



# Dissimilarity effects on house prices: what is the value of similar neighbours?

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## Abstract

Residential choice does not only depend on properties of the dwelling, neighbourhood amenities and affordability, but is also affected by the population composition within a neighbourhood. All these attributes are capitalised in the house price. Empirically, it is not easy to disentangle the effect of the neighbourhood on house prices from the effects of the dwelling attributes. We implement an agent-based model of an urban housing market that allows us to analyse the interaction between residential choice, population composition in a neighbourhood and house prices. Agents differ in terms of education, income and group affiliation (majority vs. minority). Whereas rich agents can afford to move to preferred places, roughly 13.01% of poor minorities and 8.02% of poor majority agents are locked in their current neighbourhood. We show that a preference to live among similar neighbours has a strong competitive effect on rich households and drives up their house prices. This is not the case with a preference for status. By introducing a policy that provides agents more access to credit, we find that all population groups denote higher satisfaction levels. Poor agents show the largest improvements. The general satisfaction level across all population groups increases. However, the extra credit accessibility also drives up house prices and leads to higher wealth inequality within the city. If agents have a preference for status rather than for similarity, the effect of the overall inequality is smaller, since agents become more satisfied living in areas with less similar agents.

**Keywords** Agent-based modelling · Residential choice · Housing demand · Neighbourhood characteristics · House prices

**JEL Classification** C63 · R21 · R23 · R32

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## 1 Introduction

Households seem to have a preference for being among neighbours similar to them. Such a preference was already postulated by Schelling (1971, 1978) and more recently shown empirically (e.g. Clark 1992; Luttmer 2005). Of course, the composition of the population in the neighbourhood is not the only factor that determines residential choice. Where households buy a home also depends on the properties of the house itself, amenities and disamenities in the neighbourhood and last but not least on affordability (Sirmans et al. 2006, Baker et al. 2015). House prices are not independent of the other factors. In fact, in a competitive market equilibrium, house prices capitalise the attributes of the house and the neighbourhood (see Rosen 1974). A large literature on hedonic pricing in the housing market estimates how the value of homes depends on these attributes (see Sirmans et al. 2005). Empirically, it is not easy to disentangle the effect of the neighbourhood on house prices from the effects of the dwellings attributes. It is particularly difficult to control for endogeneity effects that arise because the composition of the population in the neighbourhood is endogenous and depends on amenities and prices. Ioannides (2011) provides an overview how the literature attempts to identify and estimate these social interaction effects.

In this paper, we present an agent-based model of an urban housing market that allows us to analyse the interaction between residential choice, the composition of the population in a neighbourhood and house prices. In particular, we ask the following research questions: (1) How do house prices that different population groups have to pay depend on neighbourhood preferences? (2) What are the effects of policy measures aimed at making housing affordable to less well-off households?

Understanding how house prices depend on preferences for similar neighbours is important for hedonic estimations of house prices and their interpretations. The correct specification of empirical models that deal with the above-mentioned endogeneity problem depends on the assumptions about preferences and behaviour of the agents, which are difficult to observe. With our model, we can analyse how sensitively house prices respond to variations in unobservable preference parameters. We consider several dimensions of similarity, namely income, education and ethnicity, which are often treated either separately or implicitly in empirical studies (e.g. Green and Lee 2016; Leung and Tsang 2012). We also distinguish a *preference for similarity* from a *preference for status*. Preference for similarity means that households dislike living among different neighbours, no matter whether they are privileged or underprivileged relative to their neighbours. Preference for status, in contrast, means that households dislike being underprivileged in terms of income or education, but gain satisfaction from having higher income or better education than their neighbours. The resulting moving decisions and house price dynamics might be quite different in the two cases. Relatively rich or educated households have an incentive to leave deprived neighbourhoods if they have a preference for similarity, but with a preference for status they have an incentive to stay there.

The effect of diversity and inequality on house prices is of particular relevance for policy makers. In many countries, the ethnic and cultural diversity of the population increases due to international migration (Bove and Elia 2017). At the same time, globalisation and technological change have increased and might further increase income

inequality (Jaumotte et al. 2013). If households prefer similar neighbours, increased ethnic diversity and income inequality might exacerbate house price differentials leading to even stronger disparity in material living conditions. A related topic is policies to change the social mix of urban neighbourhoods (Graham et al. 2009). According to Galster and Friedrichs (2015, p. 175), “‘Social Mix’ is currently one of the ‘hottest’ (to say nothing of controversial) topics in urban policy-making and scholarly circles across the First World”. Proponents of socially diverse neighbourhoods argue that disadvantaged households can benefit from living among richer and more educated neighbours. Furthermore, socially mixed neighbourhoods could facilitate the social integration of minority groups and might foster creativity and productivity (Florida 2002). However, planning attempts to enhance the social mix might backfire, if households prefer to live in rather homogeneous neighbourhoods and discount the value of their homes if they are forced to live among dissimilar neighbours.

While house price differentials are surely important from a policy perspective, the recent literature of social well-being argues that well-being is a multidimensional concept (Linton et al. 2016). Well-being does not only have a material dimension, but also an immaterial one, which is in the centre of the large literature on subjective well-being or happiness (Diener et al. 2018). We hence also analyse whether the satisfaction with dwelling conditions differs systematically among population groups in our model. If poor households are locked in a neighbourhood because they cannot afford to move to a preferred location, their life satisfaction might be depressed not only due to their deprived socio-economic conditions, but also due to dissatisfaction with their neighbours.

In order to avoid such a lock-in, urban planners pursue policies aimed at the affordability of housing. Many OECD countries use a variety of policy instruments such as grants and financial assistance for home-buyers to make good-quality housing affordable to poor households (Del Pero et al. 2016). How affordability policies affect house prices and satisfaction levels is not clear a priori. It might lead to a more efficient sorting that raises social welfare, because households have more choice. On the other hand, it might also happen that grants and financial assistance only drive up house prices without any major effect on where households reside. Our model allows us to investigate how these policy instruments affect both house prices and satisfaction levels.

The use of agent-based models in this context is very common, since it enables the user to capture the heterogeneity of agents and land-market representation within an urban area. Huang et al. (2014) provide a review of fifty-one relevant contributions to offer a retrospective on the developments in agent-based models of urban residential choice. The contributions vary in their focuses, since, e.g. Jordan et al. (2012) focus on individual preference rankings with budget constraints and endogenous relocations, whereas Feitosa et al. (2011) consider agents’ own attributes, budget constraints, environmental characteristics and population composition for the moving criterion. Fossett and Waren (2005) consider budget constraints, competitive bidding and endogenous relocation by letting agents consider the ethnic mix, demographic changes and random opening vacancies. Agent-based models do not impose equilibrium conditions on market processes and make it possible to analyse behaviour and price dynamics out of equilibrium. This is an advantage of agent-based models over analytical models,

because existence, uniqueness and stability of a general equilibrium in the housing market can only be guaranteed under specific and quite restrictive assumptions (Li 2014). Furthermore, even if there is a long-run general equilibrium, we do not know how long it takes to attain it from an out-of-equilibrium state, e.g. after some external shock or policy intervention. In fact, it might be the case that housing markets are most of the time far away from any equilibrium, because the transaction costs of moving might be high and adjustments by moving might be slow.

In this model, the main social interaction effect is a pure preference for similarity or preference for status. We do not model spillover effects or indirect social effects, such as having better labour market chances if one resides in an educated or rich neighbourhood (e.g. Wilson 2012). However, we can incorporate such effects by assuming that households prefer living among neighbours with a higher socio-economic status. Our model is meant to be a theoretical investigation of mechanisms that play a role in any housing market. Therefore, the model is not calibrated to fit any particular city or validated against empirical data. The application to housing markets in specific cities could be done as a next step after the mechanisms are well understood.

In Sect. 2, we describe the model in detail. Section 3 explains how the model is parameterised and implemented in computer software. Our main results are presented and discussed in Sect. 4. Finally, we conclude in Sect. 5.

## 2 Model

We first give a short overview of the model in order to highlight its logic. Afterwards, we describe all assumptions in detail and motivate them.

### 2.1 Model overview and process schedule

The only agents in the model are  $N = 3087$  households that buy and sell houses to live in. There is only owner-occupied housing. Households decide to sell their current house and to move to a new one if they are dissatisfied with their current housing conditions. Housing transactions are managed by a virtual real estate agent, which does not make any autonomous decisions, but only serves as a market maker. For simplicity, we assume that the supply and the quality of houses are fixed. The city has a constant stock of  $H > N$  houses. Houses differ in quality, e.g. in terms of size, number of rooms, age, etc. We do not model these characteristics explicitly, but summarise them in a quality indicator variable  $Q_h \in [0, 1]$  for each house  $h$ . There can be several houses of the same quality and a larger index value indicates higher quality. Space is modelled as a two-dimensional grid of  $57 \times 57$  patches with a house on each patch, resulting in  $H = 3249$  houses. We assume a classic Thünen-type monocentric city, in which amenities are concentrated in the centre. Amenities are exogenous and do not change over time. As with the characteristics of the houses, we do not model amenities like shopping and leisure facilities explicitly. Instead, each house has an amenities index  $Q_a \in [0, 1]$  that captures the quality of the neighbourhood with regard to the availability of amenities nearby. In line with the Thünen model, we assume that

**Table 1** Schedule of events and actions

Step	Event or action
1	All households receive a stochastic income
2	All households determine how dissimilar they are from their current neighbours All households determine their satisfaction with the current house and neighbourhood
3	All households decide to stay in the current house or to move
4	Potential movers determine their willingness to accept for the current house
5	Potential movers determine the offer price for the current house
6	Potential movers determine their willingness to pay for a new house
7	The estate agent collects all offer prices of available houses Available houses are auctioned off in 3 rounds to potential movers in a second-price auction. Actual prices are determined
8	Households that bought a house sell their current house to the estate agent and move Households that were not successful in the auctions stay in their current house

$Q_a = 1$  in the city centre and declines for every unit further away linearly by  $\sim 0.0256$  vertically and horizontally and by  $\sim 0.0357$  ( $= 0.0256 * \sqrt{2}$ ) diagonally under consideration of Moore neighbourhoods. We assume discrete time steps equivalent to one month.

The sequence of events and actions is summarised in Table 1. A detailed description of the assumptions and the procedures is given in the following sections. The initial values for the simulation can be found in the Appendix: Table [7].

## 2.2 Income, education and ethnicity of households

Households have random incomes. Initially incomes are exponentially distributed with a mean income of 40,000 and a minimum income of 10,000, which roughly reflects the income distribution in the USA in 2015 (OECD 2017). In every period, each household's income is updated by the following stochastic process:

$$y_{i,t} = \begin{cases} y_{i,t-1} & \text{with prob } 0.9 \\ \epsilon_{i,t} y_{i,t-1} & \text{with prob } 0.1 \end{cases} \quad (1)$$

where  $\epsilon_{i,t} \text{ i.i.d. } \sim [0.8, 1.2]$ .

Households differ in their level of education, by which we mean formal education acquired at school or at colleges and universities. We measure education by years of schooling. Every household is endowed with a level of schooling drawn from a normal distribution with mean 13.5 and a standard deviation of 1.5. Draws below 11 and above 21 are set to these thresholds. A household's education does not vary in the course of the simulation. Furthermore, we do not model any correlation between education and income. We want to analyse the effects of both variables separately in order to distinguish between the pure income effect and the effect from potential

creative neighbourhoods, as introduced in Malik et al. (2015). Each household belongs to one of two ethnic groups, which are indicated by “majority” and “minority”.

### 2.3 Satisfaction of households

Households’ satisfaction with living conditions is a crucial variable in our model. On the one hand, we assume that dissatisfaction is a main driver of moving decisions, which is supported by empirical evidence. Coulter et al. (2011) show with British data that dwelling dissatisfaction and disliking the neighbourhood are positively related with moving desire, moving expectation and the likelihood of moving. On the other hand, satisfaction is a component of well-being, which can be measured and used for welfare analyses. Among many others, Kahneman and Krueger (2006) and Stiglitz et al. (2009) argue that the subjective dimension of well-being, as measured by questions about people’s satisfaction with their lives and living conditions, is important and should inform public policy.

We assume that households  $i$  have a satisfaction level  $S_{i,h,n,t}$  that refers to house  $h$  in neighbourhood  $n$  that they own and occupy at time  $t$ . Marans (1976) suggests three dimensions of residential satisfaction: the dwelling and its attributes (i.e. the number and size of rooms, the age of the building or the availability of a garden or a balcony), the area, in which the dwelling is located and the neighbourhood. The satisfaction with the spatial community refers to the attractiveness of the area due to the availability of local amenities such as schools or shops and the satisfaction of the neighbourhood depends on how similar the household is to its neighbours in terms of socio-economic characteristics. We follow the study of Marans (1976) and define satisfaction as follows: (1) satisfaction with the house itself,  $\text{SH}_{i,h,t}$ , (2) satisfaction with the area, where the house is located,  $\text{SA}_{i,n,t}$ , (3) satisfaction with the current neighbours,  $\text{SN}_{i,n,t}$ . Total satisfaction is the product of the three components, because they reinforce each other:

$$S_{i,h,t} = \text{SH}_{i,h,t} \times \text{SA}_{i,n,t} \times \text{SN}_{i,n,t}. \quad (2)$$

Satisfaction with the house itself depends on the quality of the house:

$$\text{SH}_{i,h,t} = (Q_h)^{\delta_1}. \quad (3)$$

We assume that  $0 < \delta_1 < 1$  in order to capture a strong responsiveness of satisfaction at low levels of quality. Since  $Q_h \in [0, 1]$  satisfaction will range from 0 to 1, too. Satisfaction with the attractiveness of the area is modelled analogously, again with  $0 < \delta_2 < 1$ :

$$\text{SA}_{i,n,t} = (Q_a)^{\delta_2}. \quad (4)$$

A crucial assumption in this paper is that households compare themselves with their neighbours. If we define  $\Delta_{i,n,t} \in [0, 1]$  as the dissimilarity of the household from its neighbours,  $(1 - \Delta_{i,n,t})$  is a measure of the degree of similarity. A household

experiences more satisfaction, the higher the degree of similarity is:

$$SN_{i,n,t} = (1 - \Delta_{i,n,t})^{\delta_3} \text{ with } 0 < \delta_3 < 1. \tag{5}$$

We focus on three dimensions of dissimilarity: income, education and ethnicity. Luttmer (2005) presents evidence from the USA that people report lower happiness if their income is lower than the average income of their neighbours. He calls this effect a psychological externality, suggesting that people’s utility functions depend on relative consumption in addition to absolute consumption. Clark and Coulter (2015) show with data from the UK that people, who feel that they belong to their neighbourhood or are similar to their neighbours, report a lower desire to move. Bourdieu (1984) argues that individuals do not only differ in the economic dimension due to their economic capital, but also in terms of their cultural capital, which is mainly determined by their education. Education is hence another important characteristic of social class or milieu. Following Schelling (1971), it is common in the literature to assume that people have a (slight) preference for neighbours of the same race or ethnicity. Clark (1992) presents evidence for the USA that this is indeed the case and that preferences for the own race or ethnicity are rather strong. Hipp (2009) shows that larger ethnic heterogeneity in the neighbourhood reduces satisfaction levels and Coulter et al. (2011) show that British households have a stronger desire to move if they are a member of an ethnic minority in their neighbourhood. We hence model the dissimilarity between a household  $i$  and the households in its neighbourhood  $n$  as a weighted sum of the dissimilarity in these three dimensions:

$$\Delta_{i,n,t} = \gamma_1 \Delta_{i,n,t}^Y + \gamma_2 \Delta_{i,n,t}^E + \gamma_3 q_{i,n,t}, \tag{6}$$

where  $\gamma_k \geq 0$  and  $\gamma_1 + \gamma_2 + \gamma_3 = 1$ . Income dissimilarity  $\Delta_{i,n,t}^Y$  and educational dissimilarity  $\Delta_{i,n,t}^E$  depend on the difference between the household’s own income or education and the average income  $\bar{Y}_{n-i,t}$  or education  $\bar{E}_{n-i,t}$  of the neighbours:

$$\Delta_{i,n,t}^Y = \begin{cases} \rho \frac{Y_{i,t} - \bar{Y}_{n-i,t}}{\text{Max}(Y_{n,t})} & \text{if } Y_{i,t} \geq \bar{Y}_{n-i,t} \\ \frac{\bar{Y}_{n-i,t} - Y_{i,t}}{\text{Max}(Y_{n,t})} & \text{if } Y_{i,t} < \bar{Y}_{n-i,t} \end{cases} \tag{7}$$

$$\Delta_{i,n,t}^E = \begin{cases} \rho \frac{E_{i,t} - \bar{E}_{n-i,t}}{\text{Max}(E_{n,t})} & \text{if } E_{i,t} \geq \bar{E}_{n-i,t} \\ \frac{\bar{E}_{n-i,t} - E_{i,t}}{\text{Max}(E_{n,t})} & \text{if } E_{i,t} < \bar{E}_{n-i,t} \end{cases} . \tag{8}$$

The relevant neighbourhood consists of the eight direct neighbours in a Moore neighbourhood of the household. We allow for a potential asymmetry of the dissimilarity effect,  $0 < \rho \leq 1$ . Fehr and Schmidt (1999) developed a theory of inequity aversion according to which individuals in general dislike unequal economic outcomes, but prefer situations in which the inequality favours themselves to situations in which others are better off. We also incorporate a preference for status into the model

by allowing for  $-1 \leq \rho < 0$ . In this case,  $(1 - \Delta_{i,n,t}) > 1$  is possible, implying that being richer or more educated than the neighbours would increase a household's satisfaction. Ethnic dissimilarity  $q_{i,n,t}$  is defined as the share of neighbours whose ethnicity is different from the one of household  $i$ .

## 2.4 Moving intention

As mentioned before, there is evidence in Coulter et al. (2011) that households which are dissatisfied with their home or their neighbours have an intention to move and a higher likelihood of moving than households with high satisfaction levels. We model the moving intention,  $MI_{i,n,t}$ , as a function of total satisfaction,  $S_{i,h,n,t}$ , and interpret it as the probability that the household will decide to move:

$$MI_{i,n,t} = \begin{cases} 0 & \text{if } S_{i,h,n,t} \geq \bar{S} \\ \frac{\bar{S}}{\bar{S} - \underline{S}} - \frac{1}{\bar{S} - \underline{S}} S_{i,h,n,t} & \text{if } \underline{S} \leq S_{i,h,n,t} < \bar{S} \\ 1 & \text{if } S_{i,h,n,t} < \underline{S} \end{cases} \quad (9)$$

If the satisfaction level is above an upper threshold  $\bar{S}$ , the probability that the household will move is zero; there is no moving intention. Likewise, the household definitely wants to move, i.e.  $MI_{i,n,t} = 1$ , if the satisfaction falls below a lower threshold  $\underline{S}$ . Between the upper and the lower threshold, the household is uncertain whether to move or to stay. The likelihood of moving is a linear function of the satisfaction level such that the moving intention is 1 at the lower threshold and 0 at the upper one. If the satisfaction level is in between the two thresholds, we draw a random number from a uniform distribution  $[0,1]$ . The household decides to move, if this random number is smaller than  $\frac{\bar{S}}{\bar{S} - \underline{S}} - \frac{1}{\bar{S} - \underline{S}} S_{i,h,n,t}$ . Note that the decision to move does not mean that the household actually will move. Whether a household with a moving intention moves or not, depends on the availability of affordable houses on the market.

## 2.5 Pricing and house sales

Households with an intention to move first determine the subjective value of the current house. Households' willingness to accept for their current home depends on the price for which they bought the house,  $P_{i,h,t_0}$ , and their current satisfaction with the home and its attributes

$$WTA_{i,h,t} = P_{i,h,t_0} (S_{i,h,n,t})^\sigma, \quad \sigma > 0. \quad (10)$$

We assume that the willingness to accept is anchored on the original purchasing price, because there is evidence that even in the housing market, sellers exhibit loss aversion (see Genesove and Mayer 2001; Einiö et al. 2008). In our model, an agent is more likely to sell the house again, if the satisfaction level is lower than it was when it was



initially bought. We call  $\sigma$  the evaluation sensitivity of the satisfaction with dwelling conditions. Since the purchasing price is discounted with the satisfaction level, the seller would experience a nominal loss. In order to avoid losses, sellers offer the house with a mark-up over their true willingness to accept. Hence the offer price, for which they would like to sell the house, is

$$\tilde{P}_{i,h,t} = (1 + \mu)WTA_{i,h,t}. \tag{11}$$

The willingness to pay for a new home determines the maximum price an agent would pay for a new house and it is given by

$$WTP_{i,h,t} = B_{i,t}(S_{i,h,n,t})^\sigma, \sigma > 0 \tag{12}$$

where  $B_{i,t}$  is agent  $i$ 's available budget for a new home at time  $t$ . For the agent's ideal home,  $S_{i,h,n,t} = 1$  holds so that the maximum amount of money the agent would be willing to pay is equal to the available budget. This WTP function implies a demand function for satisfaction of the form

$$S_{i,h,n,t}^{1-\sigma} = \sigma \frac{B_{i,t}}{p_{h,n,t}}$$

where  $p_{h,n,t}$  is the price that a unit of satisfaction would cost. The budget is determined by the minimum proceeds the agent expects from selling the old house (the willingness to accept) and access to credit or savings  $\psi$  that we assume depends on the agent's income:

$$B_{i,t} = WTA_{i,h,t} + \psi Y_{i,t}, \psi > 0. \tag{13}$$

When an agent wants to move, the agent offers the currently owned house to a (virtual) estate agent for the offer price  $\tilde{P}_{i,h,t}$ . The real estate agent collects all offers. In the next step, each agent that wants to move considers all available houses with an offer price up to the agent's personal willingness to pay for this house and expresses interest for the house for which the agent has the highest WTP. The estate agent matches all potential buyers with the available houses as follows. Each house is sold to the bidder with the highest WTP. If only one bidder has a WTP that is above the offer price, the house is sold at the offer price. If there are several buyers with a WTP higher than the offer price, the price is the second-highest price paid by the bidder with the highest WTP. Otherwise, the house is not sold in this period.

To summarise, the actual buying price  $P_{i,h,t}$  agent  $i$  pays for a new house is.

$$P_{i,h,t} = \begin{cases} \tilde{P}_{j,h,t} & \text{if } WTP_{i,h,t} > \tilde{P}_{j,h,t} \text{ and } WTP_{k,h,t} \leq \tilde{P}_{j,h,t} \forall k \neq i \\ WTP_{k,h,t} & \text{if } WTP_{i,h,t} > WTP_{k,h,t} > \tilde{P}_{j,h,t} \text{ and } WTP_{k,h,t} > WTP_{l,h,t} \end{cases} \quad \forall l \neq i, k. \tag{14}$$

**Table 2** Parameters of the model

Parameter	Value	Meaning
$\delta_1$	0.2	Sensitivity of satisfaction to house quality
$\delta_2$	0.2	Sensitivity of satisfaction to amenities
$\delta_3$	0.6	Sensitivity of satisfaction to similarity
$\gamma_1$	1/3	Weight on income dissimilarity in dissimilarity function
$\gamma_2$	1/3	Weight on education dissimilarity in dissimilarity function
$\gamma_3$	1/3	Weight on ethnic dissimilarity in dissimilarity function
$\rho$	- 0.2;1	Self-serving bias in income and education dissimilarity
$\underline{s}$	0.25	Lower threshold of satisfaction in moving intention
$\bar{s}$	0.6	Upper threshold of satisfaction in moving intention
$\sigma$	1	Sensitivity of WTA/WTP to satisfaction
$\mu$	0.05	Price mark-up over WTA
$\psi$	{2; 2.5; 3}	Liquidity parameter/ access to credit
$P_0$	300,000	Maximum House Price value for the initialisation

### 3 Implementation and simulation method

The model is not meant to be a validated representation of a housing market in a particular city. Instead, it is a theoretical model that describes important mechanisms operative in typical housing markets. Table 2 contains the parameters used in the simulations. Sensitivity analyses for the parameters can be found in Bonakdar and Roos (2021).

The model is implemented in NetLogo 6.0.2 (Wilensky 1999). The code is available upon request. All simulation results are averages over 20 runs with different seeds.

## 4 Analysis

In Sect. 4.1, we first show the general behaviour of the model and compare it to the canonical Schelling model in its implementation by Wilensky and Rand (2006). Section 4.2 discusses how satisfaction levels evolve in different socio-economic groups. Section 4.3 presents the answer to our first research question on the population sorting effects in house prices and Sect. 4.4 answers the second question on the effects of affordability policies. The section concludes with a short discussion.

### 4.1 General behaviour of the model

Figure 1 visualises the typical urban segregation arising from population sorting in an exemplary model run. Red patches show households that are highly dissimilar to their neighbours ( $\Delta_{i,n,t} \geq 0.285$ ), green patches show households with similar neighbours ( $\Delta_{i,n,t} < 0.2$ ) and the households on the yellow patches are in between. Population

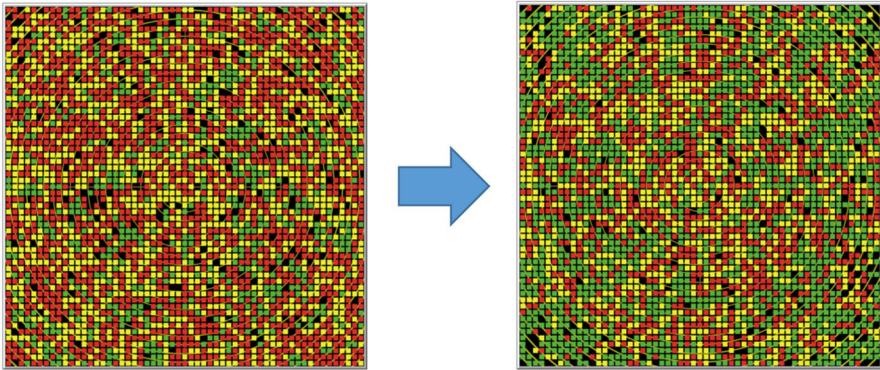


Fig. 1 Evolution of similarity due to population sorting over time, left:  $t = 0$ , right:  $t = 200$

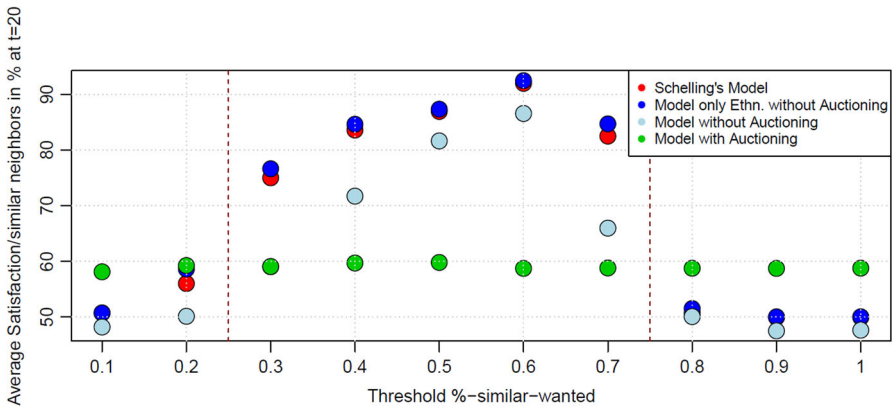


Fig. 2 Comparison with the standard schelling model

sorting leads to a strong improvement of an agent’s similarity from time  $t = 0$  to  $t = 200$ . The mean dissimilarity drops by 18 per cent from 0.2846 to 0.2332 in this exemplary run.

Our model deviates from the canonical Schelling model in three respects: (1) Our households do not only differ from each other in terms of ethnicity, but also in education and income. (2) Households have an intention to move, if their satisfaction with the current house drops below a threshold. (3) They cannot just decide to move, but must be able to find a better home in the house market. Figure 2 shows how our model is related to the Schelling model.

In the Schelling model, the tolerance threshold indicates the percentage of households of the same ethnicity a household desires in its neighbourhood. If the actual percentage is lower than this threshold, the household is unhappy and moves away. In our model, the parameter that corresponds closest to the Schelling tolerance threshold is the satisfaction level  $\underline{S}$  in Eq. (9) below which the household wants to move with a probability of 1. In order to see the effects of our model extensions, we compare

the average percentage of similar neighbours in the Moore neighbourhood after 20 simulation periods<sup>1</sup> as a function of the tolerance threshold in the Schelling model and of  $\underline{S}$  in our model. The red dots represent the Schelling model. The dark blue dots show the results of our model, if households only differ in ethnicity and are not subject to house market constraints (i.e. always move if they have a moving intention of 1). In this case, our model and the Schelling model produce almost identical results. If households also look at education and income when assessing similarity, the average similarity of neighbours drops as indicated by the light blue dots. This result makes sense, because high similarity levels are more difficult to achieve if there are several uncorrelated dimensions of similarity. If we consider the auctioning process, we need to refer to total residential satisfaction instead of only neighbourhood similarity, since housing qualities and amenities now play a role for the moving behaviour of the agent. We find that the variation of the lower threshold  $\underline{S}$  leads to rather robust results in terms of residential satisfaction, averaging at roughly 60%. The consideration of housing and area quality and a market mechanism hence neutralise the result of the Schelling model that the aggregate segregation pattern strongly depends on one order parameter.

## 4.2 Evolution of satisfaction in different groups

From a social policy perspective, it is relevant to analyse the well-being of different social groups. We assume that there are two ethnic groups, the majority group (Maj) and the minority (Min) with a minority share  $G = 30\%$ . Furthermore, we categorise the population according to income, since income is the most important indicator of living conditions. We define the following income groups:

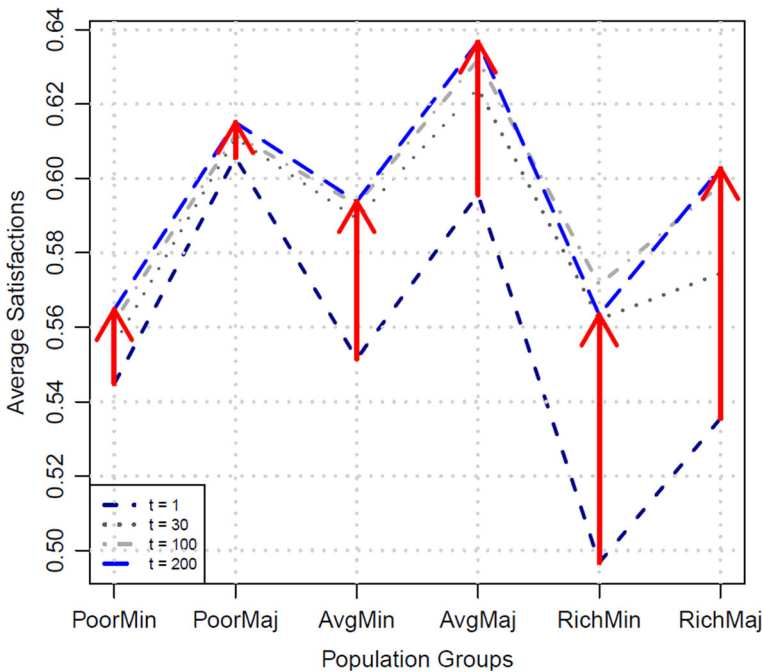
- Poor agents: If  $Y_i < \mu_Y - 0.25\sigma_Y$
- Average-income agents: If  $\mu_Y - 0.25\sigma_Y < Y_i < \mu_Y + 2\sigma_Y$
- Rich agents: If  $Y_i > \mu_Y + 2\sigma_Y$

Figure 3 shows how the average satisfaction levels of the six population groups defined by ethnicity and income evolve over time in the simulation within one specific seed. In all groups, the average satisfaction rises from period  $t = 1$  to  $t = 200$  as indicated by the red arrows.

Not surprisingly, the average satisfaction of agents in the majority group is always higher than the satisfaction of the minority members. The reason for this is that it is easier for majority members to find similar neighbours than for members of the minority. Three further results are remarkable.

First, the rich agents, both in the minority and in the majority start with the lowest satisfaction levels, which are even lower than the satisfaction levels of the poor agents. Since the exponential income distribution is very skewed, we defined the groups asymmetrically, such that there are many more poor agents than rich agents. Accordingly, it

<sup>1</sup> We choose a setting of 20 simulation periods, because the Schelling model implemented by Wilensky and Rand (2006) stops mainly before 20 periods. This still gives some extra buffer for our model, since the housing market interactions require more computational time for the model to converge. With that setting, we can compare the results more accurately. However, the choice of 20 simulation periods also implies that convergence to the long-run equilibrium has not finished as visible for the results with a similarity threshold of 0.7 in the Schelling model.



**Fig. 3** Average satisfaction among population groups at different simulation moments

is much more difficult for rich—and especially so for the rich in the minority group—to find neighbours that are similar in terms of income than it is for the poor. The initial random spatial allocation of agents on the grid in  $t = 1$  implies that most rich agents will have poorer neighbours leading to low neighbourhood satisfaction.

Second, at the end of the simulation at  $t = 200$  the average satisfaction levels of the poor and the rich agents are almost identical, while the average-income agents are more satisfied. This finding might be in contrast to the expectation that the rich agents will end up with the highest satisfaction levels and the poor are the most dissatisfied agents.

Third, the arrows show that the rich can improve their satisfaction a lot, while the improvement in the group of the poor is much smaller. The average-income agents' improvement is at an intermediate level. This result indicates that rich agents can move more freely within an urban area due to higher liquidity. Poor agents do not have that much flexibility in order to find the right peer group and are potentially locked in their current neighbourhood, if they are not located within a neighbourhood with the “right” peers.

Table 3 shows the average shares of locked-in agents across all simulation runs. “Locked-in” means that agents want to move (i.e.  $MI = 1$  in Eq. 9), but cannot do so because they either do not find a more preferred house or cannot afford it. We find that roughly 13.01% of poor minority and 8.02% of poor majority agents are especially dissatisfied with their current living condition and want to move. The

**Table 3** Shares of locked-in agents

Population group	% of locked agents
Poor minority	13.01
Poor majority	8.02
Average-income minority	4.08
Average-income majority	2.30
Rich minority	3.27
Rich majority	2.44

amount decreases with increasing disposable income so that only 3.27 and 2.44% of the rich population are locked in their current neighbourhood. Poor agents suffer under affordability problems and rich agents do not find suitable houses.

### 4.3 The effects of satisfaction levels on buying prices for various population groups with different kinds of preferences

Our first main research question is how buying prices depend on households' satisfaction levels and their preference for similarity or status. We answer these questions by estimating OLS regressions for both types of preferences:

$$\ln BP_{i,g,k,n_k,t} = \beta_0 + \beta_1 \ln SH_{i,g,k,n_k,t} + \beta_2 \ln SA_{i,g,k,n_k,t} + \beta_3 \ln SN_{i,g,k,n_k,t} + \epsilon_{i,g,k,n_k,t}, \quad (15)$$

with individual  $i$  in population group  $g$ , living in house  $k$ , in neighbourhood  $n_k$  at time  $t$ .  $BP_{i,g,k,n_k,t}$  denotes the respective buying price,  $SH_{i,g,k,n_k,t}$  the house satisfaction,  $SA_{i,g,k,n_k,t}$  the area satisfaction and the  $SN_{i,g,k,n_k,t}$  the neighbourhood satisfaction. The data are pooled over 20 simulation runs and 200 periods. Table 4 shows the regression results.

Both house satisfaction and area satisfaction are positively related to buying prices, which means that agents pay higher prices for houses of better quality and which are closer to the amenities in the city centre. The effect of house satisfaction is generally stronger than the effect of area satisfaction. For instance, a one-per cent increase in the house satisfaction of average-income minority households leads to a 1.97 per cent increase in the average buying price. A one-per cent increase in the area satisfaction of these households translates only into a 0.89 per cent increase in the buying price.

Surprisingly, the effect of neighbourhood satisfaction on buying prices is *negative* for poor and average-income households and *positive* for the rich (with the one exception of rich minority households with preference for status). For the rich households, and especially those in the minority group, it is more difficult to find similar neighbours than for those households with lower incomes. Therefore, they pay a premium on neighbourhood similarity, which they can afford. The absolute size of neighbourhood satisfaction effect is larger for the minority than for majority (with one exception).

**Table 4** Effect of satisfaction on buying prices (elasticities)

Dependent variable: buying price	Poor		Average income		Rich		
	Minority	Majority	Minority	Majority	Minority	Majority	
House satisfaction	Similarity	1.31* (.001)	1.33* (.001)	1.97* (.001)	1.68* (.001)	1.11* (.009)	1.11* (.005)
	Status	1.18* (.001)	1.17* (.001)	1.63* (.002)	1.56* (.001)	1.15* (.008)	.97* (.003)
Area satisfaction	Similarity	.58* (.001)	.42* (.001)	.89* (.003)	.71* (.001)	.98* (.012)	.49* (.004)
	Status	.41* (.001)	.38* (.001)	.65* (.002)	.60* (.001)	1.02* (.010)	.74* (.003)
Neighbourhood satisfaction	Similarity	- 1.26* (.003)	- .83* (.002)	- .86* (.005)	- .70* (.003)	.77* (.012)	.40* (.008)
	Status	- .87* (.003)	- .60* (.002)	- 1.36* (.006)	- .61* (.004)	.03 (.016)	.27* (.009)
Constant	Similarity	12.21* (.001)	12.39* (.001)	12.37* (.001)	12.47* (.001)	12.98* (.005)	12.76* (.002)
	Status	12.28* (.001)	12.42* (.001)	12.33* (.001)	12.52* (.001)	12.62* (.003)	12.59* (.001)
adj R <sup>2</sup>	Similarity	.433	.507	.318	.347	.097	.130
Status	.448	.552	.361	.396	.142	.256	
#	Similarity	2,099,323	4,888,583	1,443,936	3,382,372	176,679	413,954
Status	2,104,394	4,883,444	1,443,150	3,391,506	174,976	412,270	

All variables are in logs

\*Indicates statistical significance at the 5 per cent level. Standard errors in parentheses. Observations are pooled over 20 runs and 200 periods each

**Table 5** Price predictions from OLS regression with respective averages of independent variables—preference for similarity

Preference for similarity	Predicted house price	Mean house satisfaction	Mean area satisfaction	Mean neigh. satisfaction	Mean satisfaction
Poor minority	258,250.40	0.8341	0.8338	0.8032	0.5586
Poor majority	282,907.23	0.8338	0.8356	0.8836	0.6156
Avg income minority	290,064.54	0.8516	0.8412	0.8139	0.5831
Avg income majority	295,025.38	0.8520	0.8412	0.8786	0.6297
Rich minority	422,934.00	0.8854	0.8525	0.7349	0.5547
Rich majority	365,861.70	0.8866	0.8539	0.7865	0.5954

We also find that it matters whether households have a preference for similarity or a preference for status. The effect of neighbourhood satisfaction on prices is smaller in absolute terms with a preference for status than with a preference for similarity (with one exception). However, the constants for poor and average-income households are larger (with one exception) with preference for status than with preference for similarity, whereas the opposite holds for the rich. This result is intuitive because rich households with a preference for status benefit from living among poorer households and hence do not compete so strongly for better houses. The poorer households have less chance to benefit from status. Low status lowers neighbourhood satisfaction and increases the moving intention which generates more competition among those households and drives up prices.

We use the estimated coefficients in Eq. (15) and the mean satisfaction levels in order to predict the average house prices that the groups pay for a new house. Table 5 shows the results, if agents have a preference for similarity and Table 6 shows the results, if agents have a preference for status.

In Table 5, we see that poor minority agents have the cheapest houses and rich minority agents own the most expensive ones. House prices as well as average house and area satisfaction increase with increasing disposable income. However, mean neighbourhood satisfaction shows a different pattern. Poor- and average-income agents show higher neighbourhood satisfaction than rich agents. Although rich agents have enough financial liquidity they cannot find the right neighbourhood due to a lack of suitable houses. On average, the total satisfaction level is roughly between 0.55 and 0.63 for all population groups.

A preference for status changes the picture as Table 6 shows. While the predicted house prices for poor and average-income households are close to those in Table 5, the prices rich households pay are much lower. Compared to the case with a preference for similarity, rich majority households pay 16.2 per cent less and rich minority households pay 26.1 per cent less. As argued before, the preference for status reduces



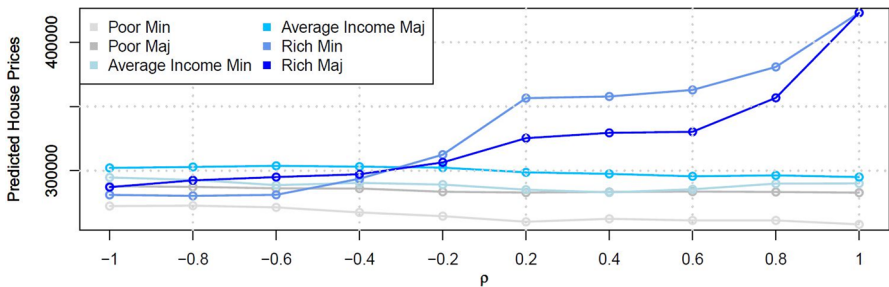
**Table 6** Price predictions from OLS regression with respective averages of independent variables—preference for status

Preference for status	Predicted house price	Mean house satisfaction	Mean area satisfaction	Mean neigh. satisfaction	Mean satisfaction
Poor minority	264,630.90	0.8335	0.8348	0.8079	0.5621
Poor majority	283,605.29	0.8344	0.8357	0.8901	0.6207
Avg Income minority	289,169.00	0.8572	0.8403	0.8732	0.6290
Avg income majority	302,382.54	0.8515	0.8387	0.9459	0.6755
Rich minority	312,476.56	0.8857	0.8619	0.8984	0.6858
Rich majority	306,459.40	0.8770	0.8480	0.9714	0.7224

the competition for houses among the rich significantly, because they experience a high satisfaction from living among poorer neighbours.

In total, preference for status hence compresses the distribution of house prices and hence reduces wealth inequality. Furthermore, we find that the mean satisfaction across all population groups is higher and increases with higher income. Rich majorities show the greatest difference of 12.7 percentage points from 0.595 to 0.722. The overall neighbourhood satisfaction is higher, because agents do not feel dissatisfied when living among neighbours who do not have the same attributes. Especially the rich and average-income households of the ethnic majority reach very high levels of neighbourhood satisfaction.

In Fig. 4, we can see how the predicted house prices depend on the parameter  $\rho \in [-1, 1]$  that determines the degree of preference for similarity or status. Even though, we set  $\rho = \{-0.2; 1\}$  for the analyses, we are interested in the sensitivity of the parameter and consequent dynamic changes.  $\rho$  has practically no impact on poor and average-income households. The competition effect of the preference for similarity that drives up prices only affects the rich households. Interestingly, the effect is nonlinear, as house prices are almost constant for  $-0.2 \leq \rho$  and increase



**Fig. 4** Predicted house prices as a function of the preference parameter  $\rho$

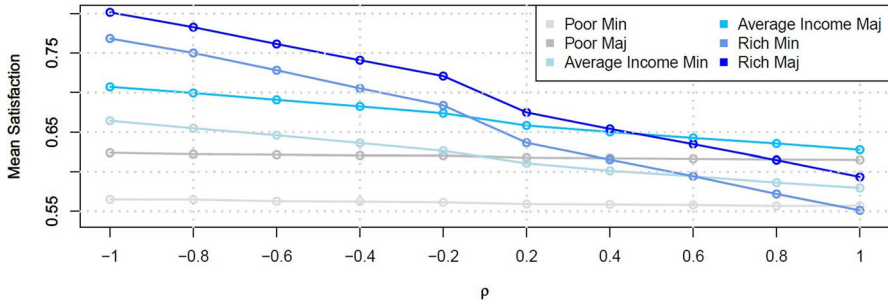


Fig. 5 Mean overall satisfaction as a function of the preference parameter  $\rho$

sharply if  $\rho > 0.6$ . In  $-0.2 \leq \rho \leq 0.6$ , the house prices for rich households show a rather constant development after the first price increases between  $-0.2 \leq \rho \leq 0.2$ .

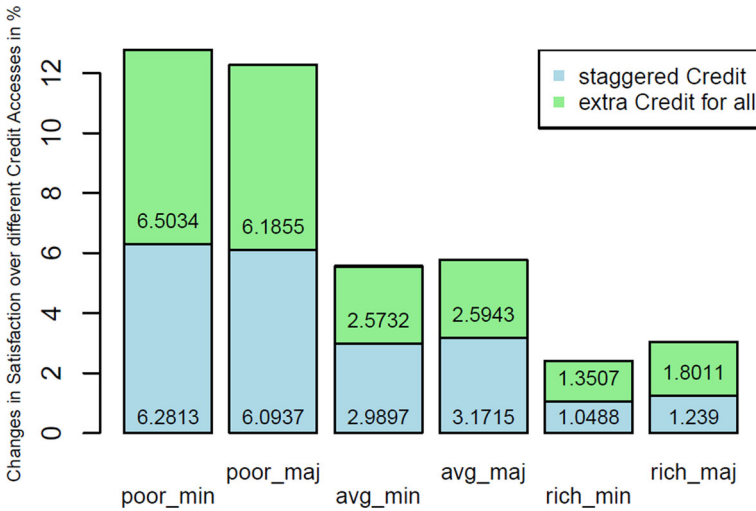
$\rho$  also has a strong effect on the mean satisfaction of households with average and high income (Fig. 5). Their satisfaction is highest, when the preference for status is most pronounced ( $\rho = -1$ ) and decreases with  $\rho$ . Between  $\rho = -0.2$  and  $\rho = 0.2$ , there is a drop in satisfaction as the households switch from preferring status to preferring similarity. For  $\rho > 0.4$  the similarity effect becomes so strong for rich households that their satisfaction levels drop below those of the households in the income class below them.

#### 4.4 The effects of varying credit access for different population groups

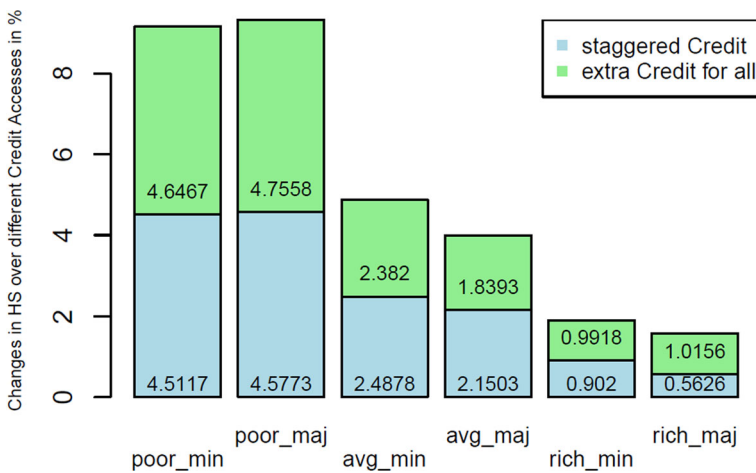
Our second research question refers to the effects of affordability policies on satisfaction levels and house prices. We change the parameter  $\psi$  in Eq. (13) so that agents have higher disposable budgets, which we interpret as better access to credit. In the baseline scenario, all agents have access to twice the amount of their individual income, thus:  $\psi = 2$ . We analyse two different affordability policies:

- 1) Policy 1: Poor agents get more access to credit than rich agents, in order to make houses more affordable and reduce social exclusion. We call this scenario “*staggered credit*”, thus:  
Poor agents:  $\psi = 3$ , average-income agents:  $\psi = 2.5$ , rich agents:  $\psi = 2$
- 2) Policy 2: All agents have higher access to credit:  $\psi = 3$ , we call this scenario “*extra credit for all*”.

Figures 6, 7, 8 and 9 show the effect of the policies on overall satisfaction and its components relative to the baseline scenario for the six population groups with preference for similarity. We find that both policies have a similar effect on overall satisfaction and increase the satisfaction of the poor households more than of the households with medium or high income. Hence extra credit relieves the lock-in of the poorer households and allows them to find better homes. Somewhat surprisingly, the extra credit for all increases the satisfaction levels of the poor and of the rich more than the staggered credit policy, whereas the opposite is true for the households



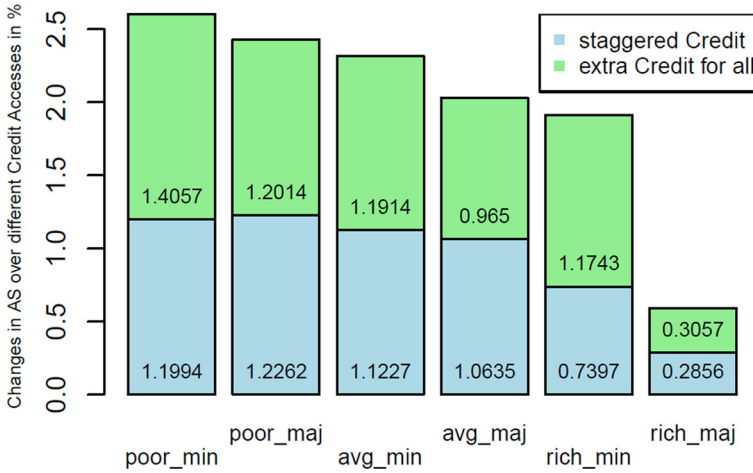
**Fig. 6** Relative deviations (overall satisfaction) of better access to credit among all population groups, preference for similarity



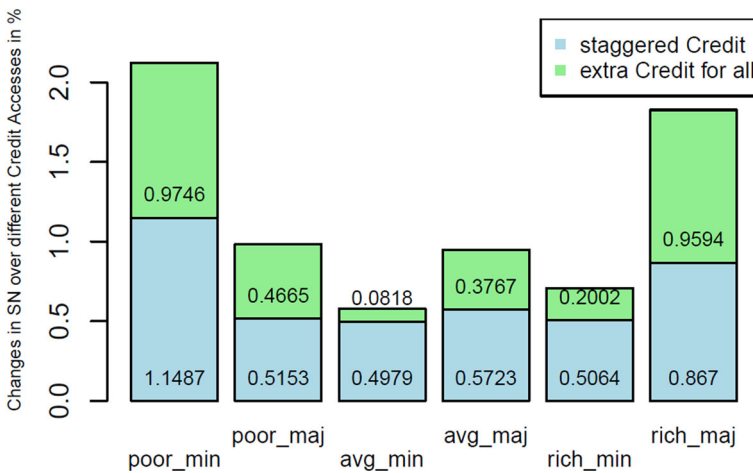
**Fig. 7** Relative deviations (house satisfaction) of better access to credit among all population groups, preference for similarity

with average income. Policy 2 raises the overall satisfaction level of the poor minority households by 6.5 per cent.

Figures 7 and 8 reveal that the affordability policies have the biggest effect on house satisfaction, followed by area satisfaction. Again, this is evidence that without extra credit, the poor are locked in bad houses in bad areas. Better access to credit enables them to afford better houses which increases their satisfaction. We also see that extra credit has little impact on the house and area satisfaction of the households in the rich



**Fig. 8** Relative deviations (area satisfaction) of better access to credit among all population groups, preference for similarity



**Fig. 9** Relative deviations (neighbourhood satisfaction) of better access to credit among all population groups, preference for similarity

majority group. They can afford good houses even without additional credit. Figure 9 shows an interesting pattern. In terms of neighbourhood satisfaction, the poor minority and the rich majority benefit more than the other groups, especially if the extra credit is staggered. We hence find that affordability policies enhance welfare in terms of satisfaction and lead to a better sorting of the population.

However, as Fig. 10 shows, affordability policies also drive up the house prices. Not surprisingly, prices paid by the households with average and high income increase more if all households get extra credit compared to the staggered credit policy. Policy 1

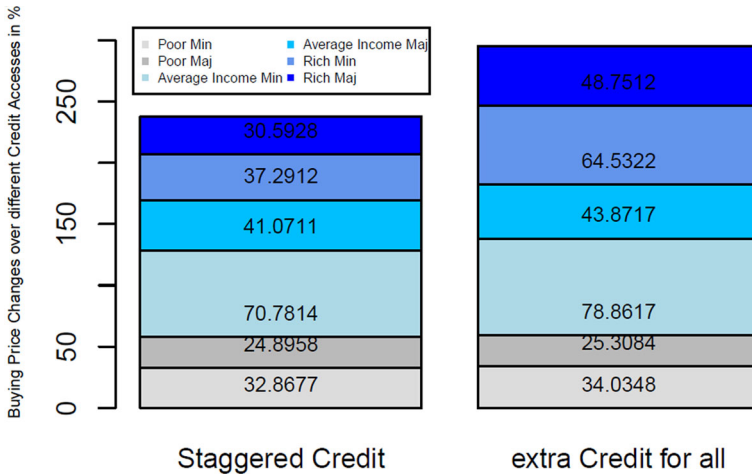


Fig. 10 Relative deviations (prices) of better access to credit, preference for similarity

forces rich households to pay higher prices, even though they do not receive additional credit. The group that experiences the highest price increases is the average-income minority, whose prices go up by 70.78 per cent and 78.86 per cent. The poor majority is least affected as prices rise by 24.9 per cent and 25.31 per cent.

Similar effects can be found if agents have a preference for status. Figures 11, 12, 13 and 14 show the deviations of higher credit access compared to the baseline case. Overall the magnitudes of the effects are rather similar to those when households have a preference for similarity. The most striking difference is that with preference for

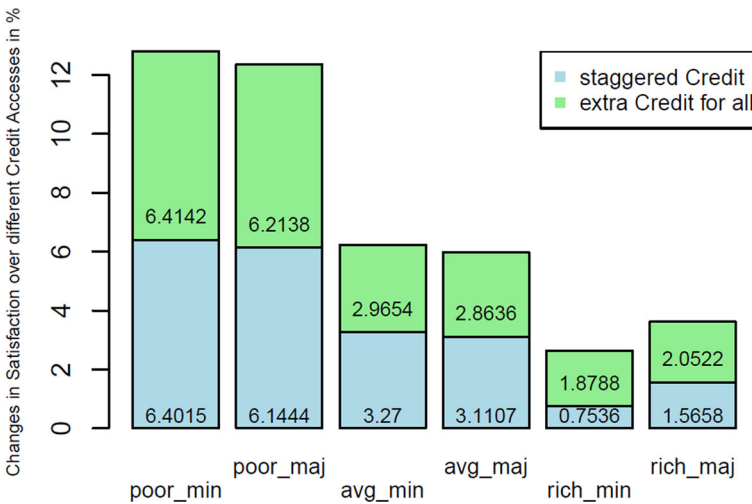
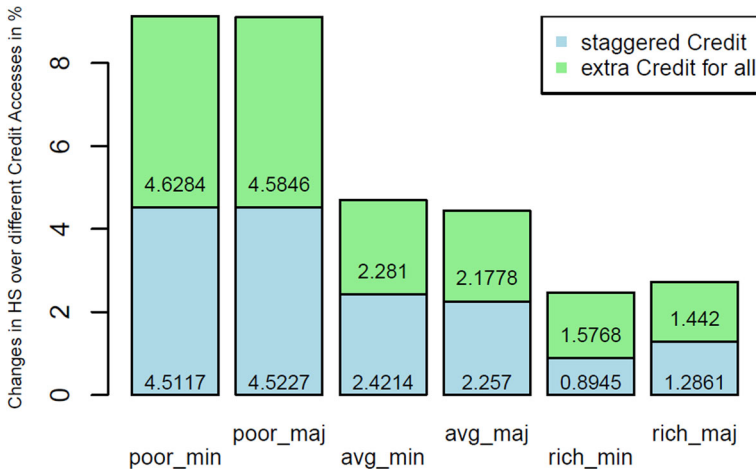
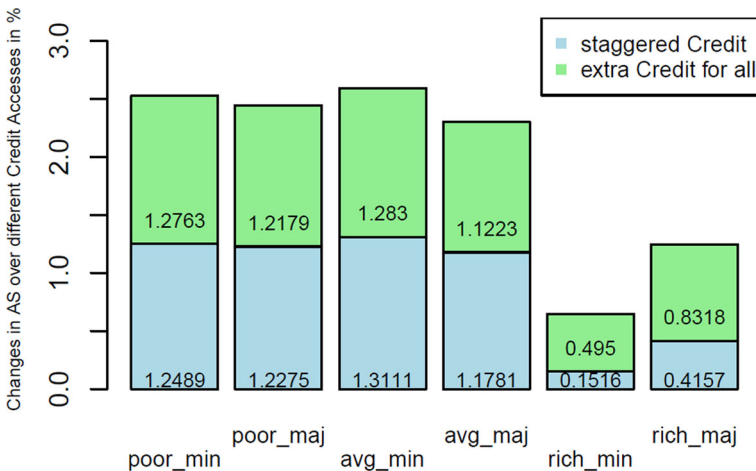


Fig. 11 Relative deviations (overall satisfaction) of better access to credit among all population groups, preference for status



**Fig. 12** Relative deviations (house satisfaction) of better access to credit among all population groups, preference for status



**Fig. 13** Relative deviations (area satisfaction) of better access to credit among all population groups, preference for status

status, additional credit improves the neighbourhood satisfaction of the rich majority only by little. Policy 2 increases the rich majority's neighbourhood satisfaction by 0.177 per cent with preference for status, whereas the increase is 0.959 per cent with preference for similarity. Given that the average neighbourhood satisfaction of this group is already very high even without the extra credit (see Table 6), it is not surprising that the affordability policy has little effect here.

The affordability policies inflate house prices with preference for status, too (see Fig. 15). However, the price increases are much less pronounced. The prices paid by

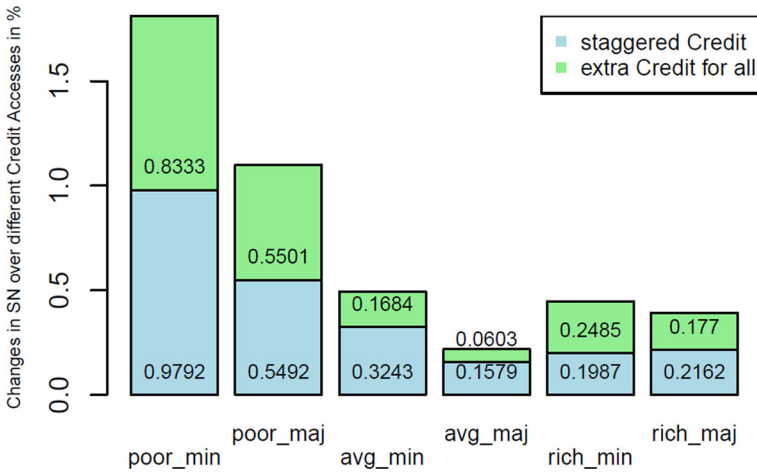


Fig. 14 Relative deviations (neighbourhood satisfaction) of better access to credit among all population groups, preference for status



Fig. 15 Relative deviations (prices) of better access to credit, preference for status

the average-income minority still increase most, 41.5 per cent and 45.73 per cent, but this about 30 percentage points lower than with a preference for similarity. We conclude that preference for similarity generates a stronger competition effect than preference for status.

## 4.5 Discussion

There is a consensus in the literature that discrepancies in socio-economic characteristics among neighbours lead to a decline in residential satisfaction (e.g. Mason and Faulkenberry 1978; Vera-Toscano and Ateca-Amestoy 2008). In our model, this result is reflected in a depreciation of the willingness to accept a price for one's own house. The relation between less residential satisfaction and lower willingness to accept is in line with the results of Jansen (2014), who explores empirically the impact of personal characteristics, dwelling aspects and match/mismatch variables on residential satisfaction. She finds a positive correlation between house prices and residential satisfaction. Our finding is also confirmed by Nordvik and Osland (2017), who estimate a random effects and a fixed effects model with data for Oslo to test how the population composition within a neighbourhood affects house prices. The authors find that neighbourhoods with a higher share of African and Asian country background, and therefore a higher diversity in ethnicity, show reduced house prices.

Brueckner et al. (1999) confirm spatial sorting by analysing the relative location of different income groups within an urban area. The authors find that if the centre has strong advantages in exogenous amenities, rich people are likely to live at those central locations. More recently, Lee and Lin (2018) also confirmed this result by combining a dynamic model of household neighbourhood choice with empirical data. The authors find that high-income agents live in neighbourhoods where natural amenities are present.

Sun et al. (2014) argue that most frequently implemented market elements in such a framework include, e.g. budget constraints. The authors find that these budget constraints can considerably reduce the projected quantity of land-use change, which is in line with our model results, which show that many households are restricted in their residential choice due to affordability problems.

Regarding the relationship between mortgages and house prices, Fitzpatrick and McQuinn (2007) report evidence that credit has a significant effect on house prices in Ireland both in the short and the long run. We find a positive relation between access to credit and house prices, too. Galster and Lee (2021) call for more research on potentially differential effects of housing demand policies on price inflation in different housing submarkets. Our research shows that there might indeed be differential effects, especially if households have a preference for similarity. We can also show that affordability policy can be welfare-enhancing despite its inflationary effect.

Admittedly, we have to be cautious generalising our results too much. We focus only on one particular interaction effect between households, which is the effect of neighbourhood composition on neighbourhood satisfaction. A reliable analysis for urban policy would have to include other neighbourhood effects on crime, educational choice, labour market behaviour or social identity. Agent-based models are ideal for this kind of research on direct interaction between agents. We leave this for future research.



## 5 Conclusion

This paper introduces a theoretical agent-based model for house price dynamics depending on housing quality, access to amenities and, especially, neighbourhood composition. The purpose of this model is to gain insights on how house prices and dwelling satisfaction are affected by (dis-)similar neighbours. Therefore, the model contains several features: agents' endowment with socio-economic characteristics like yearly income and education, a multidimensional dissimilarity index, the quantification of agents' willingness to move to a different house and an auction process for buying and selling houses in an urban area.

We analyse how population sorting and satisfaction levels affect the house prices of different groups of households defined by their income (poor, average, rich) and their affiliation to a minority or a majority group. We find that population sorting is a strong driver of house prices, if agents have a preference for similarity. In particular, competition among the rich for houses with suitable neighbours leads to very high prices of attractive houses. If agents have a preference for status, there is less population sorting and less competition among the well-off agents. The willingness to live among poorer agents increases the prices of their houses and leads to an overall compressed house price distribution and hence to less wealth inequality. If agents prefer status over similarity, the average dwelling satisfaction of all agent groups is higher, indicating more efficient population sorting.

We also analysed how policy measures aimed at making housing affordable to less well-off households affect house prices and satisfaction levels. Providing better access to credit drives up house prices of all groups, even if only poor and average-income agents are directly affected. The effect is particularly strong on houses bought by average-income agents. However, better access to credit also increases the satisfaction of poor and average-income agents, especially if they are the only ones to benefit from the policy. The poor and average-income agents can escape from the lock-in to some extent and afford houses of better quality and with better access to amenities. If agents have a preference for status, the effects of better credit access on the overall price increase are less pronounced. Second, the effects of better access to credit on satisfaction in the different dimensions in general are more favourable to the poor and the average-income agents and do not favour the rich so much. This is also true if all agents get more credit.

These findings suggest that the value of similar neighbours plays an important role for urban planning. The satisfaction from living among peers can compensate poor and minority agents to some extent for having to reside in houses and areas of poor quality. Policies of social mixing might not improve the dwelling satisfaction of agents, if they have a preference for similarity. Affordability policies such as granting better access to credit are a double-edged sword, because they have a positive effect on dwelling satisfaction, but also increase wealth inequality by driving up house prices.

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## Appendix

**Table 7** Initial value

Variable	Function	Meaning
$y_{i,t_0}$	Exponentially distributed with $E[y_{i,t_0}(X)] = 40,000$	Initial income across agents
$P_{h,t_0}$	$P_{h,t_0} = P_0 * QH_{h,t_0}^{\delta_1} * QA_{h,t_0}^{\delta_2}$	Initial house prices depending on $P_0$ , $QH_{h,t_0}^{\delta_1}, QA_{h,t_0}^{\delta_2}$
$QH_{h,t_0}$	Uniform distribution with $QH_{h,t_0} \in [0; 1]$	Initial Housing Quality as random draw
$QA_{h,t_0}$	$QA_{h,t_0} = \frac{\max\{D\} - D_h}{\max\{D\}}$	Initial Area Quality as function of the difference of the maximum distance to the centre $\max\{D\}$ and house h's distance to the centre $D_h$
$S_{i,n,h,t_0}$	0	Initial satisfaction is equal to 0

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