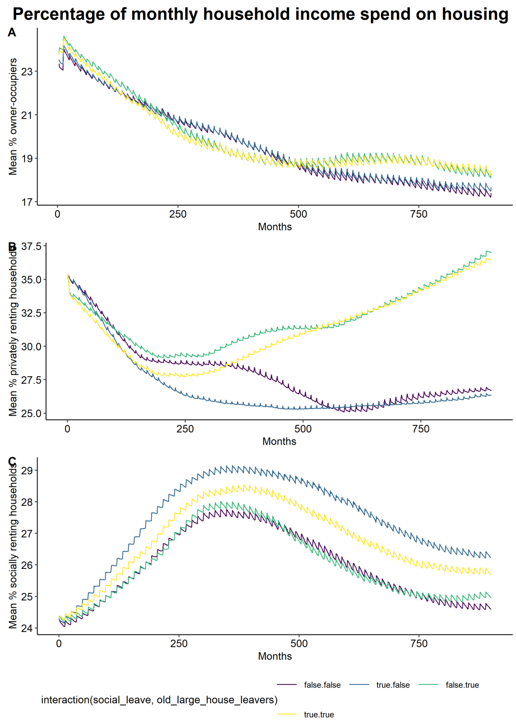
(**a**) Age of households in housing sectors.



(**b**) Count of houses in housing sectors.

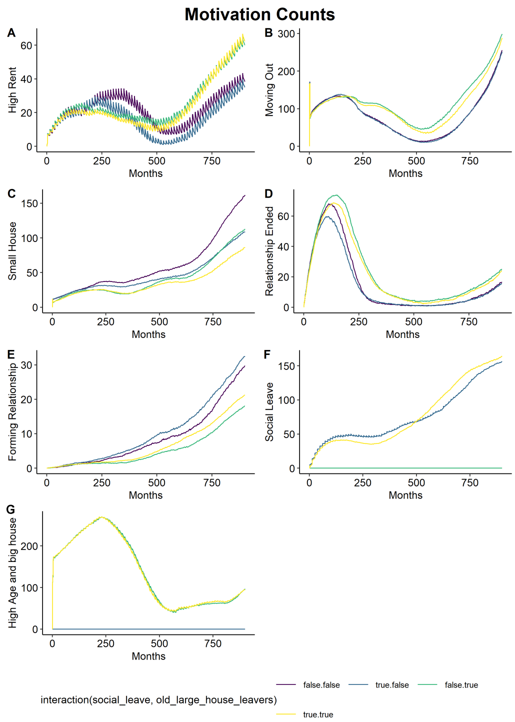


(**c**) Count of households.

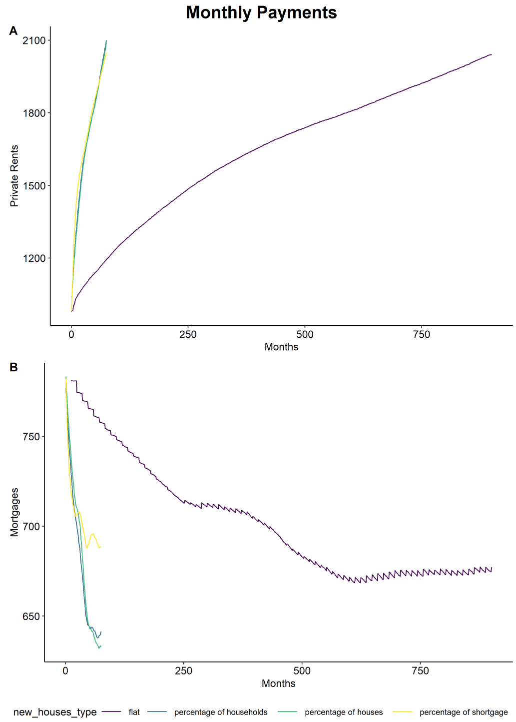


(**d**) Percentage of monthly household income spent on housing.

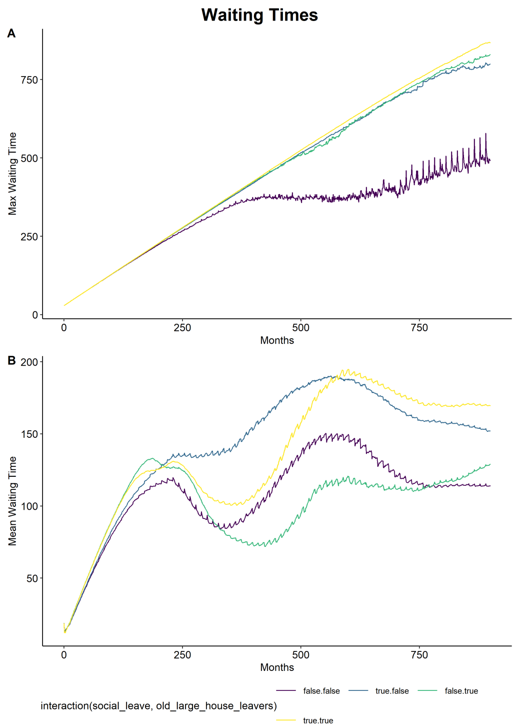
Figure A3. *Cont.*



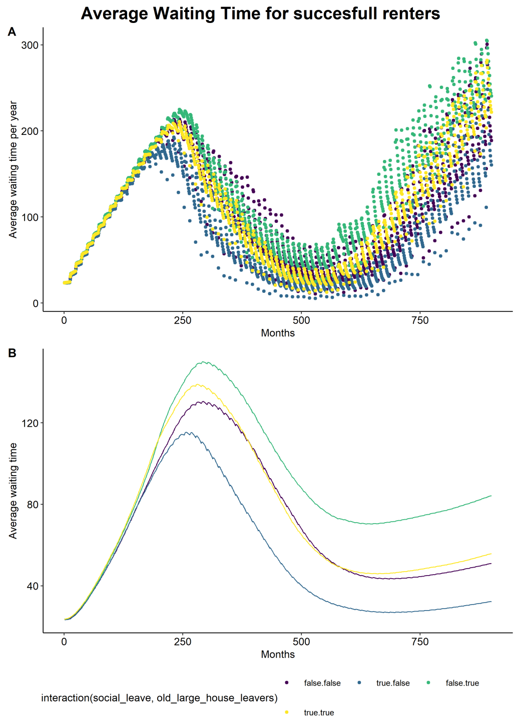
(**e**) Count of household motivations to move.



(**f**) Monthly payments for private rents and mortgages.



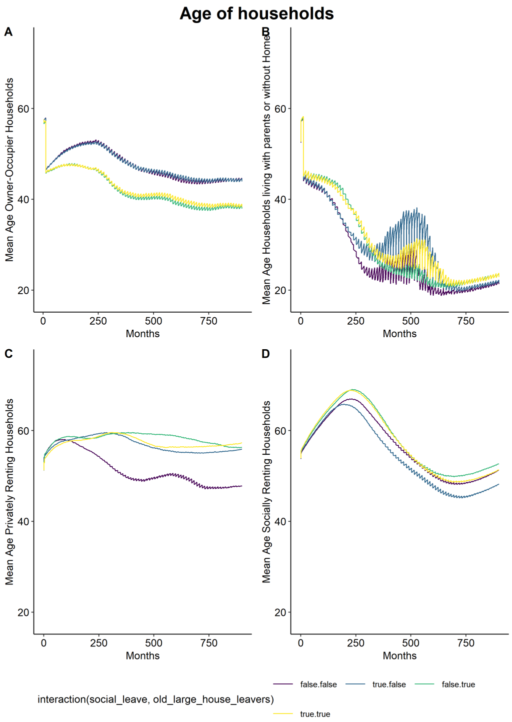
(**g**) Waiting times of households.



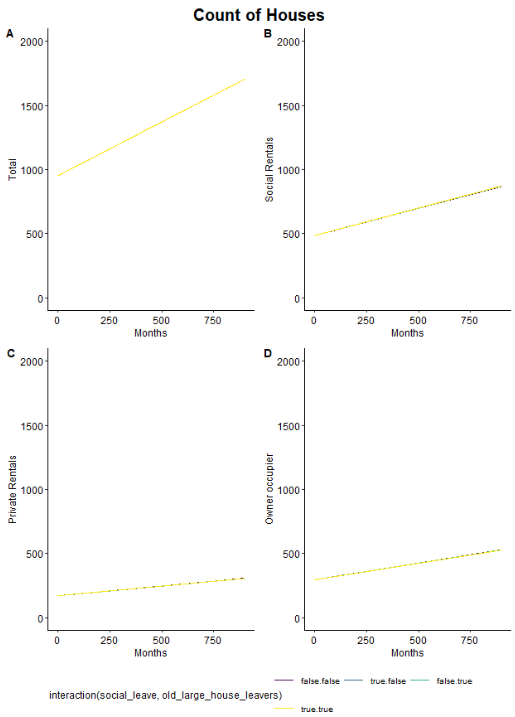
(**h**) Waiting times for households that successfully rent a social house.

Figure A3. Maximum number of reactions.

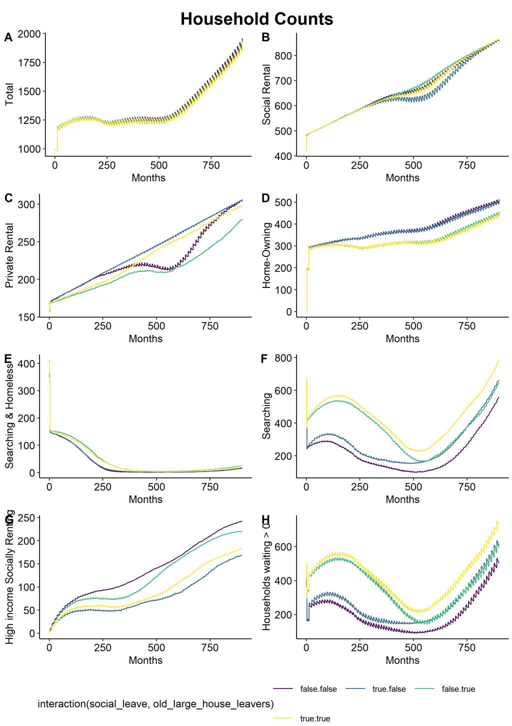
Appendix C.1.4. Increased Income Limit Social Housing



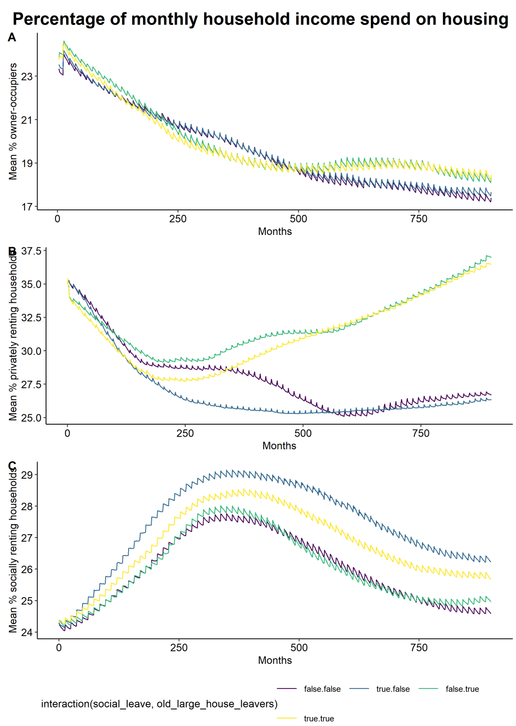
(**a**) Age of households in housing sectors.



(**b**) Count of houses in housing sectors.

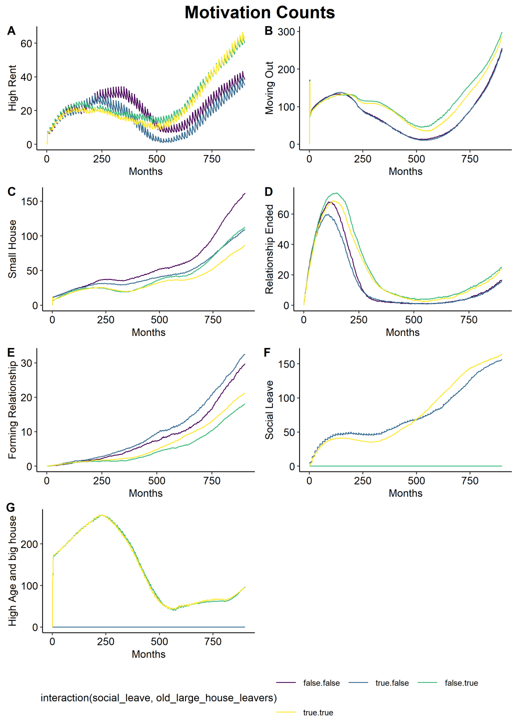


(**c**) Count of households.

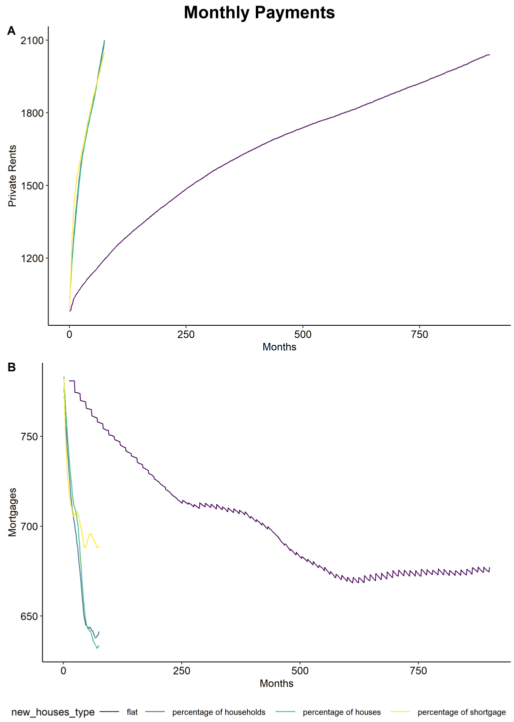


(**d**) Percentage of monthly household income spent on housing.

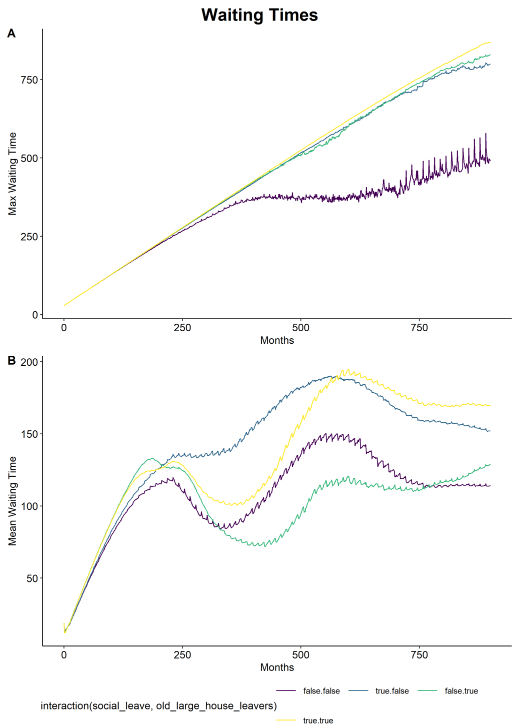
Figure A4. *Cont.*



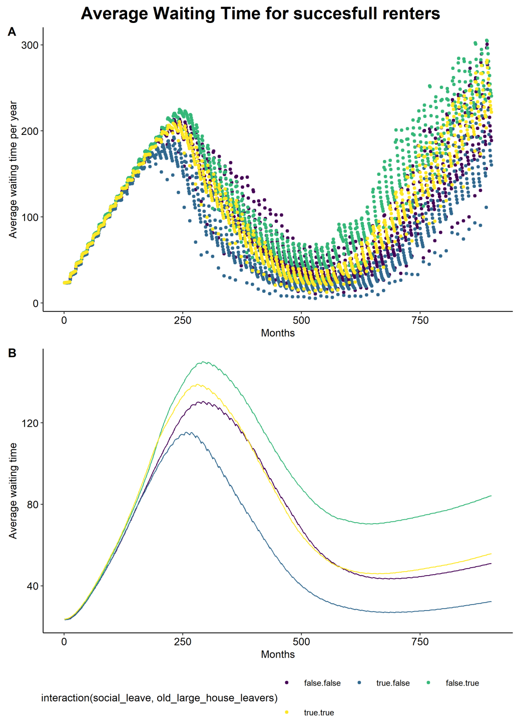
(**e**) Count of household motivations to move.



(**f**) Monthly payments for private rents and mortgages.



(**g**) Waiting times of households.

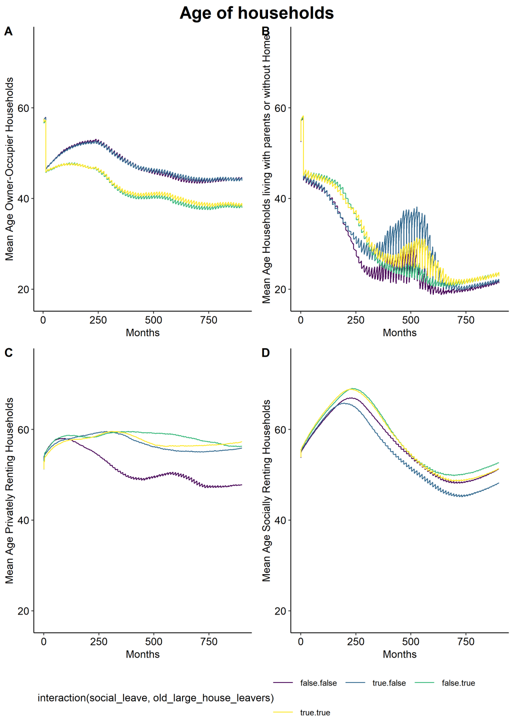


(**h**) Waiting times for households that successfully rent a social house.

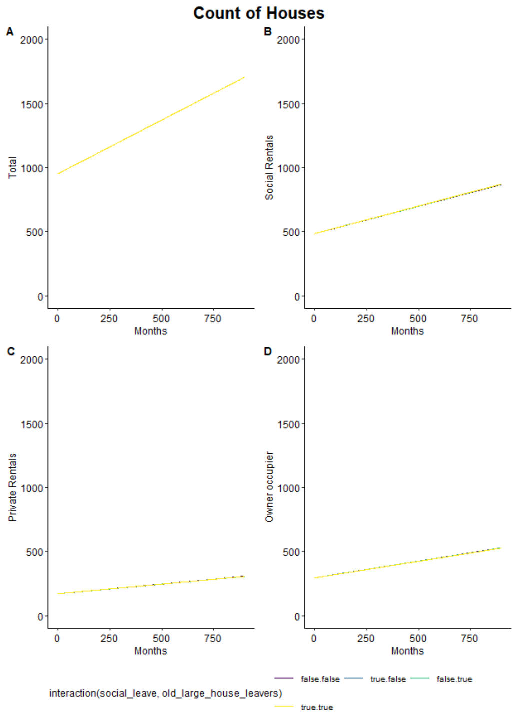
Figure A4. Increased income limit social housing.

Appendix C.2. Changing Behaviour

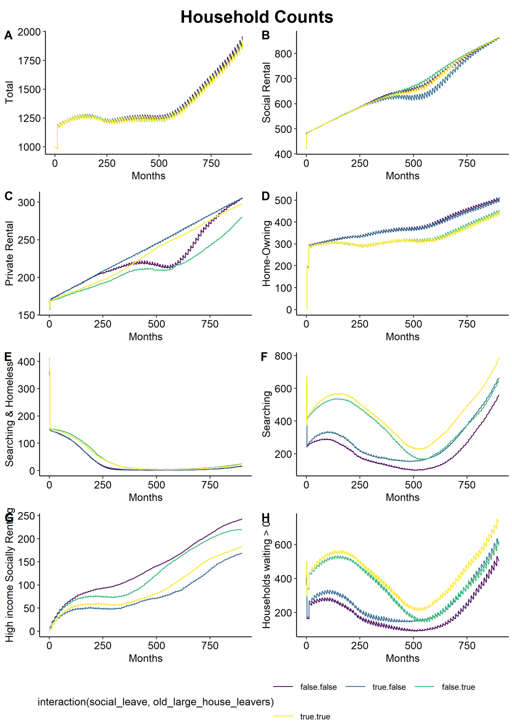
Appendix C.2.1. Waiting Time for Social Housing



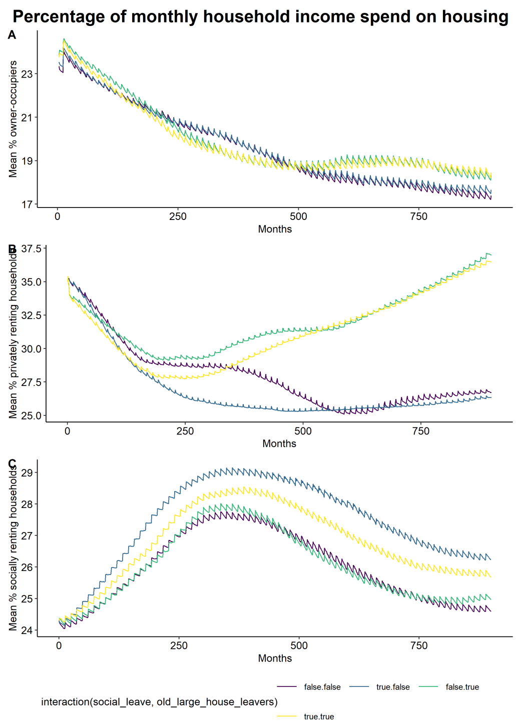
(**a**) Age of households in housing sectors.



(**b**) Count of houses in housing sectors.

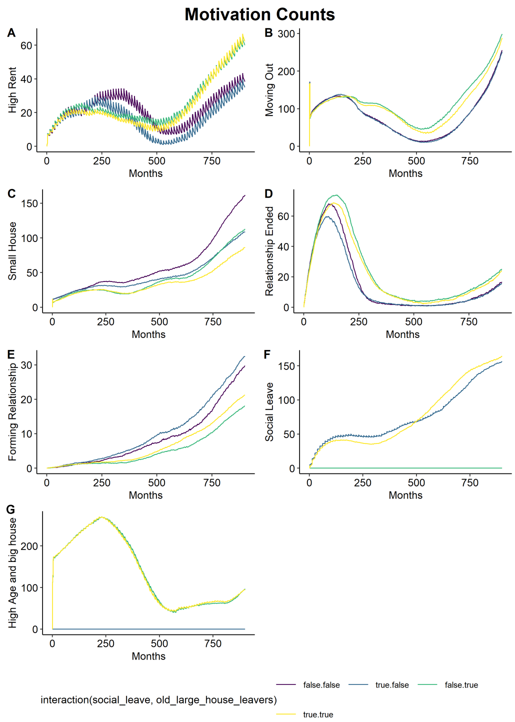


(**c**) Count of households.

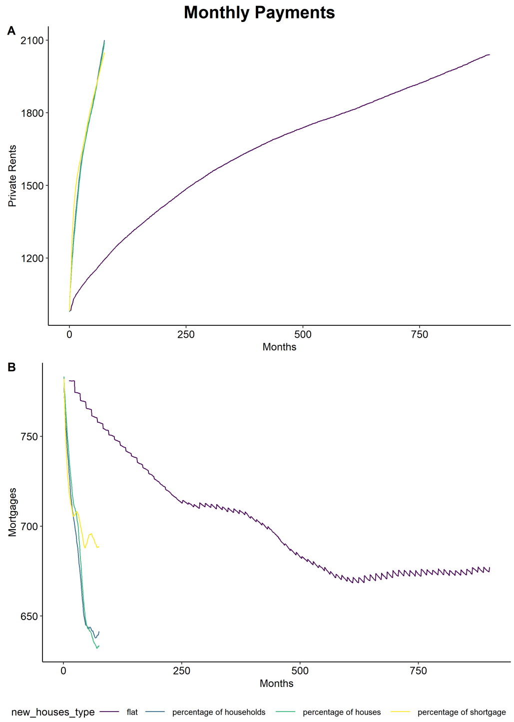


(**d**) Percentage of monthly household income spent on housing.

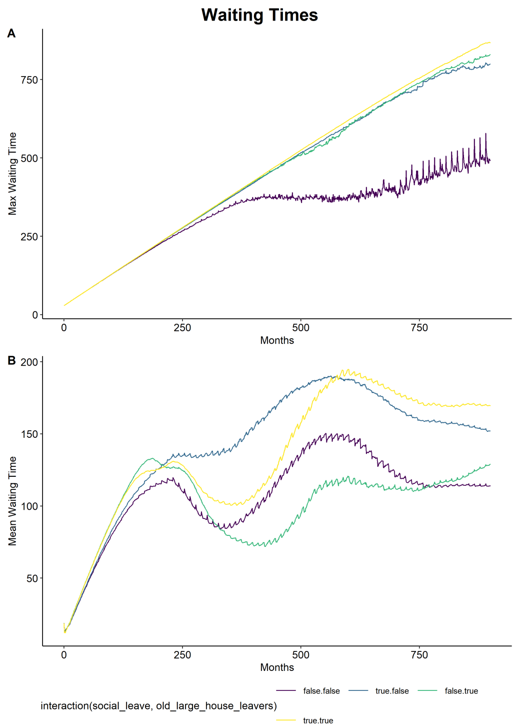
Figure A5. *Cont*.



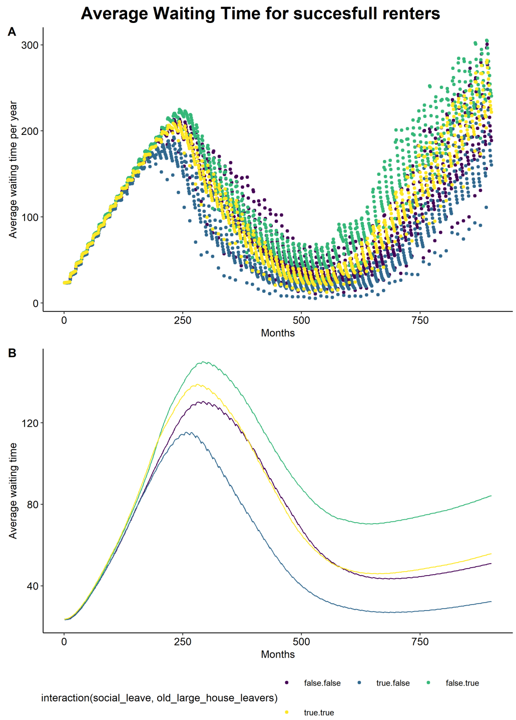
(**e**) Count of household motivations to move.



(**f**) Monthly payments for private rents and mortgages.



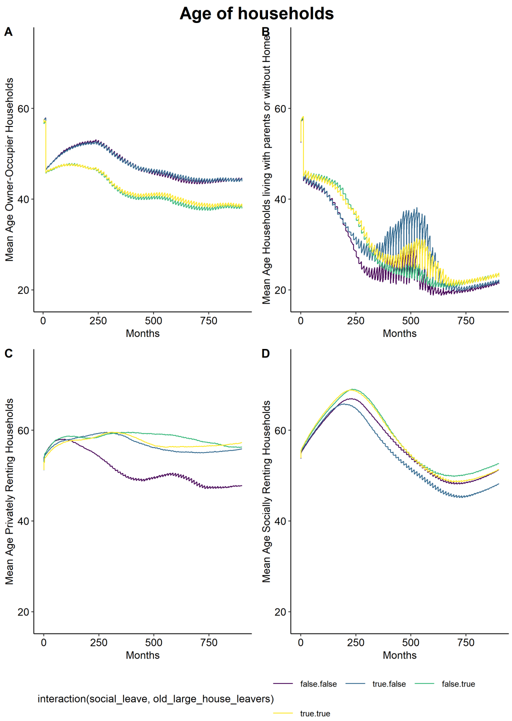
(**g**) Waiting times of households.



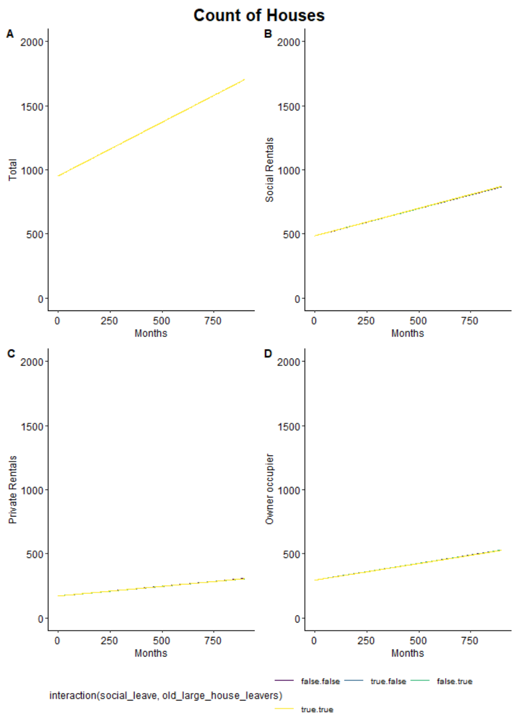
(**h**) Waiting times for households that successfully rent a social house.

Figure A5. Waiting time for social housing.

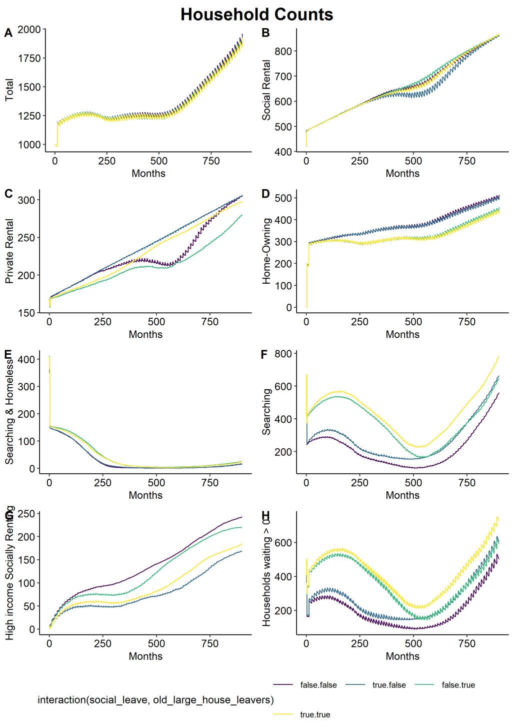
Appendix C.2.2. Willing Social Market Leavers



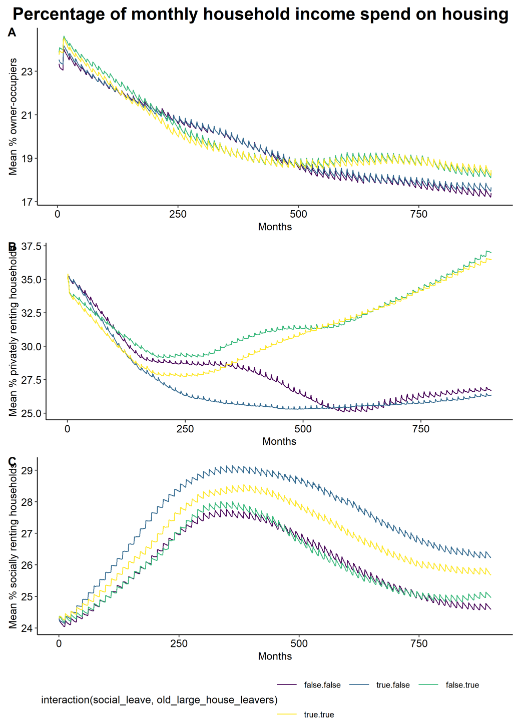
(**a**) Age of households in housing sectors.



(**b**) Count of houses in housing sectors.

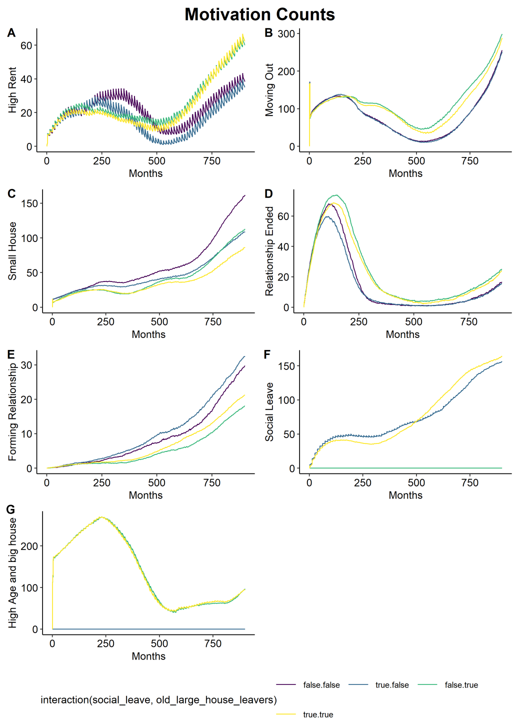


(**c**) Count of households.

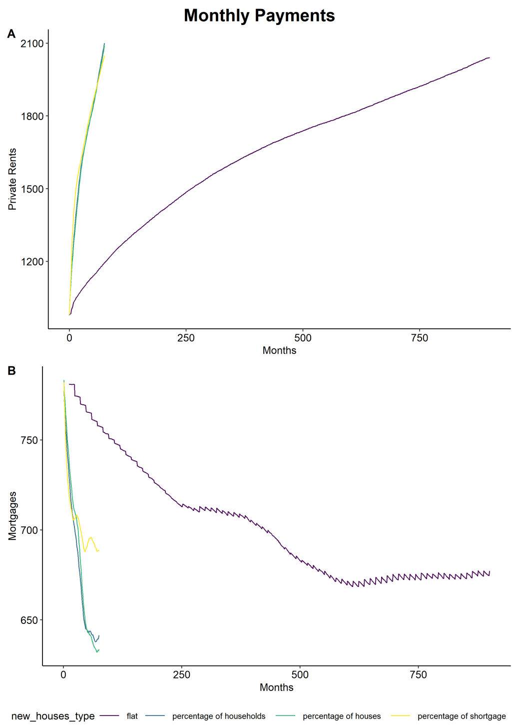


(**d**) Percentage of monthly household income spent on housing.

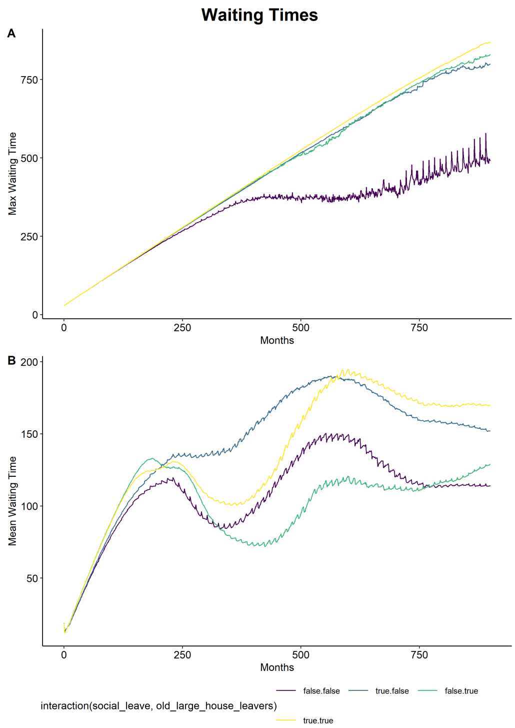
Figure A6. *Cont.*



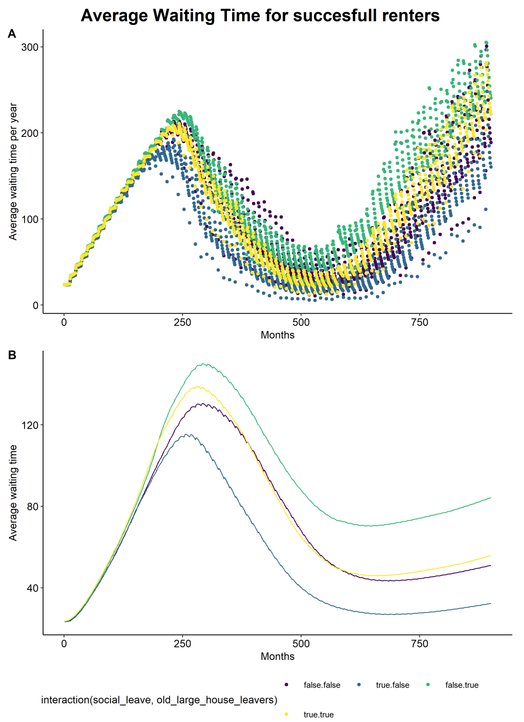
(**e**) Count of household motivations to move.



(**f**) Monthly payments for private rents and mortgages.



(**g**) Waiting times of households.

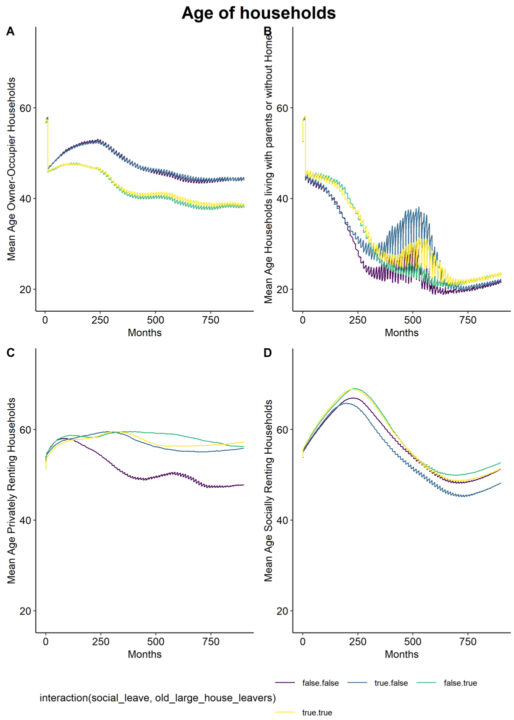


(**h**) Waiting times for households that successfully rent a social house.

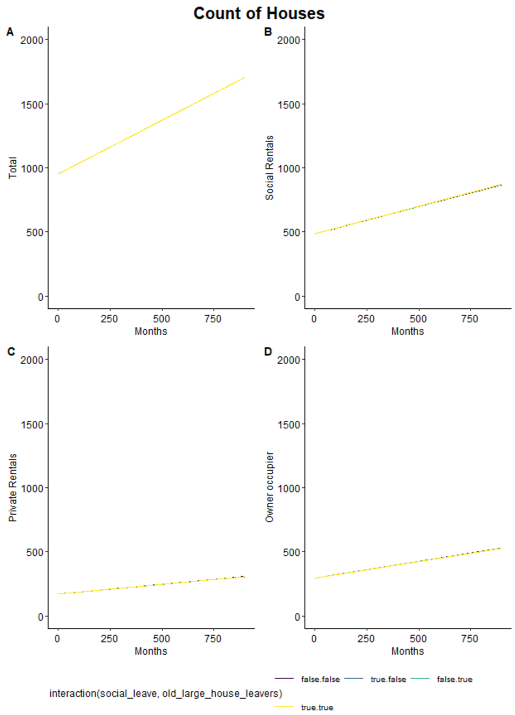
Figure A6. Willing social market leavers.

Appendix C.3. Changing Environment

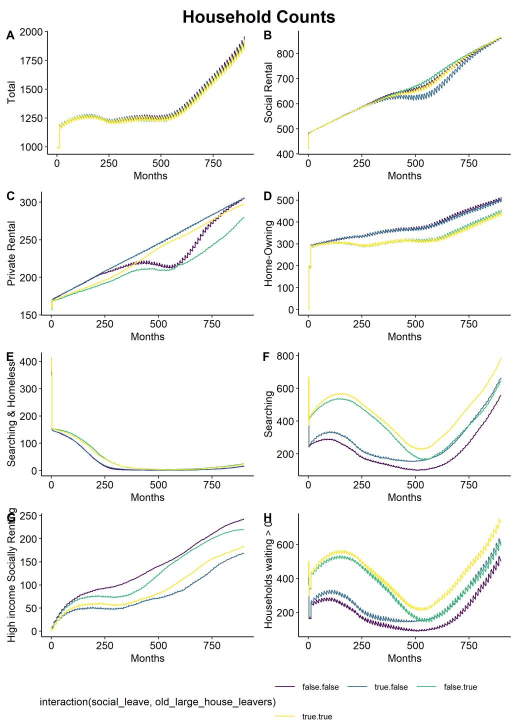
Appendix C.3.1. Migration



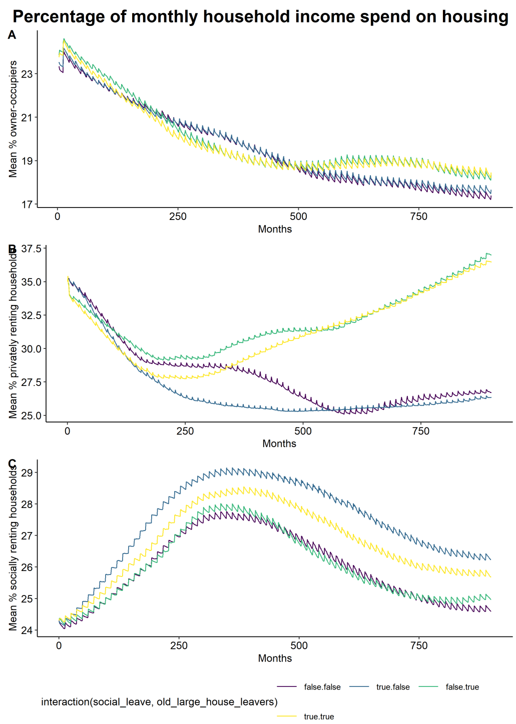
(**a**) Age of households in housing sectors.



(**b**) Count of houses in housing sectors.

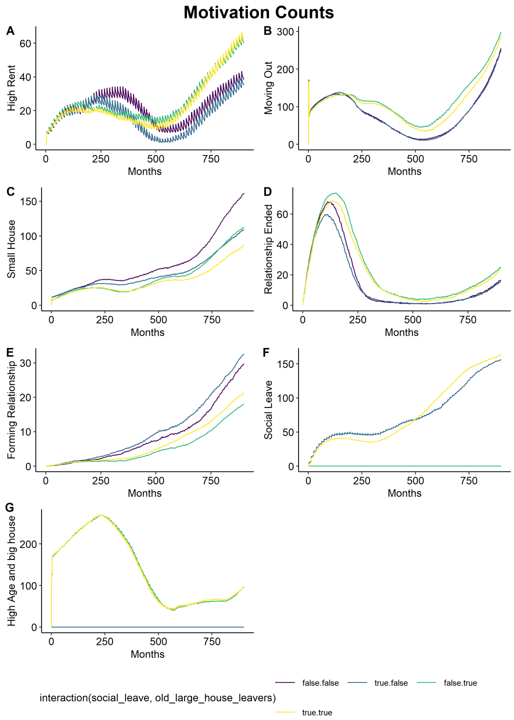


(**c**) Count of households.

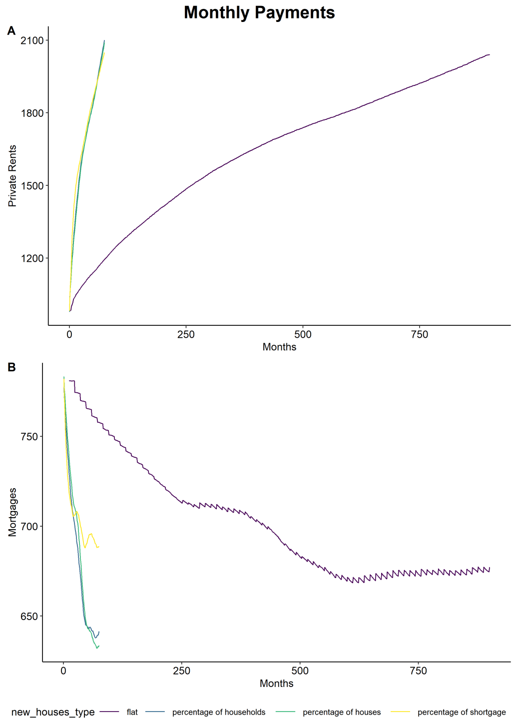


(**d**) Percentage of monthly household income spent on housing.

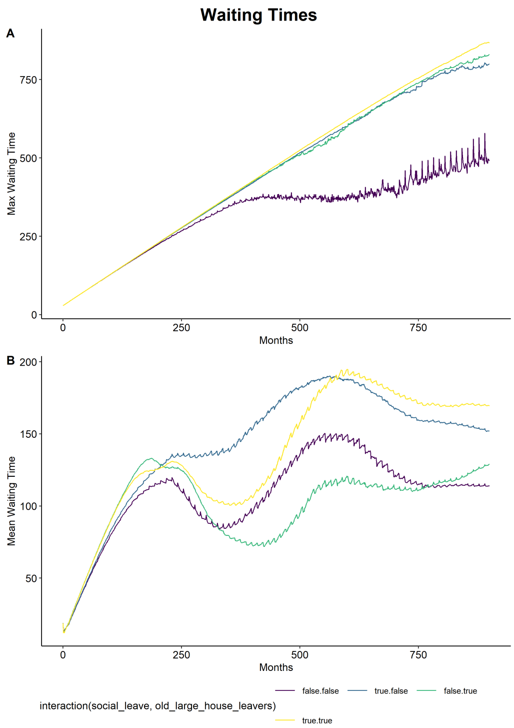
Figure A7. *Cont.*



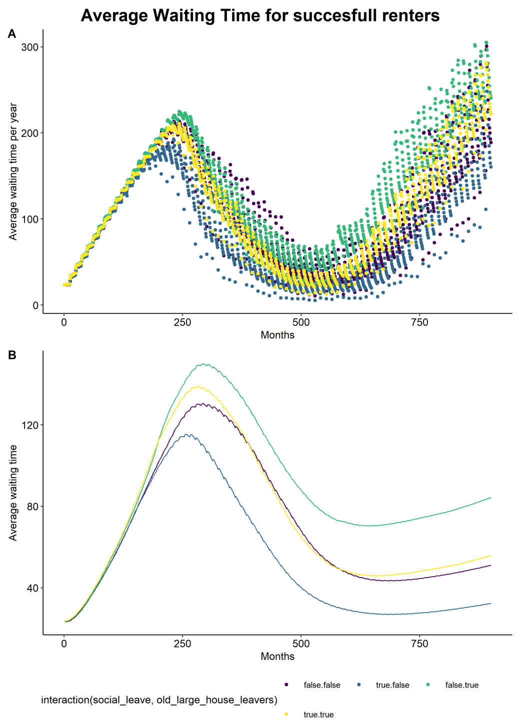
(**e**) Count of household motivations to move.



(**f**) Monthly payments for private rents and mortgages.



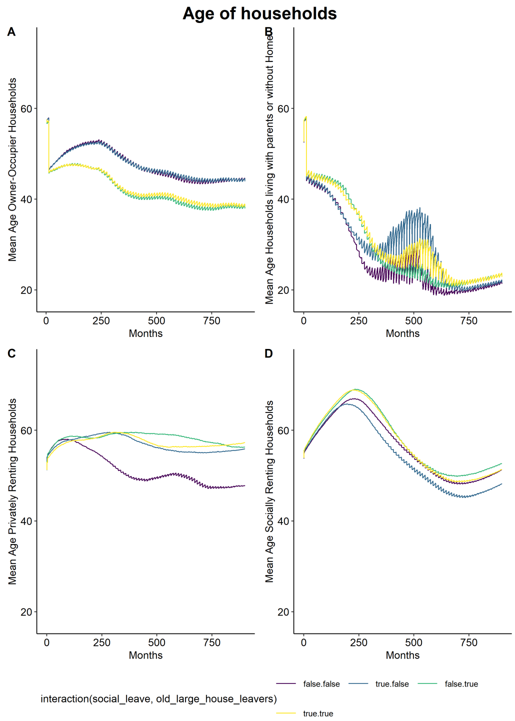
(**g**) Waiting times of households.



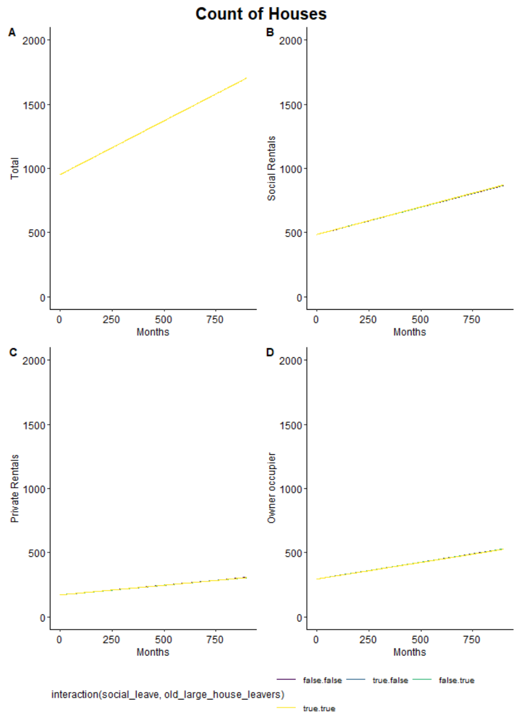
(**h**) Waiting times for households that successfully rent a social house.

Figure A7. Migration.

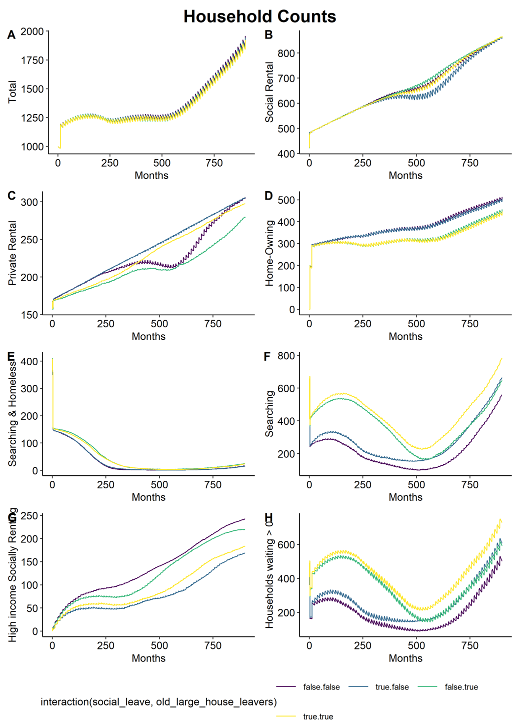
Appendix C.3.2. Varying Size Compositions



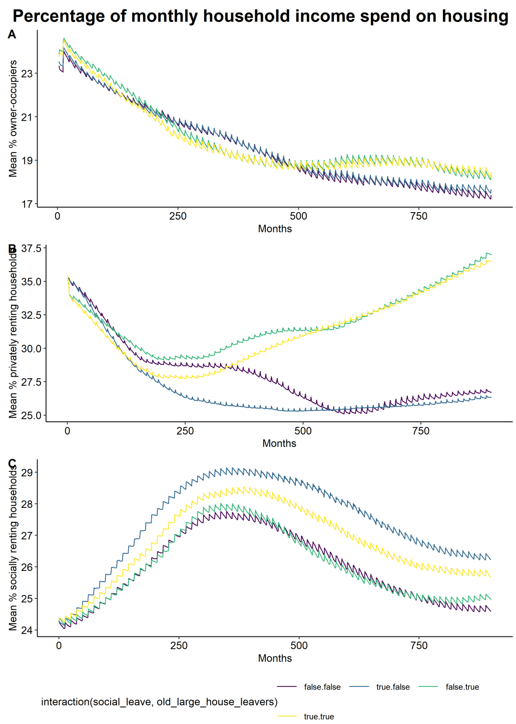
(**a**) Age of households in housing sectors.



(**b**) Count of houses in housing sectors.

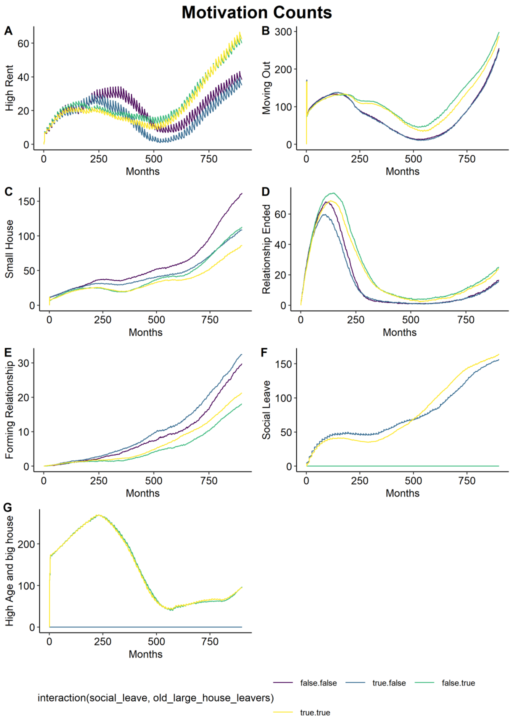


(**c**) Count of households.

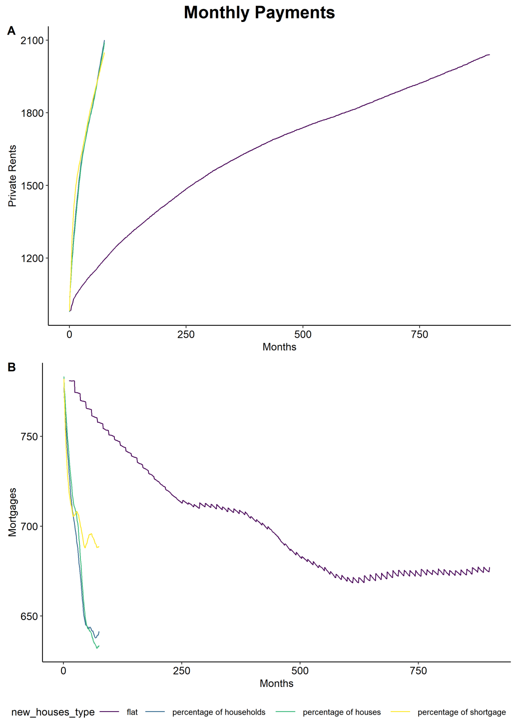


(**d**) Percentage of monthly household income spent on housing.

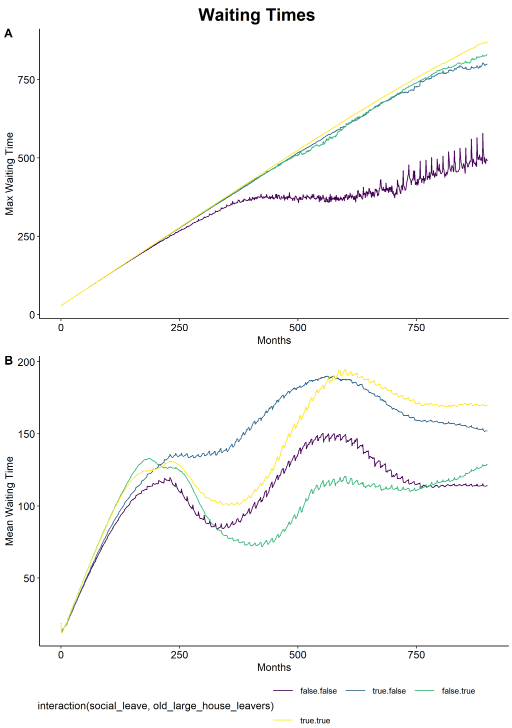
Figure A8. *Cont.*



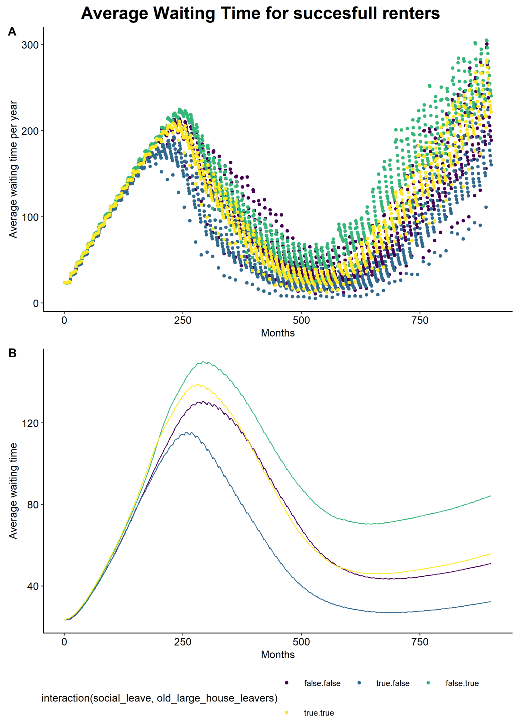
(**e**) Count of household motivations to move.



(**f**) Monthly payments for private rents and mortgages.



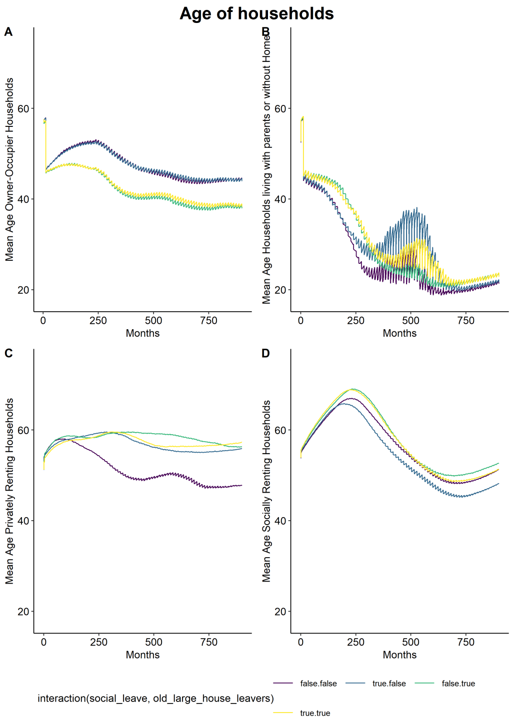
(**g**) Waiting times of households.



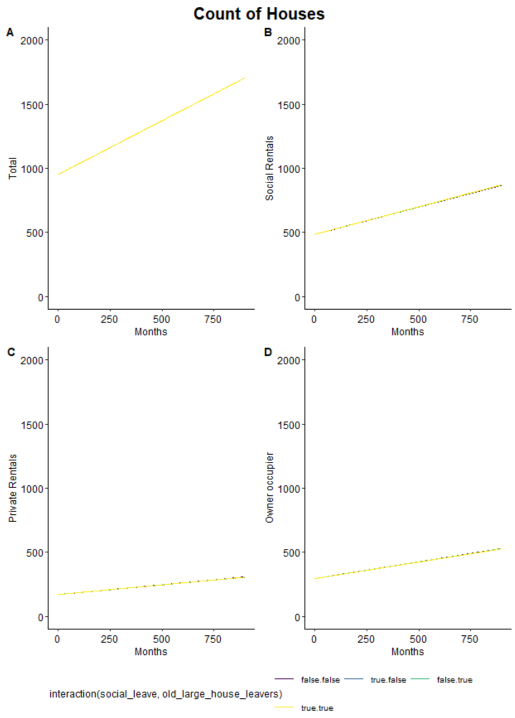
(**h**) Waiting times for households that successfully rent a social house.

Figure A8. Varying size compositions.

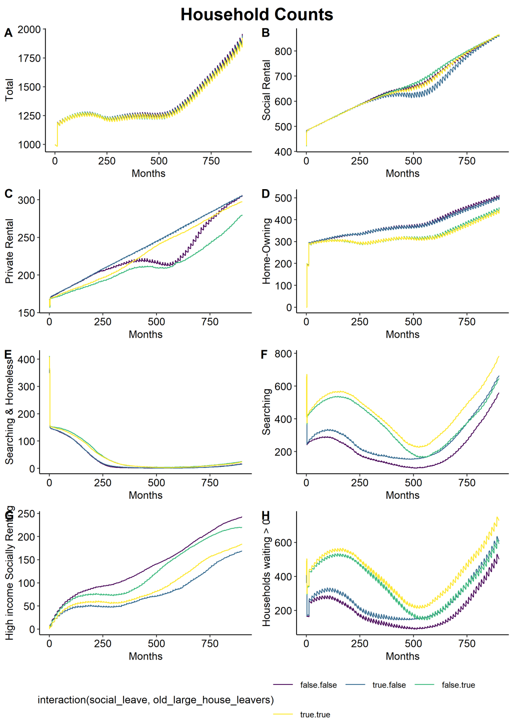
Appendix C.3.3. Varying Market Compositions



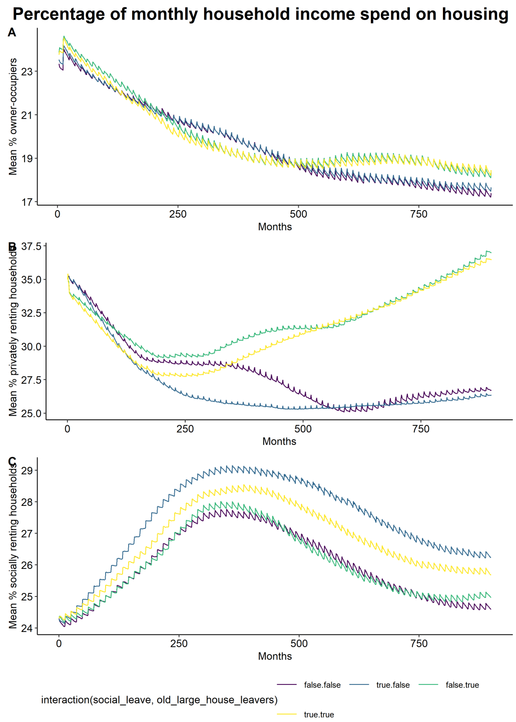
(**a**) Age of households in housing sectors.



(**b**) Count of houses in housing sectors.

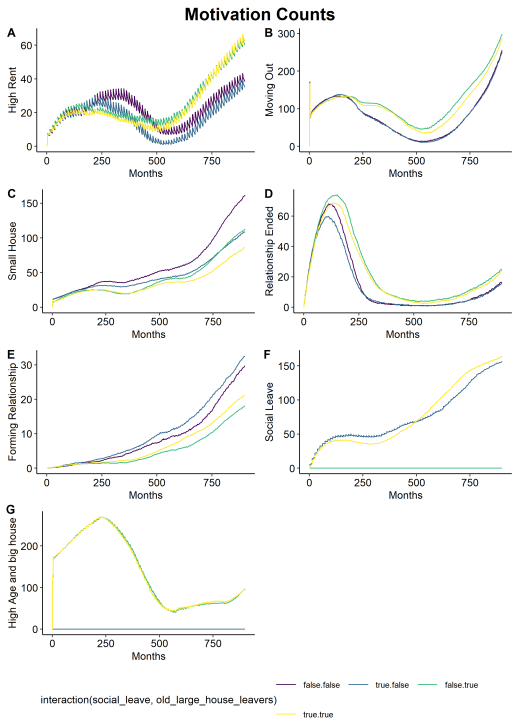


(**c**) Count of households.

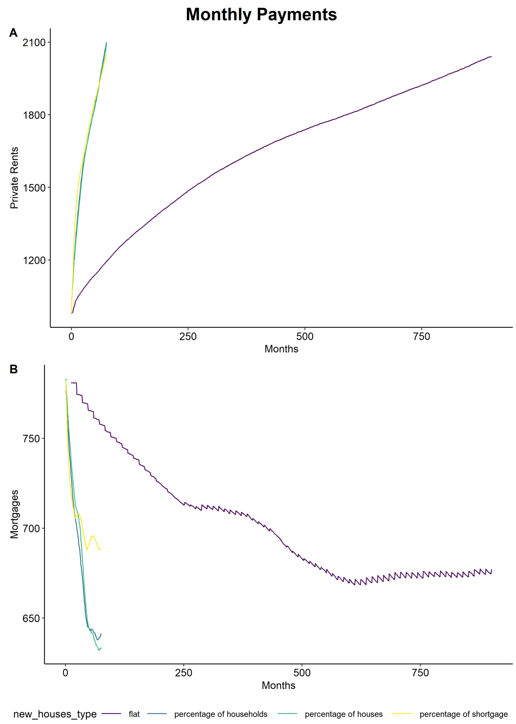


(**d**) Percentage of monthly household income spent on housing.

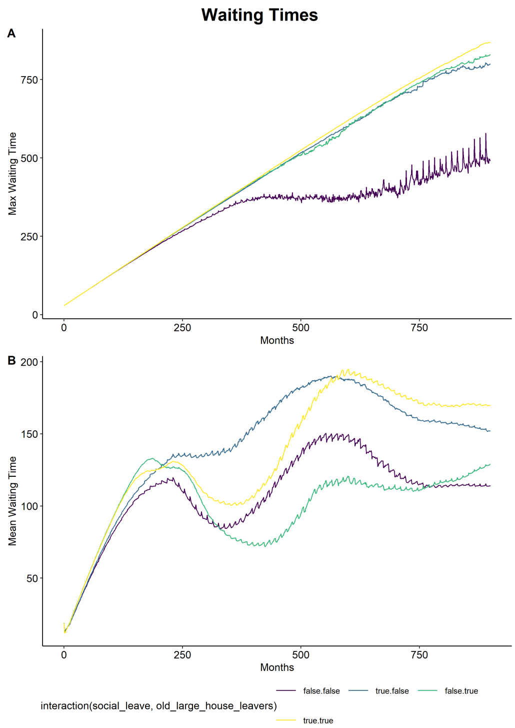
Figure A9. *Cont.*



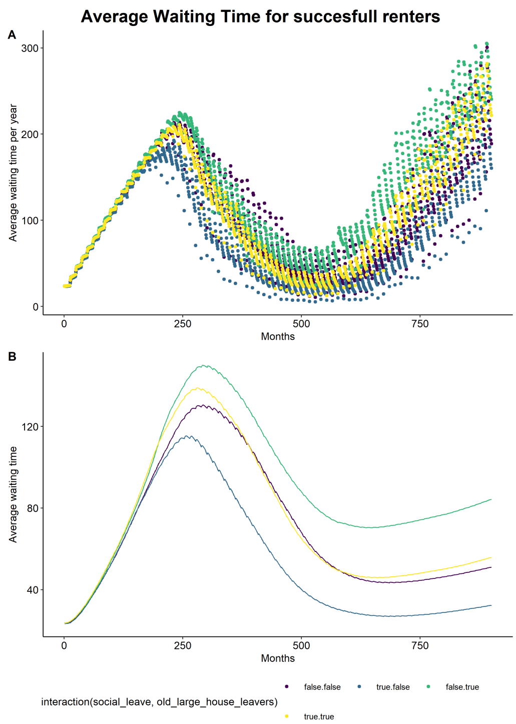
(**e**) Count of household motivations to move.



(**f**) Monthly payments for private rents and mortgages.



(**g**) Waiting times of households.



(**h**) Waiting times for households that successfully rent a social house.

Figure A9. Varying market compositions.

References

1. Musterd, S. Public Housing for Whom? Experiences in an Era of Mature Neo-Liberalism: The Netherlands and Amsterdam. *Hous. Stud.* **2014**, *29*, 467–484. [CrossRef]
2. Rigterink, T. Generation Y as Starter in the Dutch Housing Market. Master's Thesis, University of Twente, Enschede, The Netherlands, 2017.
3. Kromhout, S.; Wittkämper, L. *Wachttijden Voor Sociale Huurwoningen Nemen Toe*; Rigo: Amsterdam, The Netherlands, 2019.
4. Luijendijk, V. Gezin Komt maar niet uit Woning Met één Slaapkamer: 'Eerst Verdienden we te Weinig, Nu te Veel'. 2021. Available online: https://www.at5.nl/artikelen/207339/gezin-komt-maar-niet-uit-woning-met-een-slaapkamer-eerst-verdienden-we-te-weinig-nu-te-veel (accessed on 2 September 2021).
5. Buys, A.; Hu, M. *De (vermeende) Invloed van Alleenstaanden op de Woningmarkt*; Rigo: Amsterdam, The Netherlands, 2018.
6. van Oorschot, J.; Sprecher, B.; Rijken, B.; Witteveen, P.; Blok, M.; Schouten, N.; van der Voet, E. Toward a low-carbon and circular building sector: Building strategies and urbanization pathways for The Netherlands. *J. Ind. Ecol.* **2023**, *27*, 535–547. [CrossRef]
7. Dutch News. Amsterdam to Bring Back Flat-Sharing, Stop Social Housing Sell-Offs. 2023. Available online: https://www.dutchnews.nl/2023/02/amsterdam-to-bring-back-flat-sharing-stop-social-housing-sell-offs/ (accessed on 2 September 2023).
8. Boelhouwer, P.; Hoekstra, J. Towards a better balance on the Dutch housing market? Analysis and policy propositions. *Eur. J. Hous. Policy* **2009**, *9*, 457–475. [CrossRef]
9. Huurcommissie. About the Rent Tribunal. 2021. Available online: https://www.huurcommissie.nl/ (accessed on 2 September 2021).
10. Hochstenbach, C. Landlord Elites on the Dutch Housing Market: Private Landlordism, Class, and Social Inequality. *Econ. Geogr.* **2022**, *98*, 327–354. [CrossRef]
11. NOS. Steeds meer Gemeenten Voeren Woonplicht in voor Eigenaar Nieuwbouwwoningen. 2020. Available online: https://nos.nl/l/2343549&ved=2ahUKEwjl49nItNeFAxVIklYBHbz7DjcQFnoECA4QAw&usg=AOvVaw2H6vGUyY-w6K_NRXkyVfSV (accessed on 2 September 2021).
12. Miron, J.R.; Schiff, M. *A Profile of the Emerging Empty Nester Household*; Centre for Urban and Community Studies, University of Toronto: Toronto, ON, Canada, 1982.
13. Ministerie van Binnenlandse Zaken en Konikrijksrelaties. *Ruimte voor Wonen*; Ministerie van Binnenlandse Zaken en Konikrijksrelaties: The Hague, The Netherlands, 2019.
14. Boelhouwer, P. The housing market in The Netherlands as a driver for social inequalities: Proposals for reform. *Int. J. Hous. Policy* **2020**, *20*, 447–456. [CrossRef]
15. Anundsen, A.K.; Larsen, E.R.; Sommervoll, D.E. *Strategic Price-Setting and Incentives in the Housing Market*; Working Paper Series; Oslo Metropolitan University: Oslo, Norway, 2020.
16. Gilbert, N.; Hawksworth, J.C.; Swinney, P.A. An Agent-Based Model of the English Housing Market. In Proceedings of the AAAI 2009 Spring Symposium on Technosocial Predictive Analytics, Palo Alto, CA, USA, 23–25 March 2009; pp. 30–35.
17. Cheng, P.; Lin, Z.; Liu, Y. Competing selling strategies in the housing market. *J. Real Estate Financ. Econ.* **2020**, *63*, 394–413. [CrossRef]
18. García-Magari no, I.; Lacuesta, R. Agent-based simulation of real-estate transactions. *J. Comput. Sci.* **2017**, *21*, 60–76. [CrossRef]
19. Han, L.; Strange, W.C. The microstructure of housing markets: Search, bargaining, and brokerage. In *Handbook of Regional and Urban Economics*; Elsevier: Amsterdam, The Netherlands, 2015; Volume 5, pp. 813–886.
20. Ozhegov, E.M.; Sidorovykh, A.S. Heterogeneity of sellers in housing market: Difference in pricing strategies. *J. Hous. Econ.* **2017**, *37*, 42–51. [CrossRef]
21. Bouman, J.A. The Best-Offer-over Pricing Method: A Best-Strategy? A Case Study in the Rotterdam Housing Market. Master's Thesis, Rijksuniversiteit Groningen, Groningen, The Netherlands, 2020.
22. Haurin, D.; McGreal, S.; Adair, A.; Brown, L.; Webb, J.R. List price and sales prices of residential properties during booms and busts. *J. Hous. Econ.* **2013**, *22*, 1–10. [CrossRef]
23. Anglin, P.M.; Rutherford, R.; Springer, T.M. The trade-off between the selling price of residential properties and time-on-the-market: The impact of price setting. *J. Real Estate Financ. Econ.* **2003**, *26*, 95–111. [CrossRef]
24. Cheng, P.; Lin, Z.; Liu, Y. A Model of Time-on-Market and Real Estate Price Under Sequential Search with Recall. *Real Estate Econ.* **2008**, *36*, 813–843. [CrossRef]
25. Ettema, D. A multi-agent model of urban processes: Modelling relocation processes and price setting in housing markets. *Comput. Environ. Urban Syst.* **2011**, *35*, 1–11. [CrossRef]
26. Axtell, R.; Farmer, D.; Geanakoplos, J.; Howitt, P.; Carrella, E.; Conlee, B.; Goldstein, J.; Hendrey, M.; Kalikman, P.; Masad, D.; et al. An agent-based model of the housing market bubble in metropolitan Washington, DC. In Proceedings of the Deutsche Bundesbank Spring Conference on 'Housing Markets and the Macroeconomy: Challenges for Monetary Policy and Financial Stability', Eltville, Germany, 5–6 May 2014.
27. Benenson, I. Multi-agent simulations of residential dynamics in the city. *Comput. Environ. Urban Syst.* **1998**, *22*, 25–42. [CrossRef]
28. Song, S. Determinants of bargaining outcome in single-family housing transactions: An empirical examination. *Urban Stud.* **1995**, *32*, 605–614. [CrossRef]
29. Bazerman, M.H.; Neale, M.A.; Valley, K.L.; Zajac, E.J.; Kim, Y.M. The effect of agents and mediators on negotiation outcomes. *Organ. Behav. Hum. Decis. Process.* **1992**, *53*, 55–73. [CrossRef]

30. De Toro, P.; Nocca, F.; Buglione, F. Real Estate Market Responses to the COVID-19 Crisis: Which Prospects for the Metropolitan Area of Naples (Italy)? *Urban Sci.* **2021**, *5*, 23. [CrossRef]
31. Domínguez-Mujica, J.; González-Pérez, J.M.; Parreño-Castellano, J.M.; Sánchez-Aguilera, D. Gentrification on the Move. New Dynamics in Spanish Mature Urban-Tourist Neighborhoods. *Urban Sci.* **2021**, *5*, 33. [CrossRef]
32. Overwater, A.; Yorke-Smith, N. Agent-Based Simulation of Short-Term Peer-to-Peer Rentals: Evidence from the Amsterdam Housing Market. *Environ. Plan. B Urban Anal. City Sci.* **2022**, *49*, 223–240. [CrossRef]
33. Moss, S. Alternative Approaches to the Empirical Validation of Agent-Based Models. *J. Artif. Soc. Soc. Simul.* **2008**, *11*, 5.
34. van Dam, K.H.; Nikolic, I.; Lukszo, Z. *Agent-Based Modelling of Socio-Technical Systems*; Springer Science & Business Media: Dordrecht, The Netherlands, 2012.
35. Heath, B.L.; Hill, R.R. Some insights into the emergence of agent-based modelling. *J. Simul.* **2010**, *4*, 163–169. [CrossRef]
36. ten Broeke, G.; van Voorn, G.; Ligtenberg, A. Which Sensitivity Analysis Method Should I Use for My Agent-Based Model? *J. Artif. Soc. Soc. Simul.* **2016**, *19*, 5. [CrossRef]
37. Devisch, O.T.; Timmermans, H.J.; Arentze, T.A.; Borger, A.W. An agent-based model of residential choice dynamics in nonstationary housing markets. *Environ. Plan. A* **2009**, *41*, 1997–2013. [CrossRef]
38. Carstensen, C.L. An Agent-Based Model of the Housing Market: Steps toward a Computational Tool for Policy Analysis. Master's Thesis, University of Copenhagen, Copenhagen, Denmark, 2015.
39. Zhuge, C.; Shao, C. Agent-based modelling of purchasing, renting and investing behaviour in dynamic housing markets. *J. Comput. Sci.* **2018**, *27*, 130–146. [CrossRef]
40. Yun, T.; Moon, I. Housing Market Agent-Based Simulation with Loan-To-Value and Debt-To-Income. *J. Artif. Soc. Soc. Simul.* **2020**, *23*, 5. [CrossRef]
41. Mozaffaree Pour, N.; Oja, T. Urban Expansion Simulated by Integrated Cellular Automata and Agent-Based Models; An Example of Tallinn, Estonia. *Urban Sci.* **2021**, *5*, 85. [CrossRef]
42. Ziengs, A.H.; Yorke-Smith, N. Hot Housing: A Study of Bidding Strategies in the Dutch Urban Residential Market. In Proceedings of the Working Notes of AAMAS'19 Workshop on Agent-Based Modelling of Urban Systems (ABMUS'19), Montreal, QC, Canada, May 2019.
43. Van Duin, C.; Harmsen, C. Een nieuw model voor de CBS huishoudensprognose. *Bevolkingstrends Stat. Kwartaalblad Demogr. Ned.* **2009**, *57*, 20–42.
44. Edmonds, B.; Moss, S. From KISS to KIDS—An 'Anti-simplistic' Modelling Approach. In Proceedings of the Workshop on Multi-Agent and Multi-Agent-Based Simulation (MABS'04), New York, NY, USA, 19 July 2004; Lecture Notes in Computer Science; Springer: Berlin/Heidelberg, Germany, 2004; Volume 3415, pp. 130–144. [CrossRef]
45. Grimm, V.; Railsback, S.F.; Vincenot, C.E.; Berger, U.; Gallagher, C.; DeAngelis, D.L.; Edmonds, B.; Ge, J.; Giske, J.; Groeneveld, J.; et al. The ODD Protocol for Describing Agent-Based and Other Simulation Models: A Second Update to Improve Clarity, Replication, and Structural Realism. *J. Artif. Soc. Soc. Simul.* **2020**, *23*, 7. [CrossRef]
46. Wilensky, U. *NetLogo. Center for Connected Learning and Computer-Based Modeling*; Northwestern University: Evanston, IL, USA, 1999.
47. Wiegel, E. Decreasing Demand without Building Houses: Towards Agent-Based Market Analysis of Internal Demand. Master's Thesis, Delft University of Technology, Delft, The Netherlands, 2021.
48. Nibud. *Rapport Advies Financieringslastnormen 2021*; Nibud—Nationaal Instituut voor Budgetvoorlichting: Utrecht, The Netherlands, 2021.
49. Ministerie van Algemene Zaken. *Kom ik in Aanmerking voor een Sociale Huurwoning van een Woningcorporatie?* Ministerie van Algemene Zaken: The Hague, The Netherlands, 2021.
50. Berkers, V.; Dignum, K. *Wonen in Amsterdam 2019 Woningmarkt*; Gemeente Amserdam: Amserdam,The Netherlands, 2020.
51. Groot, N.d. Bouw van 75.000 Nieuwe Huizen Gaat Ook Komende Twee Jaar niet Lukken. 2019. Available online: https://www.ad.nl/wonen/bouw-van-75-000-nieuwe-huizen-gaat-ook-komende-twee-jaar-niet-lukken-br~aa0ba573 (accessed on 2 September 2023).
52. Sobol, I.M. Global sensitivity indices for nonlinear mathematical models and their Monte Carlo estimates. *Math. Comput. Simul.* **2001**, *55*, 271–280. [CrossRef]
53. Wilhelmsson, M. Housing Choices of Young Adults in Sweden. *Real Estate* **2024**, *1*, 4–25. [CrossRef]
54. Nye, B.D. What is between KISS and KIDS: A Keep It Knowledgeable (KIKS) Principle for Cognitive Agent Design. In Proceedings of the AAAI Fall Symposium on Integrated Cognition, 15 November 2013; Available online: https://ojs.library.carleton.ca/index.php/cmcb/article/view/2678 (accessed on 2 September 2021).
55. Huisman, C.J. A silent shift? The precarisation of the Dutch rental housing market. *J. Hous. Built Environ.* **2016**, *31*, 93–106. [CrossRef]
56. Maas, O.P. Modelling and Improving Social Housing Markets. Master's Thesis, Delft University of Technology, Delft, The Netherlands, 2020. Available online: http://resolver.tudelft.nl/uuid:a94299c9-e848-4c5b-aeed-ed1e9e01fd1c (accessed on 2 September 2021).
57. Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. *Veelgestelde Vragen over Het (Passend) Toewijzen van Woningen*; Ministerie van Binnenlandse Zaken en Koninkrijksrelaties: The Hague, The Netherlands, 2021.
58. Ministerie van Algemene Zaken. *Mag Mijn Verhuurder de Huur Opzeggen van Mijn Woning?* Ministerie van Algemene Zaken: The Hague, The Netherlands, 2021.

59. Ministerie van Algemene Zaken. *Welke Regels Gelden er voor een Huurverhoging?* Ministerie van Algemene Zaken: The Hague, The Netherlands, 2021.
60. Ministerie van Algemene Zaken. *Hoeveel Huur Betaal ik Maximaal voor Mijn Woning?* Ministerie van Algemene Zaken: The Hague, The Netherlands, 2021.
61. Dutch Government. *Artikel 274 Burgerlijk Wetboek Boek 7*; Dutch Government: The Hague, The Netherlands, 2021.
62. Ministerie van Algemene Zaken. *Bij Welke Soorten Hypotheken heb ik Recht OP Hypotheekrenteaftrek?* Ministerie van Algemene Zaken: The Hague, The Netherlands, 2021.
63. Ministerie van Algemene Zaken. *Hoeveel Kan ik Maximaal LENEN voor Mijn Koopwoning?* Ministerie van Algemene Zaken: The Hague, The Netherlands, 2020.
64. NVM. *Analyse Woningmarkt 3e Kwartaal 2020*; NVM: Utrecht, The Netherlands, 2020.
65. NVM. *Analyse Woningmarkt 1e Kwartaal 2020*; NVM: Utrecht, The Netherlands, 2020.
66. Ministerie van Algemene Zaken. *Ruimte voor Wonen Kernpublicatie Woon 2018*; Ministerie van Algemene Zaken: The Hague, The Netherlands, 2019.