Decreasing demand without building houses

Towards Agent-Based Market Analysis of Internal Demand

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TU Delft

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by

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TU Delft

Preface

This thesis written as my master thesis project to finish my masters degree in computer science at the TU Delft.

The subject once started as applying agent-based modelling to strategies applied in the housing market, but has with time turned itself into the application of agent-based modelling to evaluate policy and a description of the Dutch housing market.

This thesis has been completed during the covid pandemic, which has made the process quite difficult; the isolation and lack of clear boundaries between work and home have been trying. At times it felt like a battle between preserving my mental health and progressing my thesis.

Thank you to my supervisor, Neil Yorke-Smith, for your guidance, patience and optimism. Not only have you guided me through the creation of this thesis, but your encouragement has helped me endure the hardships experienced.

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E. Wiegel
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Contents

1 Introduction

The Dutch residential market is experiencing a housing shortage at the time of writing. This shortage means not only that there are many households which are unable to find a home, but also that households that do have a home have limited alternatives. These alternatives are further restricted by the gaps between different sectors of the market. The market comprises of three sectors: social rental (managed directly or indirectly by municipal governments), private rental (regulated by a combination of municipal and national government), and owner-occupied (affected by the mortgage market).

1.1. Problems in the market

Regulations for the social rental housing sector and 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 (Rigterink, 2017). Combined with the limited supply in the private rental sector, starters are left with very few options. Starters who are eligible for social housing experience that the social rental market has growing waiting lists in every major urban area (Kromhout and Wittkämper, 2019). This is the first problem in the housing market, a shortage of homes that especially impacts middle-income households and starters.

In the social rental sector there are families with children living in one-bedroom homes, some waiting for their turn for a larger homes and others who received 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 (AT5, 2021). At the same time, however, there are "empty nesters" (Miron and Schiff, 1982), parents whose children have moved out, who keep living in social homes (or private homes) that are big enough to support a family with children. This is the second problem in the Dutch market, households can not find large enough homes.

Similar to the imbalance in households occupying too small or large homes there is an imbalance in the rents paid by households, in which two groups can be categorized: "Goedkope Scheefwoners" (cheap skewed renters) and "Dure Scheefwoners" (expensive skewed renters), (Ministerie van Binnenlandse Zaken en Konikrijksrelaties, 2019). The first group are people living in social housing who earn more than the income limit for social housing. The second group consists of people paying too much rent compared to their income. Some of these renters entered the private sector because of the waiting list for social housing being too long. Some even end up paying a monthly rent higher than the amount they are allowed to pay monthly for a mortgage. This is the third problem in the Dutch market, some households profit from the low rents in the social secto, while simultaneously other households overpay because there is no room in the social sector.

The Dutch housing market is shaped not only by the Dutch government but also by the policies of parties involved with the housing market. The corporations in charge of social housing decide how houses are allocated, real estate agents shape how negotiations are conducted and local government is responsible for selling land to developers to build houses on. A concrete example of one of these policies is that a person has to sign up for each social housing region separately and pay a fee separately for each region they are signed up for.

1.2. Internal and External Demand

The problems set out in the previous section share that they, to a certain degree, can be resolved by swapping households, e.g. swapping a family in a single-bedroom and an empty nester household may leave both households satisfied. (A swap in this context denotes that the difference between two allocations is swapping two households, not, necessarily, forcing two households to swap as a solution.)

To better understand demand in a housing market (under shortage) two types of demand are defined: "internal demand", households who are dissatisfied with their current home like the aforementioned families in single-bedroom housing, and "external demand", households who do not have a home and want to enter the market such as the starters.

The essential difference is that internal demand can be solved by swapping households, while external demand can only be resolved by increasing the supply, i.e. creating new homes, or reducing the demand through combining or removing households. It is also possible to decrease the internal demand by swapping a dissatisfied household with a "homeless" household that would be satisfied in the house.

An example of preventing internal demand is the idea of "doorstroming" (Prinse, 2014) in the social sector: households that have an increase in income leave for owner-occupier or private rental market. If this does not happen these households become cheap skewed renters. This eventually forces people with lower incomes to be unable to enter social housing and to instead rent more expensive private housing and potentially become expensive skewed renters. This causes internal demand, as they still desire a cheaper dwelling, which could have been prevented if doorstroming did happen, which essentially "swaps" the allocation of these households.

Internal demand becomes especially interesting during a housing shortage. If during a shortage as many new homes as possible are built, it is still possible to reduce (or prevent) demand further by considering internal demand, as internal demand can be reduced without building new houses. This is also of particular interest as the housing market is currently (2020/2021) suffering from such a shortage.

1.3. Research Questions

The question we investigate is: *How is internal demand impacted by regulations in a housing market suffering from a shortage?*

To consider internal demand it is needed to focus on households, since this demand is caused by dissatisfied households, which is not only a result of the price or size of a house, but also by the changing of needs and composition of a household over time. Therefore we address the research question by developing an agent-based model (ABM) of the Dutch housing market, in particular for the city of Amsterdam. Agent-based modeling is a modeling paradigm that focuses on the behaviour of individual agents to observe results emerging from the interaction of the agents with each other and their environment (Wilensky and Rand, 2015). This simulation model intends to achieve three purposes:

1. Contrast with economical models through the use of a different modelling technique.
2. Investigate the effects of regulations on specific causes of demand for households.
3. Provide a flexible approach in which policy changes and new policy can be easily studied.

The intended contrast with economical models is in the level of detail. Existing models of the Dutch housing market often focus on macro-variables such as the house prices (De Wit et al., 2013, Francke et al., 2014) or the number of houses being build (Boelhouwer, 2005). In this thesis however the interest is on the micro-level, e.g. how many households cannot find a home after a relationship ends.

1.4. This Thesis

In the rest of this thesis we will first look at the existing work in chapter 2. Chapter 3 will describe how the Dutch housing market works. Chapter 4 describes what approach is taken in this thesis. Chapter 5 will describe the designed model. Chapter 6 will show the experiments conducted and their results. In chapter 7 we reflect on the thesis process. Then chapter 8 will discuss the results of the experiments. Finally chapter 9 concludes on the findings, the modelling process and discusses future research directions.

2
Related Work

This chapter considers previous work related to modelling the housing market, it focuses on the systematical working of housing markets and the behaviour of actors that interact in the housing market. These focuses have been chosen because of the nature of agent-based modeling, which focuses on the behaviour of individual agents within their environment (Wilensky and Rand, 2015). Therefore the focus of the related work is on understanding how the environment, the (Dutch) housing market, functions and how actors (agents) behave in it. The related work is separated in the following aspects:

- Buyer & seller searching strategies
- The role of the listing price
- Household decisions
- Negotiation

Many different approaches have been used to study these topics. These approaches include: case studies (Anundsen et al., 2020), policy analysis (Boelhouwer and Hoekstra, 2009) and agent-based models (Gilbert et al., 2009).

After considering these specific aspects close look will be given to prior work on creating agent-based models of the housing market. To create an agent-based model that includes households it is necessary to consider how households change over time. As a base to design this transformation over time the model of the CBS (the Dutch Central Agency for Statistics) (Van Duin and Harmsen, 2009) for households predictions is investigated closely as it the official method used in the Netherlands to predict which households will exist in the future.

2.1. Buyer & Seller Searching Strategies

The first step for a transaction in the housing market is that a buyer or seller looks for a partner to negotiate with. The searching strategy for buyers defines when a buyer reaches out to sellers, e.g. they may expect better market conditions and 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 consider both a theoretical optimal strategy and real strategies applied in the housing market. The contrast between real strategies and theoretically optimal strategies can reveal interesting insight: for the creation of an agent-based model the strategies are useful to define the behaviour of agents.

Cheng et al. (2020) compare two selling strategies (the stopping and number rule) under different market conditions using a 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.

Another angle is considered by García-Magariño and Lacuesta (2017). They created 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 or renters and landlords find each other. Han and Strange (2015) provide an overview of matching models used to model this process for housing markets. The first models described consider sequential matching, where a single buyer meets a single seller, and if there is no deal a different seller-buyer match can be made. This is followed by models of auctions which consider simultaneous matching, but it is noted that the choice between simultaneous or sequential matching can be caused by the state of the market or the setup of the seller. Finally the survey identifies imperfect information as one of the key factors that explains the use of real estate agents in the matching process.

The process in which buyer and sellers find each other can be the deciding factor in the housing market. This system is dependent on the spread of information and the speed of processes such as negotiation or requesting a mortgage. The work of Han and Strange also connects the matching progress to the role of the listing price.

The strategy of a seller is also dependent on the role of the seller, Ozhegov and Sidorovykh (2017) considered the effects of the time on the market on the selling behaviours of both private sellers and real estate agents. This done by applying an estimation model on a data-set of a popular real estate marketing platform in Russia. They conclude that real estate agents are more impatient sellers than private sellers.

Bouman (2020) compares 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 listing price functions more as signalling device or floor. They analysed over 50.000 transactions in Rotterdam and found no clear difference in transaction price between the strategies.

2.2. The Role of Listing Prices

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. The listing price can communicate:

- 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.

Haurin et al. (2013) recognize a different role of the listing price during booms or busts and try to explain this behaviour with a 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 Anglin et al. (2003) and Cheng et al. (2008) 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, Anundsen et al. (2020) observed a difference between the theoretically optimal and actual selling strategy for setting listing prices in Norway. By considering realtors they were able to show that the actual selling strategy was beneficial to realtors at the cost of the seller they represent.

2.3. Household Decisions

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.

Ettema (2011) and Axtell et al. (2014) 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 Benenson (1998), 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 the economical situation. Interesting about this paper is the idea that the state of the housing market can change a household.

2.4. Negotiation

After a household has decided to move and found a seller to buy a home from, the buyer and seller still need to negotiate on a final transaction price. To understand this negotiation process better for the housing market, Song (1995) investigate the influence of various factors on the outcome of the negotiation process for historical transactions. What stands out most is that there is no evidence that first-time buyers have worse bargaining outcomes compared to repeat buyers.

Bazerman et al. (1992) concluded that real estate agents may make agreement between buyer and seller 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-interest rather than part of one side of the negotiation.

2.5. Agent-Based Models for Housing Markets

There is quite a number of agent-based models that study housing markets. The focus and approach for these models vary greatly, from reproducing historic events (Axtell et al., 2014) to comparing buyer and seller strategies (García-Magariño and Lacuesta, 2017). Notably no models including the Dutch social sector were found.

Gilbert et al. (2009) model the English housing market. From their model a cycle of boom and bust and richer and poorer neighbourhoods emerged through only a small set of key features. Notable is that in this model buyers continuously enter and leave the simulation. Additionally in each simulation tick transactions are made until no transactions are possible.

Zhuge and Shao (2018) created a model that combines the purchasing, renting and investing sector into one model. The work in the paper consists of two parts, the first part simulates the demographic and provides triggers for households to look for a different home. The second part is the process of matching between offeror agents and the agents that received triggers. While there is both a rental and buying sector, they both use the same system.

Devisch et al. (2009) 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.

Ettema (2011) 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 resulted in a dynamic model in which households react to the state of the market.

The previously mentioned model created by García-Magariño and Lacuesta (2017) sets up agents with different strategies to research how strategies affect each other. In this model agents are only a buyer or seller, not both, and no new agents enter over the simulation time.

In response to a financial crisis Axtell et al. (2014) created an extensive model of the Washington D.C. housing market. Their design reproduces historical data based on rich micro data-sets, as an example the number of households is matched to census data. Notably they model both home-ownership and renting.

Carstensen (2015) 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 notable the households change their preferences with age, but do not explicitly change their needs.

2.6. Simulating Households over Time

For an agent based model it is essential to generate a fitting population for the problem at hand. The initial population for the housing market can be generated with known data of the current population. However, as simulating the housing market requires a long time-span it becomes necessary to also simulate the future population. In the Netherlands the future households are predicted yearly by the CBS. Their method for prediction is a simulation model (Van Duin and Harmsen, 2009) to which the inputs are carefully considered by experts.

The model does not model households but rather people with their position in a household and “Burgerlijke Staat” as their state. The possible household positions are:

- 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: Never Married, Married, Widowed or Divorced. In this system registered partnership and marriage is treated the same. Not for every person the state is known, and for 7% of people their households position is estimated. The CBS does their best to correct old incorrect estimations if newer information reveals that the estimation was incorrect.

To model the state of a person in the next simulation step transitions between states are utilized. 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.

Because the transitions are applied to people, and not households, inconsistencies can happen because the state change involves two parties but only one party goes through the transition. An example being divorce, where a difference can emerge between the amount of males and females that divorce. Assumed is that there is an equal amount of male-male and female-female same-sex couples, so the difference between the male and female divorcees has to be corrected for. Similar corrections are made for marriage, widowers and the forming of relationships. For childbirth a correction is made to change persons to a state with parenthood, e.g. Single-person Household to Parent in single-parent household, to make sure the amount of parents matches the amount of children.

2.7. The Novelties

In this thesis we extend the previous work on modelling of housing markets by implementing the Dutch housing market with three of its different sectors. In particular the Dutch social sector differs from previous work as it functions according to selection rules, rather than due to market forces. This work further expands upon previous work by focusing on the overall satisfaction of the households while considering the changing needs of households.

These expansions serve to fulfill the main contribution, investigating the internal demand of households.

3 Context

In contrast to the related work, in this chapter the current state of the Dutch housing market is researched through the (public) information the organisations connected to the housing market provide. The goal is to gain a broad understanding of the workings and interactions of the systems in each of the social, private and owner-occupier sectors.

The social sector consists of all houses rented out at a price under the so called “liberalization” limit, which is current set to a monthly rent of €752,33. Conversely the private sector contains all houses rented out above the liberalization limit. The owner-occupier sector consists of all houses that are occupied by the owner of the house.

For each of these sectors the stakeholders, the possible actions of the agents, relevant laws and relevant policies will be considered. The distinction between policy and law is, in this case, that laws apply to all agents while policies only apply to agents the policy-maker has influence over. For example the rules set by real estate agency can be easily ignored by independent real estate agents. Finally common “problems” in the Dutch housing market will be set out to provide insight into the perceived issues with the functioning of the market.

The laws and policies both change quite regularly, especially when compared to the rate at which households move. This chapter describes a limited view of the “current” situation of the housing market as of January 2021. Even over the course of this thesis laws have changed, one such example being a temporary limit to rent increases in the private sector (Ministerie van Algemene Zaken, 2021d).

3.1. Social Sector

The Social sector consist of all houses that, at the start of their contract, were rented out under the liberalization limit. Most of the social sector is organized by housing corporations. The main task of the housing corporations is to provide social housing, which is stated in article 47 of the “Woningwet” law (Dutch Government, 2021b). This is done in various degrees of cooperation and connection to the government. The goal of the social sector is to house the lowest-income households.

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 (Huurcommissie, 2021a). Where the other sectors use a free market to match renters and landlords or buyers and sellers, the social sector generally uses a regulated, regionally centralized system to match houses and households. The information on the social sector is retrieved from the explanations provided on `https://www.woningnetregioamsterdam.nl/Help%20en%20uitleg/` about the Amsterdam region.

3.1.1. 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 allowed to live in the Netherlands. A small fee has to paid yearly to each regional system a person is signed up for.

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” (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2021) limits what rents can be matched to what incomes and the corporations further imposes 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 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 they lose their priority.

The other common variant, besides the waiting time system, is a lottery, which utilizes the same restrictions for who can apply, in which from all eligible applicants a random application is selected. 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 sign 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 aforementioned case of partners, only the registrant loses their accumulated points, the co-registrant does not.

3.1.2. 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 (Ministerie van Algemene Zaken, 2021e). What is different for these households with a higher income is that their rent can be increased more than their lower income counterparts (Ministerie van Algemene Zaken, 2021c). The increased rent however may never exceed the maximum rent decided by the “Huurcommissie” (Ministerie van Algemene Zaken, 2021b). It should be noted that the maximum rent for a house can be higher than the liberalization limit. This faster rent increase may motivate households to leave the social sector if the cost becomes comparable to the private or owner-occupier sector.

3.2. Private Sector

While the private sector consists only of houses rented out above the liberalization 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. If a house in the private sector scores below the liberalization limit following the scoring system, the Huurcommissie can force the owner of the houses to lower the rent, and due to the lowered rent, force the house to become part of the social sector. A private renting household can only request this in the first three months of a contract.

If a house does score above the liberalization limit the Huurcommissie can advice or act as a mediator, but it is unable to enforce any ruling (Huurcommissie, 2021b). Therefore a household should consider how this request changes their relation to their landlord.

3.2.1. 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 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 the renter has 1 month to either accept the rent increase or end the rental contract (Dutch Government, 2021a).

Traditionally the rent 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 lived in the home (Ministerie van Algemene Zaken, 2021e).

There has however been a increase in the prevalence of temporary contracts in the Dutch housing market as warned for by Huisman (2016).

3.3. Owner-occupier Sector

The owner-occupier sector consists of all owner-occupied houses. 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 have started to require owners to occupy their homes to prevent investors from buying new houses and renting them out (NOS, 2020).

3.3.1. 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 (Ministerie van Algemene Zaken, 2021a).

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 by an advice of *"Stichting Nationaal Instituut voor Budgetvoorlichting"*(Ministerie van Algemene Zaken, 2020). Banks giving out mortgages can deviate from this calculation if they provide a good motivation.

3.3.2. Auction & Negotiation

The buying and selling process for houses is regulated 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 Coöperatieve Vereniging van Makelaars en Taxateurs in onroerende goederen"* (The Dutch Cooperative Association of Real Estate Agents and Valuers), This organization claimed a market share of 69% in 2020 (NVM, 2020a,b). 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 favorable 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 his experience, this auction is more common currently than twenty years ago.

3.4. Problems in the Market

In this section the perceived problems in the Dutch housing market are discussed. It is important to consider that there can be disagreement on what the problem is for the described situations. This can in turn shape which solution is proposed. This will be illustrated for the first situation.

For first-time home buyers ("starters") with a middle income the regulations for the social rental housing sector and for mortgages have resulted in a situation where they are both ineligible for social housing and unable to purchase a property (Rigterink, 2017). Combined with the limited supply in the private sector, this situation leaves a starter with very few options. This situation can be approached in different ways;

- Homeless middle income households pay for the social sector thus they should be allowed to apply for it if there are no other homes for them.
- Homeless middle income households cannot apply for the social sector and do not have a home themselves, thus they should not be forced to pay for people living in the social sector.
- Homeless middle income households cannot afford to buy a home, thus they should be allowed to have larger mortgages to be able to buy a home.
- Homeless middle income households cannot find a home to rent privately or buy, thus more houses should be build.

The goal is not to argue which approach is correct, as this is a complex topic, but to highlight that it is important to consider that views can differ. In this thesis problems are approached with the goal of satisfying as many households as possible in the existing system.

There are two cases where there are two groups that exist as each other's counterpart. Firstly there are those who live in too small a home with their counterpart being people living in a larger home than they need. Secondly there is 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 left, "empty nesters" (Miron and Schiff, 1982). The expanding families are searching for a larger home while the empty nesters occupy these larger homes.

The second case is the opposition between households that 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) (Ministerie van Binnenlandse Zaken en Konikrijksrelaties, 2019). 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.

The issues described can also overlap, as in the case reported by the Amsterdam local broadcaster AT5 (2021). This family was unable to find a larger home in the social sector, and when they did their income had increased above the maximum in the social sector, making them ineligible. They are a expanding family looking for a larger home with, now, a middle income. They can even be considered cheap skewed renters, as their income is higher than intended in the social sector.

3.5. Summary

The three sectors in the Dutch housing market have been researched to identify the main components that decide their functioning. The social sector is limited in the maximum rents by the Huurcommissie, the quality of the house decides how high the rent can be. The housing corporations have various systems that decide how houses are allocated, which have to adhere to government laws about allocation. Finally the social sector is limited in their ability to make people leave a social house.

The private sector is similarly limited in the ability to end a rental contract. This sector does not have a maximum rent, but do have a minimum quality, required by the Huurcommissie, to be allowed to rent in the private sector. Rents can only be increased yearly or in special circumstances and has to be done in agreement with both landlord and renter, or enforced through a judge.

Next the home-ownership sector is strongly connected with the mortgage market, which are limited in size by law. Due to the prevalence of real estate agents they are influential in deciding through which method house transactions are made. This has resulted in two common methods: negotiation with only one buyer at a time and a blind auction.

Finally the perceived problems in the Dutch housing market have been revisited.

4 Methodology

The previous chapters have considered research into the housing market, policy, regulations and the specific workings of the Dutch housing market. In this chapter a methodology is presented to answer the research question: "How is internal demand impacted by regulations in a housing market suffering from a shortage?". With three additional goals:

1. Contrast with economical models through the use of a different modelling technique.
2. Investigate the effects of regulations on specific causes of demand for households.
3. Provide a flexible approach in which policy changes and new policy can be easily studied.

Section 4.1 describes the method chosen to investigate the system. This is followed by the methods chosen for design in section 4.2. Then section 4.3 will discuss the approach to data collection. Finally section 4.4 will set out the method of analyzing the results.

4.1. Methodological Approach

As the focus of the research question is on the demand caused by individual households, the methodology chosen to answer the research question is agent-based modelling. This choice is made because in order to investigate the internal demand in a housing market, that is caused by the mismatch between a households needs (or wants) and the properties of the house they current inhabit, it is needed 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. Agent-based modelling fills these need through its focus on individual agent behaviour.

To model the Dutch housing market it was necessary to first research how the market works; the results of this research have been described in chapter 3. The research and modelling were done simultaneously. This approach was taken for two reasons; first, modelling tests the understanding of the system being researched, if it not possible to model the part being researched, it is clear that it requires more attention. Second modelling raises questions about the system being researched, if the model requires additional components to function the research can be expanded to include them. The downside of this approach is that parts of the system may be implemented, only to be discarded or stay unused for simplification or abstraction. The final step of this process has been abstracting the now understood system to focus on the research question.

The first part of the modelling process filled in the technical parts of the model, it answers which rules form the systems in the housing market. The second part of the modelling process attempts to fill the data-driven and social-logical parts of the model. Data about the points of interest in the housing market were often (publicly) unavailable, disconnected or possibly non-existent. Additionally the data that does exist was often private information divided over many parties. Due to these factors, the choice was made to model restricted by available data instead. The design choices made because of this restriction are further elaborated on in Chapter 5.

4.2. Methods for Design

The agent-based model in this thesis is designed following the steps set out by Van Dam et al. (2012):

1. Problem Formulation and Actor Identification
2. System Identification and Decomposition
3. Concept Formalisation
4. Model Formalisation
5. Software Implementation
6. Model Verification
7. Experimentation
8. Data Analysis
9. Model Validation
10. Model Use

The largest difference was that the model was designed incrementally with components being implemented side by side with the research. Both before and after designing the ideas presented by Edmonds (2017) and Epstein (2008) have been used to consider the purpose of the model, which is description. The Dutch social sector has not been previously modelled, the created model attempts to abstract the Dutch housing market. The focus is put on the effect of policy changes on internal demand to provide bounds for the model design.

The model description follows the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al., 2006), as updated by Grimm et al. (2020).

4.2.1. Agent-Based Modelling

Agent-based modelling focuses on the interaction between individual agents, with individual properties and decision making progress, and systems in the environment of interest. As the research question focuses on the motivation of individual households to decide to move, agent-based modelling becomes a necessity to be able to consider this factor.

4.2.2. NetLogo

The simulation tool NetLogo was chosen for the implementation of the agent-based model (Wilensky, 1999). NetLogo is an open-source multi-agent simulation tool that is widely used for agent-based modelling.

NetLogo was chosen for the features that help in simplifying the creation of an agent-based model. It has a visual interface that can be used to visualize the results of a model in user-friendly way, which can help in understanding the workings of the model. The visualization of the model combined with a powerful command line that can be used during a simulation run is helpful with debugging the model. Finally NetLogo is specifically made for agent based modelling and provides many methods that consider an agent-based design, such a random ordering when a group of agents is addressed.

The first downside of NetLogo is in the writing of experiment results which is quite limited in it expressiveness. Secondly the language used for NetLogo is fairly limited in allowing methods to be passed as variables, which limits the design patterns that can be used. Finally there is a poor separation of the GUI elements and the code of the model, variables can be defined and set in the GUI but not checked for valid inputs, this has to be done separately in the code. Nevertheless these problems are inconveniences compared to the advantages NetLogo offers.

4.3. Methods for Data Retrieval

As an agent-based model tries to model the decision making process of agents it is useful to base the properties used for this process and the process itself on observed data in reality. By using observed data the model more accurately represents the real behaviour of agents. First we will discuss quantitative data gathered then the qualitative data.

4.3.1. Quantitative Data

The quantitative data in this thesis consists of external data retrieved from public data-sets and the results of the experiment. The data-sets retrieved from external sources originates from the “Centraal

Bureau Statistiek" (CBS), Township Amsterdam, 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" was requested from the CBS and can be found in Appendix A.

For the initialization of households the most recent data available in the datasets: "Personen in huishoudens naar leeftijd en geslacht, 1 januari" (Identifier: 37620) and "Particuliere huishoudens naar samenstelling en grootte, 1 januari" (Identifier: 37975) from CBS were used. The former to calculate the ages of children in households, while the later is used to know which households with which compositions exist.

To generate the initial incomes of households the data-set on household incomes retrieved from `https://www.cbs.nl/nl-nl/visualisaties/inkomensverdeling` was fitted to a Gaussian distribution as in Gilbert et al. (2009). The data was separated on households with one or two breadwinners.

For the transitions of households the data from the five most recent years for which all points of interest were available is used. This data was transformed using the same R script, a detailed explanation of this transformation and the reasoning to use one data-set over another is described in Appendix B.

As there is no centralised public data-set for the supply of houses that includes the desired features, the data for houses was selected to be the most recent data available about the housing supply in Amsterdam. The data-sets used for this are originate from https://data.amsterdam.nl/ . How this data is transformed to input variables is discussed in Section 6.1.

The calculation for the maximum mortgage as per 2021 was retrieved from Nibud (2021).

4.3.2. Qualitative Data

The qualitative data used in this thesis originates from the web-pages of "Rijksoverheid" (The Dutch Central Government), "Woningnet Regio Amsterdam" (The central allocation system for the social sector in Metropolitan Amsterdam) and Dutch legal documents. The webpages of Rijksoverheid and laws are cited when they are used. For the social sector in Metropolitan Amsterdam the information can be found at `https://www.woningnetregioamsterdam.nl/Help%20en%20uitleg/`. Due to the spread of information the sub-pages are not cited in the text for clarity, the important sub-pages are:

- Help%20en%20uitleg/Inschrijven/Inschrijven%20woningzoekende
- Help%20en%20uitleg/Reageren/Inkomensvoorwaarden
- Help%20en%20uitleg/Reageren/ReagerenHuur
- Help%20en%20uitleg/Zoekinfo/Passend%20toewijzen
- Help%20en%20uitleg/Zoekinfo/Lotingwoning
- Help%20en%20uitleg/Zoekinfo/UrgentiesIndicaties
- Help%20en%20uitleg/Zoekinfo/WoningVoorGezinnen
- Help%20en%20uitleg/Zoekinfo/Jongerencontract

4.4. Methods for Analysis

A global sensitivity analysis is need to understand the influence of the input parameters on the outcomes of the model. This gives insight in to the working of the model, it's (correct) functioning and interesting avenues for further experimentation.

The comparison by ten Broeke et al. (2016) was used to select a sensitivity analysis method. As there is an interest in the interaction of input parameters and there is not a single output parameter on which could be regressed only the Sobol method (Sobol, 2001) could be applied.

After the sensitivity analysis multiple sets of experiments were designed to evaluate the behaviour of the model. The experiments were created to investigate specific policy changes, different agent behaviour and different starting scenarios. Each variation has been run 100 times to counteract the effect of the randomness used in agent-based modelling.

Each simulation records the data-points of interest for each simulation step. These results are aggregated in a R script that creates a line graph with an average result of each variation. These results are first investigated on whether they are the consequence of a programming or modelling error. If it is identified as a programming error the error is rectified and the experiment rerun.

The results are evaluated with two different views, first whether the experiment reveals problems in the model design, secondly whether the experiment reveals insight into the housing market.

5

Model Description

In this chapter a description of the model createt will be set out. The model description follows the ODD (Overview, Design concepts, Details) protocol for describing individual- and agent-based models (Grimm et al., 2006), as updated by Grimm et al. (2020).

5.1. Purpose and Patterns

The main purpose of this 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. This goal alone however is not clear enough to asses what the model needs to contain, therefore we additionally try to understand how regulations in the housing market affect the demand of individual households. This encapsulated in the research question: *How is internal demand impacted by regulations in a housing market suffering from a shortage?*.

Due to the uniqueness of the Dutch social sector, the relative slow speed of housing markets and often changing laws related to housing there is 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.

5.2. 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 is motivated due to the motivation of a household to leave a sector is 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 and 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, 5.1, 5.2, 5.3 and 5.4, respectively.

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-occupier sector.

Spatial factors are not modeled, 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 a household cannot find a large enough house it is needed that all possible houses have been considered.

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 5.1: State variables of the Observer

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 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 5.2: State variables of houses

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 and becomes older.
waiting time	integer, dynamic	The waiting time a person has accumulated for the Social sector.

Table 5.3: State variables of persons

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.

Table 5.4: State variables of households

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. While most processes in the model follow the 1-month time step, income shocks happen every 12 months. Auctions for owner-occupier houses take 2 months to complete. Ideally the simulation length would be infinite, or at the very least considered multiple generations, to see cyclic behaviours, but the simulation length of the implementation is limited by the population growth which grows the run-time exponentially.

5.3. Process Overview and Scheduling

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 to 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” submodel:
   (a) Owner-occupier 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 order of ascending rents

   Households that win a house update their house state variable, owner-occupier 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 its 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, updating 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 consider 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 done first so that the new houses and released houses and households can act in same tick. Households evaluate whether they want to search for a new house and then evaluate if their original reason they start searching is still present. Households decide whether to search before the searching process begins so they can start searching in the tick they made this decision. As households first evaluate whether they want to start searching and then whether their searching reason is still present 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. 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:

- Prefer to own a house, as 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-occupier 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-occupier 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 done at the start of the tick but by placing it at the tail end it has become possible to use the first tick to finalize the initialization. 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 longer would evaluate that they need to search.

Relationships are first ended and then started because the original data did not measure relationships shorter than a month. Relationships are handled before the population sub-model as the change in relationships changes the chance of child-birth and death. The income shock is done after the relationships to ensure the shock is only applied to households that will exist in the next tick, it is done before the population sub-model so that the income shock does not affect children that turned 18, their income has been newly generated, a change to this income would not be experienced as a shock but as a different starting income. It is done 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 to 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 either order of births and deaths is equal.

5.4. Design Concepts

5.4.1. 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 optimize 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.

5.4.2. Emergence

The emergent results of the model are which motivations to move 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 due to changing needs decide which households inhabit which house at any moment.

The number of households in the simulation is caused by the life events of childbirth, death and relationships forming or ending. As 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.

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

5.4.3. Adaption

Owner-occupier houses and private rental houses have an adaptive behaviour to set their auction price and rent price respectively. Owner-occupier houses set their list price equal to the mean latest sale-price of the ten owner-occupier houses that have the most similar quality (including itself). This design tries to model 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 every month nobody is renting the house the rent drops by 25 (but never below its minimum rent). This design models a slow dutch auction, where 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-occupier houses a household considers itself to have a chance of winning, they will bid their maximum mortgage on these houses. If there are no owner-occupier 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-occupier homes change a state variable, the offers made on that house. In addition to other requirements, a empty nester only reacts to houses with size 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, randomly. Private rental houses select the household with the highest income while owner-occupier houses select the households with the highest bid. If a winner is selected the house associated with a household is changed and the house itself become occupied, while any house previously inhabited by a household instead changes it status to being empty.

5.4.4. Objectives

The implicit objective of private rental houses is to optimize the total rent paid, the objective of owner-occupier 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 preference for higher quality. Households desire to have a home that is affordable, this is chosen to be 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. Household also desire a large enough home, the size a household wants is calculated with: $min(2 + (\frac{number\ of\ children}{2}), 5)$. Assumed is that the parents/adults in the household share one bedroom, one room is counted as a living room and then a maximum of 2 children share a bedroom (based on the number of rooms for houses advertised for large or small families). And finally a household at most 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.

5.4.5. Learning

Learning is not implemented.

5.4.6. Prediction

Private rental and owner-occupier houses act under the assumption that a shortage will remain, and only increase their prices. (This prediction however can be incorrect, these issues are further discussed in section 6.3). 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 a 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.

5.4.7. 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 landlord in reality posing income requirements. Private rental houses know the average rent being paid in the market as 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 are required to be reported to the social sector to sign-up.

Owner-occupier 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, which public information in the Netherlands.

5.4.8. 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.

5.4.9. Stochasticity

First, the model is initialized 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 initialization, below). The initialization 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 is 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, and 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-occupier 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 an income shock are chosen randomly.

5.4.10. Collectives

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

5.5. Initialization

Various data sources were used to create distributions for the initialisation of the model. The creation of these distributions is discussed in section 4.3.1.

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 and 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 on 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-occupier houses use this data, the distribution is only know for all houses, thus the assignment is done 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, 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 initialized 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 1 or 2 adults using the income submodel.

A known distribution of ages of children is used to generate an amount of ages equal to the amount of children, starting from the oldest age, each age is assigned to a child. The child is chosen from households that are either at least 16 years older than the child or if none exist to 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 is randomly set to value between 0 and 11. Assuming a uniform distribution of birth-months.

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” (Ministerie van Algemene Zaken, 2019) is 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 on descending size first and descending rent secondarily. 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 between 35 and 65
- Single person households between 35 and 65
- Pairs without children above 65
- Single persons above 65
- Pairs without children below 35
- Single person households below 35

First, families are assigned to the largest houses, as they have a motivation to get into these larger houses. Then households between 35 and 65 are assigned to the next largest houses, they are in the age groups where they have the most financial means and are most likely to still consider having children. Then houses are assigned to households above 65 as they have had the most time to get 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 (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2021) are used to assign houses. The rent of private rental houses is set to be 35% of the monthly income of the household.

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

5.6. Input Data

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

5.7. Submodels

5.7.1. 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-occupier 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-occupier houses with a quality at most 0.1 larger or smaller then the quality of the generated house or if there are none the average of all owner-occupier houses. The initial status is set “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”.

5.7.2. Relationship

Relationships are both formed and ended, depending on the age and type of a household the probability that a relationship ends or start is known. How this data has been calculated is described in Appendix B.

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 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 relationships 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 2 persons, the probability of forming a relationship then 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 submodel 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 do also roll for a chance to split, in which case the collective is removed and both households resume participating in searching and advertising.

5.7.3. Income

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

$$\text{(random-gamma } 2.4055239\ 0.14532885) * 1000 + 13000 \tag{5.1}$$

For the income of a pair:

$$\text{(random-gamma } 3.2113136\ 0.13220595) * 1000 + 13000 \tag{5.2}$$

These distributions have been created by fitting a gamma distribution with R to the data retrieved from `https://www.cbs.nl/nl-nl/visualisaties/inkomensverdeling`.

5.7.4. Income-shock

Ideally incomes would have followed a change over the lifetime of a household, but no system or data was found to facilitate this. Instead the system for income-shocks of Gilbert et al. (2009) 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:

$$income = income * (1 + 0.01 * shock\_size) \tag{5.3}$$

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

$$income = income * (1 - 0.01 * shock\_size) \tag{5.4}$$

5.7.5. 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-occupier 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-occupier house with the "for_sale" status communicate their list_price, size, quality and auction date to all households.

5.7.6. Population

The population submodel 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 done 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 know. The origin of this probability is described in Appendix B. A value between 0.0 and 1.0 is randomly generated and if it's lower than the probability, a child is born, that is a person of age 0 with the current month as 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 Appendix B. A value between 0.0 and 1.0 is randomly generated for each child (under or at 18) and adults and if it's 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). Updating the status of the house that was occupied 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 is filled with 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 submodel and decrease their mortgage time left by 1.

5.7.7. 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 of the outstanding mortgage balance.

The calculation for the maximum mortgage is:

$$monthly\_interest = \frac{mortgage\_interest}{12}$$

$$power = (monthly\_interest + 1)^{mortgage\_length}$$

$$maximum\ mortgage = \frac{income * fin/12}{(monthly\_interest * power)/(power - 1)}$$

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 5.5 and originate from Nibud (2021). 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.

Income	Financing Norm
income <= 22500	0.195
income <= 23000	0.205
income <= 24000	0.215
income <= 24500	0.22
income <= 25000	0.225
income <= 26000	0.23
income <= 27000	0.235
income <= 28000	0.24
income <= 29000	0.245
income <= 32000	0.25
income <= 41000	0.255
income <= 43000	0.26
income <= 44000	0.265
income <= 45000	0.27
income <= 46000	0.275
income <= 47000	0.285
income <= 50000	0.29
income <= 63000	0.295
income <= 67000	0.30
income <= 70000	0.305
income <= 73000	0.31
income <= 77000	0.315
income <= 83000	0.32
income > 83000	0.325

Table 5.5: Financing Norms for yearly incomes

5.7.8. 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 it's 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-occupier 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 it's 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 it mortgage to the bid of the second highest bidder, and sets it mortgage time left 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 form all filtered applicants.

Social rental houses that have the assignment_type selection filter out applicant 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
- single person households with an income $\leq$ 23.650
- households with 2 persons with an income $\leq$ 32.200 with the oldest adult younger than 65
- households with 2 persons with an income $\leq$ 32.075
- households with 3 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:

- single person households with an income $>$ 23.725
- single person households with an income $>$ 23.650 with the oldest adult than 65
- households with 2 persons with an income $>$ 32.200
- households with 2 or more persons with an income $\leq$ 32.075 with the oldest adult older than 65
- households with 3 or more persons with an income $\leq$ 32.200

If the rent of the social house is above 678.66:

- single person households with an income $>$ 23.725
- single person households with an income $>$ 23.650 older than 65
- households with 2 persons with an income $>$ 32.200
- households with 2 persons with an income $>$ 32.075 with the oldest adult older than 65

If the filtered group instead all applicants with an income under the maximum income 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, it's status is set to "occupied", the previously inhabited house has its status changed to "empty" or "preparing_sale".

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

5.8. Verification

The software implementation of the design needs to be checked on whether it is correctly implemented. The previous model description is based on the implementation. Various methods have been employed by the modeller to verify the code and the implementation match.

Firstly the program has been verified by reviewing the code, varying the parameters and running the simulation during the implementation process. This removes the most basic of errors, and part of this is the code verifying that the input parameters are set to valid values.

Secondly 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 completes has not violated these constraints, even if the code can reach an invalid state in other scenarios.

Finally, in the experiments an hypothesis about how the results are caused by the code is formulated as an additional layer of verification that there is no unintended consequence of the code.

6 Experiments

With the simulation made, it is now possible to explore the Dutch housing market. This is done by exploring the results of the simulation under different settings. The goal of the exploration is not to predict the future or measure the effects of any given setting; instead the goal is to find emergent behaviours or patterns. The patterns or behaviours have to then been checked on whether they are caused by a feature of the abstraction, assumptions, the code or the housing market itself. The results can provide insight in the housing market and the limitations of the model, but also are able to point in a direction to research further.

The experiments fall under three categories, firstly those that pertain to policies set by corporations and the government, which can be changed most easily. After that different behaviour of households is explored; these behaviour might be hard to incentivise in practice but the simulation can explore the consequences without having to consider how the behaviour could happen. Finally experiments that change the environment are explored; these changes can only result from a large or time-consuming process, but can be of great importance.

Every variation in the experiments has been run 100 times with a length of 75 years, these values are chosen in consideration of the run-time and a larger number of samples. The results of the experiments are averaged out to generate results. A global sensitivity analysis is performed to gain insight into the importance of the input variables.

Before considering the experiments the default configuration of the simulation is described.

6.1. Defaults

As there was no sufficiently detailed national data-set 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 6.1 summarizes all input variables, their default value and if applicable the motivation for the value. For the variables that reference being calculated using datasets, the datasets originate from `https://data.amsterdam.nl/`, the calculations simply exclude the unknown parts of the relevant statistics and recalculate only for the known groups.

Table 6.1: The 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 maximum_simultaneous-_reactions_lottery_social_market	8 8	Simulates the 2 reactions per week as 8 reactions per month.
supply_lottery	10%	
maximum_income_social-_rental_market	40024	The maximum income for the social market is set to 40024 according to current dutch law (van Algemene Zaken, 2021).
mortgage_length mortgage_type mortgage_interest	360 months annuity 0.0210	
population_size	1000	A compromise between population size and simulation length
housing_supply	951	
free_housing_supply% private_housing_supply% home_ownership-_housing_supply%	18 51 31	Based on the reported composition for Amsterdam in Berkers and Dignum (2020).
Size1/2% Size3% Size4% Size5%	31.29 34.35 23.69 10.67	Calculated using ”Woningvoorraad naar stadsdelen en aantal kamers per woning, 1 januari 2021
social_rent_432.51% social_rent_432.51_to_619.01% social_rent_619.01_to_663.40% social_rent_663.40_to_737.14%	21.22 53.37 11.16 14.25	Calculated using ”Corporatiebezit naar huurklassen en stadsdelen. 1 januari 2020”
house_worth_to_221000 house_worth_221000_to_310000 house_worth_310000_to_385000 house_worth_385000_to_511000 house_worth_511000_plus	12.21 22.18 22.48 22.48 20.65	Calculated using ”Woning voorrraad naar stadsdelen en waarde van de woning, 1 janurari 2020 (procenten)”
new_houses_monthly new_houses_type	0.84 flat	Follows the plans reported construction goal in Groot (2019) scaled down with the house supply in the simulation.
social_leave old_large_house_leavers spouse_waiting_time building_waiting_time migration migration_type	disabled disabled ”always” ”while_searching” 0.00 percentage of households	Other values for these variables are used to introduce variations
shocked% shock_size	20% 20%	These values are set according to the defaults in Gilbert et al. (2009), from which the income shock system originates.

6.2. 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 originally published in Sobol (2001). For Sobol for each input variable, of interest a range of values needs to be provided, which are shown in Table 6.2. For values that require a Boolean or string a uniform distribution is mapped to the possible options. This analysis has been executed on an older version of the code, and has not been redone due to time constraints.

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, and instead only the the impact of the set of variables together is know.

The technical way this had been done is by creating a list of all possible valid combinations for the sets of variables using natural numbers. As input variable for Sobol an integer between 0 and the size of this list is generated, which is used to look up a combination in the created list. To ensure the values selected by the Sobol sequence do have the intended variety the lists are ordered, the combinations for size are ordered from large total size to small total size of houses, the combinations for sectors are ordered from a large owner-occupier sector to a large social sector.

Table 6.2: Overview of the input variables analysed; for each value range and data type is indicated

Variable	**Range**	**Type**
seed	[100000, 200000]	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	[35000, 45000]	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, 176850]	Integer

Now that the input variables have been considered, the output results to evaluate the effects in the housing market are considered. Firstly the number of households that are unhappy with their current living situation, separated by motivation, as a strong indicator of how well households are served. The number of relationships being formed is left out due to a bug in the model, which has been fixed before the other experiment were run. Secondly the age in each sector to evaluate whether a market is biased to a certain generation. Thirdly the monetary factors, to consider potential cost increases. Finally the waiting times, to consider the prospects of new households searching in the social sector and fairness, i.e. do few households wait very long or do many households wait short.

Due to the large amount of output variables the results are briefly summarized in Table 6.3, while Appendix D shows the full results.

Mostly notable is the fact that the distribution of houses across sectors is often the most influential factor. Which, while an interesting factor, makes analysis of lesser factors difficult.

For the number of households the interaction of the seed and the division of market sector is most influential, the importance of the seed suggest there is no connection between the inputs and the number of households.

The inputs of “*maximum_simultaneous_reactions_social_market*”, “*supply_lottery*”, “*max_income_social*” and “*maximum_simultaneous_reactions_lottery_social_market*” have a little influence in all but the amount of households, which is likely to be independent of all variables.

Notable are the often large confidence intervals, suggesting that the results may be inaccurate. A larger number of experiments can make these confidence intervals smaller.

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

Table 6.3: 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-occupier 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-occupier 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	
Avg. % of income spent in owner-occupier 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

6.3. General Observations

In all experiments a trend is seen in the number of households, where the number of households rapidly increases after roughly 45 years. This coincides with the moment the number of houses temporarily exceeds the number of households. A simple experiment without an increase in the number of houses shows that the number of households expands this way regardless of new houses being build. The cause of this phenomenon is partly because of how relationships function. When relationships are ended one partner keeps all children, while the other one becomes independent. The split-off partner can now form a new relationship in which they can again have many children. Additionally relationships can form between two households with many children, which can also end, leaving another person without children. An option to mitigate this is to introduce gender and have childbirth depend on how many children a woman has had before as this can make the number of children born independent of the current state of relationships. Important is also that in the current model the lack of a house does not prevent childbirth, which could be more restricting in real life.

The experiments do not always generate the most interesting results in the period in which there are more houses than households. But due to the population growth some growth in houses is necessary to create a simulation were there is not only a growing shortage. Additionally many experiments would have benefited from a longer simulation length to expose cyclic effects, but also to see whether variations are beneficial to younger/older households or instead to specific generations. Here the initialization of the simulation is also influential, initially all existing households are given a similar waiting time, running a longer simulation allows a start-up period after which the simulation is in a more realistic scenario. Together these problems reveal a need for a different approach to population and housing supply growth.

In the experiments it became clear that the approach for the modelling of motivations is limiting. As only one motivation can be present for a household problems can be hidden if a household experiences multiple problems but can only report one. Additionally it is valuable to measure why searching households fail to find a home, as households being homeless because they cannot find affordable homes or because they cannot find a large enough homes is quite different.

Finally there the averages show a clear up and down pattern every 12 months, this coincides with the income changes, however this pattern is also seen in the number of households. The number of households changing could be explained by income changes freeing up houses and relationships being able to form. The motivation for relationships forming however does not show this pattern at all. What could cause this pattern is the change in the chances of child birth or deaths related to age. When households age up they change their monthly probability of having a child and dying. As the probability is the same for each month they are more likely to occur in the earlier months, as a second child has a lower probability to be born and people only decease once.

6.4. Changing Policy

As policies are created and used by centralised organisations it is comparatively easy to change them. This makes policies a fast and easy way to change the housing market. In this section four different policies present in the Dutch housing market are explored. Firstly, the size of the supply that is handed out using lotteries instead of selection. Secondly, the option for couples to posses two independent waiting times. Thirdly, the number of reactions each person can use in a week and finally the maximum income limit in the social sector.

6.4.1. Lotteries for social housing

Motivation

In Amsterdam houses are assigned with two methods, lottery and selection. The selection prioritizes 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, investigated is how the simulation changes when a different amount of the supply is dedicated to lottery.

Hypothesis

As the lottery selects randomly and the selection prioritizes high waiting times, a larger degree of lotteries is expected to result in lower waiting times for successful social renters and a larger amount of waiting time overall. As there is a large group of young adults trying to move out, their odds of moving out become better with a larger degree of lotteries.

Setup

The experiment varies the parameter *supply_lottery* in the range 0 to 100 in steps of 10.

Results

For a higher degree of lotteries Figure 6.1.B shows that the social sector is younger. Conversely Figure 6.1.A and C shows that the homeless and private rental households are older on average.

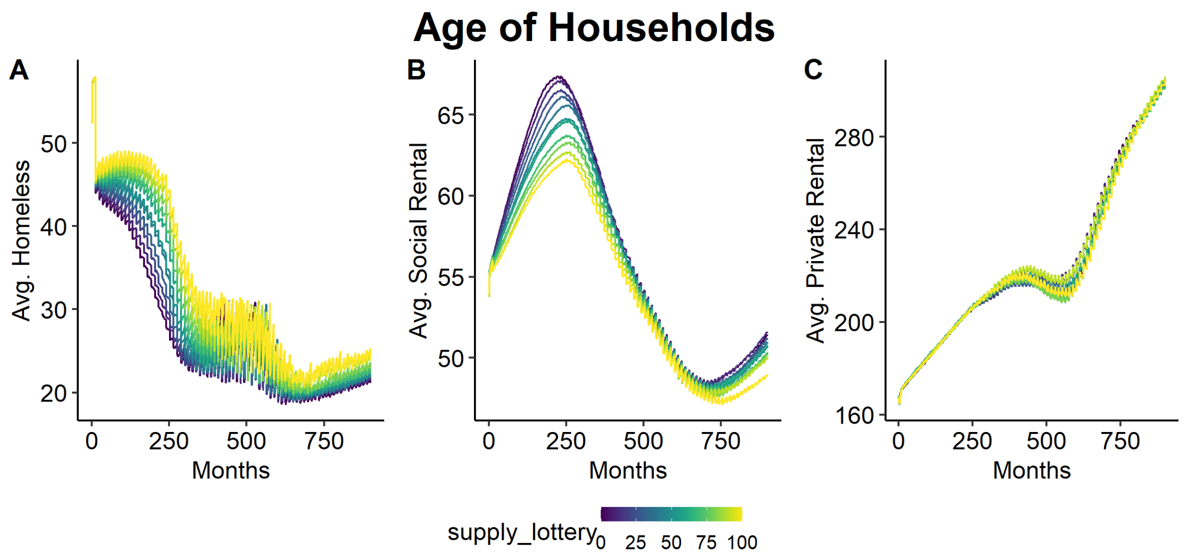

Figure 6.1: Age of households in the social sector and households homeless or living with parents.

Figures 6.2.A and 6.2.B show that with a higher degree of lotteries households with a lower waiting times are successful and that the average waiting time is higher.

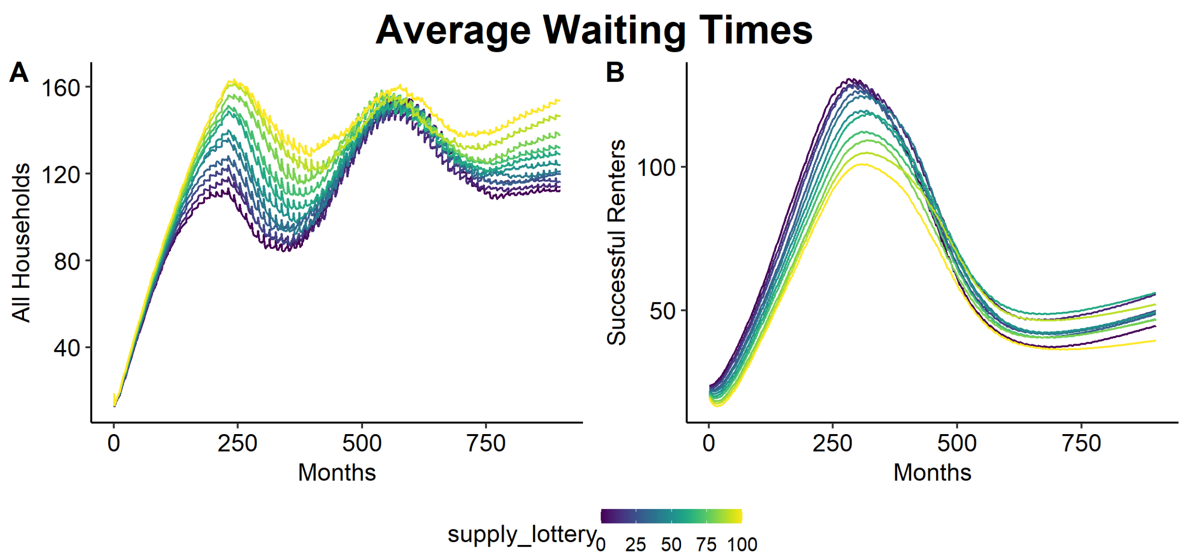

Figure 6.2: Average waiting time for all households and all successful renters.

In the number of searching households reported in Figure C.1c.F there is quite a difference between the variations. A higher degree of lotteries results in more searching households.

The motivations in Figure C.2a shows that a higher degree of lotteries increases all motivations besides the motivation of moving out. Figure C.2b.A shows a lower private rent, but Figure C.1d.B also shows that it represents a larger percentage of the incomes.

Discussion
An interesting effect of selecting through lottery is an initially higher amount of households searching for a home. An explanation for this is that a lottery selects households without a home more often, as it selects households with low waiting times that live with their parent more often, and this means that it only satisfies one household. In comparison selecting a household with a home also frees up a home that can satisfy an additional household. While this is a positive effect of the selection system, it is dependent on the distribution of waiting times. It could instead be intentionally codified as a priority for households that free up a home, but for this the long term ability to move out should be considered.

The motivations changing has two parts, whenever a lottery selects a household with the motivation of moving out it does not select a household with a different motivation and any household selected with the motivation of moving out now has the opportunity to display a different motivation.

The change in the average age of households suggests that the lottery is beneficial to younger households, and as seen in the motivations primarily those trying to move out from their parents.

6.4.2. Divorce and Secondary Waiting Times

Motivation
In the social market in the Netherlands any person can be signed up two times, one time as registrant and one time as co-registrant. As a co-registrant you do not build up any time, but it does allow you 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 when these partners divorce or split, that the partner that was a co-registrant does not have to start building waiting time from zero. To investigate the potential impact this benefit for couples has an experiment with alternative systems for the waiting time of the co-registrant is created.

Hypothesis
The secondary waiting time reduces the amount of households with the motivation of ”relationship ended” as they have a higher waiting time at the point a relationship ends. It also gives an advantage to couples, as they retain a higher waiting time even after moving.

Setup
Two variants are created:

1. The partners are only able to use one of their waiting times as couple, the other can only be used in the case of a divorce or split by the leaving partner. Assumed is that couples do not split and rejoin intentionally to abuse this system.

2. The partners are able to use either of their waiting times, but in the event they are assigned a house both their waiting times are reset. In the case of a divorce or split a leaving partner has their own independent waiting time, but it is lower than in the other scenarios.

The variants are chosen with the variable ”spouse_waiting_time” which takes inputs ”divorce” and ”never” respectively for the variations. The input ”always” represents the default.

Results
Firstly it is clearly visible how the variation effect on households with the motivation ”Relationship Ended” in Figure 6.3.B. If the second waiting time is dedicated to divorce there are fewest households searching with this motivation, if the second waiting time is not used there are the most.

The differences seen in 6.3.A in waiting times are higher for the divorce because the waiting times function differently in each variation, some waiting times are reset less often in the “divorce” variant. A small difference in the total number of households can be observed in Figure C.3c.A. Which could cause the decreased motivations for the “divorce” variant seen in Figure C.4a, regardless, it is difficult to distinguish the indirect effect of the second waiting time on non-divorcing households.

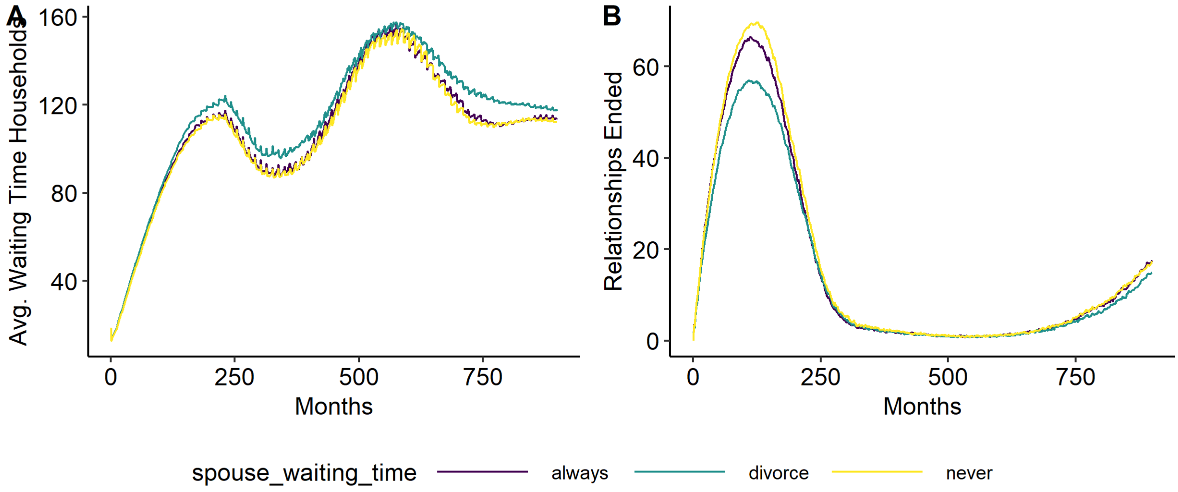

Figure 6.3: Average waiting time and number of households unable to find a home after a relationship ended.

Discussion

While the effect on divorcees is quite clear there is an unexpected change in the population size in the variations. The original desire to understand how non-divorcing couples can utilize the secondary waiting time is hard to evaluate because of this. The low number of total movements of households may also make utilising the secondary waiting time less effective, and the households do not strategize to use this secondary waiting time. To better understand the possible usage of the secondary waiting time it would be useful to consider an expected amount of times a household moves, as that may dictate when a households is best off using their secondary waiting time. The secondary waiting does however show to be effective for divorcees, although the long-term consequences or effectiveness of this is not clear.

6.4.3. Maximum number of reactions

Motivation

The social market assigns houses using selection rules to assign a house to a household fitting for a house. 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 it more or less likely the best fitting household is able to react to the house, changing how efficiently the houses are utilized.

Hypothesis

As a larger amount of reactions is expected to increase the amount of time the best fitting household for a house is selected the expectation is that the total number of searching household decreases. Additionally the waiting time of successful households should be slightly higher, as the chance of a household with lower waiting time winning is lower.

Setup

To investigate the effect of the amount of reactions has in the simulation 5 different scenarios are considered with 2, 4, 8, 12 and 16 monthly reactions per households for both houses assigned with lotteries and selection.

Results

Slight differences are seen in total number of searching households in 6.4.B, where the scenario with 12 monthly reactions is slightly more favourable. Figure C.6c shows a lower maximum waiting time but 6.4.A shows a similar average waiting time. The average waiting time of successful renters is notably lower in Figure C.6d for 12 reactions.

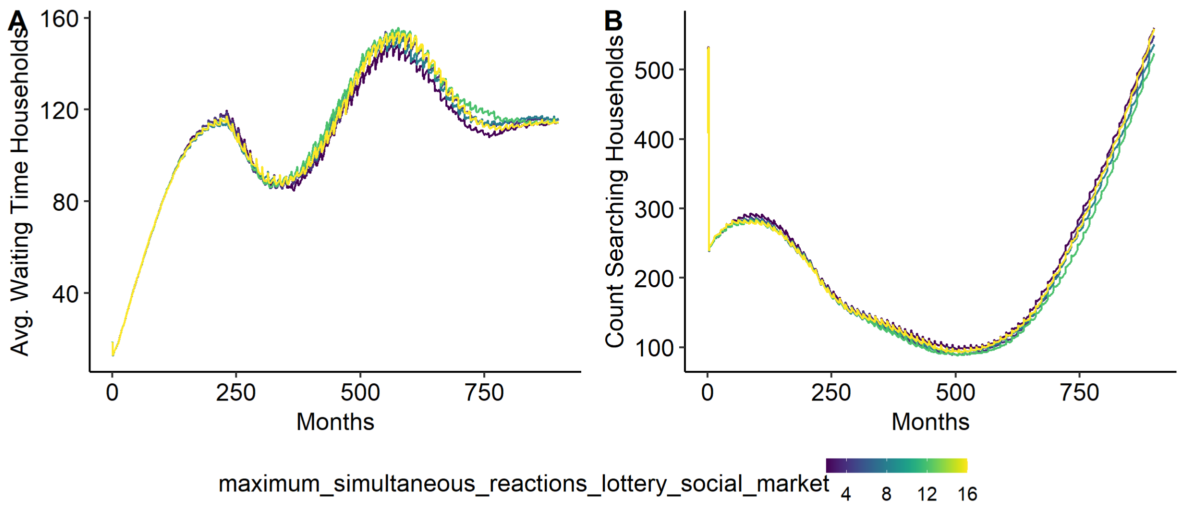

Figure 6.4: Average waiting time of households and number of households looking for a home.

Discussion

The lower successful waiting times can be understood by the same households with the highest waiting time being selected earlier and thus having a lower waiting time at the point of being successful. This can also be seen in a lower maximum waiting time. The increased number of reactions seems beneficial, but the difference is rather small. It should be noted that scaling the amount of reactions in comparison the number of houses is impossible as one can not use half a reaction and two reactions on 100 or 10 houses is quite different. A larger scale is needed to more accurately represent the ratio of reactions to available houses. 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. The core question of this experiment could be investigated in a simplified model, focusing on matching applicants to products without the context of the housing market. This would allow for the large scale that is missing in this experiment.

6.4.4. Increased Income Limit Social Housing

Motivation

In the Netherlands households with middle incomes have a hard time getting a house, for which increasing the income limit of the social housing is proposed as a solution. This experiment simply changes the income limit to investigate the effects. Due to how the code is implemented only the highest bracket is expanded in size in this variation.

Hypothesis

A larger group of households is allowed to enter the social sector, thus the sector is expected to be slightly older as the selection now has more older households that are prioritized.

Setup

A single variation is made where the maximum income for entering the social market is set to 50000.

Results

Most clear are the results in Figure 6.5 the group of homeless households is slightly younger, while the social sector is slightly older.

Further differences are visible in the waiting time of successful renters and the average waiting time in Figures C.8d and C.8c, which is explained by the group of households that can enter the social sector being bigger, thus allowing more waiting times to be reset, and the bigger group results in a longer waiting time before being successful.

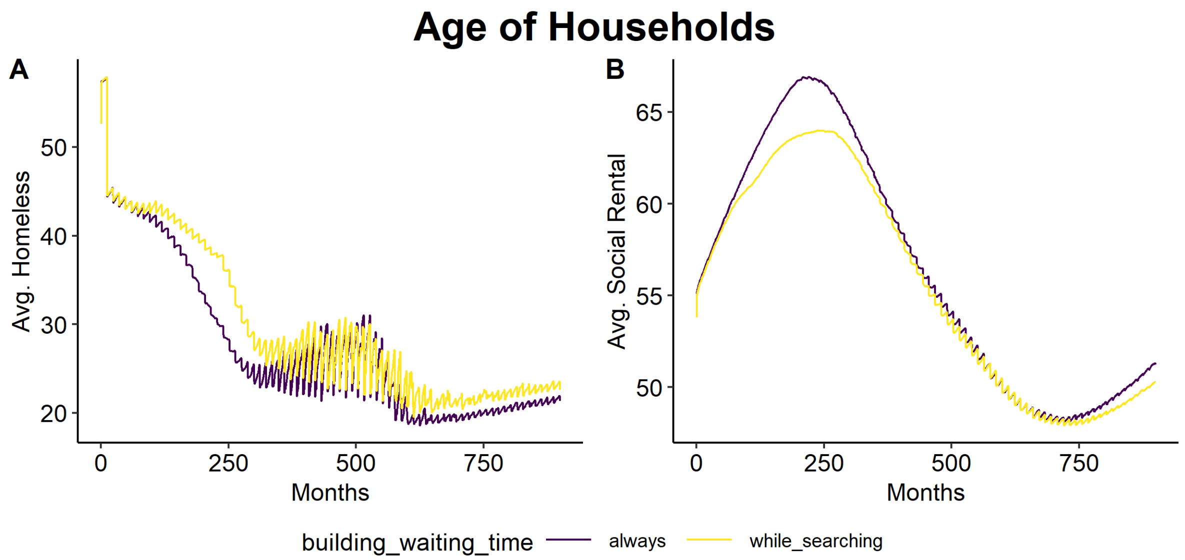

Figure 6.5: Average age of households without home or living with parents and average age of households socially renting

Figure C.7c.G shows that less households in the social market have an income above the maximum, which is related to the maximum being higher.

Interestingly C.7c.F shows that the higher income limit reduces the amount of households searching during the period that the number of houses exceeds the number of households.

Discussion

The differences made by the variation are only beneficial during the period when there are empty social houses. Outside of this it benefits older households that now can enter the social sector at the cost of younger households who now can not. Waiting times become longer with an increased target group for the social market. In conclusion higher social income can help older households at the cost of future/younger households but otherwise changing the maximum income does not seem particularly beneficial unless there are empty social houses. This is in line with the small sensitivity to the *maximum_income_social_rental_market* variable seen in Section 6.2.

6.5. Changing Behaviour

In this section it is examined how the simulation changes if behaviour is modelled differently and when households are successfully incentivised to change their behaviour. First a different way that households build waiting time is examined. After that the behaviour of households is changed to behavior assumed to help other households. Creating a change in behaviour may be more difficult in reality, 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.

6.5.1. Waiting Time for social housing

Motivation

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, the household passively builds up waiting time, regardless of 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 it is 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 to build up waiting time preemptively, and can to a certain extent model households in the social sector that do not sign up again after receiving a social house.

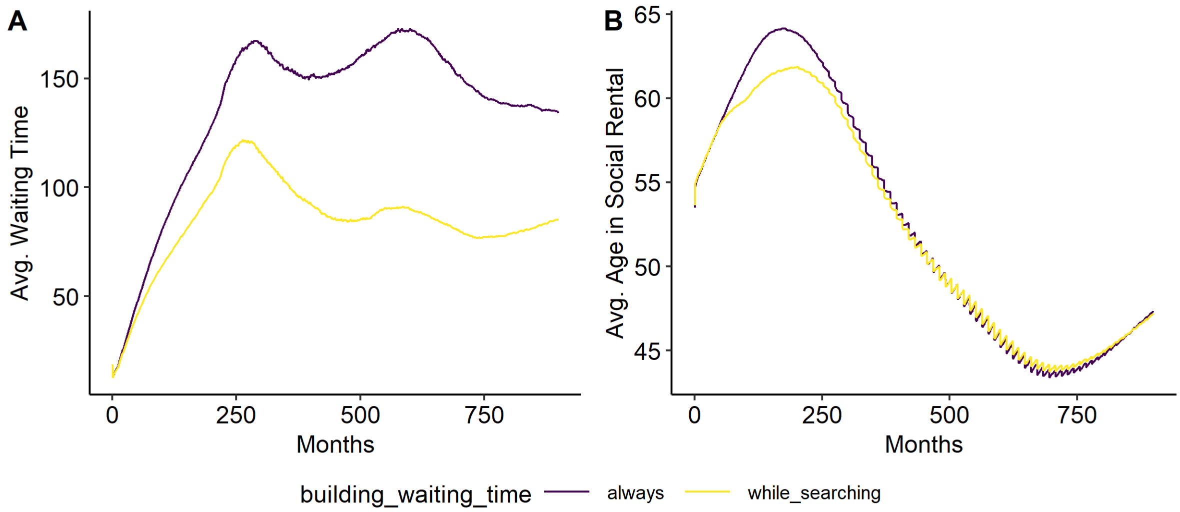

Figure 6.6: Average waiting time of households and average age of households socially renting

Hypothesis
Younger households have an easier time moving out, as older households build up less waiting time. This should show as an decrease in the motivation to move out, and an increase in other motivations.

Setup
The system is altered to only increase the waiting time of households that are searching for a different house.

Results
Firstly Figure 6.6.A 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 6.6.B shows that younger households get into the social sector.

Additionally Figure C.10a shows increased motivations due to high rent, too small houses and ended relationships.

It should be noted that while figure C.10b.A shows a slight lower rent for the variation, figure C.9d.B shows it represents a similar percentage of the income of the households.

Discussion
This experiment essentially shows that, if all households always are signed up, the waiting effectively helps when families are expanded, relationships are ended or when rent is too high. This is however done while limiting how many younger households can move out. It is interesting to consider that many younger people do not sign up at 18, possibly setting households trying to move out even further back.

This experiment has been quite limited, an interesting consideration is how the results change when some households always search, and others only when they have a motivation. This can also include households owning a home or having too high income not signing up.

6.5.2. Willing Social Market Leavers

Motivation
In the dutch housing market there are two common occurrences which lead to inefficient or unintended usage of houses. First the cheap skewed renters as previously described in Section 3.1.2, 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 ”Lege nesters” or empty nesters, parents whose children have move out but still inhabit a large house that could house a family instead.

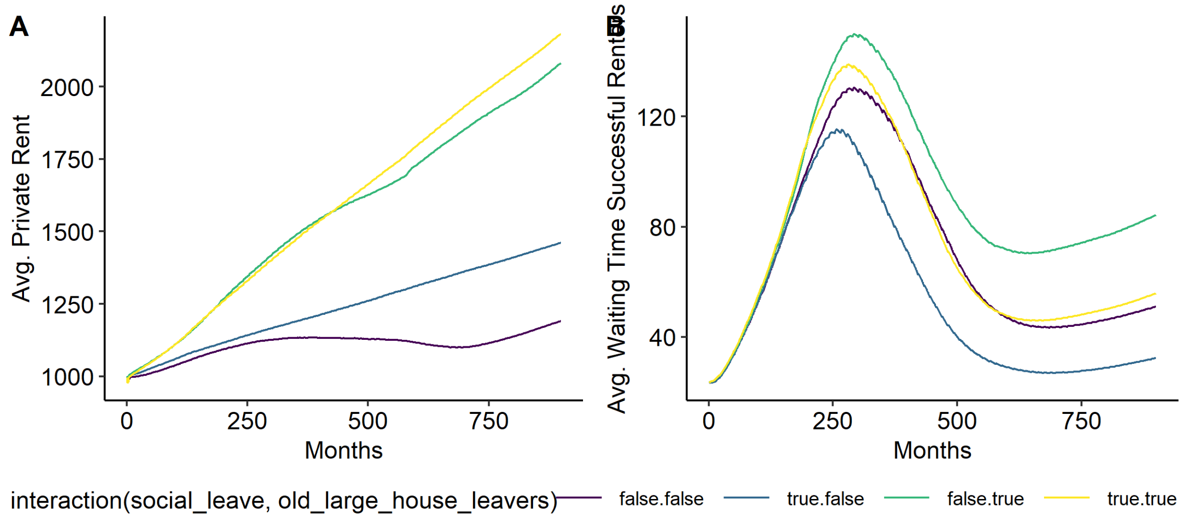

Figure 6.7: The average private rent and average waiting time for renters successfully entering the social sector.

These households can be incentivised to search for are more fitting home. In this experiment it is investigated what would happen if all these households would be successfully pushed to start searching.

Hypothesis
If these households successfully leave their homes the overall amount of searching households should decrease.

Setup
The first variation makes households in the social sector that earn above the maximum income search for a new dwelling that is affordable and either be of higher quality or if their current house is not big enough, a bigger house.

The second variation tackles the problem of empty nesters, households above age 65 that have no children and live in a house bigger than the smallest size of 2 start searching for any house that is affordable and of size 2.

The third variation uses both these changed behaviours.

Results
The first observation is that in Figure 6.7.A an increase in rents is observed for both variations where older households try to free family homes. This is also visible in the number of households still searching in Figure C.11c. Figure 6.7.B does also show a longer waiting time for households 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 6.7.B are decreased compared to the baseline. Figure C.11c.C shows that in this variation the private rental sector is utilised more. Both variations where the social sector is voluntary left show a much smaller motivation for households looking for a larger house as shown in Figure C.12a. This figure also shows an increase in households unable to move in together while forming a relationship for all three variations. Sub-figure F shows a large amount of households remains in the social market while they desire to leave, indicating they either cannot find a affordable or high enough quality home. While figure 6.7 shows an increase in private rent costs for this variation, however C.11d shows that this represents a similar percentage of the income.

Discussion
It is very interesting that the variation where households with a higher income leave the social sector leads to a smaller count of households that are looking for a larger home. However the experiment

highlight a problem with the measurement of motivations, as a household that has the motivation to leave the social market can not indicate that it is currently living in too small a home. The decrease in the waiting time for the social market and the larger utilisation of private homes does indicate however that this variation is still effective.

The variations that make old households leave family homes creates a large demand in the market. As these households aim for two person homes their target market is relatively small. This represents a possible problem where the extra demand caused by these households wanting to leave is more problematic than them occupying large homes. The situation however does change if there is a separate senior market, as in that case they stop directly competing with young households. However, the existence of a sector for seniors does mean that other sectors should be modelled smaller. Nevertheless, the current model does not handle the increased demand appropriately, seen in the severe under-usage of the private rental homes.

The main lessons to take away from this experiment is to create a motivation system that considers multiple motivations simultaneously and to improve the strategy that sets rents.

6.6. Changing Environment

In this section the environment is varied to understand the impact of the environment. The simple migration mechanism is considered first to examine how influential its inclusion can be. Then different supplies of houses are considered, firstly the sizes of houses are varied, secondly the size of market sectors is varied.

6.6.1. Migration

Motivation

In this experiment the impact of migration is tested. It was previously excluded from the sensitivity analysis due to its large impact on run time.

Hypothesis

The expectation is that migration can cause better matches between households and houses and through this decrease total demand.

Setup

The level of migration is varied between 0% and 0.1% of all households moving monthly in steps of 0.01%.

Results

The most important for this experiment are the differences seen in the motivations for searching reported in Figure C.14a. While motivations to move are decreased the total number of searching households has increased as seen in Figure 6.8.F.

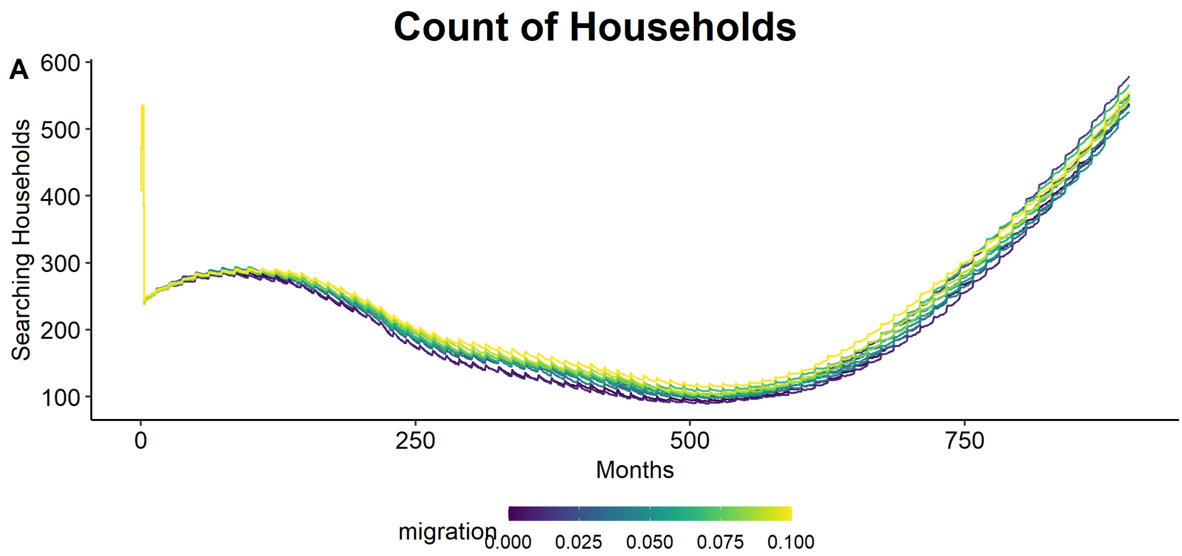

Figure 6.8: Number of households searching for a home

Discussion

Noticeable in Figure C.13c.D shows a lower amount of owner-occupied houses being used. Here migration does not consider that a household moving out of a bought house would be more willing to compromise on sale price or possibly not try to migrate. Especially at the end of the simulation the mortgage payments are clearly increased in Figure C.14b. Despite the higher the private rents more private rental homes are used as seen in Figure C.13c

In conclusion, while migration reduces motivations besides migration it also decreases how many houses are used. The model require a better measurement of motivations and systems better able to handle increases in demand. Migration does however show potential to improve matching between households and houses.

6.6.2. Varying Size Compositions

Motivation

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

Hypothesis

Bigger houses are better, as they can satisfy more different kinds of households.

Setup

Experiments are run with the compositions:

- (Size1/2%, Size3%, Size4%, Size5%)
- 25, 25, 25, 25
- 10, 30, 30, 30
- 10, 20, 30, 40
- 0, 0, 0, 100

In addition to the default composition.

Results

The simple result seen in Figure 6.9.A is that less households are searching with larger houses. The compositions (0, 0, 0, 100) and (10, 20, 30, 40) have similar performance, but the motivations in Figure C.16a shows the differences between them. 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

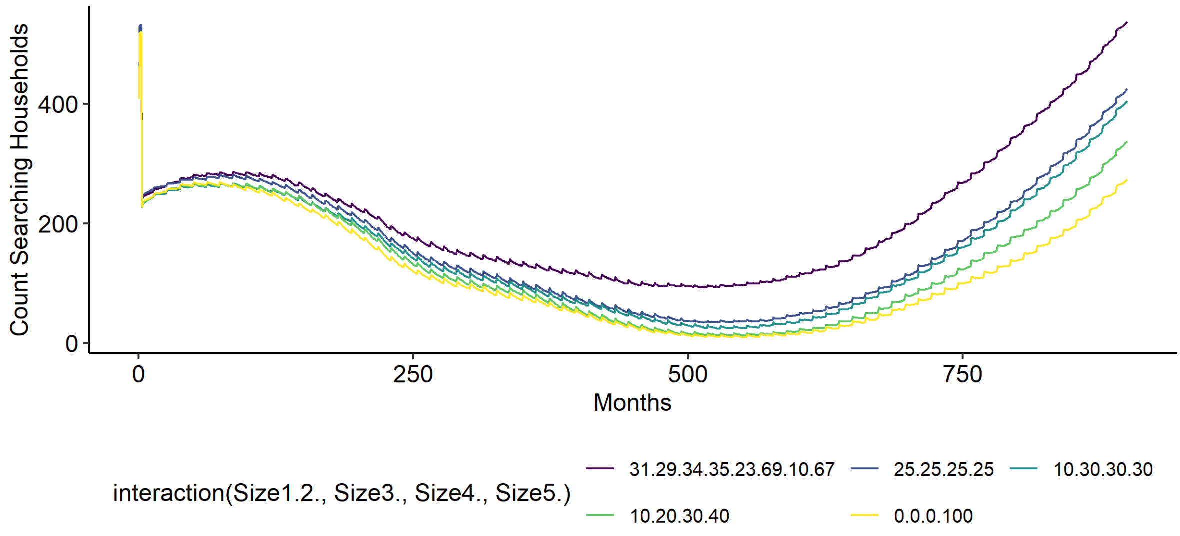

Figure 6.9: Number of households searching for a home and average monthly rent paid in the private sector.

contrast the (10, 20, 30, 40) composition has less problems when relationships end or when people want to move out, but in return has some problem with too small houses.

Additionally Figure 6.9.B does show a much lower private rent for the (0,0,0,100) composition.

Discussion

Making houses larger seems simply effective, it should however be taken into account that households in the model can become quite large through relationships ending and two large households combining, which creates a bias towards larger houses. Nevertheless the (10, 20, 30, 40) composition shows that smaller houses can be used while resulting in a similar demand. While the (0, 0, 0, 100) composition has the lowest rents, this model does not take into account the higher monetary and spatial costs involved in building and maintaining large houses.

6.6.3. Varying Market Compositions

Motivation

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

Hypothesis

An increased social sector decreases the average waiting time but has limited effect on how many households want to move. More private houses or more owner-occupied houses makes these houses cheaper and decrease how many households want to move as these sectors are more flexible in having new households enter.

Setup

Experiments are run with the compositions:

- (Private, Social, Owner-occupied)
- 28, 41, 31
- 18, 41, 41
- 18, 61, 21
- 8, 51, 41
- 8, 61, 31
- 18, 51, 31

Results
Figure 6.10.A shows that for both variations with an increased owner-occupied sector that there are more searching households.

Figure 6.10.B shows for private rents that a larger private sector (and smaller owner-occupier sector) has the lowest private rents. Figure C.17d however also shows that this scenario has the highest percentage of income spent on the rent. The mortgage sizes in C.18b show a linear relation between the size of the owner occupier sector and the mortgage size.

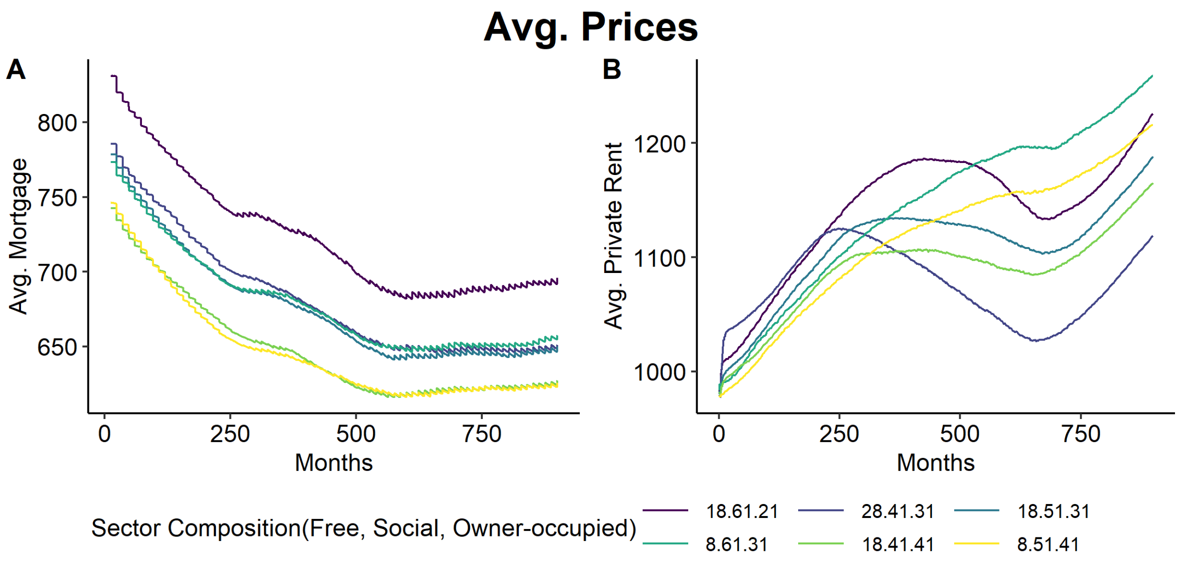

Figure 6.10: Average monthly mortgage payment and average monthly rent paid in the private sector.

Figure C.18a shows that the variations that have a similar amount of households searching do vary in the motivations for searching. When the variations have a larger owner-occupier sector there are more households searching.

Discussion
The composition of sectors has already shown itself to be an important factor in the sensitivity analysis. The results here show very different effects in the various markets, the private rents and mortgage sizes vary if very different ways.

Additionally in considering different market compositions it should be considered that change in the size of a market sector should also change the strategies in the model. A large social sector might require the limits for who is allowed in the social sector to become larger, a larger private or owner-occupies may mean that prices should grow slower as households have more alternatives within the sector.

Nevertheless, due to the market mechanisms working differently the compositions of sectors can change results of the housing market. A starting point for research on the importance of the composition of sectors is comparing regions with different compositions not only outcomes, e.g. how many households have too small a house, but also on differing policies or strategies used in the region, as these may provide the most insight on how the housing market works.

7 Reflection

Looking back over the process of making this thesis I recognize many points that I would, with the knowledge gained from making the process, do differently. Firstly the model created in this thesis is unfocused, it does not answer a single question but tries to answer a lot of them. This results in varying difficulties, for example in the sensitivity analysis it would have been better to separate the combinations of sectors from other factors, as the combinations of sectors works on quite a different scale than other factors.

The many questions the model tries to answer also resulted in having a great range of outputs, which makes it more difficult to analyse results. A focused model could possibly reduce the number of output variables need. The best gain that could be made is if I could leave out certain mechanisms, making the model simpler, depending on the more focused question. One of these mechanisms I intended to improve was the system for private rent, it currently uses hard-coded value for rent increases and decreases, which works but does not give much confidence in the results of the model.

On the other hand, this thesis started with researching how the Dutch housing market functions, because there was no clear prior work that summarised this. This also makes it difficult to pin the research question down to a very focused one. In the consideration that this unfocused model has lead to a wide range of interesting questions (as can be seen in the future work section) I consider this successful.

My inexperience with creating agent-based models and NetLogo does show in the design and implementation of the model. There is quite some code that can be made less error-prone by using more functions. I should have put more consideration into making a model that can show emergence, rather than just a model that abstracts reality. Most importantly I should have made the model able to run longer simulations to allow for cyclic behaviour. On similar note, using percentages as inputs is easy to reason with, absolute values are a bit easier to apply sensitivity analysis to.

8 Discussion

In this thesis the consequences of policy and regulation in the Dutch housing for the demand of households already inhabiting a home is explored. This is motivated by the concrete problems individual households experience in the Dutch housing market.

The experiments showed that the model is effective in considering the effect of different scenarios on the demand of households. The clearest results are seen in Section 6.4.2, the secondary waiting time is influential in the success of divorcees finding a different home, and Section 6.5.2 which suggests that empty nesters leaving large homes has a bigger negative effect through an increased demand than a positive effect on utilization due to families using their large homes.

In the other experiments various problems were found that limited the conclusions that could be drawn from their results:

- A small scale of the simulation, making the difference between scenarios smaller and for the experiment in Section 6.4.3 not enough agents to make a difference.
- A short length of the simulation, preventing insight into cyclic behaviours and long-term consequences.
- The addition of houses ”resetting” the demand, which prevent insight into whether the change is temporary or also lasts in the long-term.
- A limited measuring of the motivations, currently only one motivation is tracked while households can suffer from a high rent in too small a home while also trying to form a relationship. Additionally, the results are not different between e.g. 20 households having too small a home for 30 years and for 30 years every year there are 20 households that have too small a home that year. Which can be interpreted as: some households will have too small a home for a long time, or households with too small a home will only stay in this state for a year.

The first three problems share root causes, unlimited population growth and the addition of new houses. Both require the simulation to start a smaller scale to accommodate their growth and limit the maximum length of the simulation, as their growth increases run-time. As the number of houses exceeds the number of households a period of time exists in which the demand is reduced to almost zero, making a part of the small length of the simulation effectively wasted. Alternating periods of shortage and abundance of houses can be an interesting scenario, but in this limited simulation length it is a waste. More fundamentally the problem is the difficulty of avoiding a pattern of shortage and abundance with the current model setup.

The solution to these problems is a fundamental redesign of the way population and houses are simulated. As this redesign aims to simulate an even longer time period the natural growth of population can be abandoned, the assumption that population growth stats constant becomes unrealistic on the scale of centuries. Instead such a system should have the following features:

- The population size and number of houses should be bound by a ceiling. This is to ensure that run-time only linearly increases with time.

- The population should follow the trends seen over generations. This to simulate different needs due to different compositions of the population.
- The number of houses should be defined in relation to the size of the population as a cyclic function. This allows a stronger control of an expected supply of houses over a simulation of infinite length.

The first feature can be considered a limitation, as simulating generational difference in sizes may be difficult within a limited population size. It is also possible to instead make a model that does grow the population, but scales well enough to run for a sufficiently long simulation length. In this case it is still recommended to define the number of houses in relation to the populations to allow for easier scenario setting.

The last fundamental problem of the way motivations are measured and is closely related to the research question: *"How is internal demand impacted by regulations in a housing market suffering from a shortage?"* and the first two of the three purposes:

1. Contrast with economical models through the use of a different modelling technique.
2. Investigate the effects of regulations on specific causes of demand for households.
3. Provide a flexible approach in which policy changes and new policy can be easily studied.

For the first purpose the key aspect is how agent-based modelling can contrast with other economical models through its focus on agents. Agent-based modelling has the potential to consider problems individual households experience, which can provide contrast with economical models that are limited to a macro view.

The second purpose explicitly states this aspect as a desired outcome, by aiming to investigate on "specific causes of demand". Both factors that limit the measuring of motivations prevent the model from measuring for specific causes on an individual level. Firstly, as only one motivation can be reported at any given moment, the experiments cannot show that a specific demand has reduced as households may have a different kind of demand preventing the targeted demand from being reported. Secondly, because the motivations are aggregated the detail at the household level is lost. As previously mentioned, there is 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 factor of time needs to additionally be measured. For motivations it may also be useful to expand this to measure the reasons households are unable to find a home in addition to why they are unhappy with their current home.

The research question itself is mostly unaffected by these problems, as the specific cause of demand does not change the total demand. The exception is the experiments in Section 6.5.2 in which the way the variations are introduces changes the total demand.

On the third purpose the model is more successful, comparing the difference between having 2 reactions per month or 16 reaction per month is easily configured. However some policy changes can not be covered by existing household behaviour, e.g. the different styles of secondary waiting times allow for different long-term strategic behaviour. Researching this particular aspect is better served by an algorithmic approach exploring what strategies are effective. Especially new policy may be difficult to implement, however the question: "How would household behaviour change under this policy?" may serve as excellent starting point.

There are some design limitations that became apparent during the experimentation. Firstly, 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.

Secondly 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 makes children look for their own home very early on.

Validation is an important step in the creation and usage of agent-based models, as they are a mere abstraction of real systems, their results should be carefully examined before assuming they apply to the real system. In this thesis experiments were "what-if" scenarios, that look into a possible future. For these kinds of models Van Dam et al. (2012) specifically mention: "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, the lessons learned about what went wrong, this knowledge can be validated by making new models with the lessons learned. The knowledge and insight that would also apply to the real housing market is more difficult. Due to the many errors already found these conclusions are questionable, and due to the broad scope of the current model the conclusions are still unspecific. This results in knowledge that would be difficult to validate, especially if it is related to topic for which the possible data to compare with is limited. In this consideration further experiments and modelling are more likely to yield useful results than trying to validate a questionable claim with limited data.

9 Conclusion

In this thesis it was examined how different policies in the housing market impact demand during a shortage.

As preparation for the modelling process research on the systems in the Dutch housing market was investigated. The results of this investigation have been described in Chapter 3.

9.1. Research Questions

The model is limited by its small scale and short simulation length. Furthermore the growth of houses & population and limited motivation measurement obscures the effects of different policies. These both limit how well the model can answer the research question. As the an agent-based model is merely an abstraction of reality, it should be noted that it does not (and cannot) predict the future of the housing market. Nevertheless, the experiments create some interesting suggestions for the original research question of: *How is internal demand impacted by regulations in a housing market suffering from a shortage?*

Section 6.4.1 the results shows that selection may be preferable to lottery due to it's bias towards households that already own a home, as households that already own a home also free up a home for a different household to inhabit. Next, it was seen in Section 6.4.2 that the secondary waiting time can be effective in helping divorcees find a home, but the benefit for couples that don't divorce is not completely understood. The experiment to increase the income limit for the social sector in Section 6.4.4 suggest that an increased income limit favors older households. Finally, section 6.5.2 suggests that policies that encourage a change to behaviours expected to help the overall utilization can instead increase demand.

The model was also created with three purposes in mind:

1. Contrast with economical models through the use of a different modelling technique.
2. Investigate the effects of regulations on specific causes of demand for households.
3. Provide a flexible approach in which policy changes and new policy can be easily studied.

The contrast was intended to exist in the way an agent-based model can focus on the level of households. Due to the way motivations are measured however these goal is not achieved, as the model cannot differentiate between a situation where one household pays too much rent for 30 years and a situation where 30 households pay too much rent for 1 year in turns.

Similarly the specific causes of demand cannot be measured because the model only allows a single motivation per household. This means that a reduction in one motivation can simply mean that the households are reporting a different motivation earlier. The solution to these two problems is to measure both multiple motivation and the duration a motivation is held.

The model does show that the potential of agent-based models to easily consider policies changes in a model. By slightly changing components different policies are simulated in the same model. It should however be taken into account that a change to simulate a different policy might change values that are measured or require a change in agent behaviour that is not already supported.

The contribution of this Thesis is a first step in modelling the social sector of the Dutch housing market and a proof of concept for using agent-based modelling to investigate the effects of systems and policies on the level of individual households. It also provides an agent-based model that focuses on the satisfaction of individual housholds under changing needs.

9.2. Future Work

A necessary step before expanding the model is improving the created model by redesigning the way population is simulated to avoid a poor scaling of execution time with an increased simulation length. This will allow the experiments to consider the effects over multiple generations. Additionally the measurement of motivations needs to be expanded to measure multiple motivations and to consider the length a households holds these motivations.

Additionally during the process of researching, modelling and experimenting various directions for future work were revealed. These directions will be divided in four categories:

- Expansions on the model created in this thesis
- Research using different ABM's
- Data that could be gathered to support research on the Housing Market
- Research that does not use ABM's

9.2.1. Expansions

In Section 6.5.2 the experiment of older households with large houses willingly searching for smaller houses resulted in these older households competing with other households for smaller houses, increasing the demand for smaller households. In the Netherlands however there is senior housing that better suits the needs of older households and is exclusively available for this target group. If older households try to transfer to these dedicated houses they do not directly compete with younger households. The created model could be expanded to consider this "senior" sector and investigate the effects of how large a part of the total supply is set to be exclusively for seniors.

In the created model all three sectors have the same distribution of house sizes, which is modeled to not change during the simulation. Similarly the relative size of each sector also stays consistent over a simulation run. Firstly an expansion can be made to setup all three sectors with their own distribution of houses, as this may reveal emergent behaviour because the sectors provide different supplies.

Secondly the relative sizes and distribution of house sizes can be changed over time. This can be done by building new houses, simulating a building policy, or by transforming houses from one sector to another. In the Netherlands the transformation of houses from one sector to another is relevant as for example investors convert houses in the owner-occupier sector into houses in the private sector. This is a concern in the Dutch housing market, with townships requiring buyers to occupy their houses for a minimum period to counteract the process.

9.2.2. Different ABM's

An analysis on how the selection rules interact with the number of reactions can be done with a model only considering the social sector. The core question is: "How does the system for assigning houses to households perform under different populations sizes, supply sizes and reaction amounts?". By narrowing the model to this core question a greater degree of abstraction is possible, which allows for a larger amount of agents. The consequences of agents needing time to inspect houses and possibly refusing a house after an inspection are important factors 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.

An important direction to consider is the work presented in Huisman (2016), which highlights a shift to temporary rental agreements in the private sector. It could most directly be related to the experiments regarding migration, as it forces households to move more often, but temporary rental agreements also limit the time in which households can search for a new home without becoming homeless, which can change the searching behaviour quite drastically. The effect of temporary rental agreements could be modelled in a model focused purely on the private sector.

The government limits the ability of housing associations to raise rents in the social sector. Modelling the behaviour of how housing associations raise rents under these limitation and how this affects households and their motivation to move out of the social sector can evaluate the effectiveness of the limitations set by the government.

9.2.3. Data Collection

A fundamental problem in investigating the housing market in the Netherlands has been a lack of national count of the supply of houses in each sector. Attributes such as the number of rooms or the intended usage (such a house being exclusively for seniors) of a house may additionally be helpful in gaining insight into the housing market.

To study the social market it may be essential to gather data on when and who signs up for the social sector, as this can strongly influence who does enter the social market.

9.2.4. Different Techniques

The results in Section 6.6.2 suggests 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: Firstly an investigation into the design of houses, “What is the trade-off between house sizes and the amount of houses?” which can consider both monetary cost or spacial cost. This is followed by using the trade-off to setup different scenarios for either a model or simply to compare to known demand. A similar consideration can be made for creating houses that can support seniors removing the need for them to move out of houses they already inhibit. A factor that also could be considered is that single-person households or pairs could potentially to share a larger home, if a small family home can be shared by two single-person households or pairs, it may be more effective than two smaller homes.

The consequences of couples being able to utilise two separate waiting times can be explored further through the view of optimal behaviour. By focusing on an expected amount of moves in a life time it is possible to strategize when to use the waiting times. The core questions are: “How does a household optimally utilize the ability to hold two separate waiting times?” and the follow-up question “How does this impact the outcomes in the social market?”. Important is to also consider the real behaviour of households: “How are households currently utilizing the ability to hold two separate waiting times?”.

While researching the social sector it became clear that different regions use different selection rules to select a winner. Most notably was a first come, first served system that released houses at the same time each day. This system may be problematic for households that have other obligations at the moment houses are released. A survey and evaluation of the different selection methods could be done.

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A

Relationship Forming and Breaking

Data behind the relevant graphs originally published in Jaargang 50 of ”Maandstatistiek van de bevolking”, februari and march as respectively ”Nieuwe samenwoners”Steenhof and Harmsen (2002b) and ”Ex-samenwoners”Steenhof and Harmsen (2002a).

Age	Married	Unmarried
20	0,034	0,176
21	0,034	0,151
22	0,031	0,131
23	0,030	0,113
24	0,027	0,099
25	0,025	0,090
26	0,024	0,083
27	0,023	0,079
28	0,022	0,075
29	0,021	0,072
30	0,020	0,070
31	0,019	0,069
32	0,018	0,067
33	0,018	0,065
34	0,017	0,064
35	0,017	0,064
36	0,016	0,063
37	0,015	0,062
38	0,015	0,061
39	0,014	0,061
40	0,014	0,060
41	0,013	0,059
42	0,013	0,058
43	0,012	0,058
44	0,011	0,058
45	0,010	0,060
46	0,010	0,060
47	0,009	0,058
48	0,009	0,056
49	0,008	0,054
50	0,007	0,053
51	0,006	0,052
52	0,006	0,049
53	0,005	0,048
54	0,005	0,047
55	0,004	0,046
56	0,004	0,045
57	0,004	0,043
58	0,004	0,043
59	0,004	0,040
60	0,003	0,038
61	0,003	0,036
62	0,003	0,036
63	0,003	0,038
64	0,003	0,037
65	0,003	0,035
66	0,002	0,030
67	0,002	0,029
68	0,003	0,029
69	0,003	0,030
70	0,003	0,031
71	0,003	0,032
72	0,003	0,033
73	0,004	0,031
74	0,005	0,030
75	0,005	0,031
76	0,006	0,035
77	0,006	0,036
78	0,007	0,037
79	0,008	0,037
80	0,009	0,043
81	0,010	0,046
82	0,011	0,052
83	0,012	0,049
84	0,013	0,055
85	0,014	0,048

Table A.1: Chance of a relationship breakdown for heterosexual cohabitants in 2000

Age	Percentage	Age	Percentage
0	8,6365226517404200000	36	0,061949740539910200
1	16,8007696344236000000	37	0,061220920062970100
2	14,3963908809982000000	38	0,049559792431928200
3	12,1975395020698000000	39	0,037898664800886200
4	9,9556877150020400000	40	0,043729228616407200
5	7,8151419742289100000	41	0,036441023847006000
6	5,9770567313859300000	42	0,030610460031485000
7	4,6746545390939300000	43	0,026237537169844300
8	3,6448312051775400000	44	0,025508716692904200
9	2,7950265290653600000	45	0,037169844323946100
10	2,2039531222669200000	46	0,024051075739024000
11	1,6806600198239200000	47	0,019678152877383200
12	1,3577925485394400000	48	0,016762870969622800
13	1,1369599440265900000	49	0,021135793831263500
14	0,8971780071132880000	50	0,008017025246341320
15	0,7470409888636230000	51	0,015305230015742500
16	0,5670223310594130000	52	0,018220511923503000
17	0,4664451052416770000	53	0,018220511923503000
18	0,4008512623170660000	54	0,015305230015742500
19	0,3512914698851380000	55	0,009474666200221560
20	0,2893417293452280000	56	0,017491691446562900
21	0,2864264474374670000	57	0,013118768584922200
22	0,2550871669290420000	58	0,010932307154101800
23	0,2193749635589760000	59	0,005830563815520960
24	0,2150020406973350000	60	0,011661127631041900
25	0,2084426564048740000	61	0,004372922861640720
26	0,1596116844498860000	62	0,005101743338580840
27	0,1443064544341440000	63	0,002915281907760480
28	0,1457640953880240000	64	0,005101743338580840
29	0,1362894291878020000	65	0,005830563815520960
30	0,1260859425106410000	66	0,001457640953880240
31	0,1071366101101980000	67	0,002186461430820360
32	0,1005772258177370000	68	0,002915281907760480
33	0,0896449186636348000	69	0,003644102384700600
34	0,0743396886478923000	70	0,001457640953880240
35	0,0677803043554312000	71	0,001457640953880240

Table A.2: Difference In Age for New cohabitants

	Lower Threshold		Higher Threshold	
Age	**Male**	**Female**	**Male**	**Female**
15	0,001	0,001	0,001	0,002
16	0,004	0,011	0,005	0,012
17	0,009	0,027	0,011	0,030
18	0,017	0,050	0,021	0,057
19	0,026	0,075	0,033	0,088
20	0,040	0,101	0,051	0,121
21	0,059	0,127	0,073	0,154
22	0,081	0,147	0,100	0,181
23	0,102	0,158	0,126	0,200
24	0,119	0,159	0,148	0,207
25	0,127	0,155	0,161	0,208
26	0,128	0,146	0,167	0,202
27	0,126	0,137	0,169	0,194
28	0,121	0,128	0,167	0,185
29	0,116	0,120	0,162	0,174
30	0,108	0,113	0,153	0,164
31	0,101	0,106	0,144	0,152
32	0,094	0,098	0,135	0,140
33	0,089	0,091	0,128	0,130
34	0,083	0,083	0,121	0,120
35	0,079	0,078	0,116	0,113
36	0,074	0,071	0,111	0,104
37	0,070	0,066	0,106	0,097
38	0,066	0,060	0,101	0,089
39	0,062	0,055	0,096	0,084
40	0,058	0,050	0,091	0,079
41	0,054	0,046	0,087	0,073
42	0,052	0,042	0,085	0,068
43	0,050	0,039	0,083	0,065
44	0,048	0,038	0,081	0,064
45	0,045	0,036	0,078	0,062
46	0,043	0,035	0,075	0,060
47	0,042	0,032	0,075	0,059
48	0,041	0,031	0,075	0,058
49	0,041	0,030	0,075	0,057
50	0,040	0,029	0,075	0,055
51	0,039	0,027	0,074	0,053
52	0,037	0,025	0,073	0,052
53	0,036	0,023	0,072	0,049
54	0,033	0,020	0,070	0,045
55	0,033	0,018	0,068	0,041

	Lower Threshold		Higher Threshold	
Age	**Male**	**Female**	**Male**	**Female**
56	0,030	0,017	0,066	0,040
57	0,029	0,016	0,065	0,038
58	0,027	0,015	0,063	0,036
59	0,027	0,013	0,062	0,033
60	0,025	0,012	0,060	0,030
61	0,024	0,011	0,058	0,028
62	0,022	0,010	0,055	0,026
63	0,022	0,009	0,052	0,024
64	0,021	0,009	0,048	0,021
65	0,019	0,008	0,046	0,019
66	0,017	0,007	0,042	0,016
67	0,015	0,005	0,038	0,014
68	0,014	0,005	0,034	0,013
69	0,012	0,004	0,031	0,012
70	0,011	0,004	0,029	0,011
71	0,011	0,004	0,027	0,010
72	0,010	0,004	0,024	0,009
73	0,010	0,003	0,023	0,008
74	0,009	0,003	0,021	0,007
75	0,009	0,003	0,020	0,007
76	0,009	0,003	0,018	0,006
77	0,008	0,003	0,016	0,006
78	0,006	0,003	0,014	0,006
79	0,006	0,003	0,014	0,006
80	0,005	0,002	0,012	0,006
81	0,006	0,002	0,012	0,006
82	0,005	0,002	0,010	0,005
83	0,005	0,002	0,010	0,005
84	0,004	0,002	0,008	0,005
85	0,004	0,002	0,009	0,004
86	0,004	0,002	0,008	0,004
87	0,004	0,002	0,008	0,004
88	0,003	0,002	0,006	0,004
89	0,003	0,002	0,005	0,004
90	0,003	0,002	0,005	0,004
91	0,003	0,002	0,005	0,005
92	0,002	0,002	0,004	0,005
93	0,001	0,002	0,003	0,005
94	0,001	0,002	0,003	0,003
95	0,000	0,001	0,002	0,002

Table A.3: Chance for non-cohabitants to become cohabitants in 2000

B

Data

In this appendix the choices made to calculate the chances of a households having a child, a person dying, a relationship forming and a relationship ending are explained. Assumed is that all events happen linearly over the year in line with household prognosis of the "Centraal Bureau Statistiek" Van Duin and Harmsen (2009).

B.1. Births

To calculate the chance that any given households has a child, the dataset "Levend geboren kinderen; huishoudenssamenstelling en migratieachtergrond" (Identifier: 82056NED) from the CBS is used. This table was chosen over the other tables about childbirth as it includes information about the composition of the household.

Unlike other tables, this table uses the age of the mother on the day of the birth, which means that we do not know the exact amount of households of a certain type and composition, but as the ages are grouped in 5-year groups, it should still be approximately correct.

To find the chance of married pairs with 0 children, it is needed to divide by the amount of children born in families that, after the birth, has 1 child. This is because the table indicates the composition of the household *after* the child is born. The number of households needed for the division is retrieved from the data-set: "Particuliere huishoudens naar samenstelling en grootte, 1 januari" (Identifier: 37975).

In the group of households under 20 this method results in impossible odds, married couples would have over 600% chance of having a child. Fundamentally this is caused by the assumption that a household experiences either a childbirth or a marriage, and not both. There is a bigger group of married couples under 20 with 1 child at the end of the year, then there is a group of married couples under 20 with 0 children at the start of the year. In the other age groups this assumption is mitigated by the size of the groups. To generate more sensible data for ages under 20, all households types and compositions are grouped together.

Additionally if the reference person for the household turns 20 in the year of the childbirth they move to a different age group, due to the different age measurement used in the table for births.

B.2. Deaths

To calculate the chance for any given person to decease the table "Overledenen; geslacht, leeftijd en positie in het huishouden" (Identifier: 83910NED) from the CBS is used. This dataset seperates on the position in the household and the composition of the household (Married, Unmarried, Single or Single-parent). To calculate the percentage of persons that deceases in any specific group the table "Personen in huishoudens naar leeftijd en geslacht, 1 januari" (Identifier: 37620) is used to find the size of the group that reaches the next year.

To calculate the percentage, the number of deceased person in any group is divided by the number of deceased person plus the number of persons that reaches the next year. Slight inaccuracies are introduced because one table measures the age of a person on the 31st of December, and the other measures the age on the 1st of January.

B.3. Relationships

Data on the forming and ending of relationships is very limited, marriage is known but only at the point of the marriage and not the start of the relationship. In the context of the housing market we would like to know the rate at which relationships arrive at a point where both sides are willing to live together. At this point the question arises of how the state of a housing market interacts with the willingness to live together. One can imagine that if there is an infinite supply of houses that are free, two partners only decide on factors relating to their relationship. Conversely if there is a shortage of houses, two partners might decide on living together because on partner has no house, or decide against living together because if the relationship would end it would be hard to move out.

Nevertheless data on the rates at which relationships start and end does give insight into the process. In 2002 two articles where published in by the cbs in “Maandstatistiek van de bevolking” under the names “Nieuwe samenwoners” (Steenhof and Harmsen, 2002b) and “Ex-samenwoners” (Steenhof and Harmsen, 2002a). These articles go into specifically the rate at which people of a certain age move in together, or move out. The data behind the graphs has been retrieved from the CBS, and the relevant tables are included in appendix A.

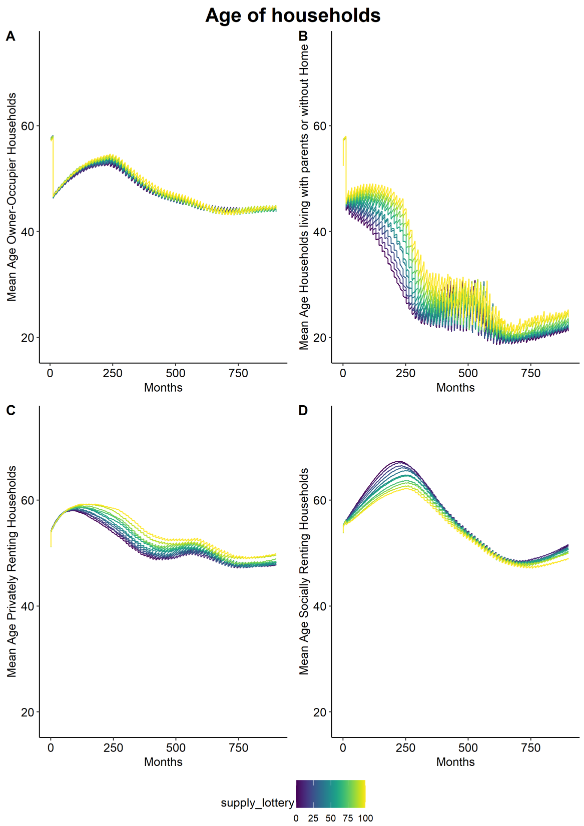
For the age difference in new relationships the data in Table A.2 is used, for the chance a relationships forms Table A.3 is used and finally for the chance a relationship ends Table A.1 is used.

The biggest downside of this data, similarly to the definition of households, is that it does not account for relationships that are unable to move in together. Additionally it is confined to only the year 2000, as publicly only the total amount of households are available, and not the change. At the very least this is an approximation of how relationships form.

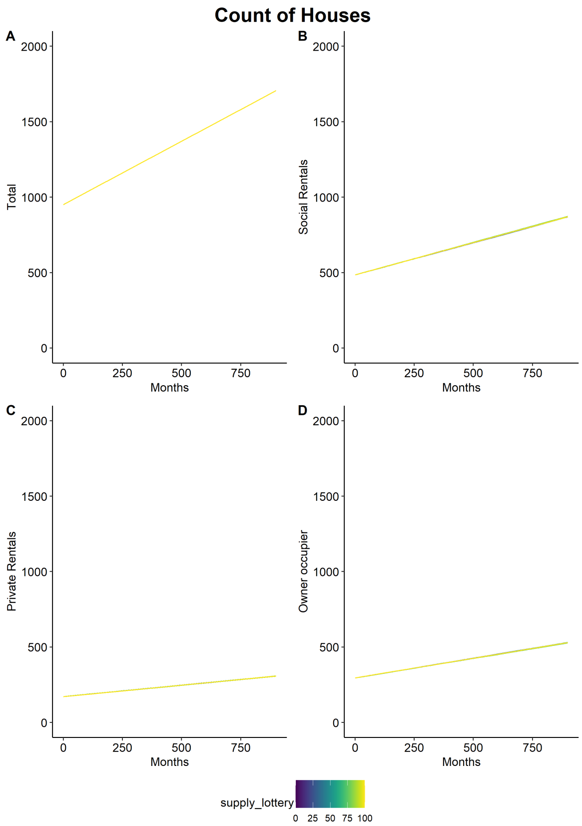
C
Analysis results

C.1. Changing Policy

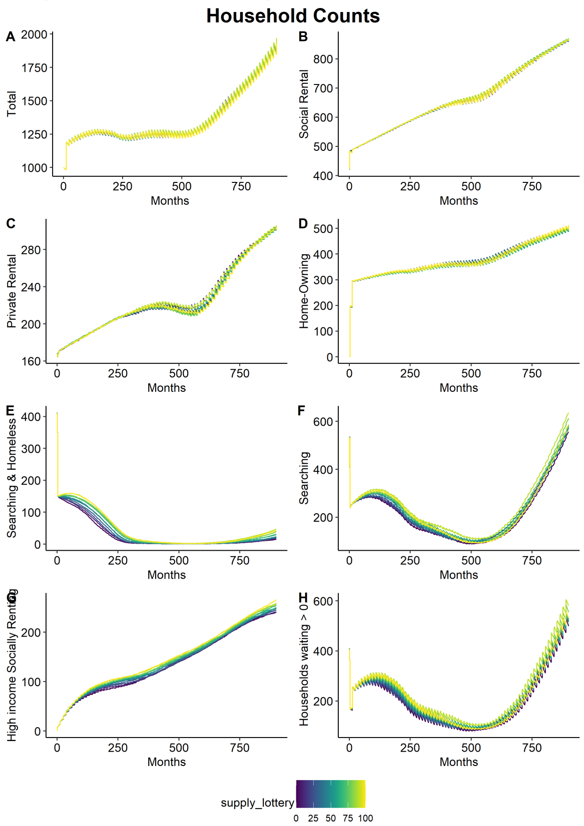
C.1.1. Lotteries for social housing



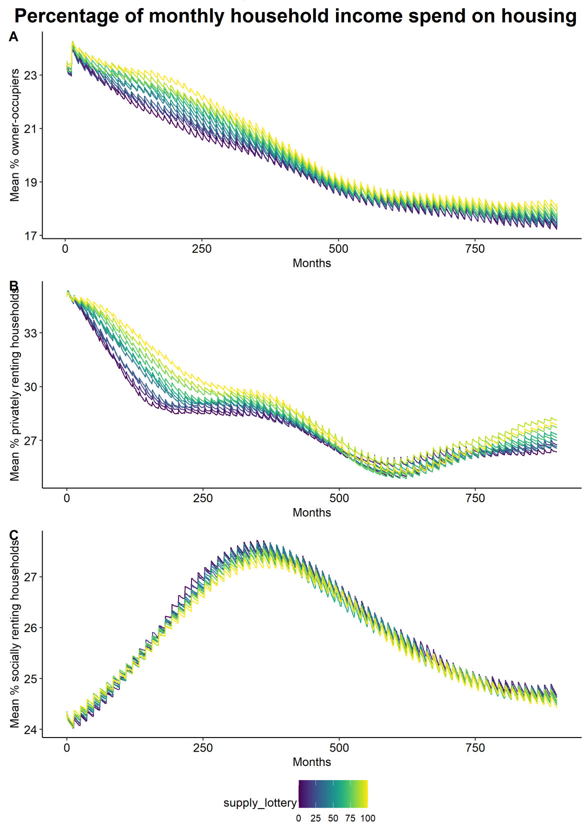
(a) Age of households in housing sectors



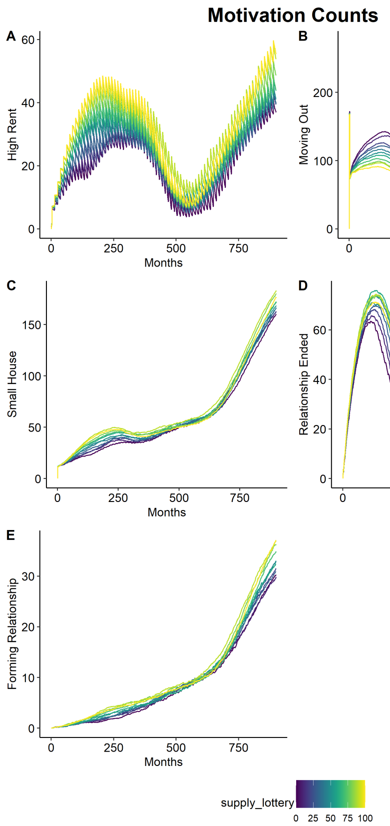
(b) Count of houses in housing sectors



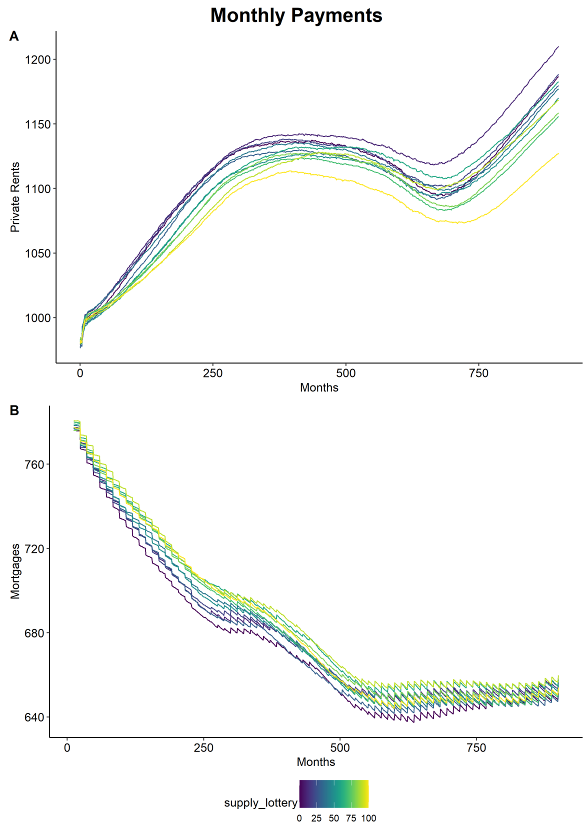
(c) Count of households



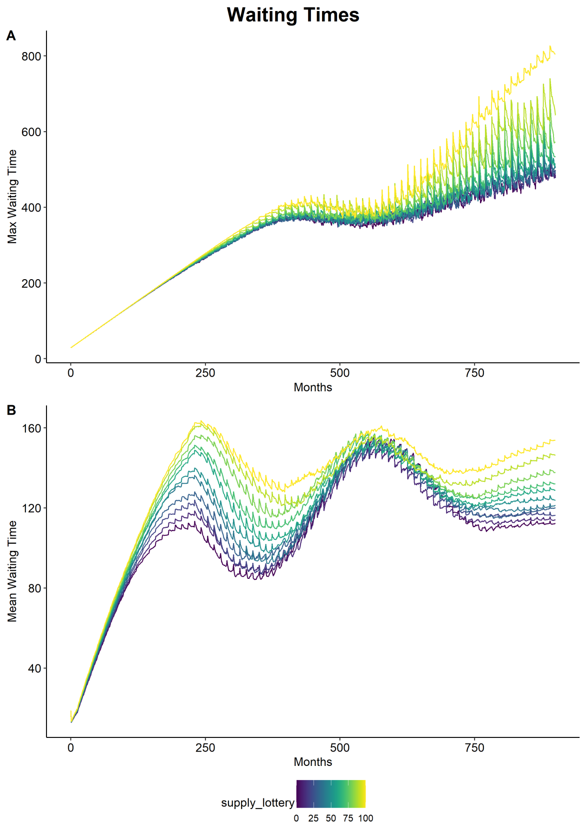
(d) Percentage of monthly household income spend on housing



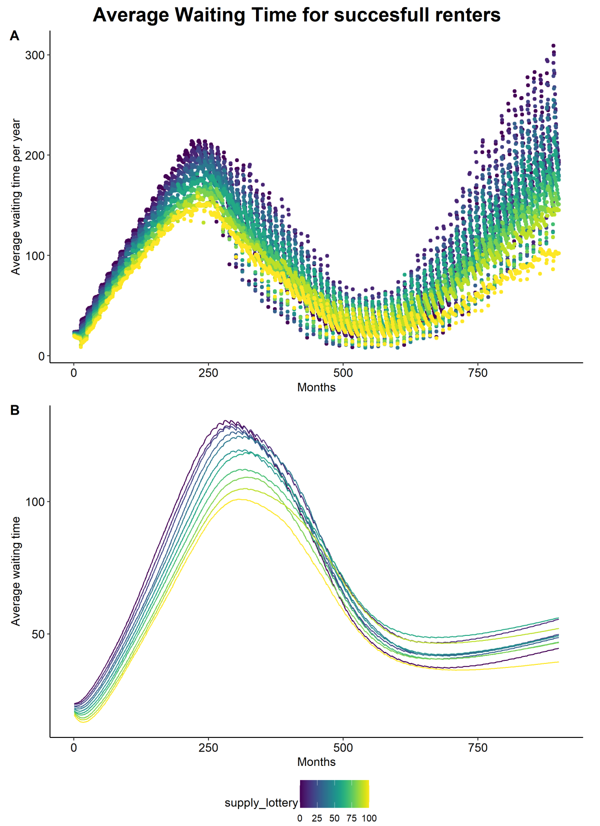
(a) Count of household motivations to move



(b) Monthly payments for private rents and mortgages

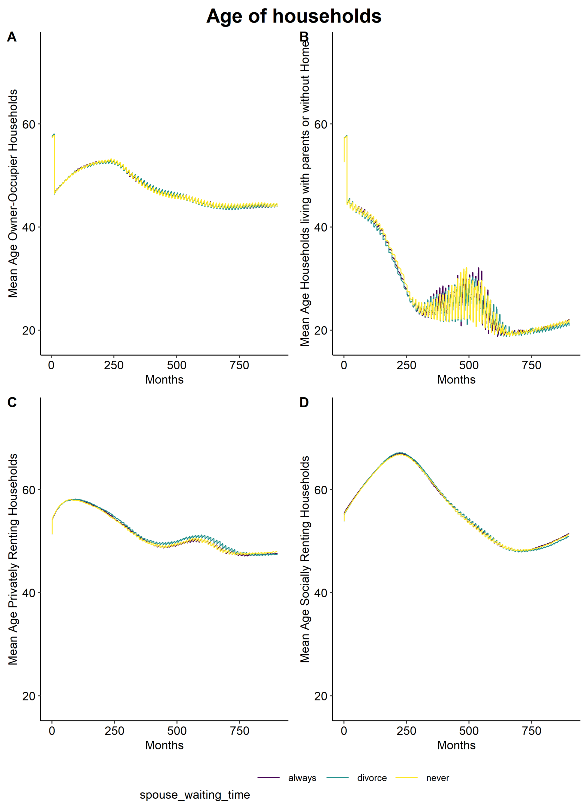


(c) Waiting times of households

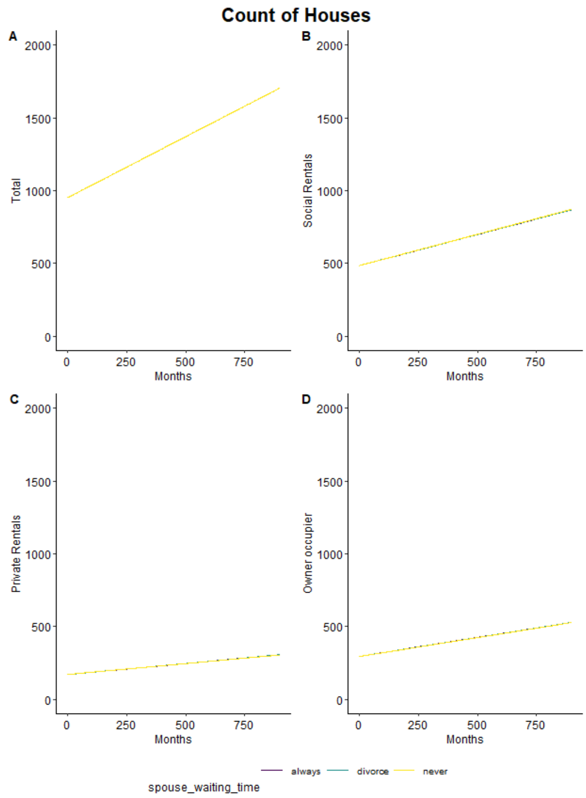


(d) Waiting times for households that successfully rent a social house

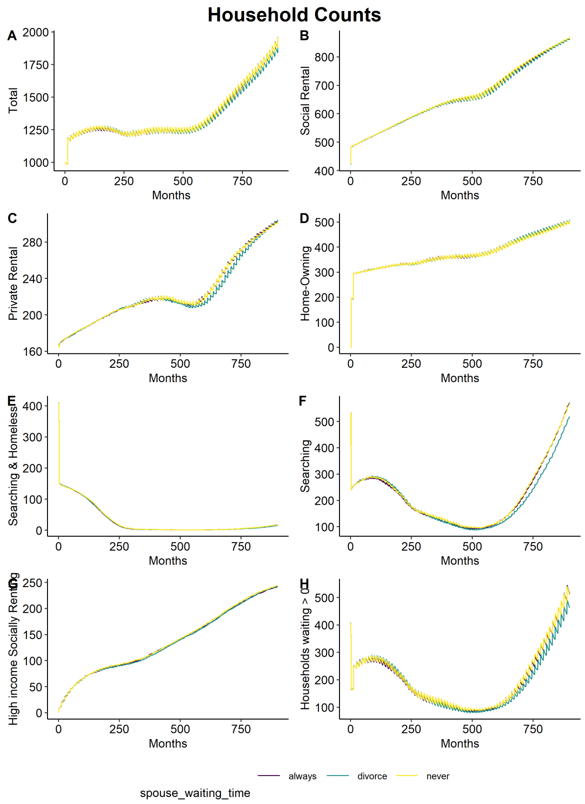
C.1.2. Divorce and Secondary Waiting Times



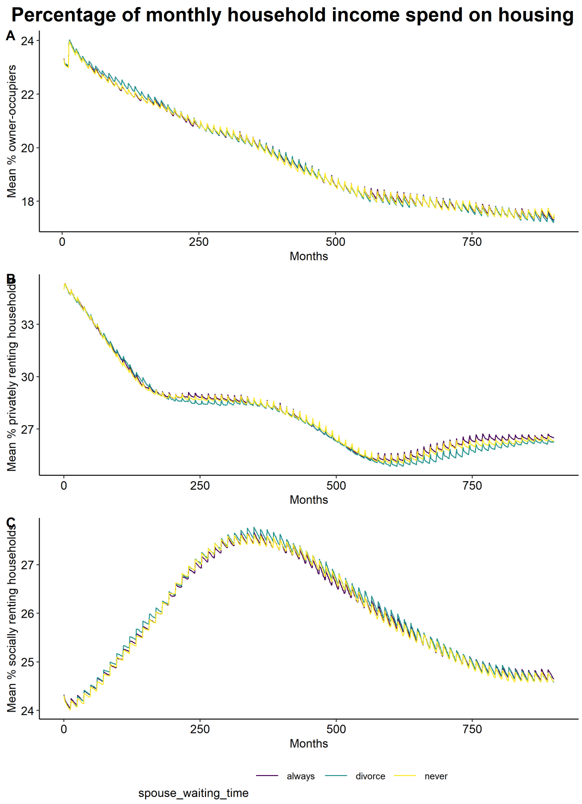
(a) Age of households in housing sectors



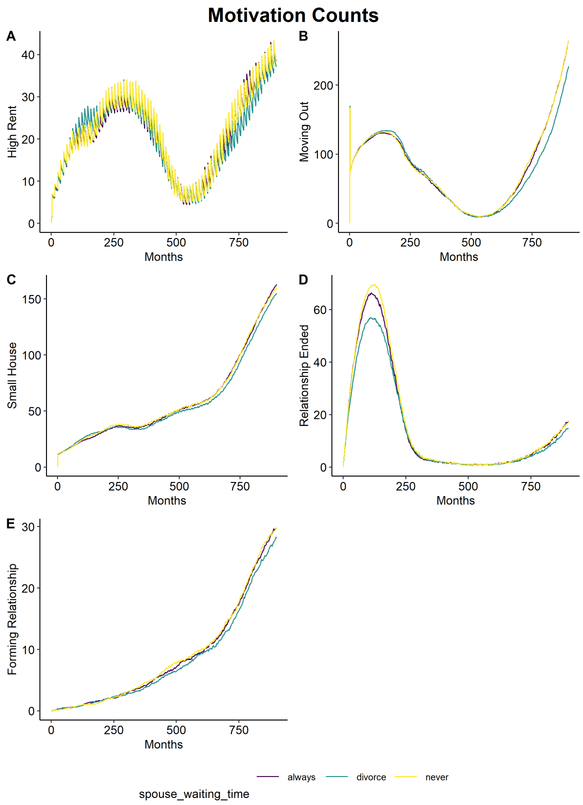
(b) Count of houses in housing sectors



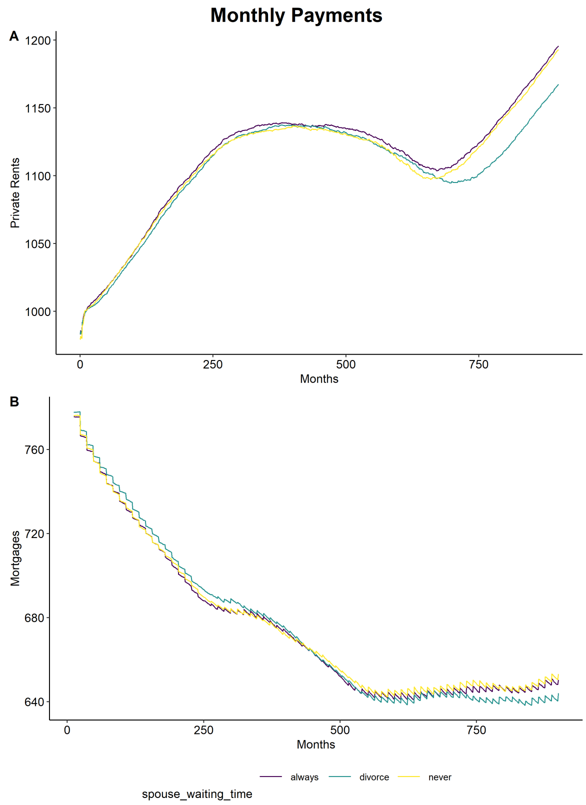
(c) Count of households



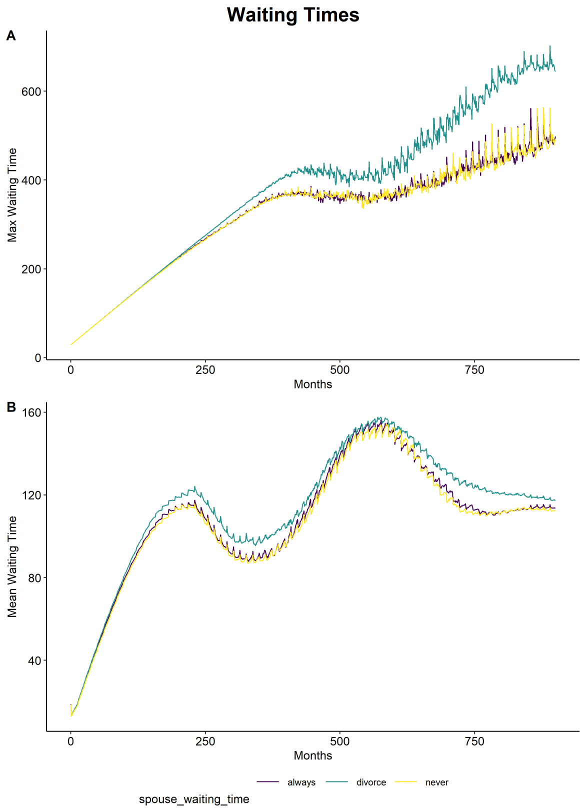
(d) Percentage of monthly household income spend on housing



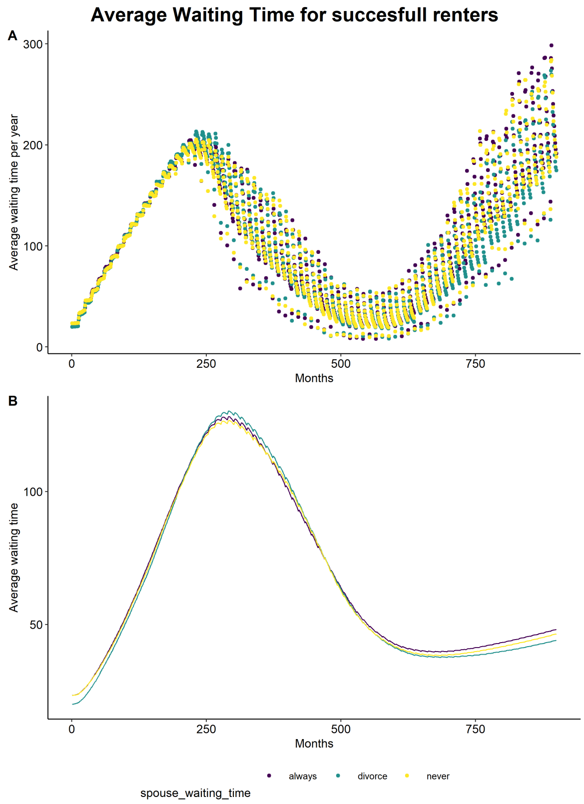
(a) Count of household motivations to move



(b) Monthly payments for private rents and mortgages

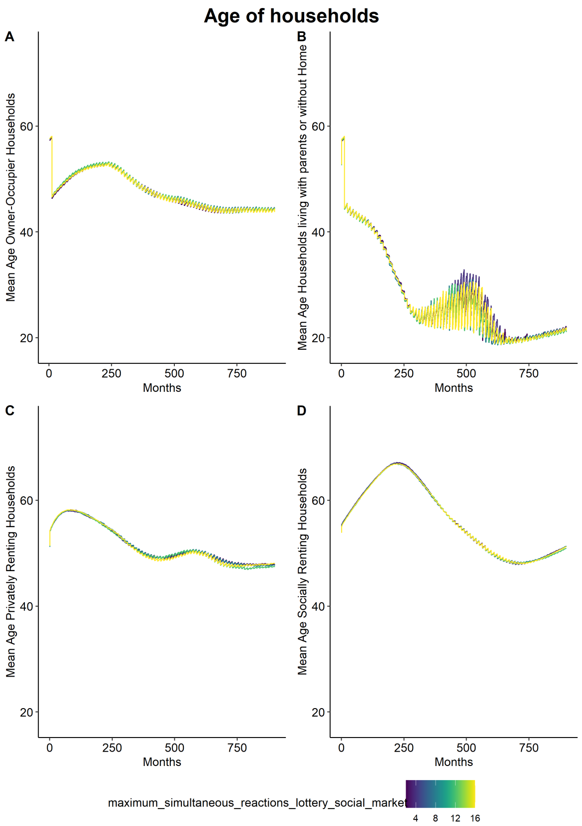


(c) Waiting times of households

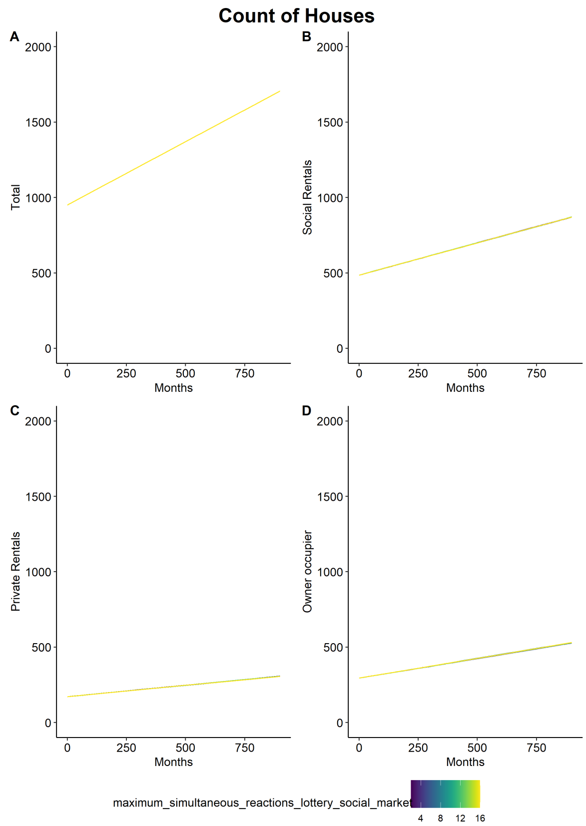


(d) Waiting times for households that successfully rent a social house

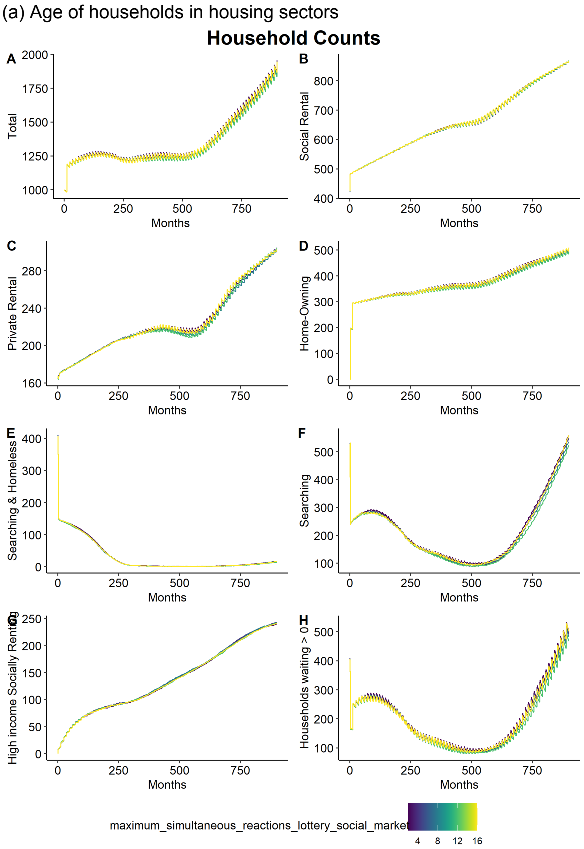
C.1.3. Maximum Number of reactions



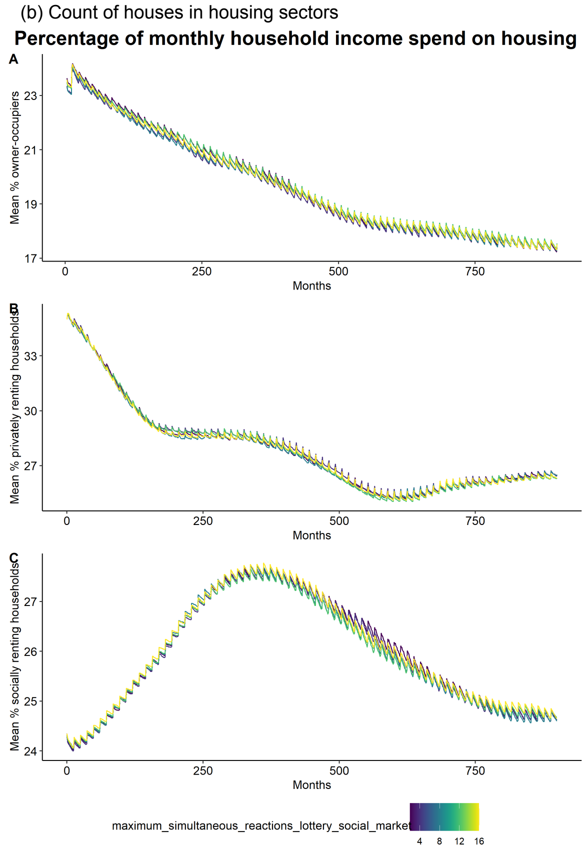
(a) Age of households in housing sectors



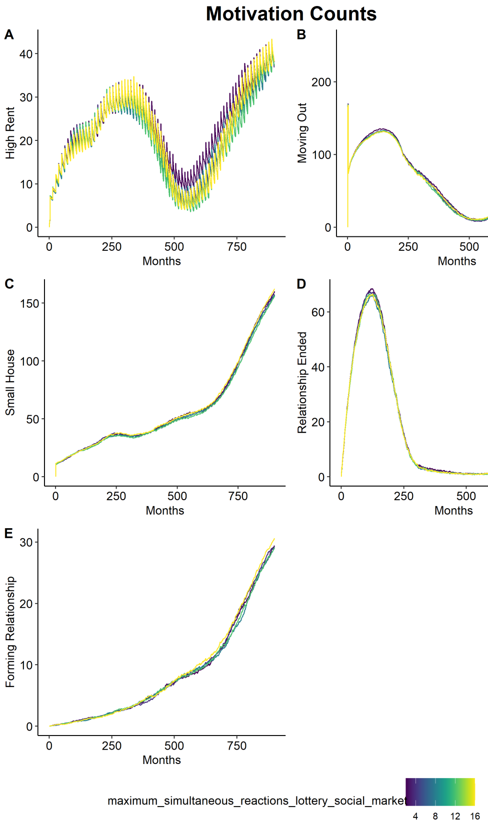
(b) Count of houses in housing sectors



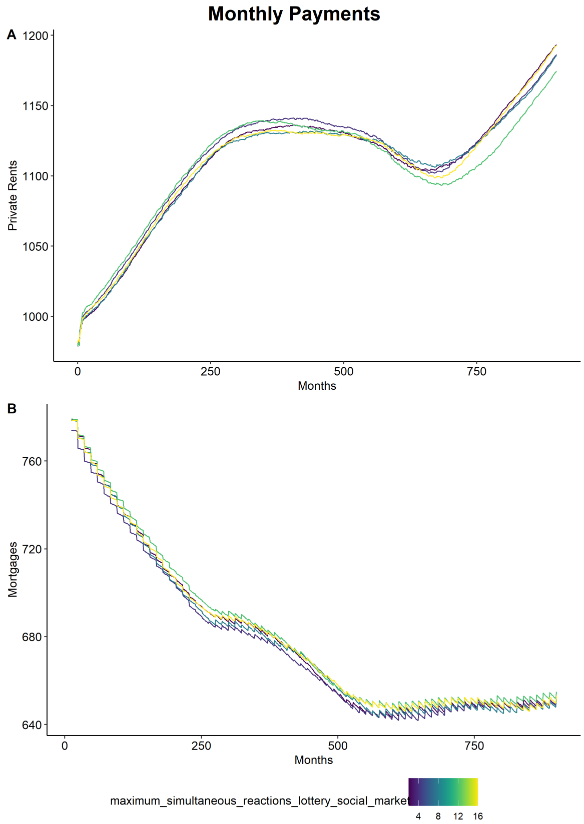
(c) Count of households



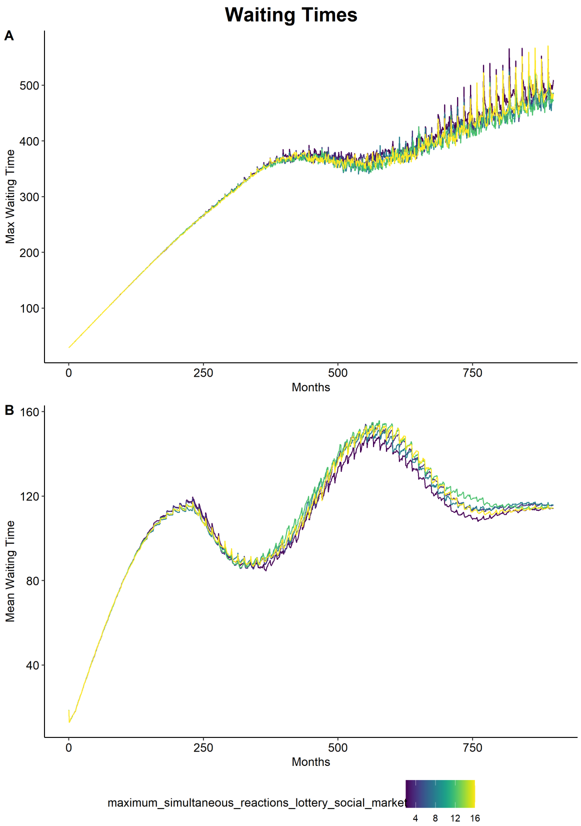
(d) Percentage of monthly household income spend on housing



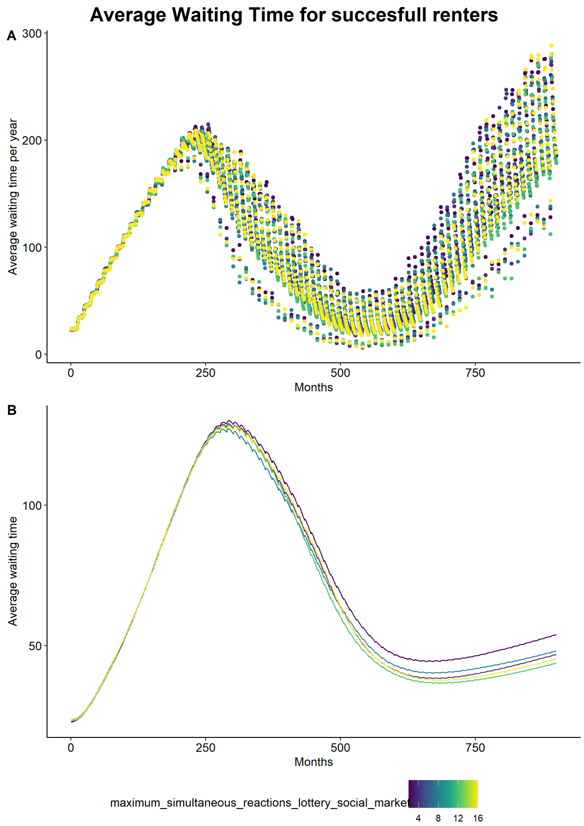
(a) Count of household motivations to move



(b) Monthly payments for private rents and mortgages

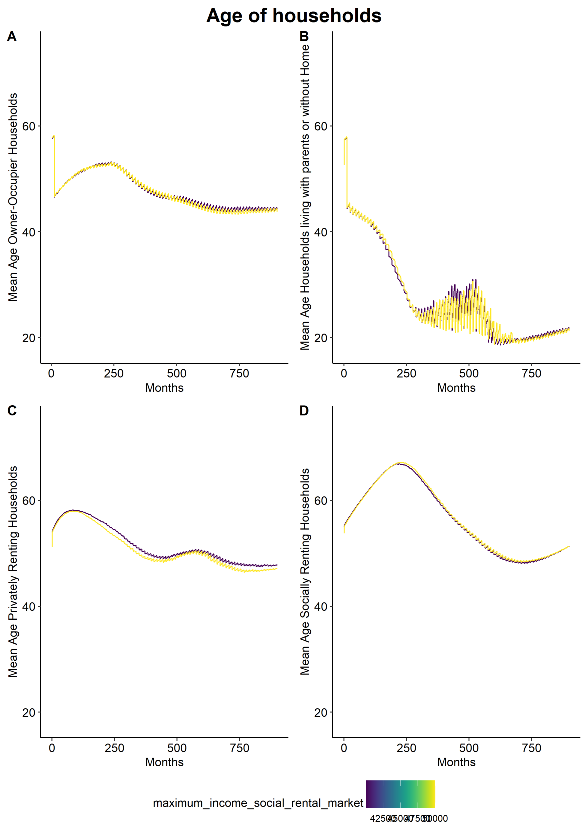


(c) Waiting times of households

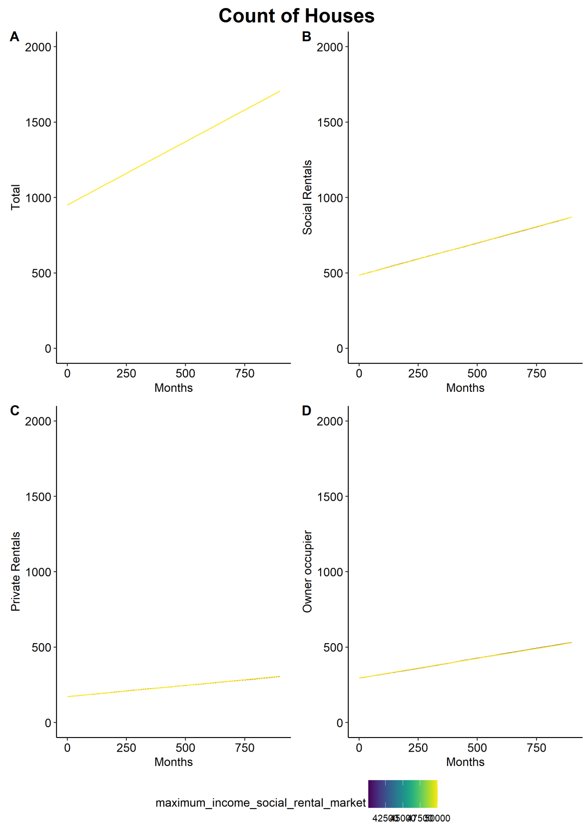


(d) Waiting times for households that successfully rent a social house

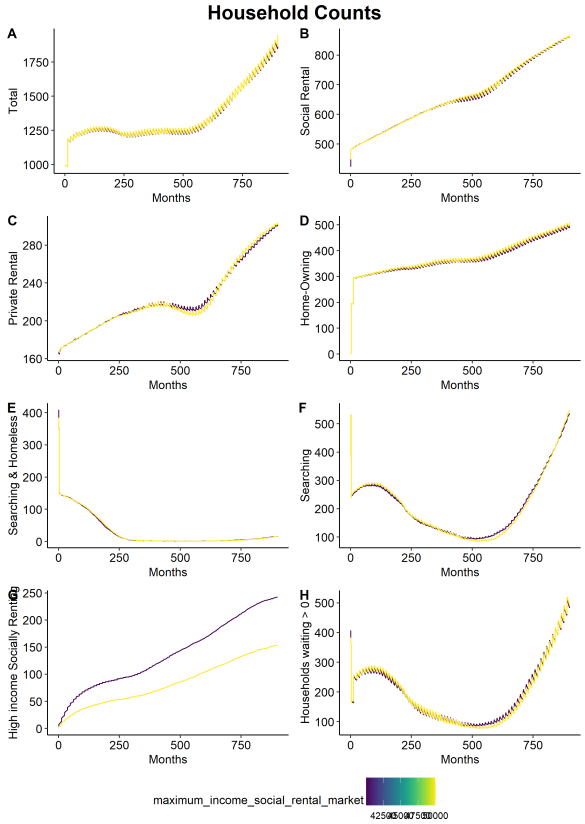
C.1.4. Increased Income Limit Social Housing



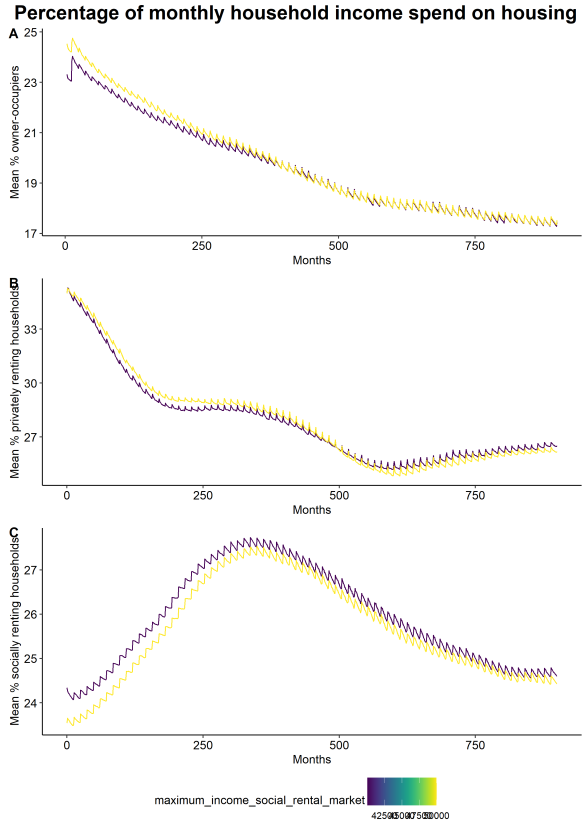
(a) Age of households in housing sectors



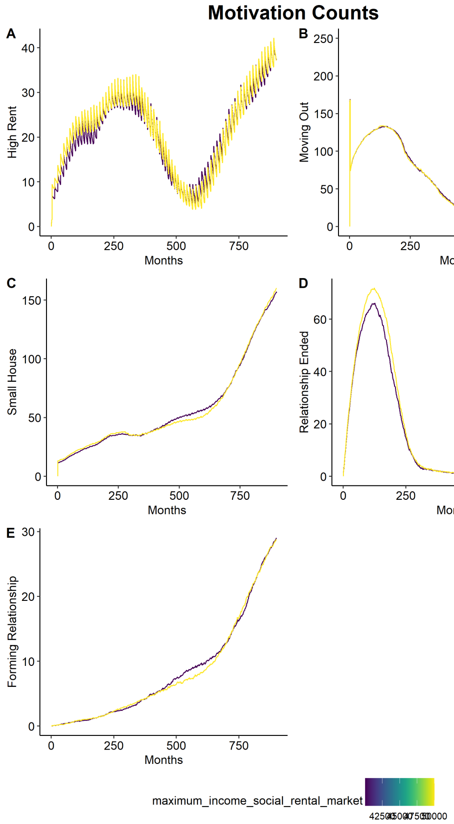
(b) Count of houses in housing sectors



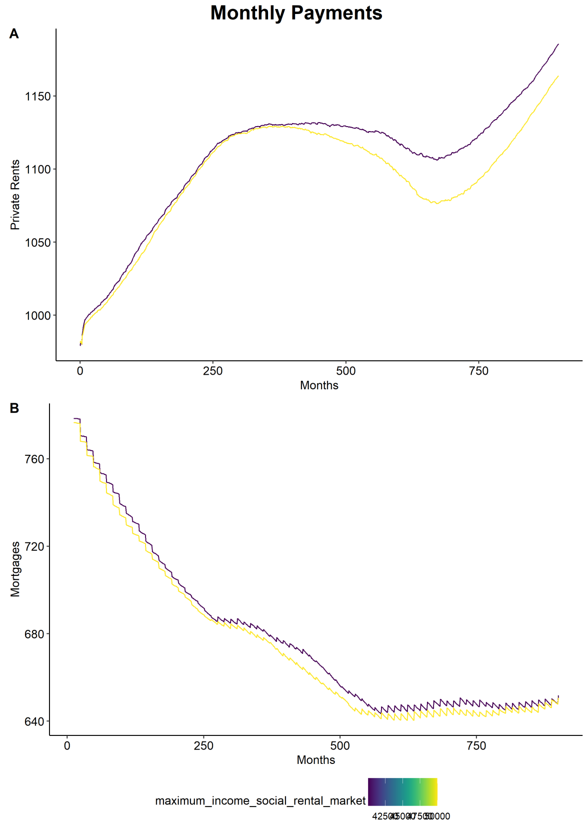
(c) Count of households



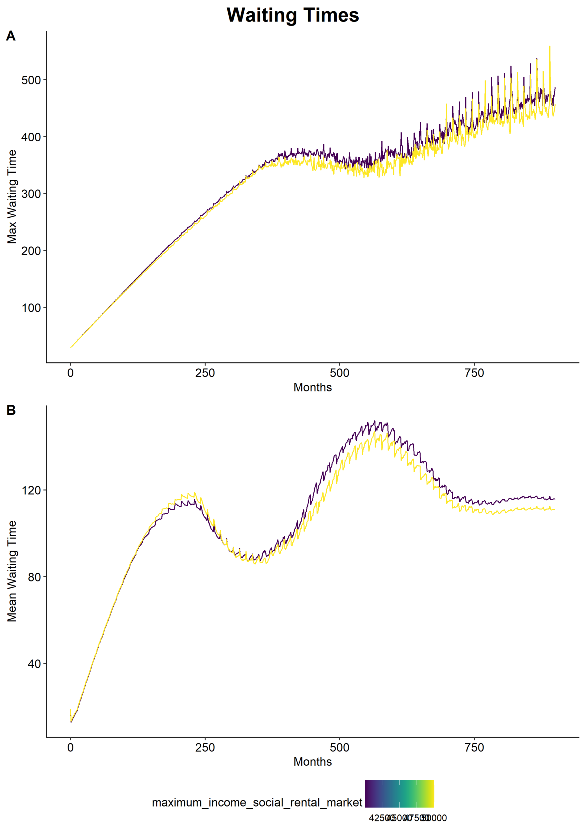
(d) Percentage of monthly household income spend on housing



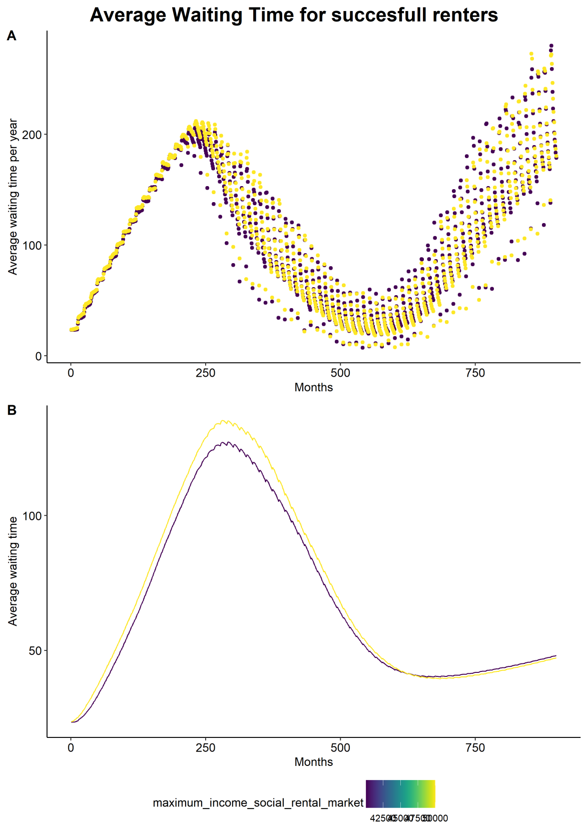
(a) Count of household motivations to move



(b) Monthly payments for private rents and mortgages



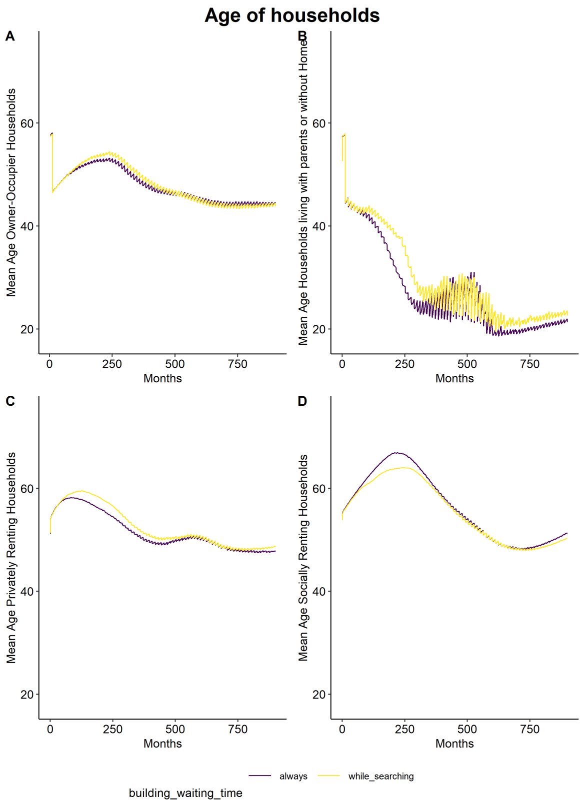
(c) Waiting times of households



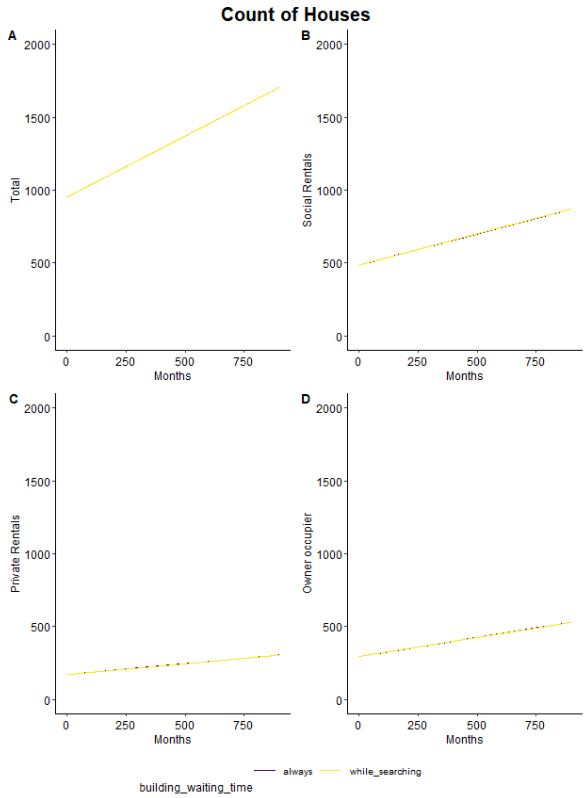
(d) Waiting times for households that successfully rent a social house

C.2. Changing Behaviour

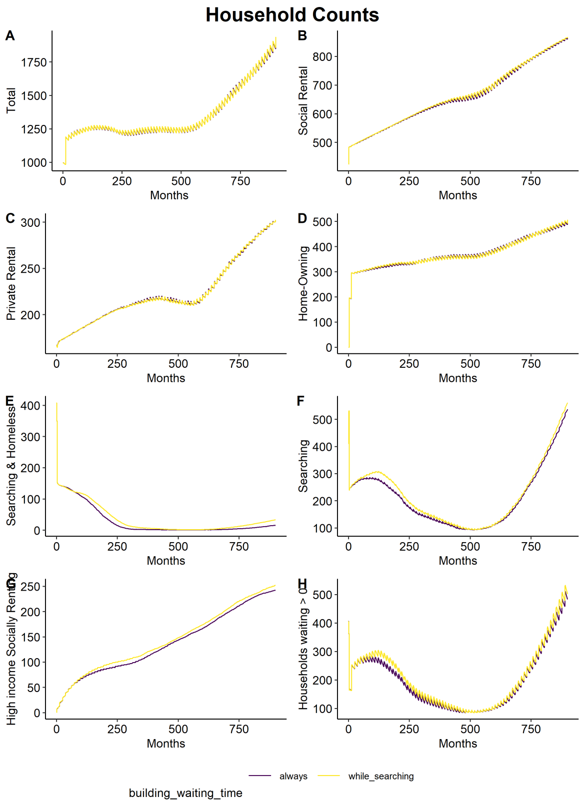
C.2.1. Waiting Time for social Housing



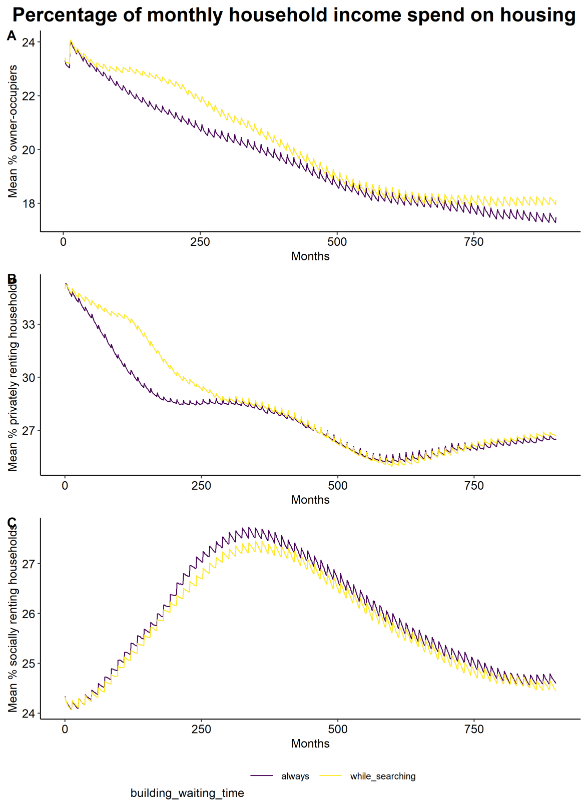
(a) Age of households in housing sectors



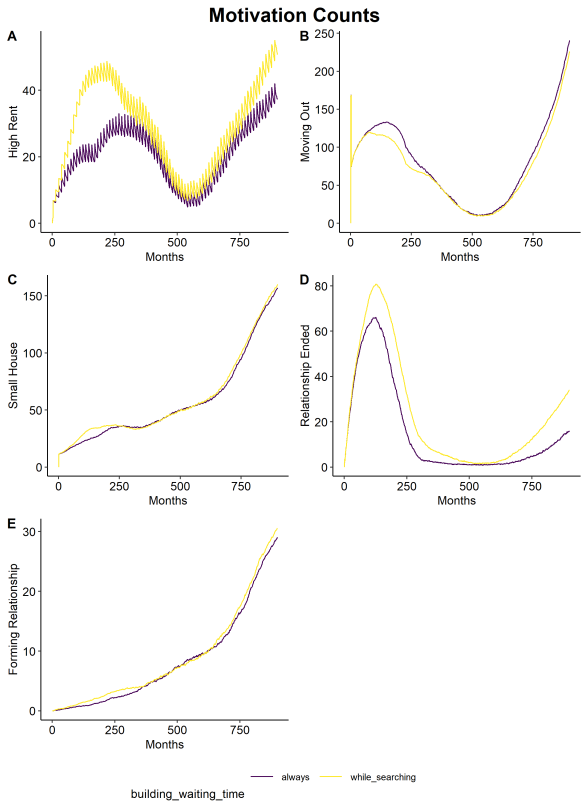
(b) Count of houses in housing sectors



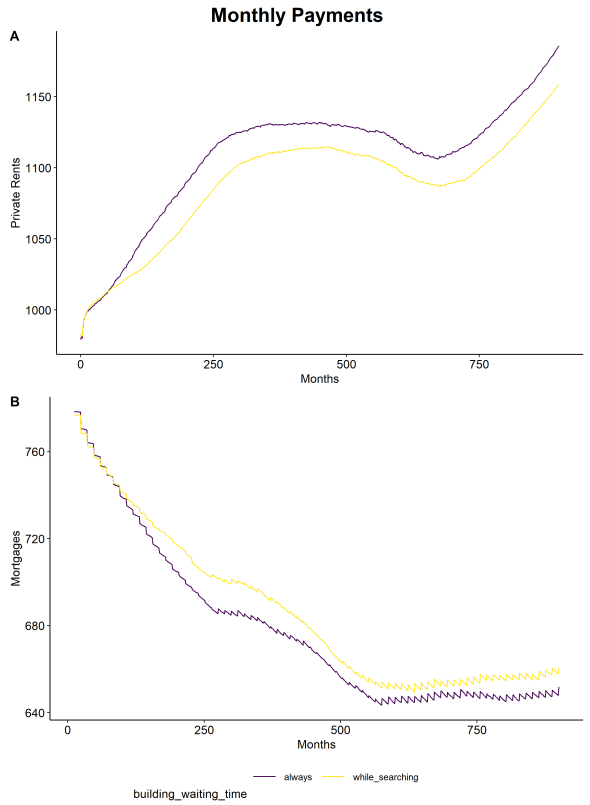
(c) Count of households



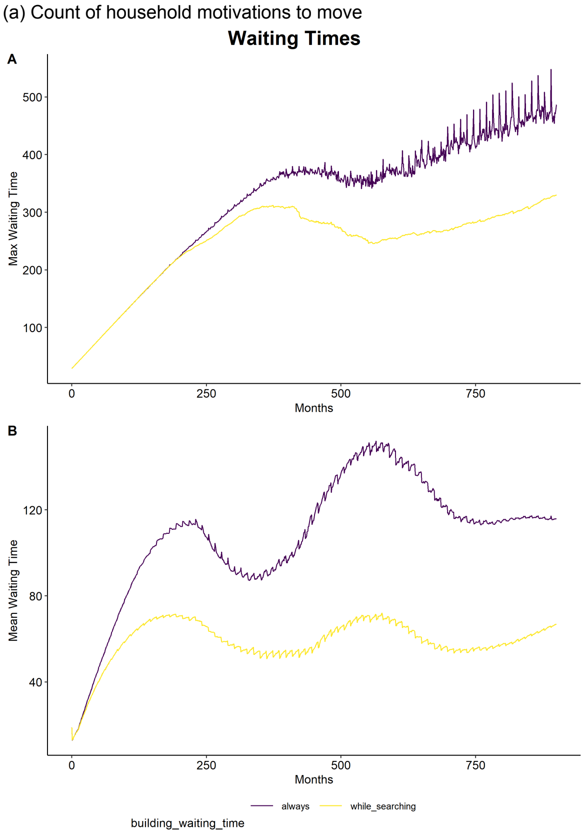
(d) Percentage of monthly household income spend on housing



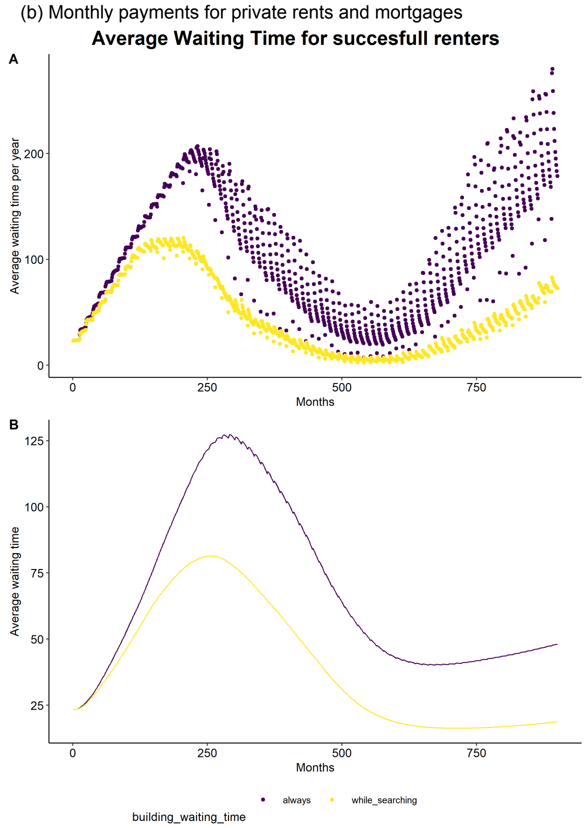
(a) Count of household motivations to move



(b) Monthly payments for private rents and mortgages

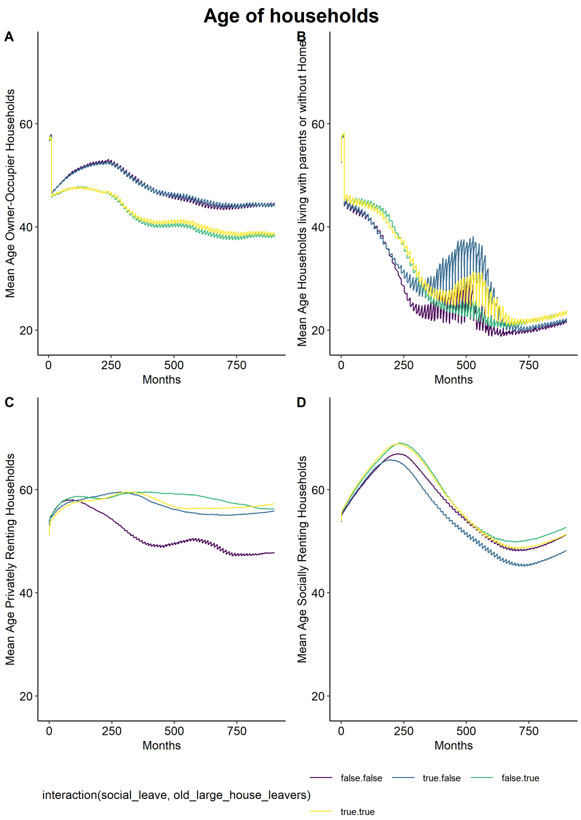


(c) Waiting times of households

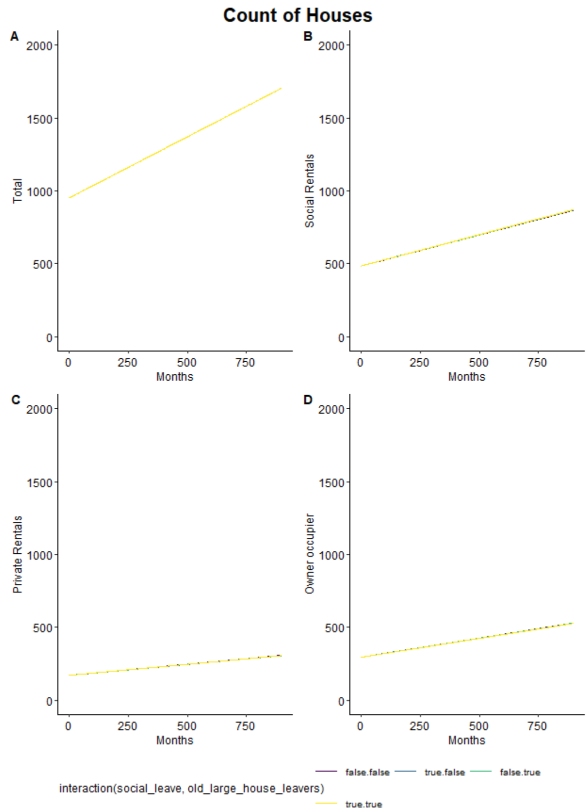


(d) Waiting times for households that successfully rent a social house

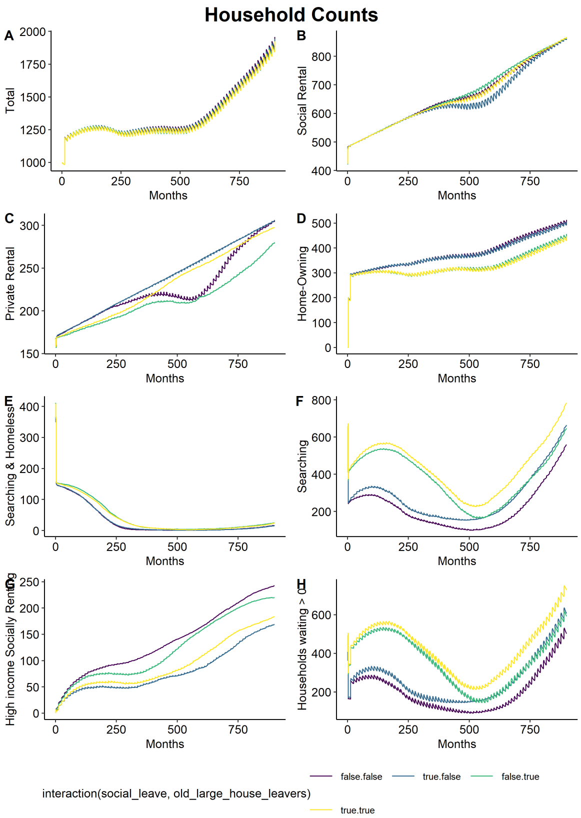
C.2.2. Willing Social Market Leavers



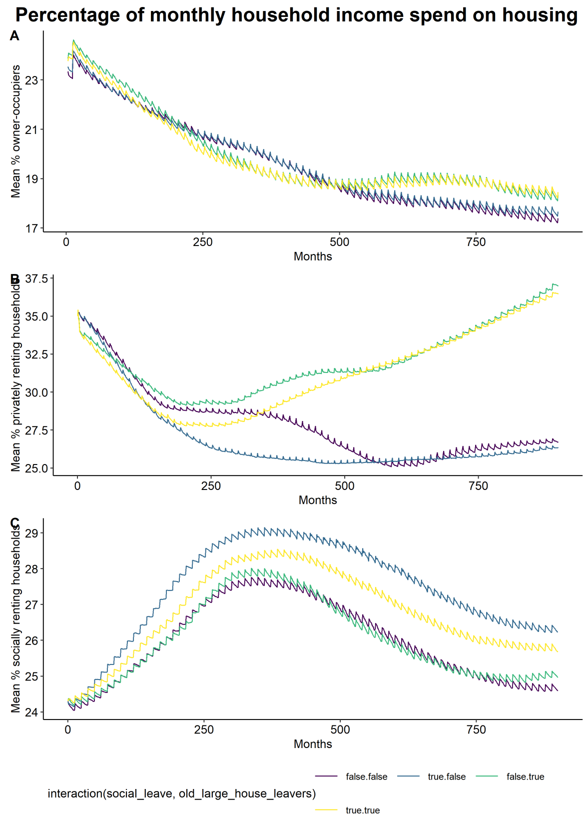
(a) Age of households in housing sectors



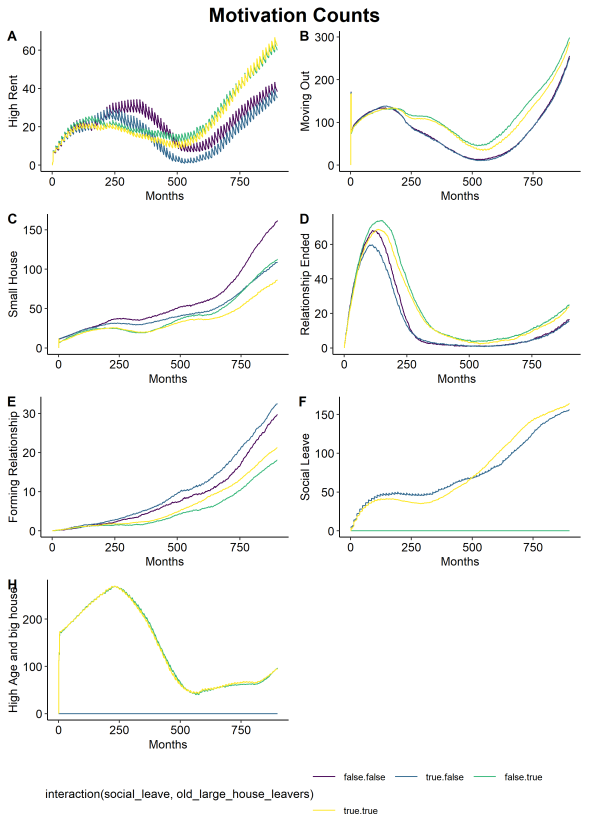
(b) Count of houses in housing sectors



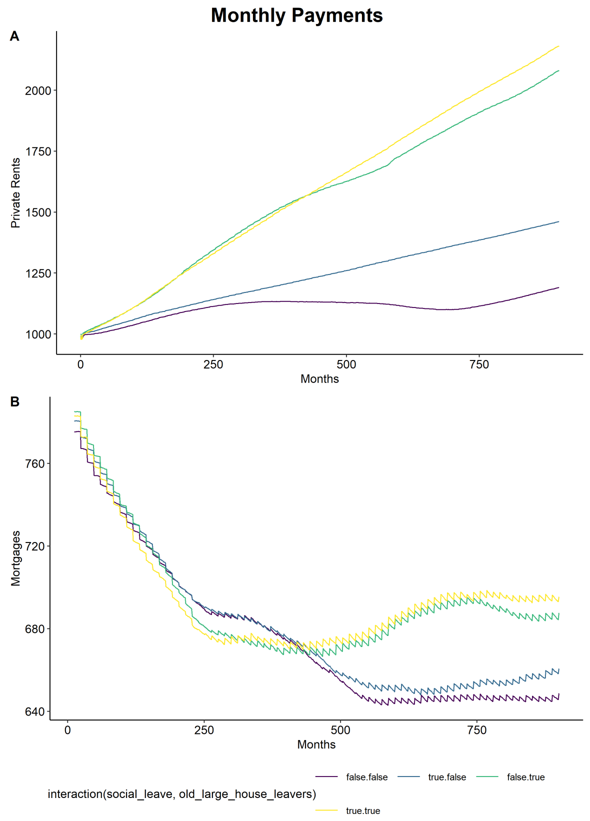
(c) Count of households



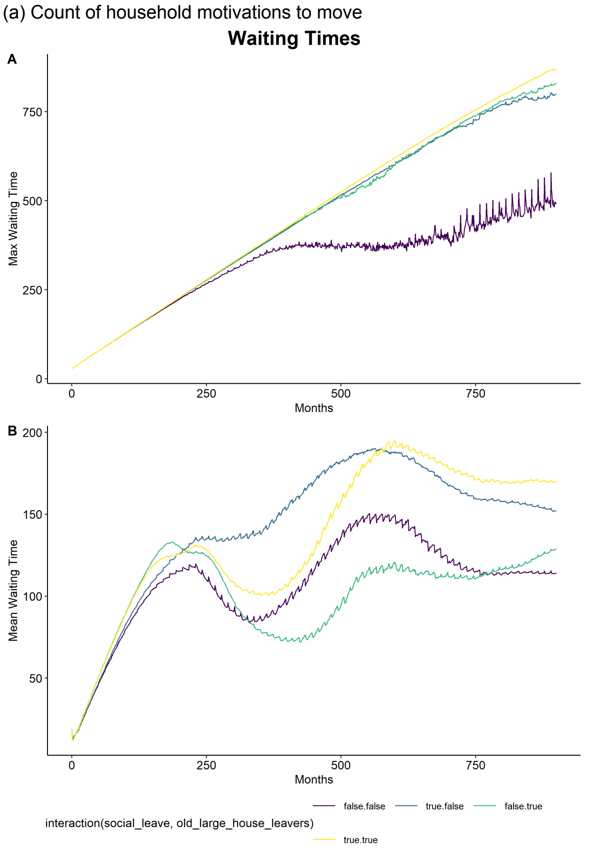
(d) Percentage of monthly household income spend on housing



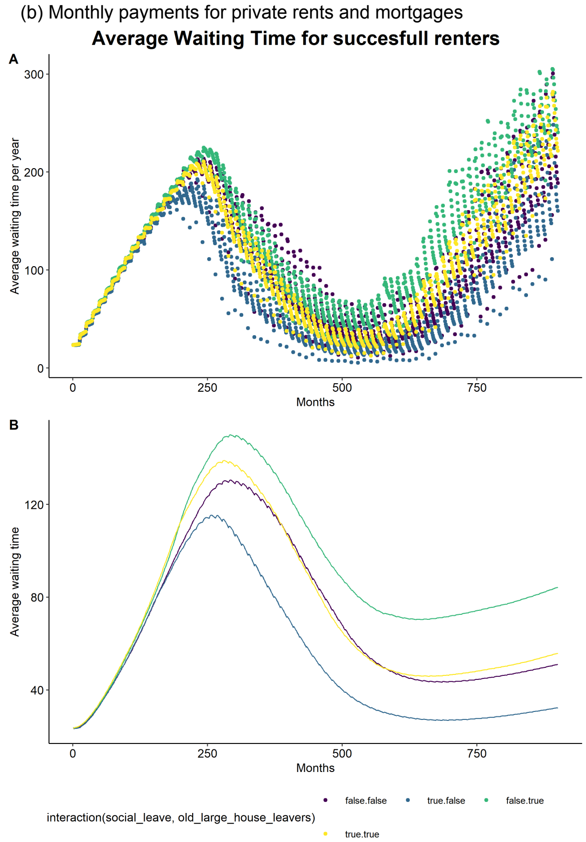
(a) Count of household motivations to move



(b) Monthly payments for private rents and mortgages



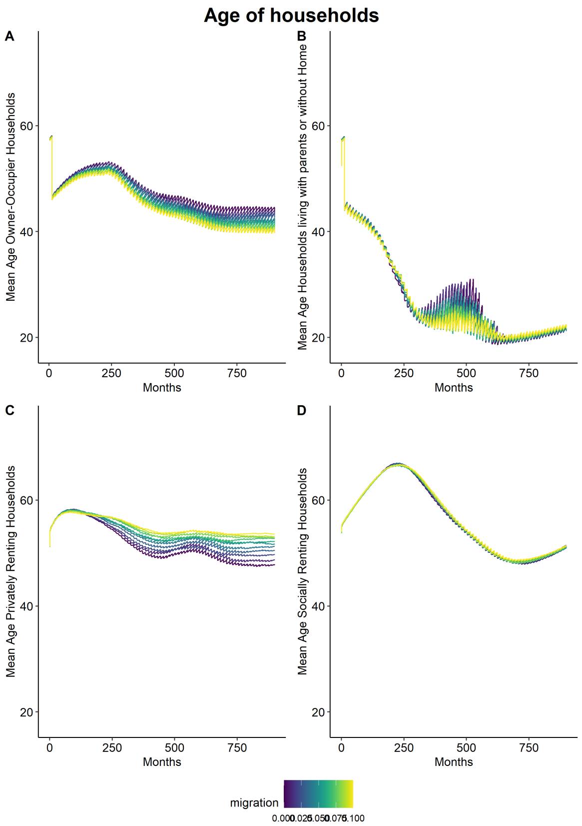
(c) Waiting times of households

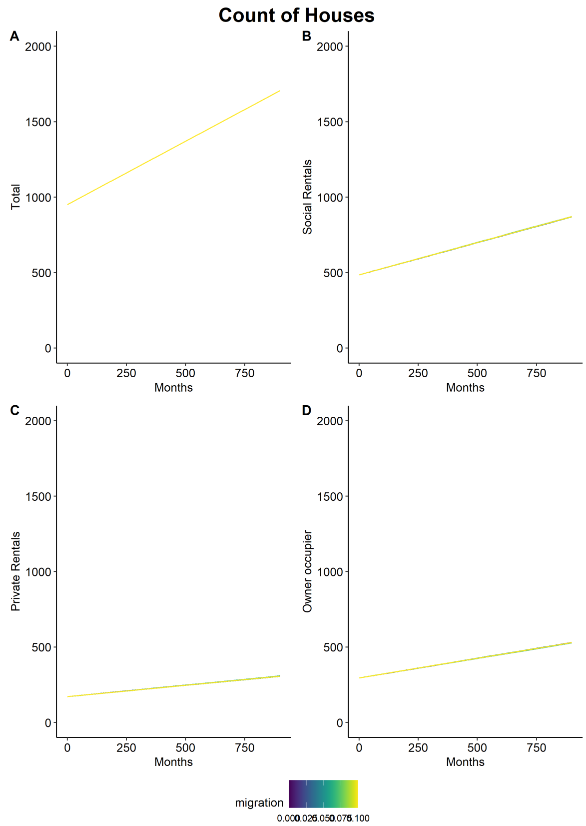


(d) Waiting times for households that successfully rent a social house

C.3. Changing Environment

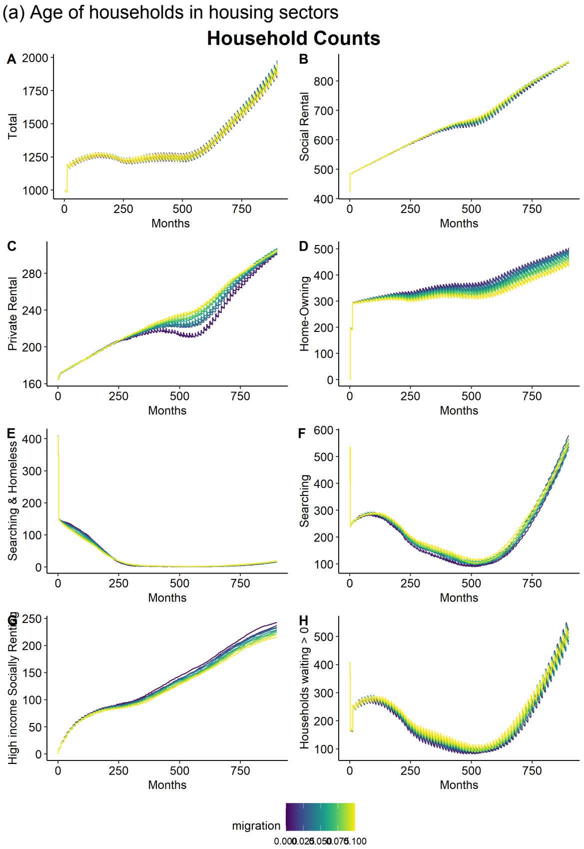
C.3.1. Migration

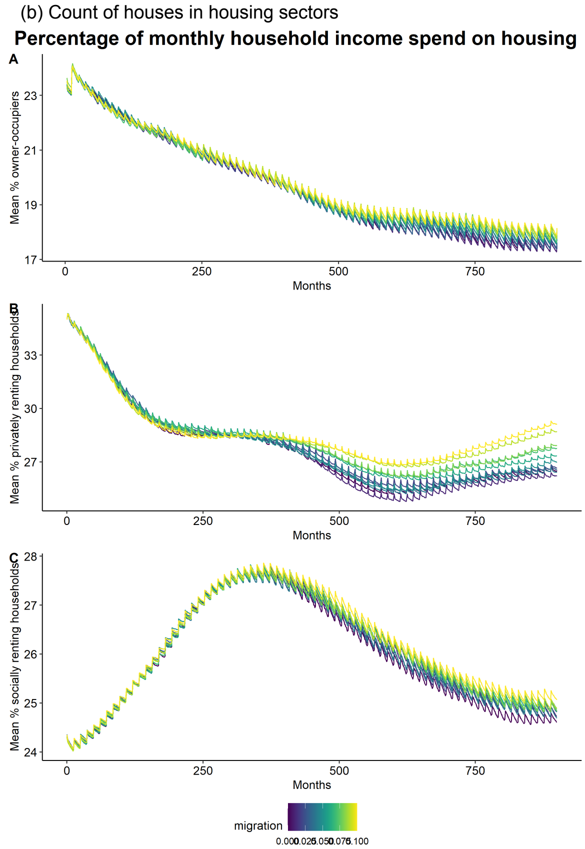




(a) Age of households in housing sectors

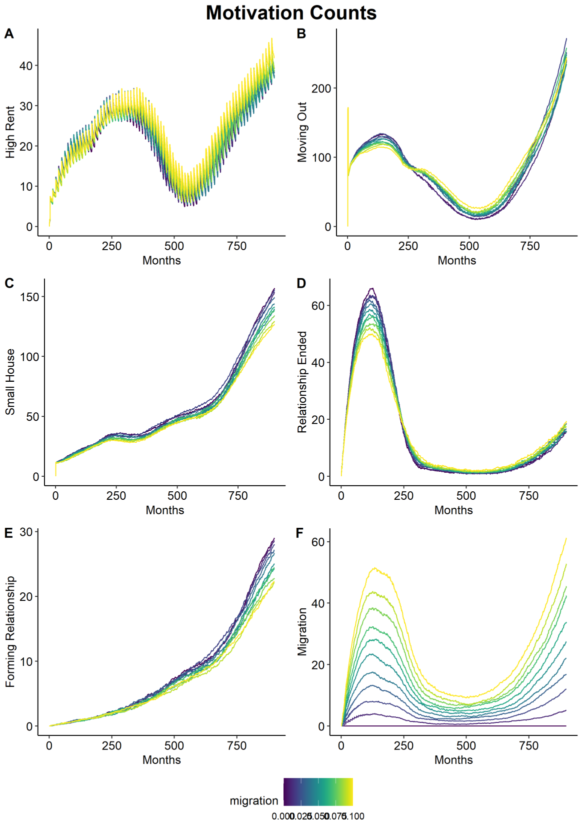
(b) Count of houses in housing sectors



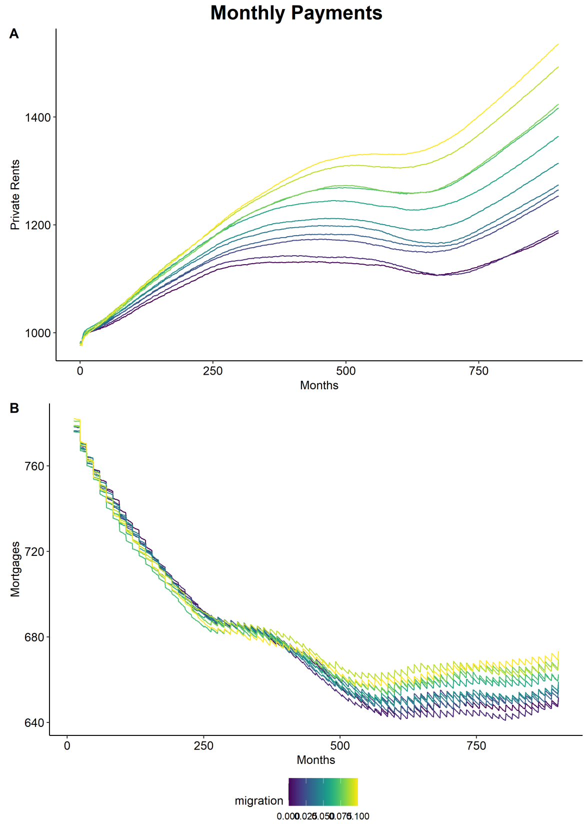


(c) Count of households

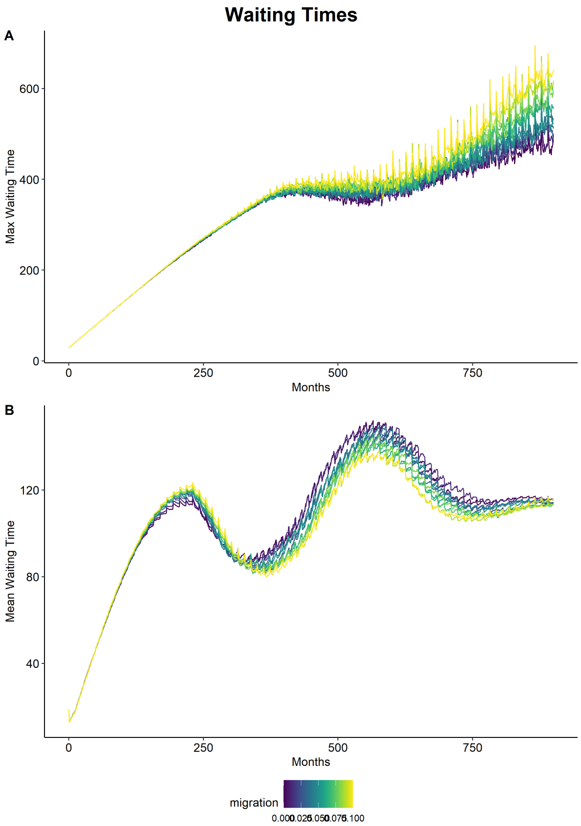
(d) Percentage of monthly household income spend on housing



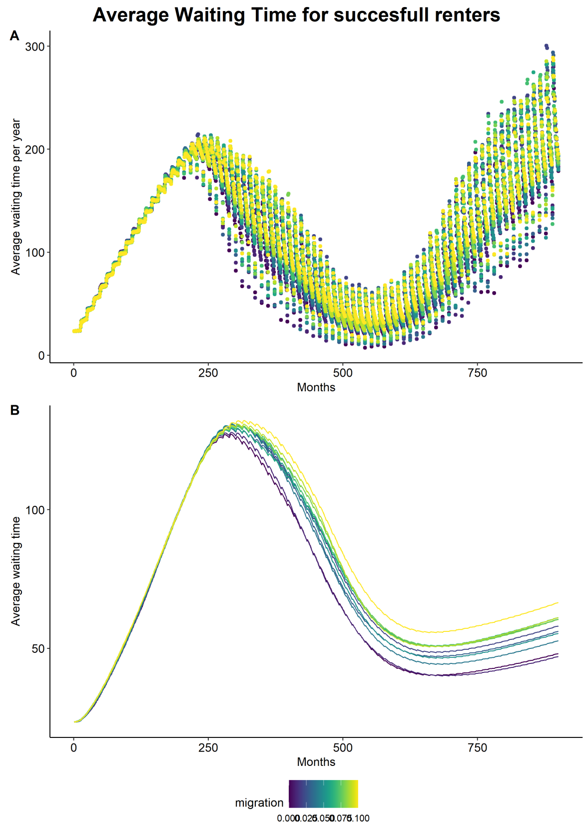
(a) Count of household motivations to move



(b) Monthly payments for private rents and mortgages

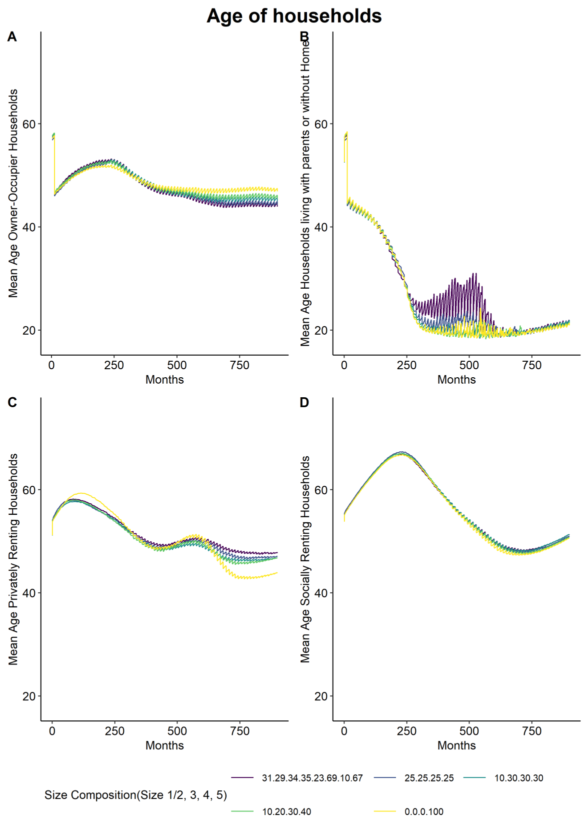


(c) Waiting times of households

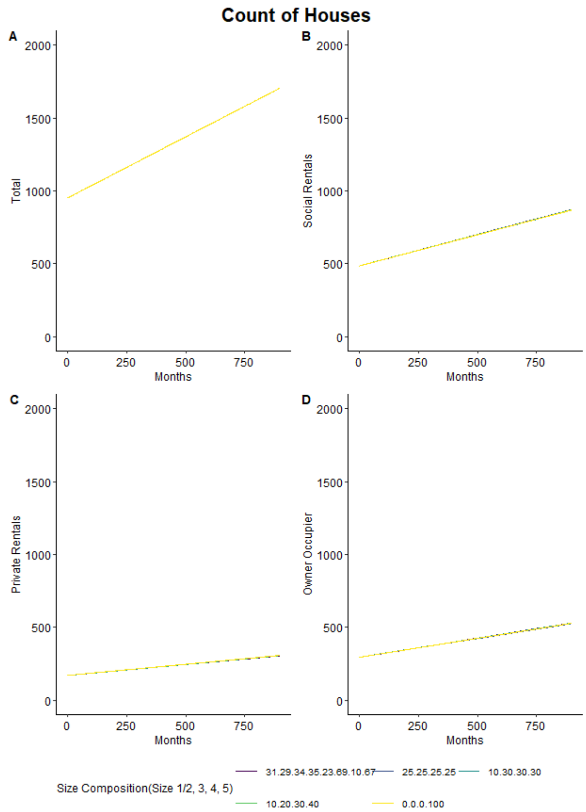


(d) Waiting times for households that successfully rent a social house

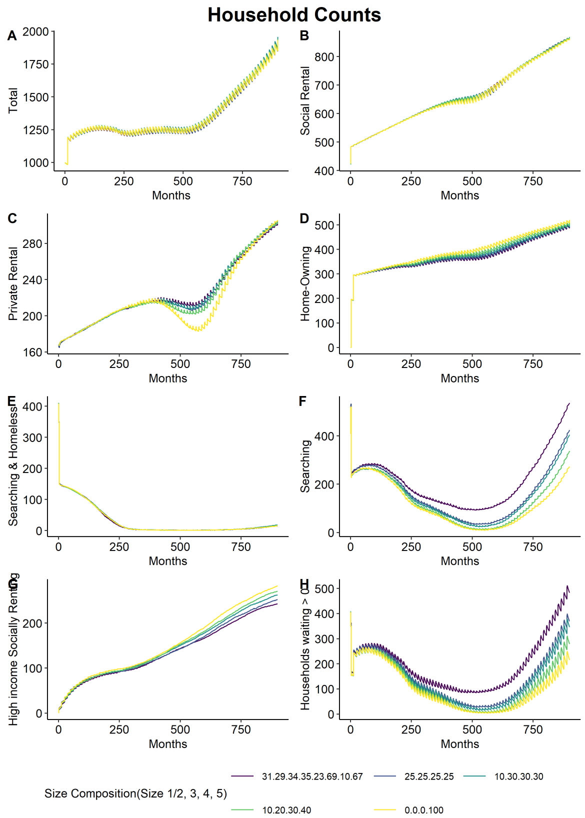
C.3.2. Varying Size Compositions



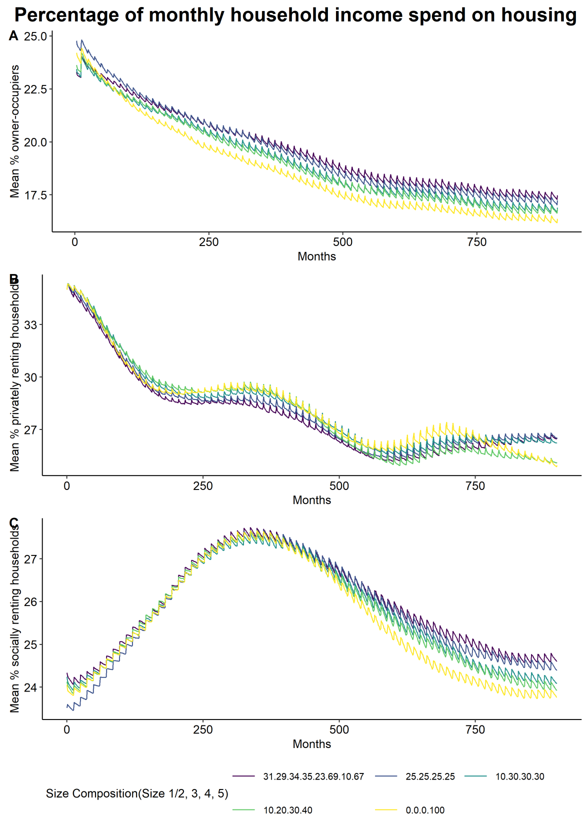
(a) Age of households in housing sectors



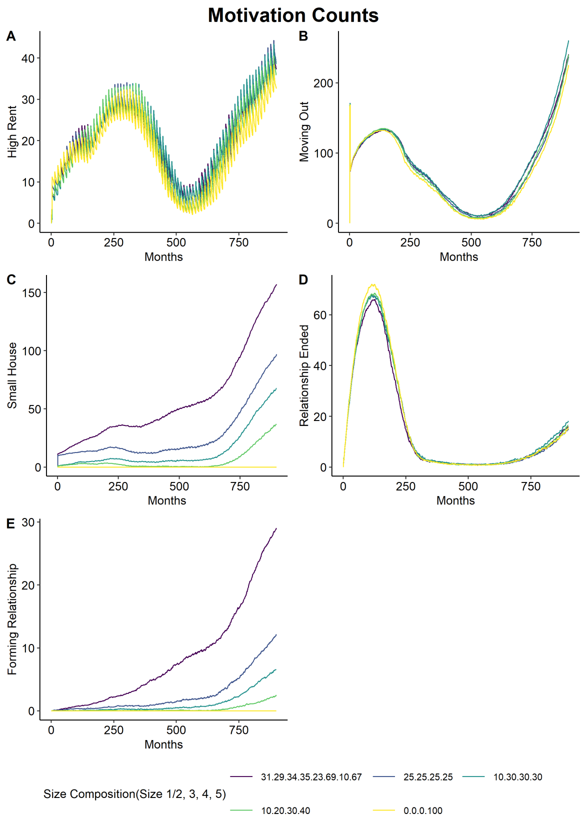
(b) Count of houses in housing sectors



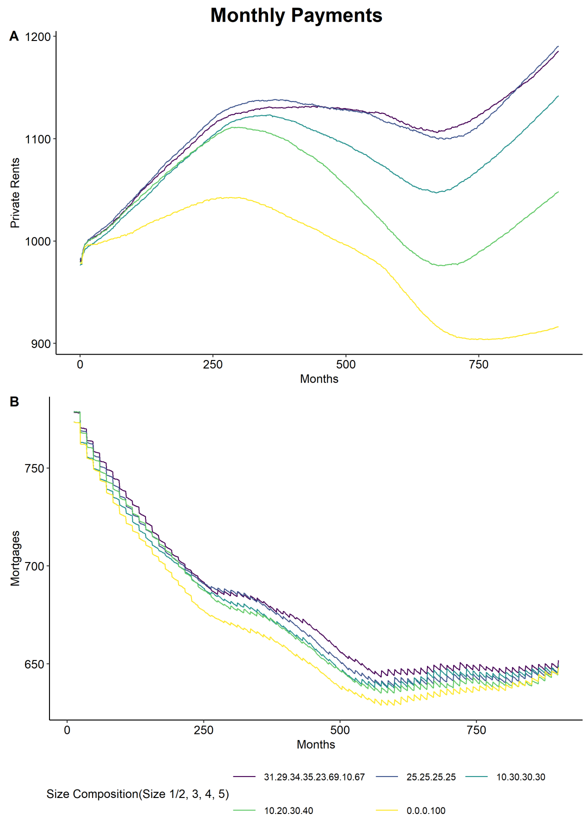
(c) Count of households



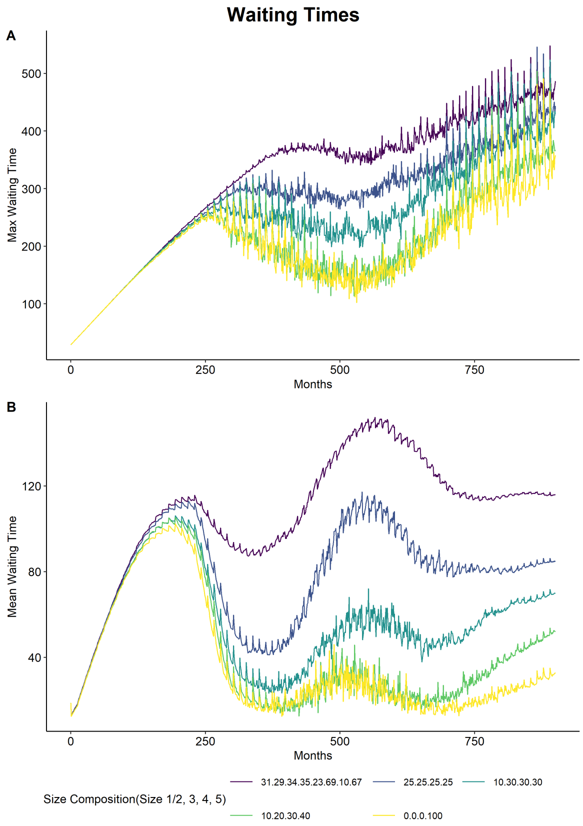
(d) Percentage of monthly household income spend on housing



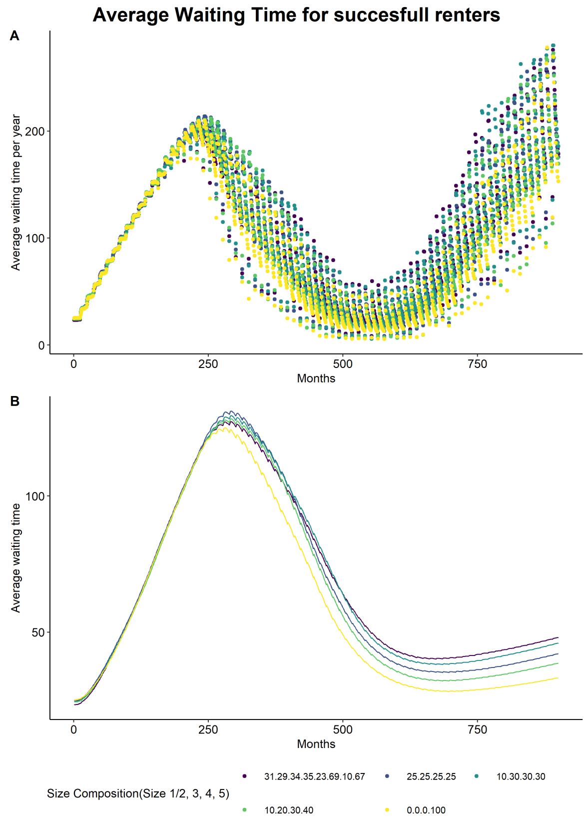
(a) Count of household motivations to move



(b) Monthly payments for private rents and mortgages

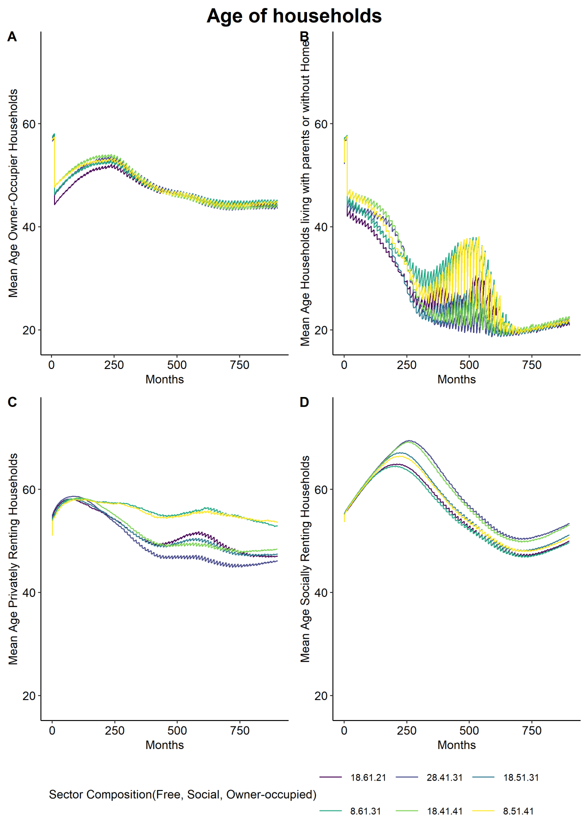


(c) Waiting times of households

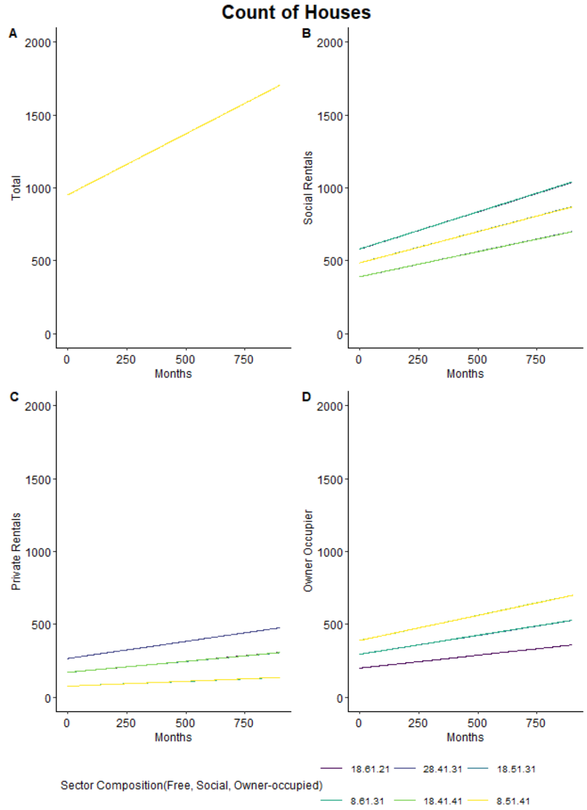


(d) Waiting times for households that successfully rent a social house

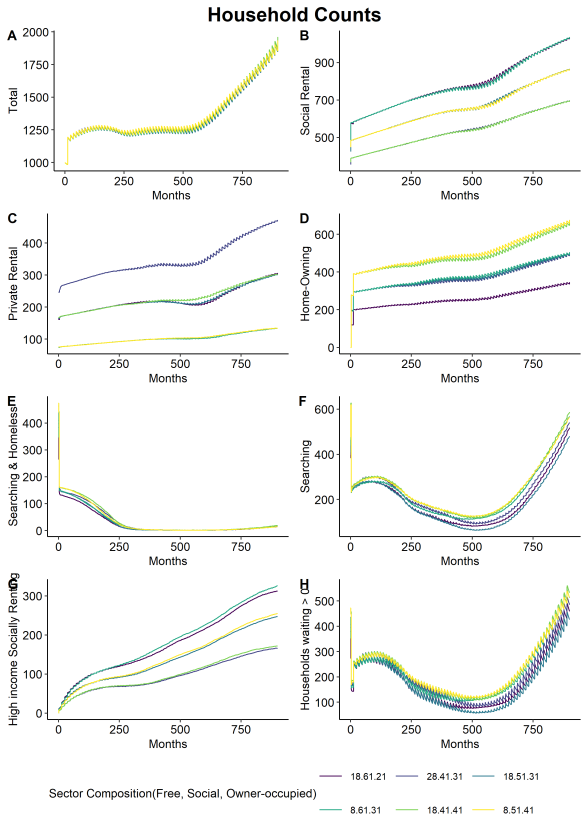
C.3.3. Varying Market Compositions



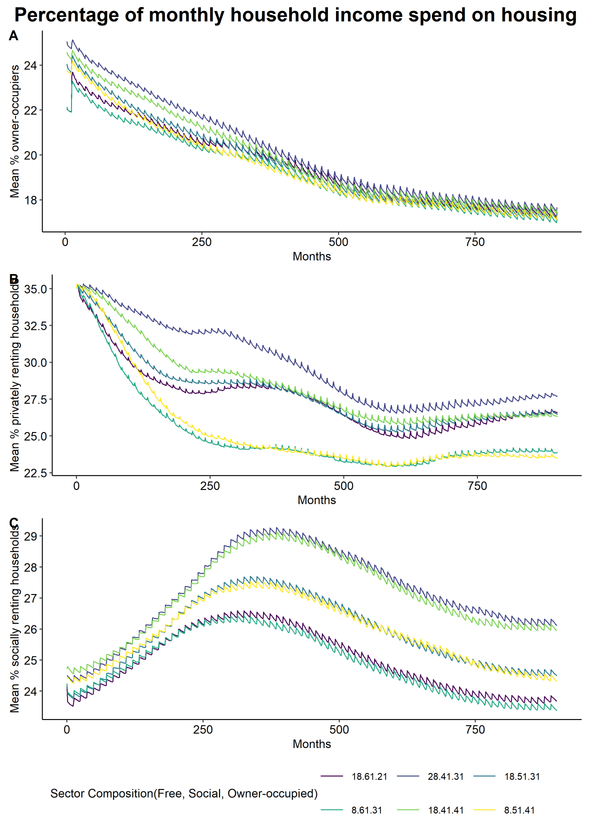
(a) Age of households in housing sectors



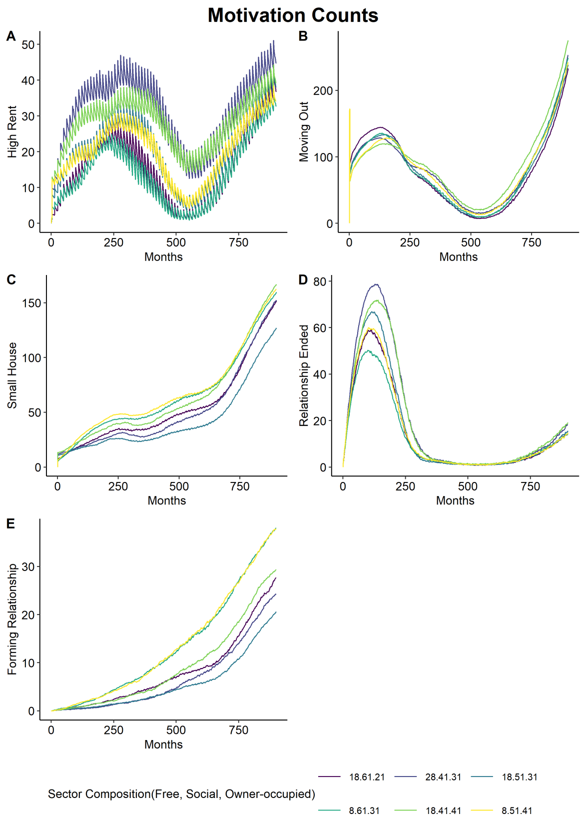
(b) Count of houses in housing sectors



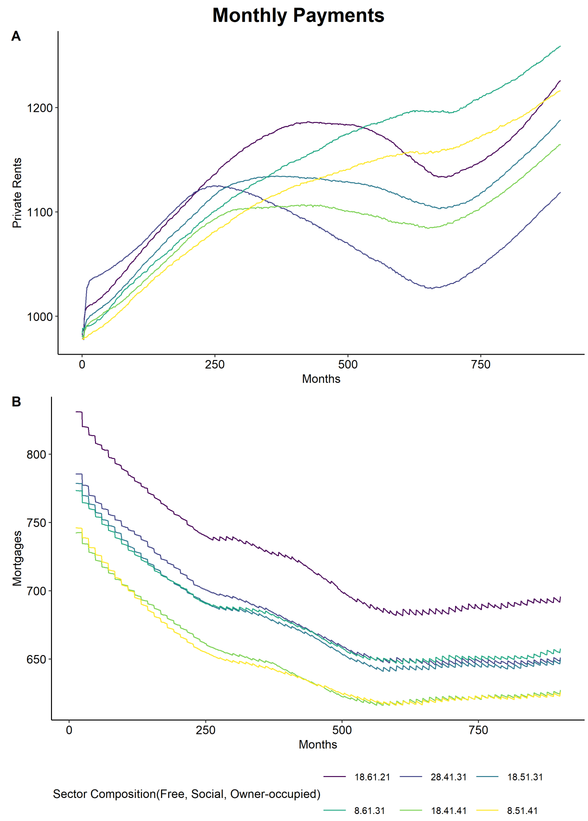
(c) Count of households



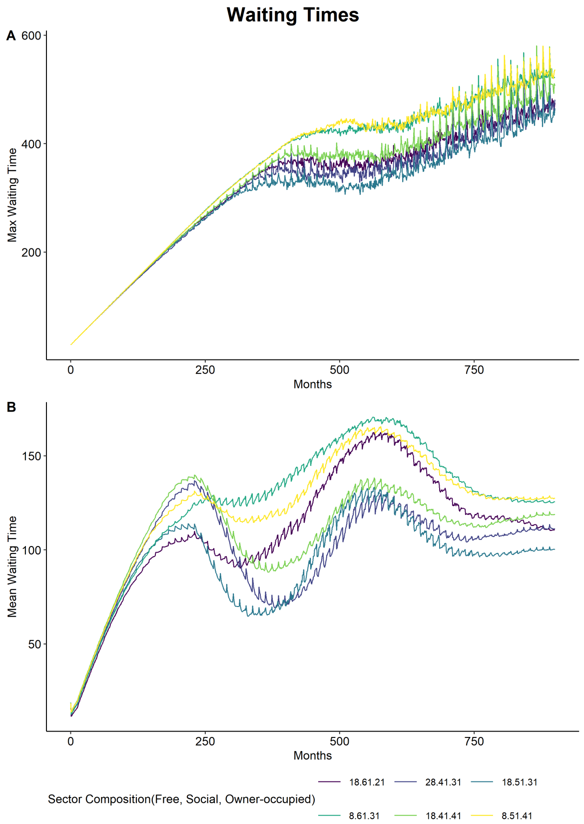
(d) Percentage of monthly household income spend on housing



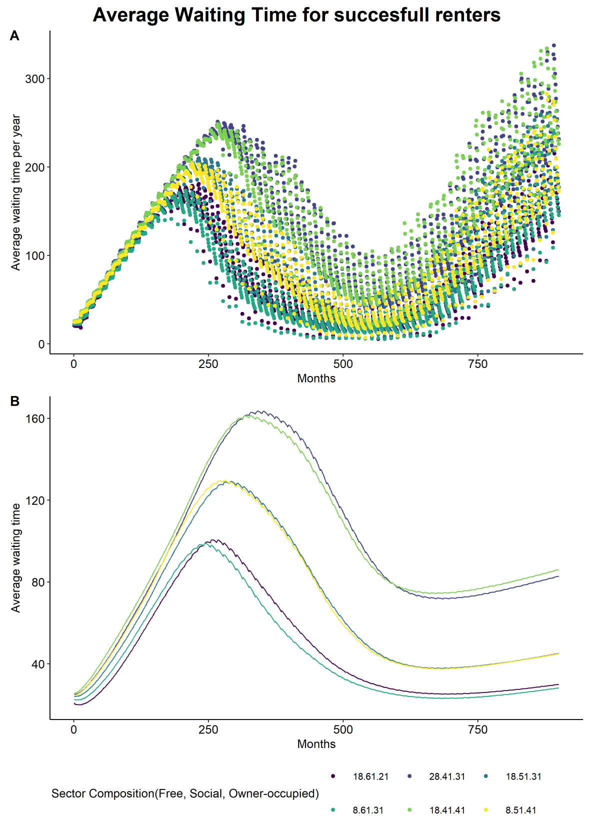
(a) Count of household motivations to move



(b) Monthly payments for private rents and mortgages



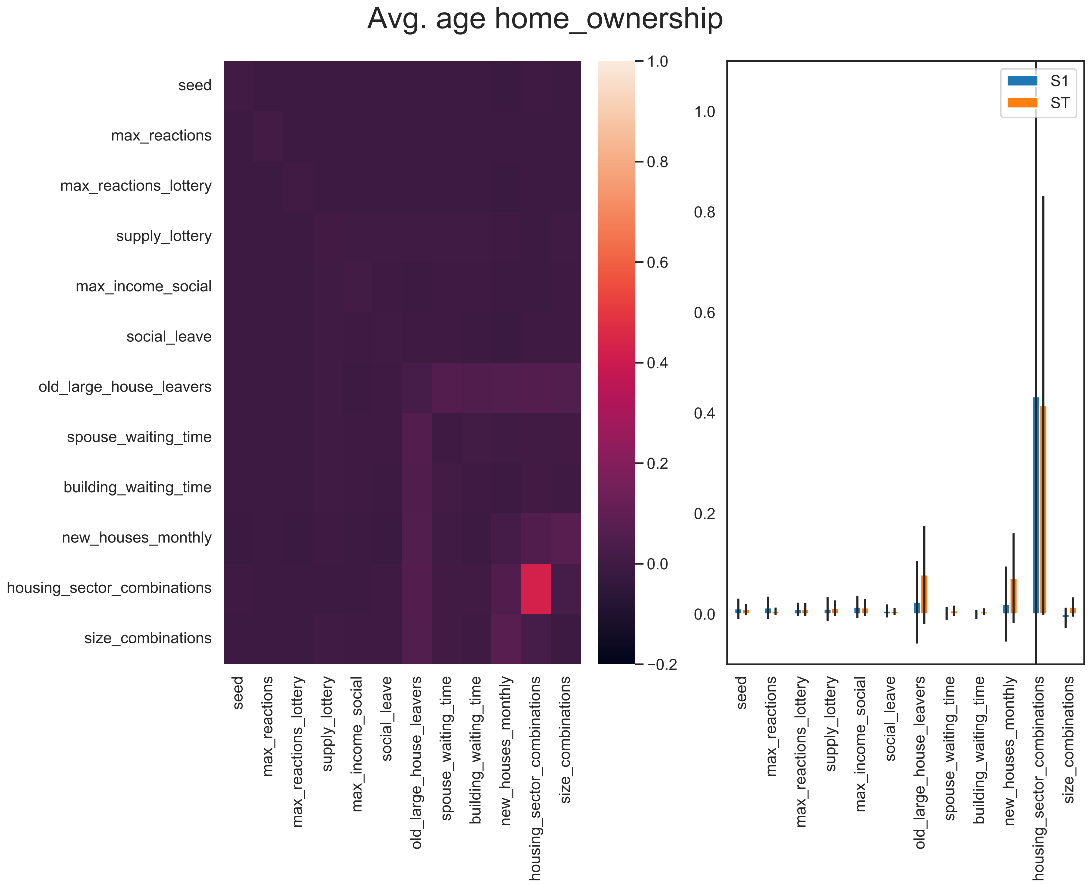
(c) Waiting times of households

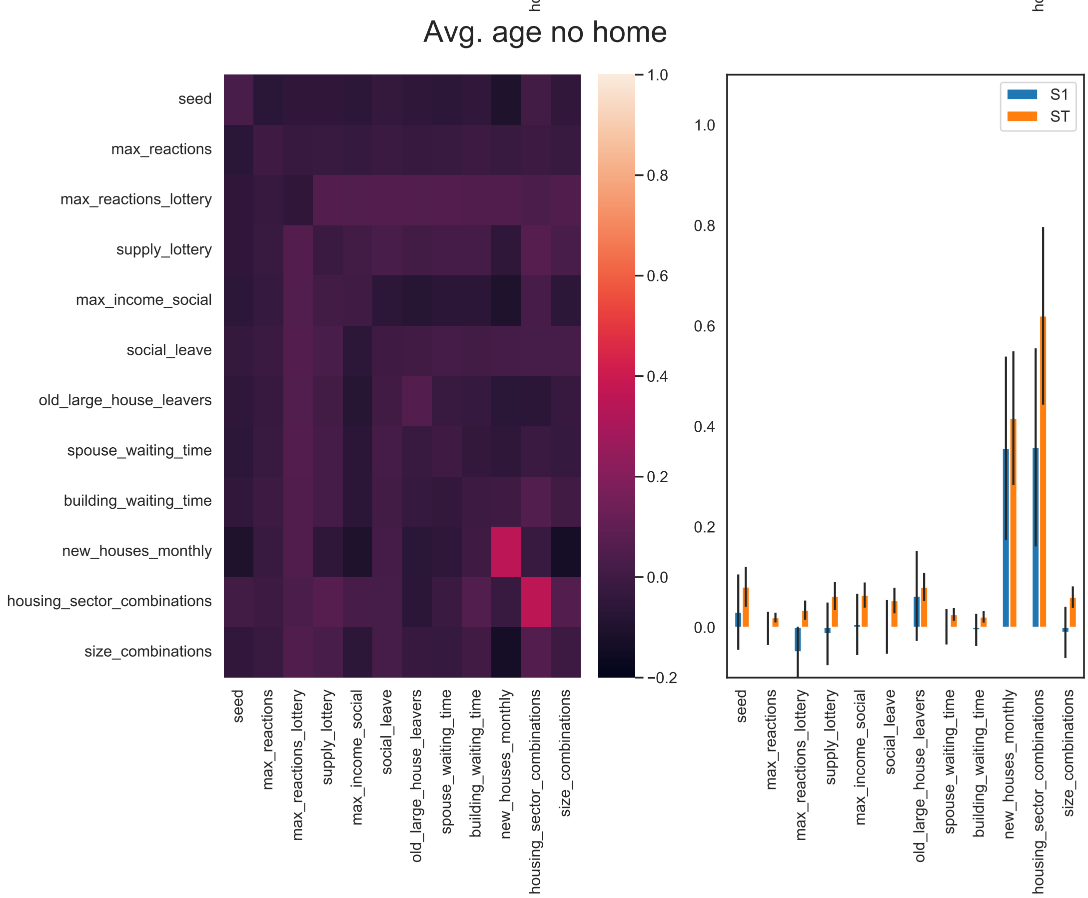


(d) Waiting times for households that successfully rent a social house

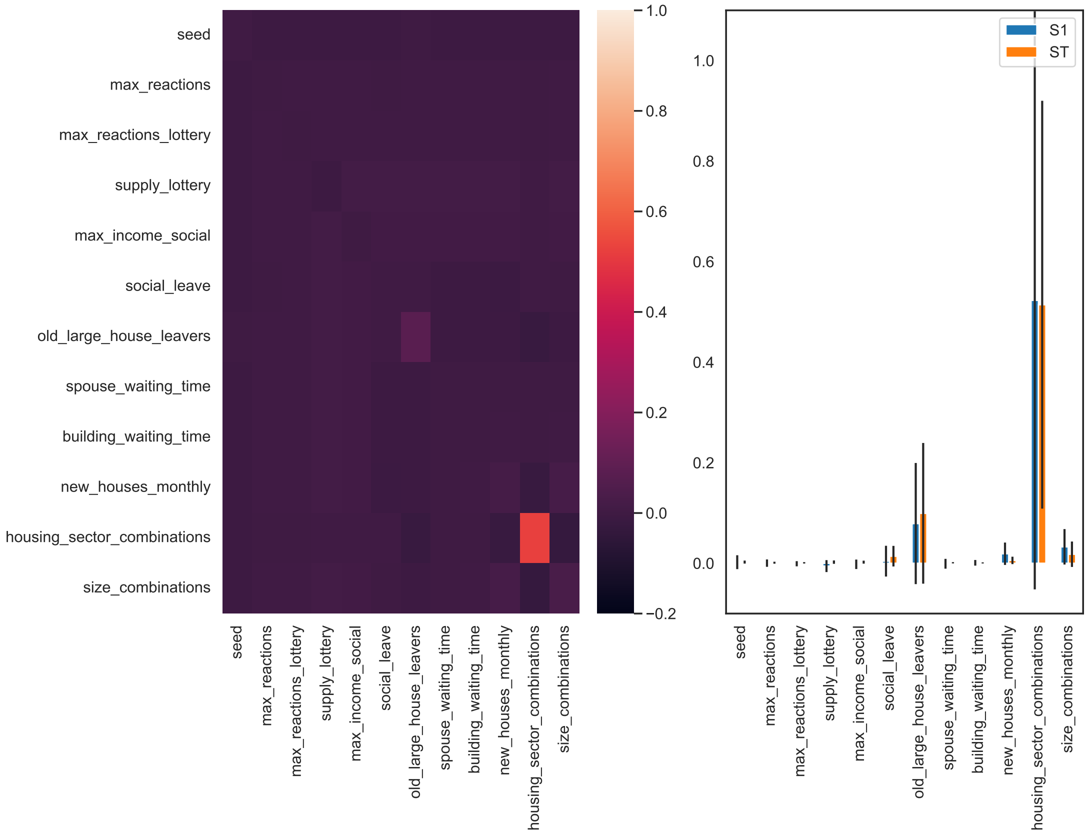
D

Sensitivity Analysis Results

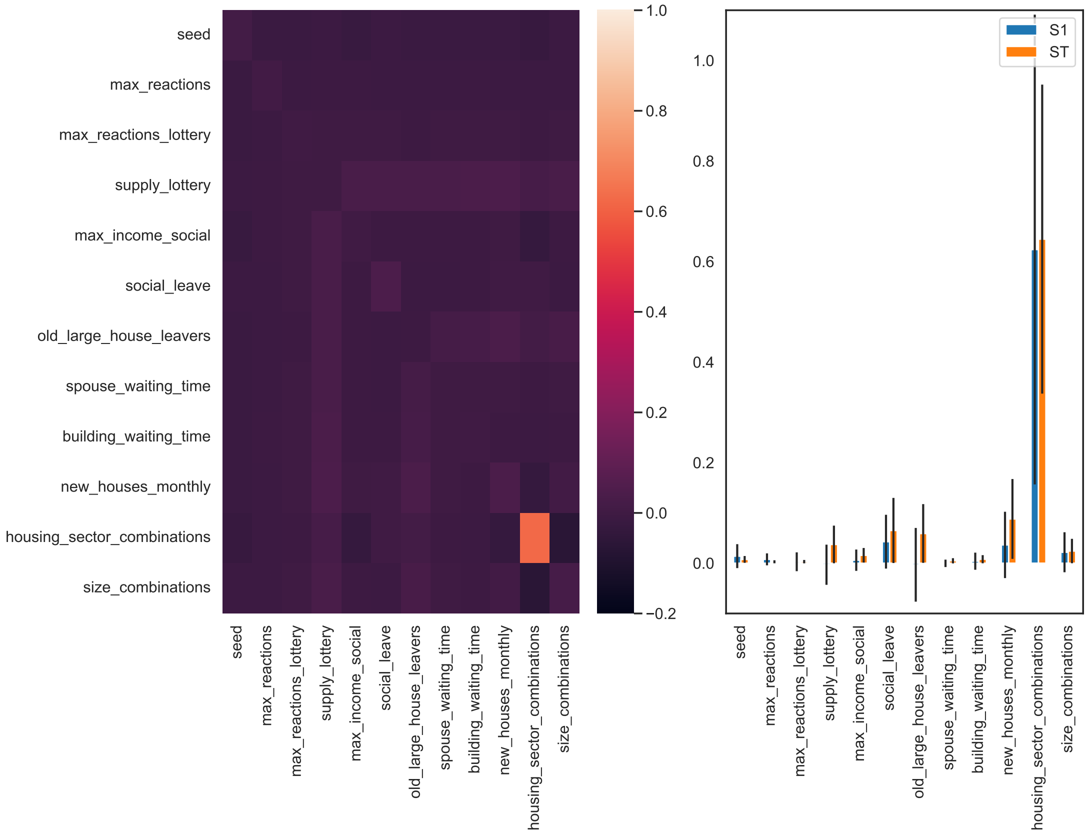

Avg. age home_ownership
seed
max_reactions
max_reactions_lottery
supply_lottery
max_income_social
social_leave
old_large_house_leavers
spouse_waiting_time
building_waiting_time
new_houses_monthly
housing_sector_combinations
size_combinations
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
S1
ST


Avg. age no home
seed
max_reactions
max_reactions_lottery
supply_lottery
max_income_social
social_leave
old_large_house_leavers
spouse_waiting_time
building_waiting_time
new_houses_monthly
housing_sector_combinations
size_combinations
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
S1
ST

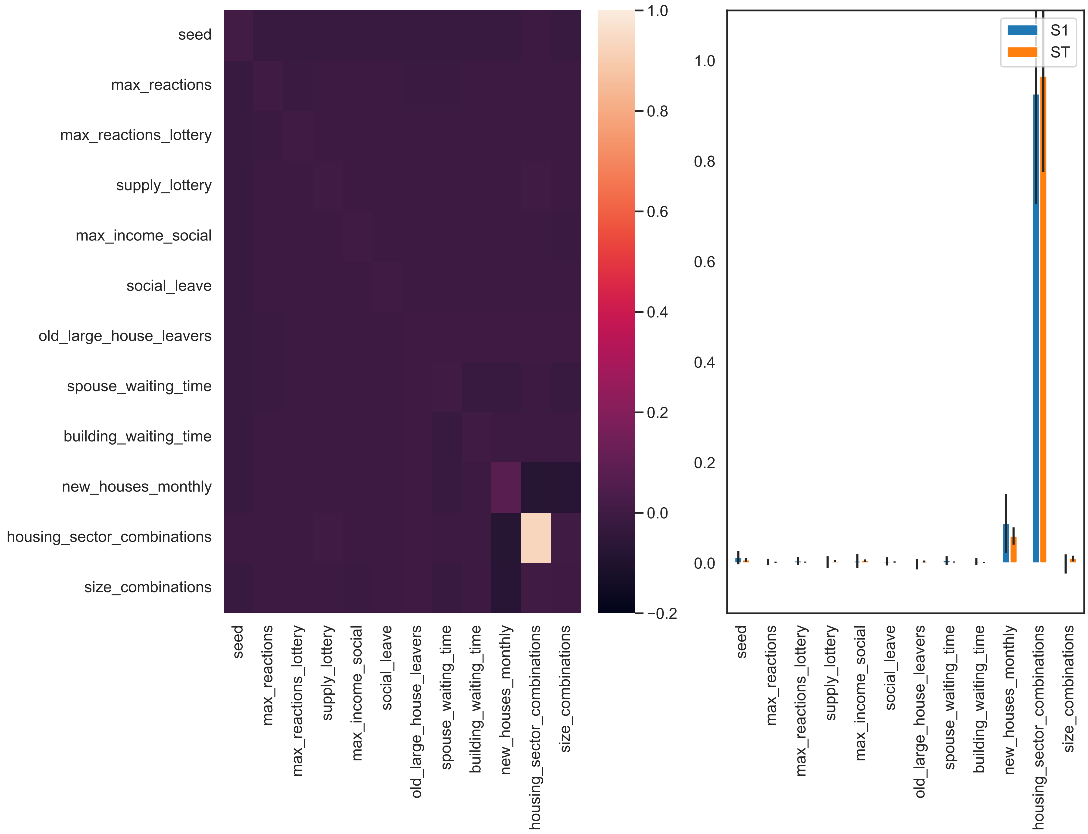
Avg. age private



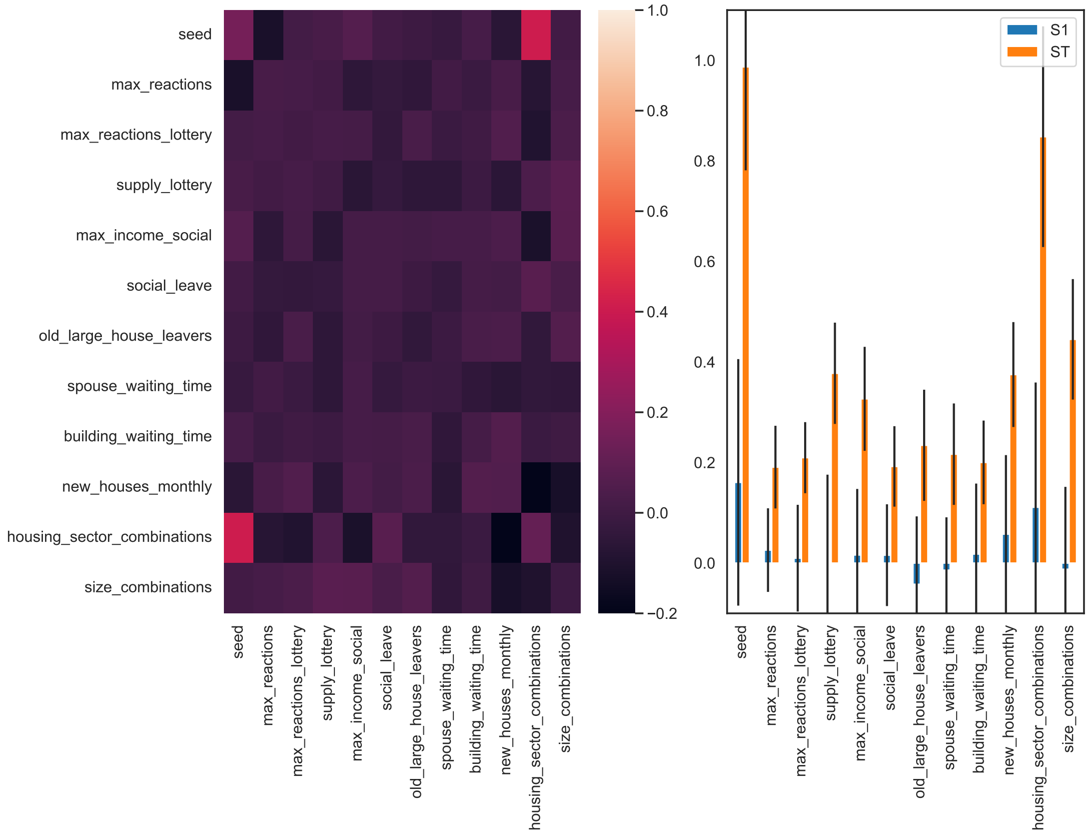
Avg. age social



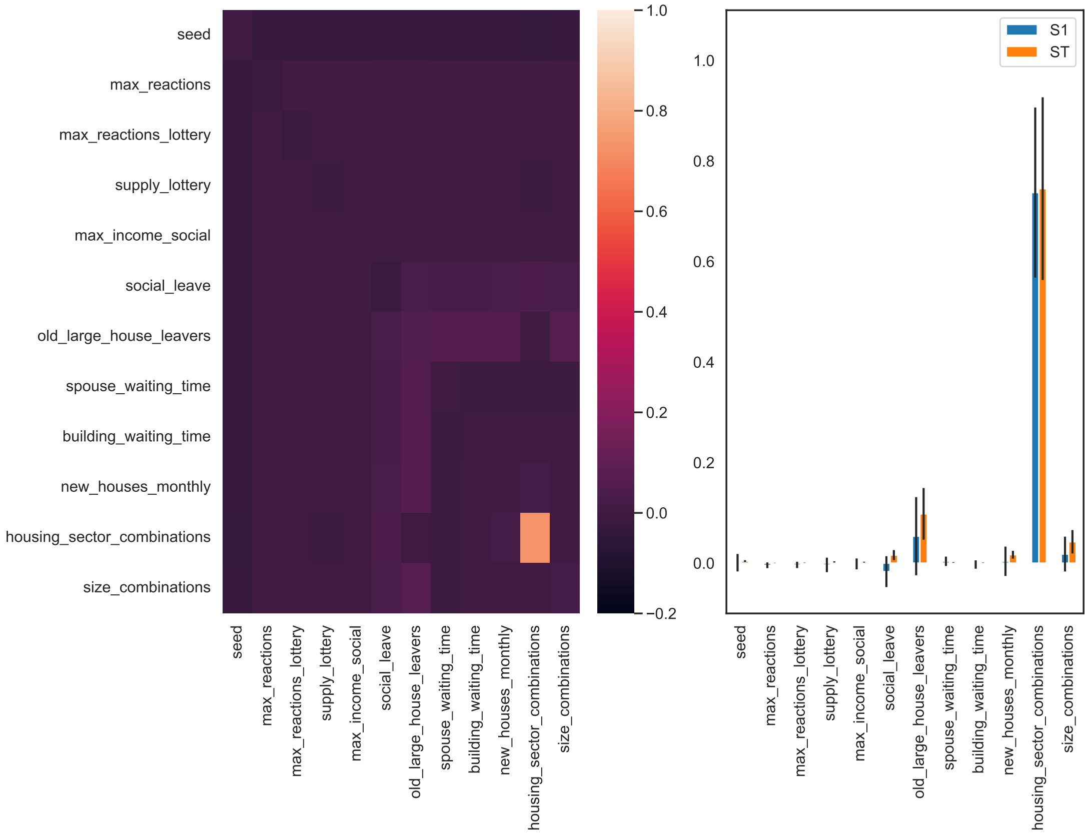
Avg. Amount of home ownership households



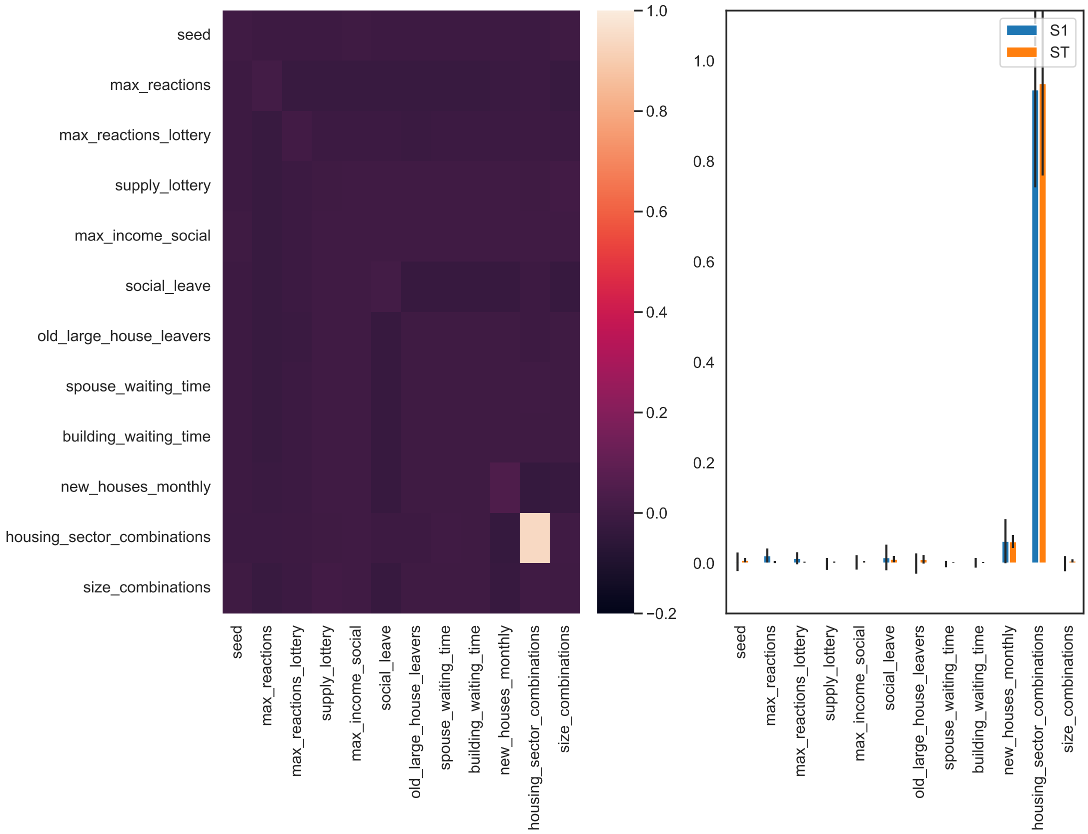
Avg. Amount of households



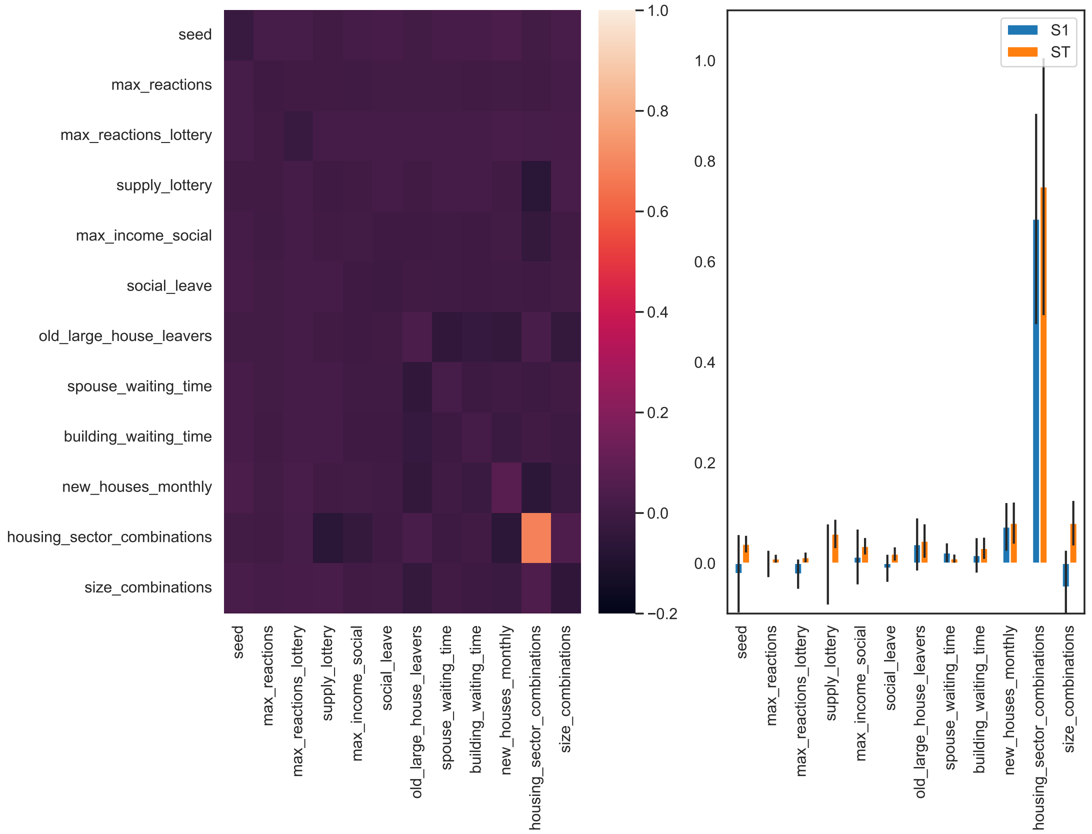
Avg. Amount of private rental households



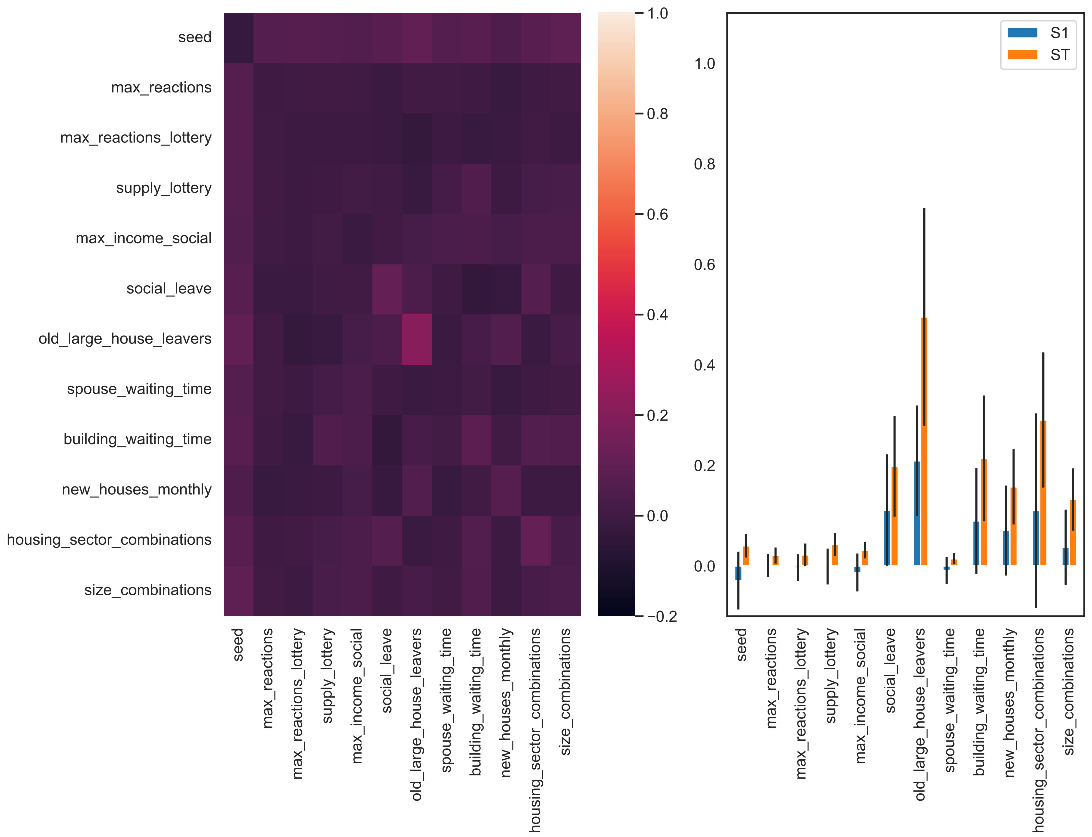
Avg. Amount of social rental households



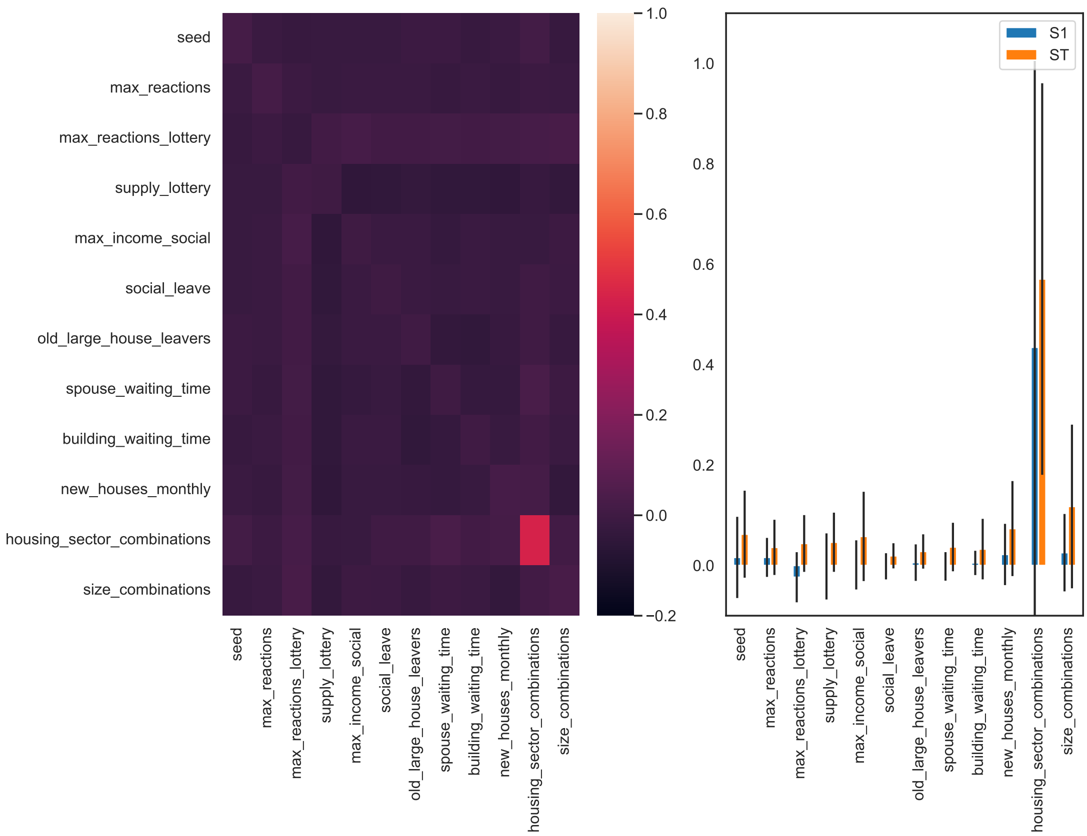
Avg. High rent count



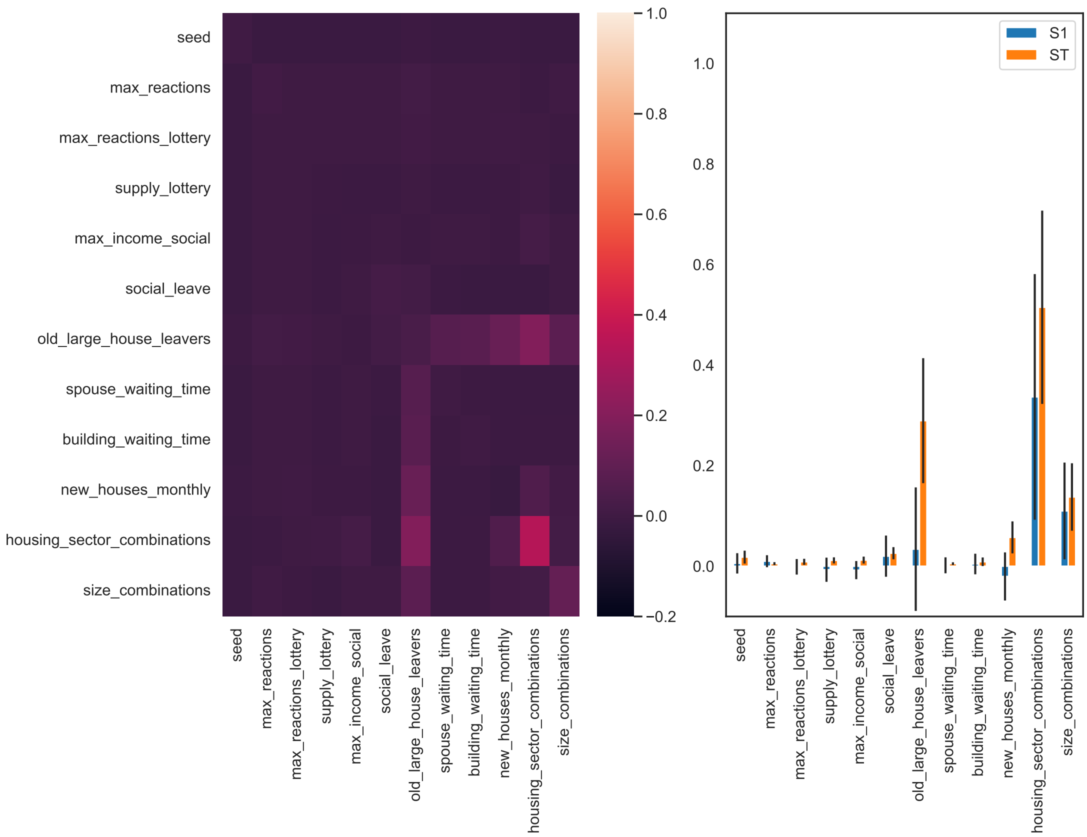
Avg. Highest waiting time



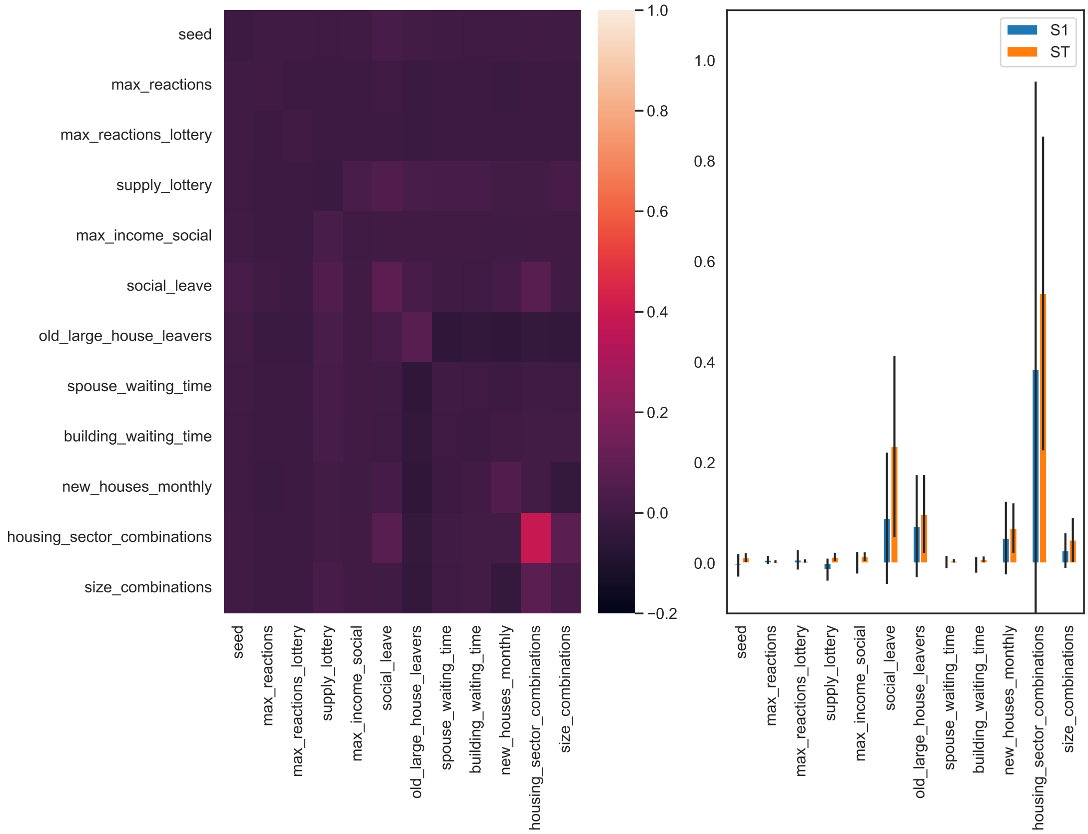
Avg. IncomePer Home Ownership



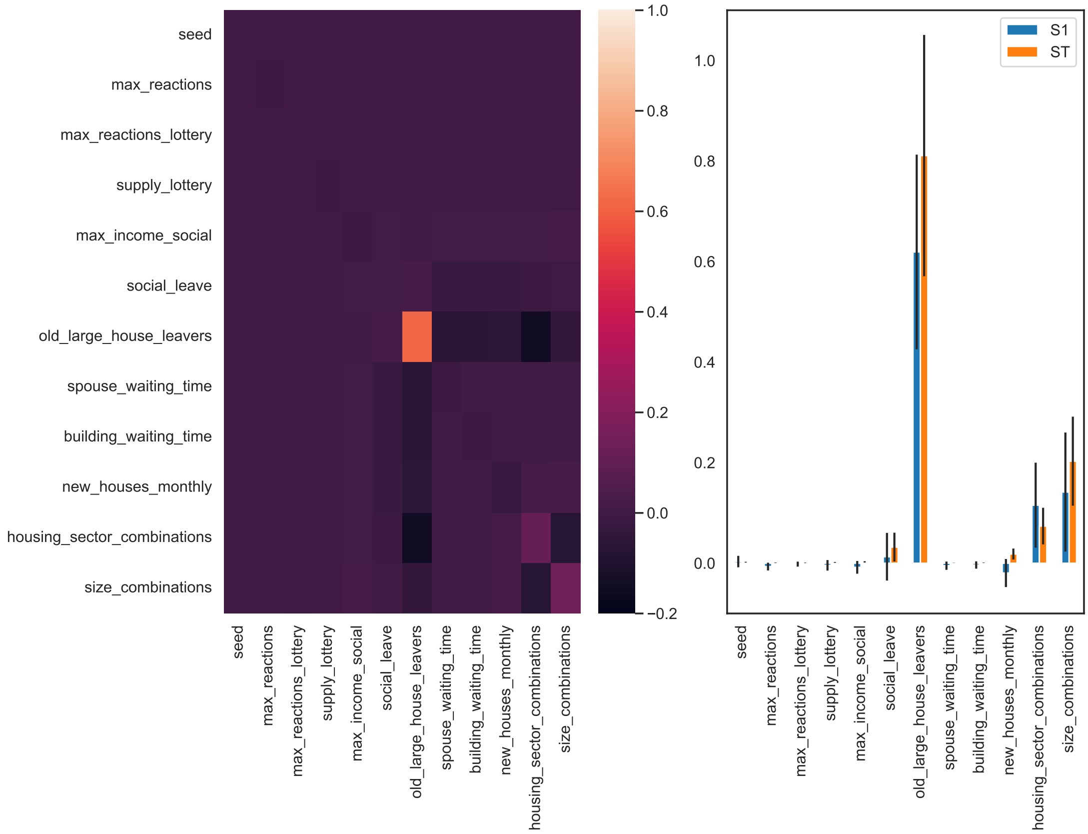
Avg. IncomePer Private rent



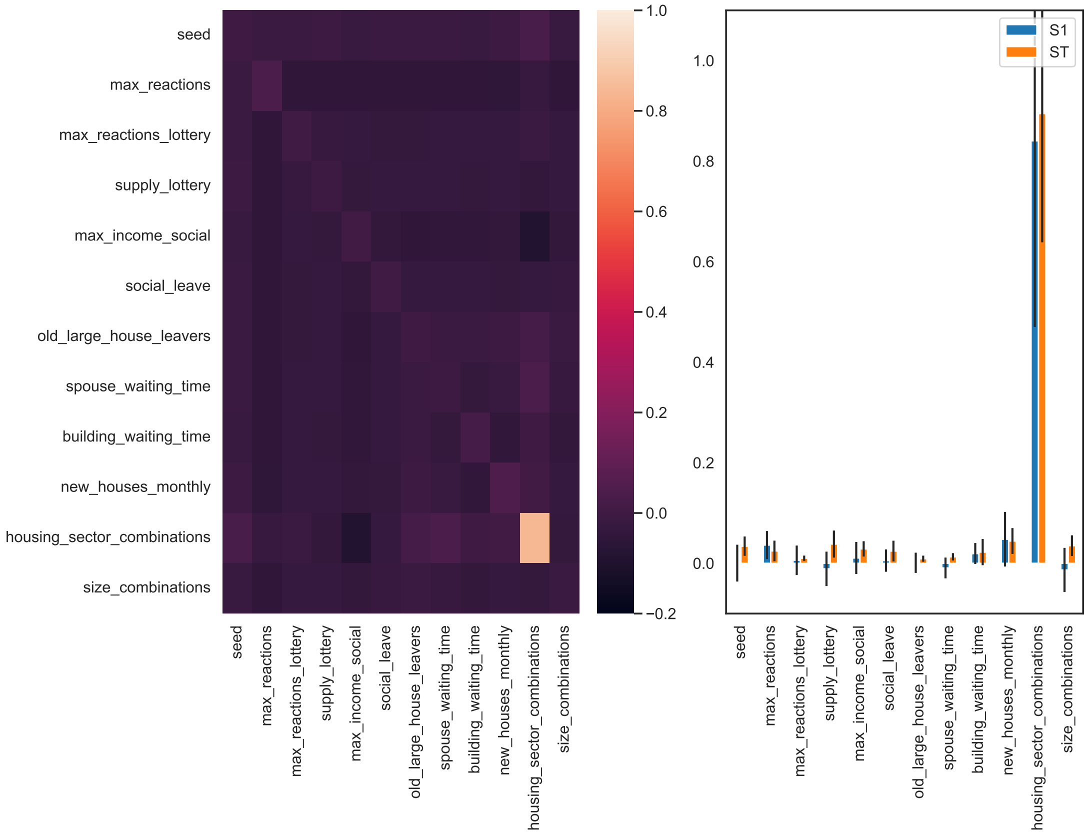
Avg. IncomePer Social rent



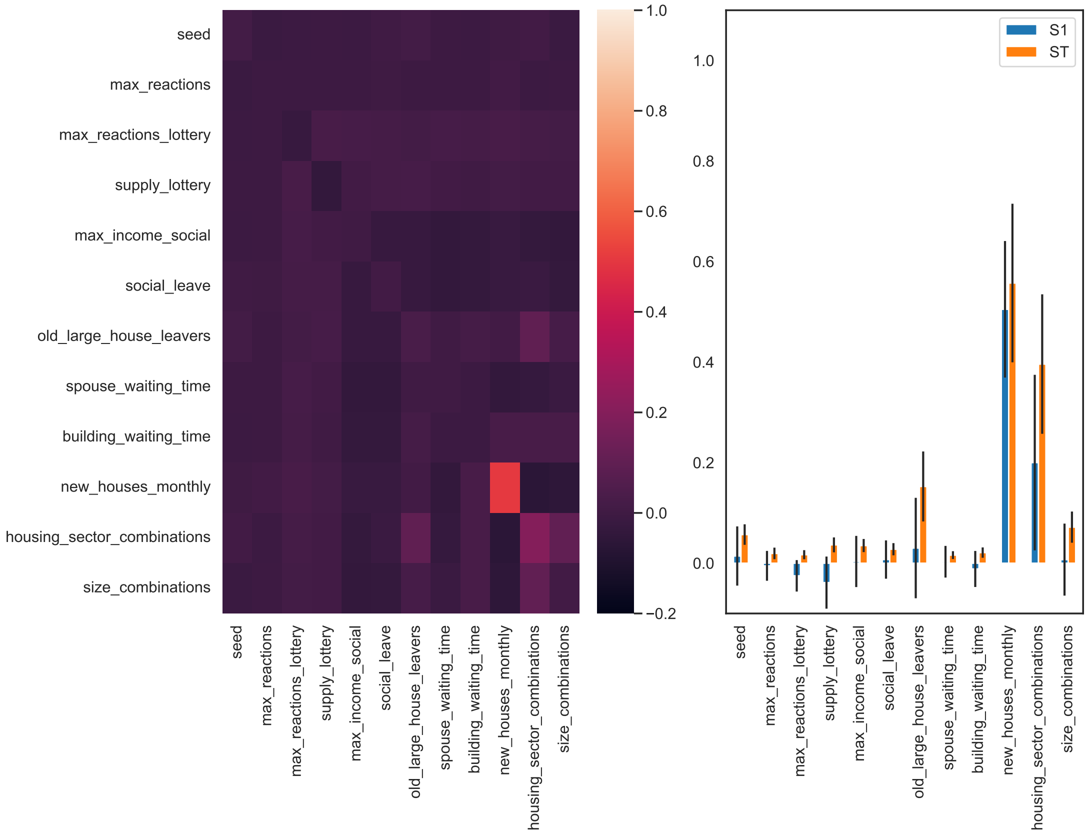
Avg. Large house and old count



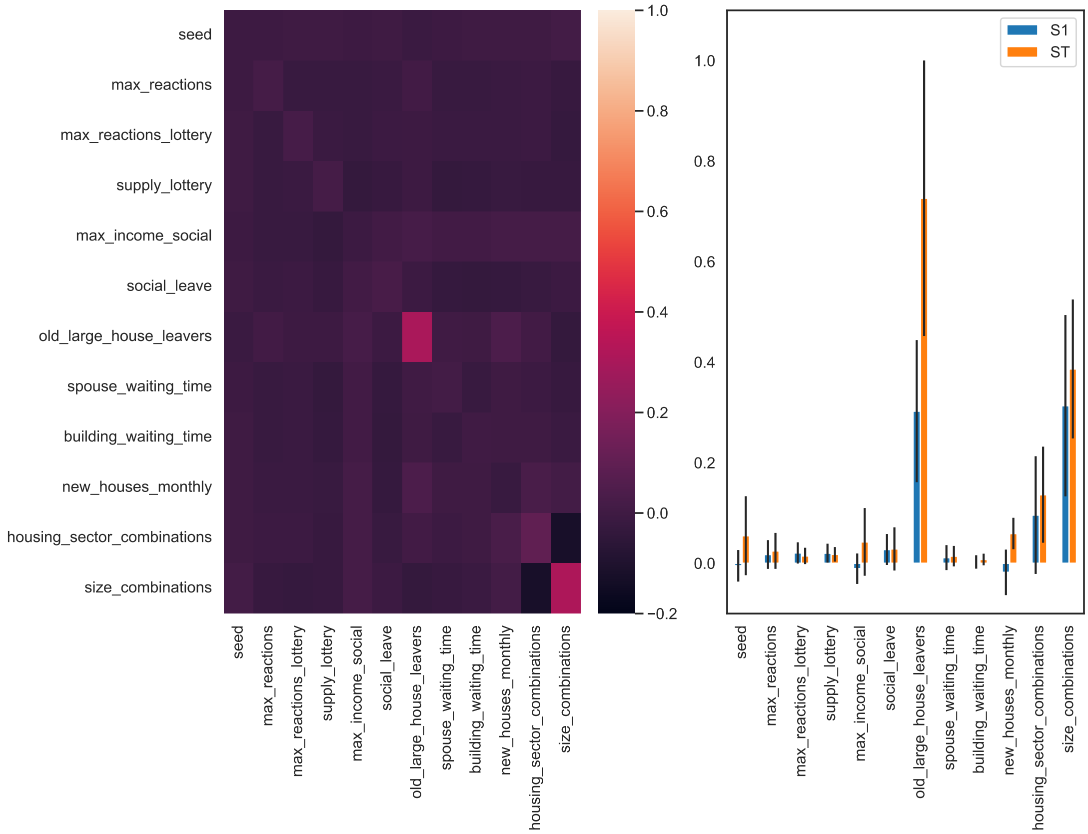
Avg. Mortgage



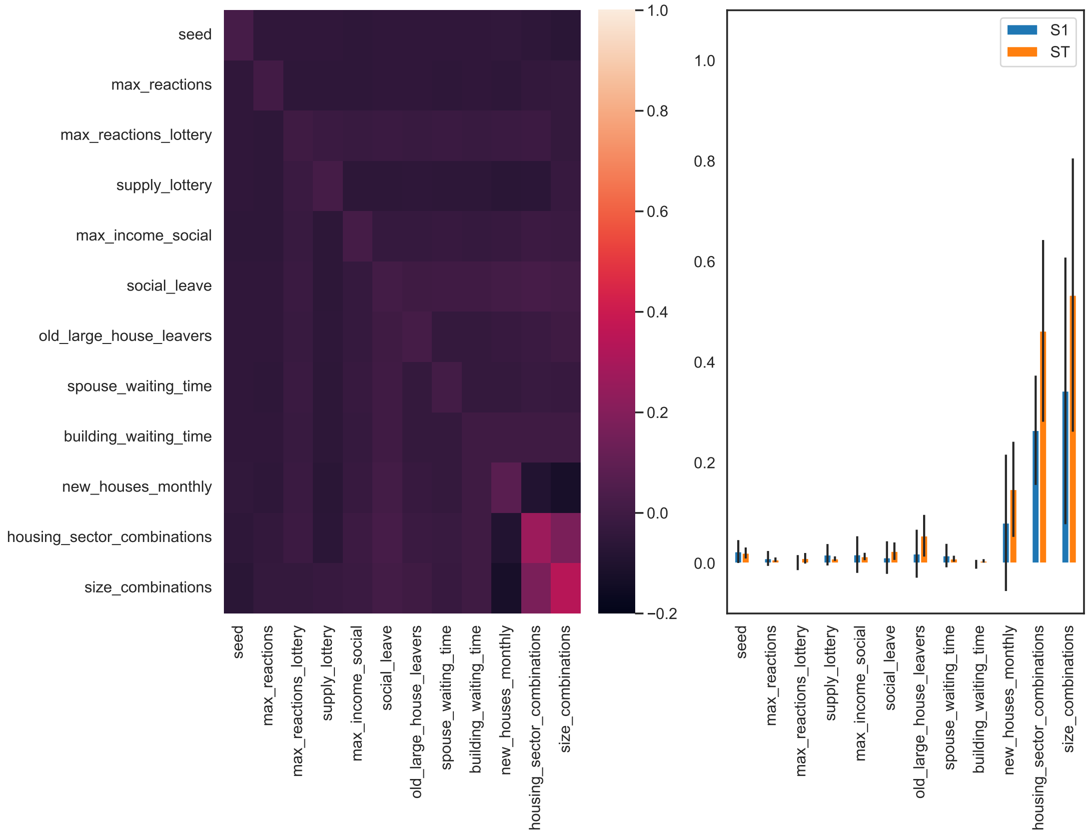
Avg. Moving out count

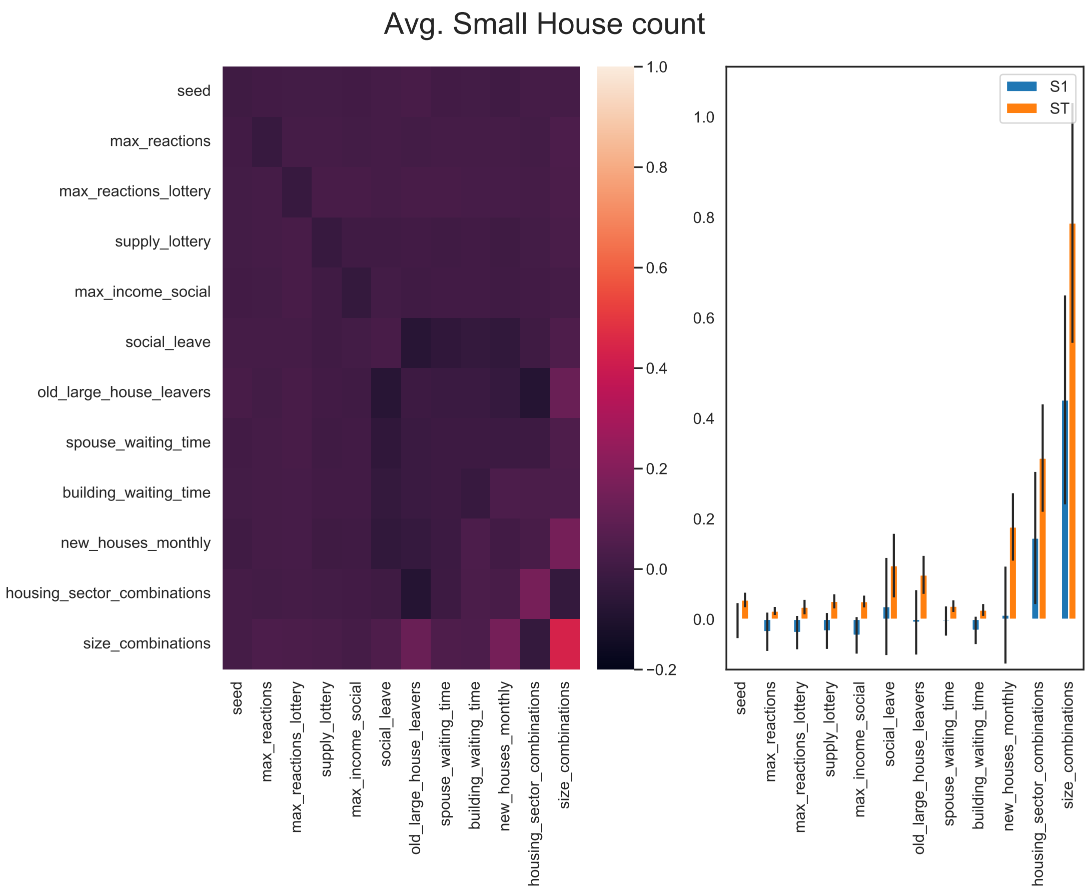


Avg. private rent

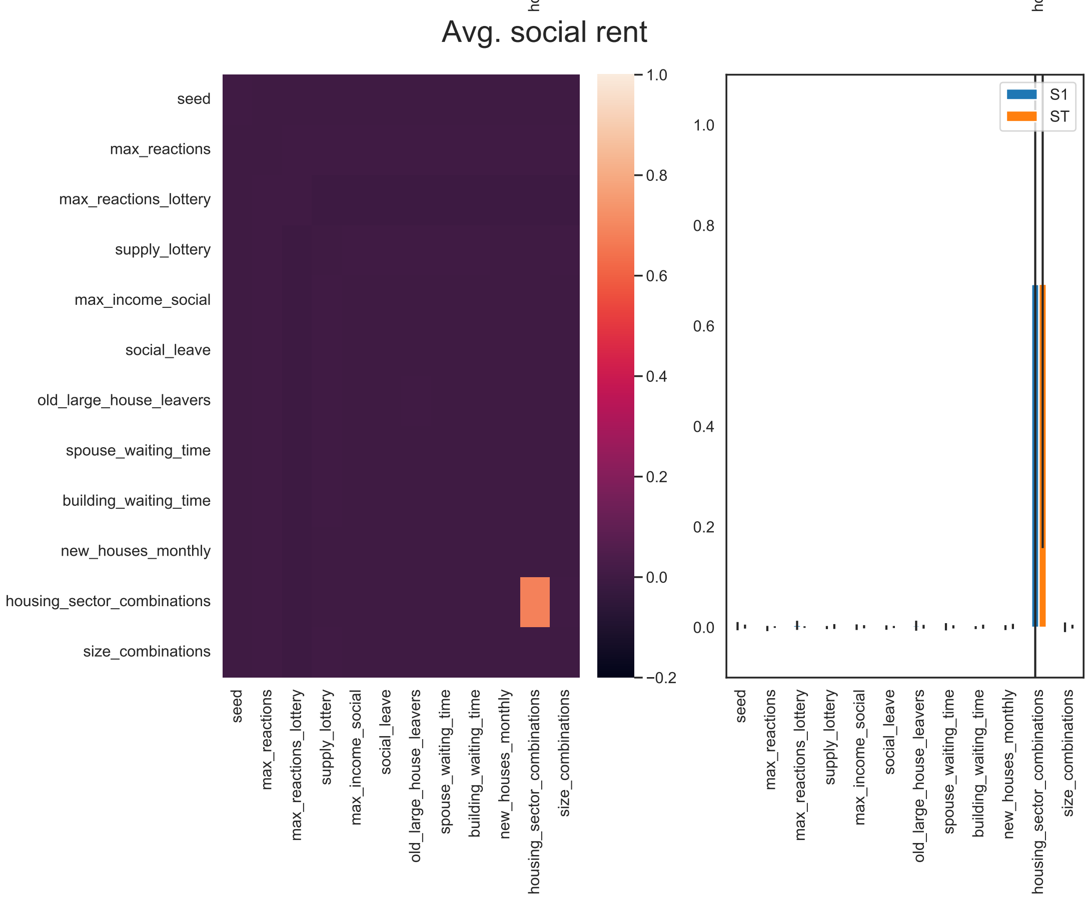


Avg. Relationship count



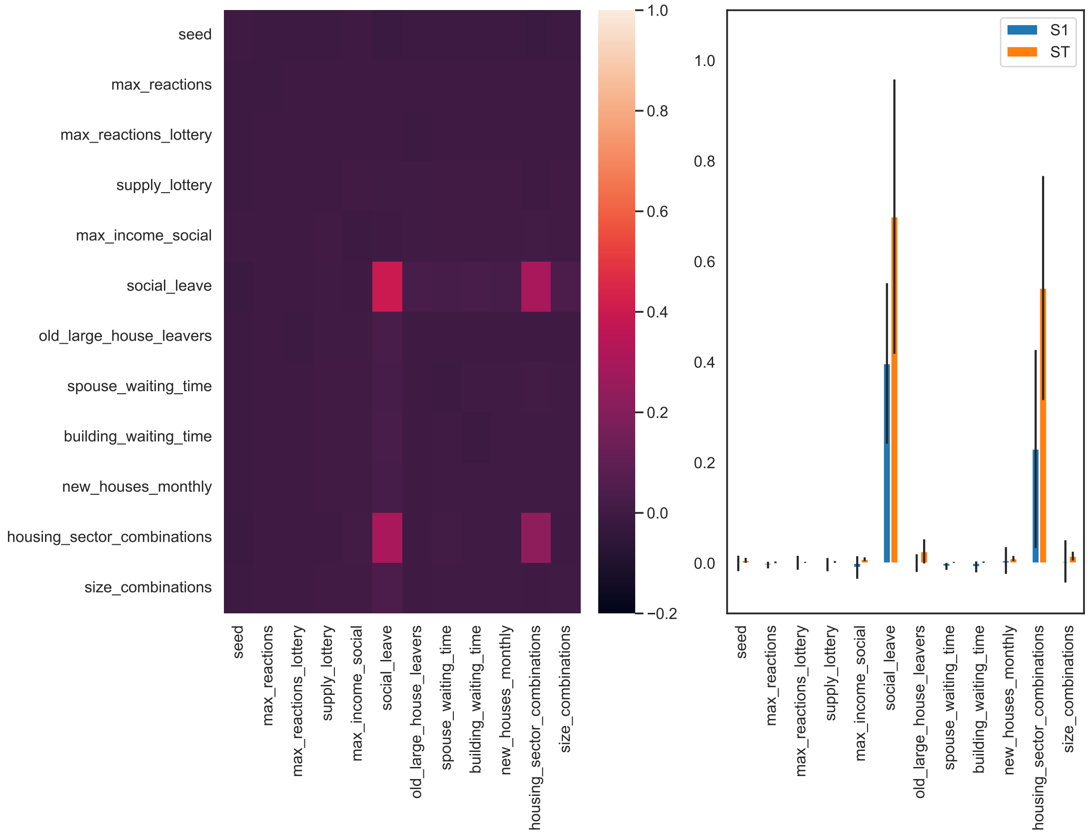


Avg. Small House count
seed
max_reactions
max_reactions_lottery
supply_lottery
max_income_social
social_leave
old_large_house_leavers
spouse_waiting_time
building_waiting_time
new_houses_monthly
housing_sector_combinations
size_combinations
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
S1
ST

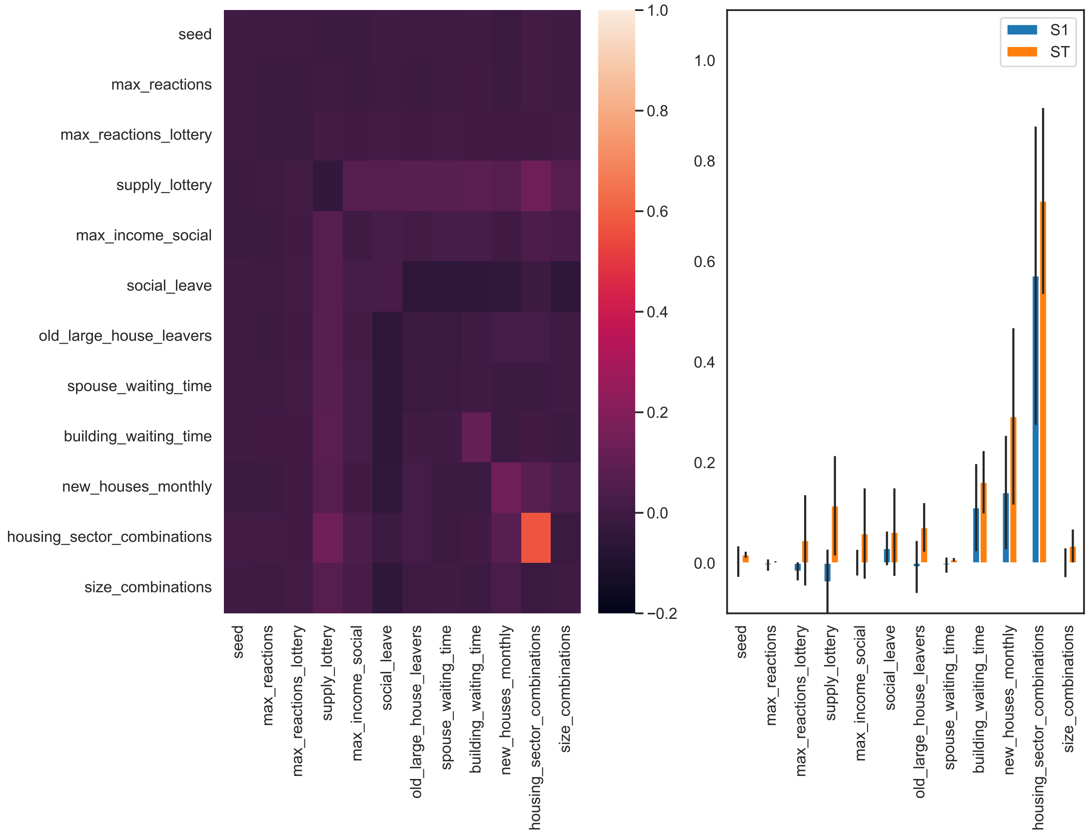


Avg. social rent
seed
max_reactions
max_reactions_lottery
supply_lottery
max_income_social
social_leave
old_large_house_leavers
spouse_waiting_time
building_waiting_time
new_houses_monthly
housing_sector_combinations
size_combinations
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
S1
ST

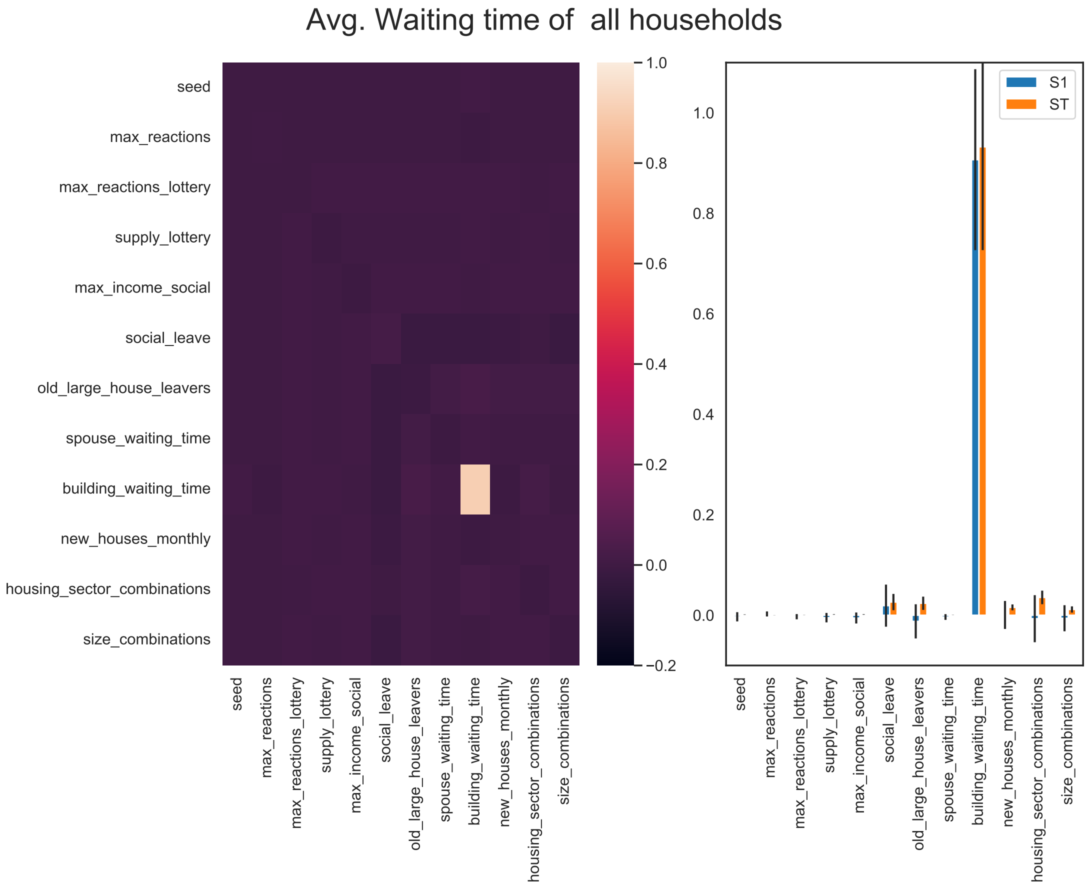
Avg. Social_Leave count

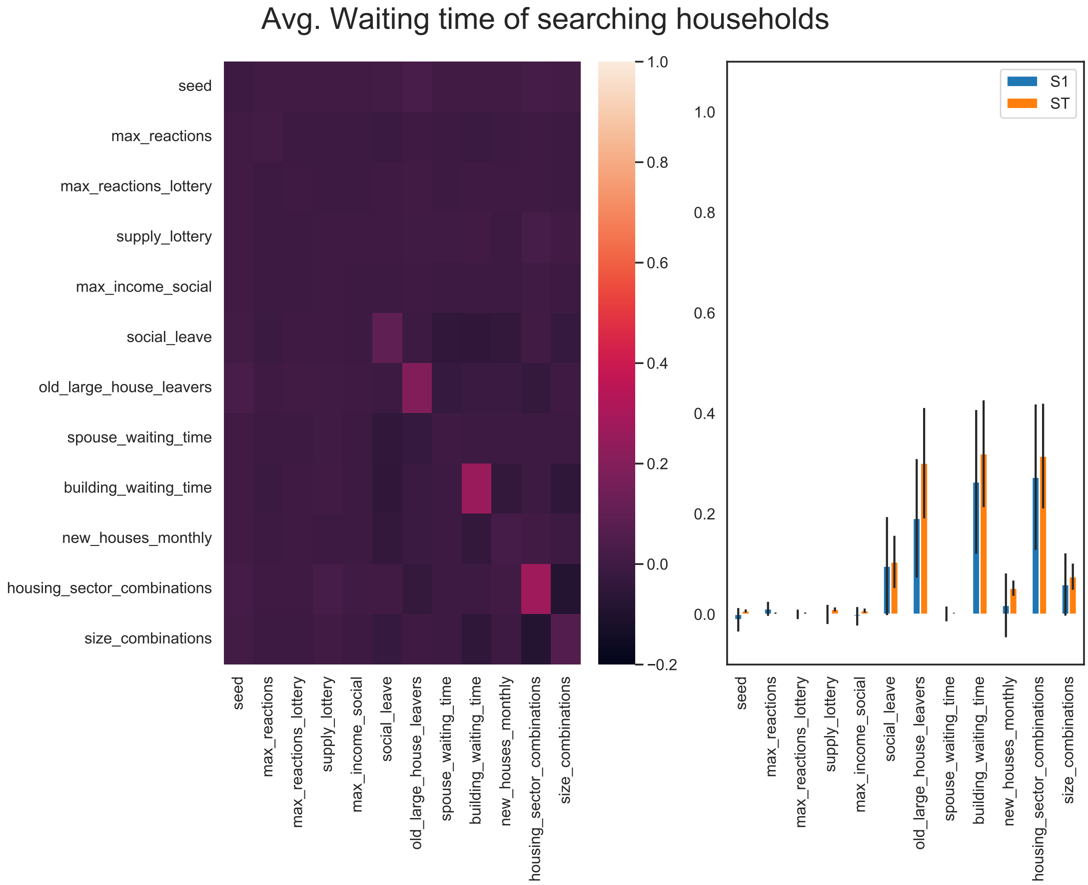


Avg. waiting time at transfer




Avg. Waiting time low-incomes
seed
max_reactions
max_reactions_lottery
supply_lottery
max_income_social
social_leave
old_large_house_leavers
spouse_waiting_time
building_waiting_time
new_houses_monthly
housing_sector_combinations
size_combinations
S1
ST


Avg. Waiting time of all households
seed
max_reactions
max_reactions_lottery
supply_lottery
max_income_social
social_leave
old_large_house_leavers
spouse_waiting_time
building_waiting_time
new_houses_monthly
housing_sector_combinations
size_combinations
S1
ST


Avg. Waiting time of searching households
seed
max_reactions
max_reactions_lottery
supply_lottery
max_income_social
social_leave
old_large_house_leavers
spouse_waiting_time
building_waiting_time
new_houses_monthly
housing_sector_combinations
size_combinations
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
S1
ST