# How different homophily preferences mitigate and spur ethnic and value segregation: Schelling's model extended

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**Abstract**

In Schelling's segregation model agents of two ethnic groups reside in a regular grid and aim to live in a neighborhood that matches the minimum desired fraction of members of the same ethnicity. The model shows that observed segregation can be the emergent result of people interacting under spatial constraints in pursuit of such homophily preferences. Even mild homophily preferences can generate high degrees of segregation at the macro level. In modern, ethnically diverse societies people might not define similarity based on ethnicity. Instead, shared tolerance towards ethnic diversity might play a more significant role, impacting segregation and integration patterns in societies. Bearing this consideration in mind, we extend Schelling's model by dividing the population of agents into value-oriented and ethnicity-oriented agents. Using parameter sweeping, we explore the consequences that the mutual adaptation of these two types of agents has on ethnic segregation, value segregation, and population density in the neighborhood. Such consequences are examined for equally sized ethnic groups and for majority-minority conditions. The introduction of value-oriented agents reduces total ethnic segregation when compared to Schelling's original model, but the new phenomenon of value segregation appears to be more pronounced than ethnic segregation. Furthermore, due to cross-contagion, stronger ethnic homophily preferences lead not only to greater ethnic segregation but also to more value segregation. Stronger value-orientation of the tolerant agents similarly leads to increased ethnic segregation of the ethnicity-oriented agents. Also, value-oriented agents tend live in neighborhoods with more agents than ethnicity-oriented agents. In majority-minority settings, such effects appear to be more drastic for the minority than the majority ethnicity.

## 1 Introduction

Residential segregation can be defined as the spatial and unequal distribution of different groups in a city (Clark 2015). ~~It is a critical topic~~ This topic is critical for policymakers and social research because it reduces the probability of interaction between diverse groups (Massey and Denton 1988). ~~As regards~~ Regarding social integration, ~~such lack of probability of~~ the reduced likelihood of interaction is considered to be a major obstacle to ~~the participation of minorities~~ minority participation in the mainstream society ~~,~~ (e.g. ~~for immigrants~~immigrants) (Esser 2010). Therefore, ~~the "acceptance of diversity " is seen as~~ diversity acceptance is an essential ingredient ~~of~~ in social cohesion (Dragolov et al. 2016). Although there is ~~not~~ no unanimous agreement that residential proximity ~~would be~~ is associated with successful integration, researchers are mainly interested in the reasons ~~of~~ for this observed segregation (Bolt, Sule Özüekren, and Phillips 2010). Two main explanations ~~in the social sciences are that~~ are that first, the physical distance between diverse groups is a reflection of their social distance, ~~or~~ and second, this distance is the result of local residents' active strategies ~~opposing~~ to oppose ethnic minorities (Clark and Fossett 2008; Bruch 2014). On the contrary, the theoretical observation of Thomas Schelling (~~Schelling~~ 1969) is that segregation might be the emergent result of the mutual adaptation of people who seek to live close to members of ~~the own group in~~ their own group within spatial constraints, without implying negative attitudes ~~against~~ towards other groups. Although the term was not used by Schelling, we can define these individual choices ~~of people~~ as homophily preferences. Homophily is the tendency to associate ~~to those considered as~~ with those that are considered similar (McPherson, Smith-Lovin, and Cook 2001). Even ~~thoguh it~~ though this concept is mainly used in the field of network science, it can be applied to aggregation in neighborhoods. As a matter of fact, some studies on segregation dynamics based on Schelling's work expressely ~~use the term homophily as drive to~~ consider homophily as a driver of residential moves and neighborhood preferences (Müller, Grund, and Koskinen 2018; Mägi et al. 2016). Schelling's model is built on the definition of similarity as a "twofold, exhaustive and recognizable distinction" (Schelling 1969, 488), which he applied to the racial segregation ~~between~~ of black and white ethnic groups in the U.S. census. The population in the model is divided ~~in two groupswhose members locate~~ into two groups, whose members live in a neighborhood as long as its composition matches the desired fraction of ~~people considered as similar~~ perceived similar people (Schelling 1969, 1971). The main contribution of Schelling's work is ~~to show~~ that it shows how segregation at the societal level can emerge as a stable outcome from

the "interplay of individual choices" (Schelling 1969, 488)~~even from low~~, even from less desired fractions (Schelling 1969, 1971). Nowadays, Schelling's model is a recognized as a seminal agent-based model (Hatna and Benenson 2015) and one of the first contributions in ~~the~~ computational social sciences and complex systems dynamics (Epstein and Axtell 1996). In the field of residential segregation, it is often cited as a prototype of checkerboard models (Zhang 2011) and tipping behavior in residential dynamics (Card, Mas, and Rothstein 2008).

In this paper, we focus on the ~~individual conceptualization~~ concept of similarity in Schelling's model. The definition of similarity is based on a "twofold, exhaustive and recognizable distinction" (Schelling 1969, 488) and has been associated with a binary definition of ethnic segregation (Clark 2015; Zhang 2011). Nevertheless, as already Schelling pointed out, similarity ~~needs not~~ does not need to be based on ethnicity (Schelling 1969, 1971). In modern societies, people might be part of diverse social groups (Roccas and Brewer 2002)~~, and in multicultural contextthis~~. In a multicultural context, this diversity might include not only different ethnic ~~background~~backgrounds, but also different ~~cultural~~ values (Schwartz 2012) or attitudes towards integration (Bourhis et al. 1997). In these societies, people might differ in their way ~~to construct~~ of constructing similarity out of the different categories ~~they are~~ that they are a part of. According to the ethnic boundary making perspective, in multicultural contexts~~the distinction~~, distinctions between different groups ~~derives~~ derive from the reciprocal construction of symbolic boundaries ~~between~~ distinguishing "us" and "them" (Bail 2008). ~~The~~ This process emerges from the constructivist, subjective and interactive definitions of similarity and inclusion that people engage in, ~~independently~~ independent of their ethnic membership (Wimmer 2007, 2013). ~~That means~~Thus, homophily preferences assoociated with these dynamics can be conceptualized in ~~different ways, and this~~ various ways, which can have interesting implications for segregation scenarios. Lazarsfeld and Merton (~~Lazarsfeld and Merton~~ 1954), as reviewed by McPherson, Smith-Lovin, and Cook (2001), distinguished between two determinants of homophily behavior. Status homophily is based on characteristics ~~stratifying society, e.g.~~ that stratify society, such as ethnicity, whereas value homophily ~~on~~ is grounded in internal status such as attitudes and opinions (McPherson, Smith-Lovin, and Cook 2001). We focus here on homophily that is created through shared values of tolerance for two reasons. On the one hand, it has a direct effect on the acceptance of an ethnically diverse neighborhood (Van Doorn 2014) and ~~favor~~ favors contacts between groups (Brewer and Pierce 2005). On the other hand, tolerance can cause conflicts with members of ~~the own~~ an individual's group who do not share similar attitudes, so ~~to~~ that the mismatch of attitudes can threaten the group's unity (Verkuyten 2010). When tolerant agents subscribe to Popper (1945), they should not tolerate intolerance, which is called the "Paradox of Tolerance~~".~~." Similar to the agents in Schelling's original model~~they~~, these tolerant agents would prefer to live in a neighborhood with at least some others who share their tolerance values.

~~Additionally, we are~~ We are additionally interested in the role of relative group sizes, which ~~received less~~ did not receive much attention in Schelling's demonstrations (Schelling 1971). Indeed, most of the following studies typically assume equal sizes of ethnic groups in the model (Troitzsch 2017). However, the equal distribution of different groups is likely to not be the case in multi-ethnic societies, with understandable consequences on segregation. As a matter of fact, relative group sizes ~~is~~ are an important topic in ~~applied segregation studies. Historically, segregation indexes are based on the uneven distribution of groups in space (Massey and Denton 1988). As two sides of the same coin, dissimilarity indexes so computed measure the probability to meet members of other groups (e. g. Duncan) or being isolated within the own ethnic group (e.g. Lieberson) (~~segregation studies, due to their direct effect on the likelihood of interaction with members of the own group or other groups. The main interest is in the consequences that such uneven probability can have on integration between groups (Massey and Denton 1988). ~~The~~ As regards migrant integration, literature suggests that the smaller the group, the greater ~~is~~ the chance of interacting with and assimilating ~~to~~ into the local population (Esser 2010). Nevertheless, isolation can favor segregation over assimilation by reducing the actual chances of interaction (Massey and Denton 1988). To the best of our knowledge, there is only one study ~~(Troitzsch~~ by Troitzsch (2017) ~~simulating~~ that simulates minority and majority group sizes ~~and measuring~~ in Schelling's model and the impact of desired fraction ~~for both groups on~~ of each group on the overall emerged segregation. ~~Investigating the consequences~~ We therefore consider of additional interest to investigate the role of group sizes combined with ~~value similarity in a Schelling's type model might therefore be of additional interest~~different homophily preferences such as ethnic and value homophily.

In sum, we are interested in ~~what consequences~~ the consequences that different homophily preferences~~based on cross-categories of ethnicity and shared values of ethnic tolerance~~, here ethnic homophily and value homophily, can have on ~~the~~ emergent segregation in Schelling's model. To this aim, we extend the model by dividing the population of both ethnic groups ~~in~~ into value-oriented and ethnicity-oriented agents. ~~We explore with parameter sweepingwhat~~ Utilizing parameter sweeping, we determine what

outcomes of ethnic segregation, value segregation~~and density neighborhood outcomes~~, and population density in the neighborhood emerge from different homophily thresholds ~~of such~~ with agents in equal group sizes and ~~majority/minority~~ majority-minority conditions.

## 2 Model and Simulation Experiments

Agents represent individuals who are relocating. Each agent is defined by two overlapping static state variables: ~~her~~ *ethnicity*, as in ~~the~~ Schelling's original model, and ~~her~~ *value orientation*, which constitutes to our extension of the model. Ethnicity is modeled ~~through~~ by a color tag~~:~~, whereby each agent is ~~attributed either to~~ assigned to either ethnicity 1 (~~red~~blue), or ethnicity 2 (~~green~~orange). Value attribution is modeled through a shape tag, dividing agents into ethnicity-oriented agents (~~shape~~ square) and value-oriented agents (~~shape~~ circle). ~~According to~~ Agents, based on their value attribution, ~~agents~~ use different criteria to define their homophily preferences. Value-oriented agents are tolerant ~~, meaning they consider as similar those agents who~~ with respect to ethnicity but not tolerant to intolerance. This means that they consider agents are similar when they share the same tolerance values~~but ignore their~~; they ignore ethnicity. Ethnicity-oriented agents are intolerant, meaning they consider ~~as similar agents who~~ agents are similar when they share their ethnicity~~but ignore if they have tolerancevalues or not~~; these agents ignore the level of tolerance. Homophily preferences do not change during the simulation.

We implemented our model by extending NetLogo's version of Schelling's model (Wilensky 1997), specifically version NetLogo 6.0~~.3~~.4 (Wilensky 1999), and keeping the standard periodic boundary conditions of the model (torus world) within a 51 times 51 patches regular grid. Thus, there are 2601 patches where agents can live, and each patch has eight neighboring patches (Moore neighborhood). On each patch, there is space for one agent to live.

The initial configuration is ~~set up~~ based on two parameters: the expected *density* and the *fraction of the majority ethnicity*. Both ethnic groups are ~~split between half~~divided in half, who are then split into value-oriented agents and ~~half~~ ethnicity-oriented agents. The initialization goes as follows. For each patch, an agent is positioned there with a probability determined by the expected density. The ethnicity (color) of the agent is set to ~~red~~ blue, with probability determined by the fraction of the majority ethnicity. A final random draw~~decides with probability~~, with a 0.5 ~~about~~ probability, decides the value orientation (shape), which is set to either ~~square or~~ a square or a circle. For agent $i$, we call her ethnicity $E(i)$ and her value orientation $V(i)$.

Global parameters for a simulation run are the *ethnic homophily threshold* and the *value homophily threshold* $\theta^{\mathrm{E}}, \theta^{\mathrm{V}} \in [0, 1]$. ~~The~~ For the ethnicity-oriented agents, the ethnic homophily threshold determines ~~for the ethnicity-oriented agents the minimal~~ the minimum fraction of agents with the same ethnicity that they want in their neighborhoods. ~~Analog,~~ For the value-oriented agents, analog, the value homophily threshold determines ~~for the value-oriented agents the minimal~~ the minimum fraction of other value-oriented agents that they want in their neighborhoods. We define $\Theta_i^{\mathrm{E}} = \frac{\#\{j \in N(i) | E(j)=E(i)\}}{\#N(i)}$ as the *ethnic segregation in the neighborhood* of agent $i$ and $\Theta_i^{\mathrm{V}} = \frac{\#\{j \in N(i) | V(j)=V(i)\}}{\#N(i)}$ as ~~her~~ the *value segregation in the neighborhood*, where $\#N(i)$ stands for the number of agents $j$ in her current Moore neighborhood. An ethnicity-oriented agent $i$ is *happy* when $\Theta_i^{\mathrm{E}} \geq \theta^{\mathrm{E}}$. A value-oriented agent is *happy* when $\Theta_i^{\mathrm{V}} \geq \theta^{\mathrm{V}}$. Agents are also happy when their neighborhood is empty. Fig. **??**A shows the different types of agents in our model, demonstrating which other types of agents in the neighborhood contribute to ~~their happiness~~ the happiness of ethnicity-oriented and value-oriented agents.

The dynamic flow of the model is as follows. At each time ~~step~~ point after initialization, all unhappy agents ~~relocate in a random order, each~~ randomly relocate to a free spot~~at random~~. There is no targeted relocation. We kept the recursive relocation mechanism of the NetLogo implementation. Then, the happiness state of all agents is updated based ~~an~~ on recalculation of $\Theta_i^{\mathrm{E}}$ and $\Theta_i^{\mathrm{V}}$.

On the societal level, we measure the *ethnic* and *value segregation*, $\Theta^{\mathrm{E}}$ and $\Theta^{\mathrm{V}}$, as the average ethnic and value similarities in the neighborhoods of all agents. For a deeper analysis, we also measure the ethnic and value ~~segregation~~ segregations of the subgroups of the ethnicity-oriented and the value-oriented agents, as well as these two groups further divided into the two ethnic groups. ~~Naturally, the averages are~~ These averages are naturally only computed over agents whose neighborhood is not empty. ~~Additionally, we~~ We additionally measure the neighborhood density of agent $i$ as $d_i = \frac{\#N(i)}{8}$ and the average *neighborhood density* of the society $d$. ~~Also the~~ The neighborhood density can also be computed for different ~~subgroups of agents~~agent subgroups. Finally, we also measure the fraction of happy agents.

Tab. **??** lists all static and dynamic agent variables, ~~and~~ parameters of the model ~~, as well as~~ and the output measures used in the following section. We provide the NetLogo model for reference (Paolillo and

Lorenz 2018).

We performed a parameter sweep to explore the consequences of our extension on the aggregated results of the happiness of the agents, their ethnic segregation $\Theta^{\mathrm{E}}$, their value segregation $\Theta^{\mathrm{V}}$ and their neighborhood density $d$. Parameter sweep ~~is~~ was run in NetLogo's BehaviorSpace. Two datasets were collected to compare our extension with the original Schelling's model. The first dataset, which is from Schelling's original model, ~~manipulating also~~ also manipulates the relative group size but without value-oriented agents. The second main dataset is from our extension, including both value-oriented agents and varying size of the majority ethnic group. We provide both datasets for reference (Paolillo and Lorenz 2018). The results can also be reproduced by re-running the BehaviorSpace computation ~~as set up~~ in the NetLogo file.

We initialized each simulation with an expected agents density of 0.7. The fraction of the majority ethnicity was swept over 50%, 60%, 70%, 80% and 90%. The core parameter sweep was over the two different homophily thresholds $\theta^{\mathrm{E}}$ and $\theta^{\mathrm{V}}$. Both of these thresholds were scanned from 0 to 1 in ~~steps~~ increments of 0.1. The values of the parameter sweep are shown in Tab. **??**. For each point in the parameter sweep space, we ran 10 simulation runs. All output measures are averages over these ~~ten~~ 10 runs. Each simulation was run either until all agents were happy, or until 1000 ~~time steps~~ increments had passed. Output measures were saved ~~only~~ for the last time step of each simulation run.

# 3 Results

~~For comparison, we report~~ To provide a comparison, in fig. **??** we report the emergent segregation in Schelling's original model, in which all agents are ethnicity-oriented. With an ethnic homophily threshold of $\theta^{\mathrm{E}} = 0.3$, an ethnic segregation of $\Theta^{\mathrm{E}} = 0.735$ emerges. The baseline ethnic segregation of the initial configuration is 0.5. Thus, all agents would be happy ~~when the initial segregation would be realized~~ with the realization of the initial segregation in their neighborhood. This is not ~~the case just~~ only the case because of random fluctuations in the initial condition. The dynamics of the repeated relocation of unhappy agents triggers the evolution of an equilibrium configuration~~where~~, whereby all agents are happy. ~~Somehow surprisingly, the~~ The ethnic segregation of 0.735 in this configuration is larger than the initial baseline segregation of 0.5 and way beyond the homophily threshold of 0.3.

Fig. **??** compares the emergent ethnic segregation in Schelling's original model with our extension~~where~~, in which half of the agents in each ethnic group are value-oriented. In this analysis, the value-oriented agents have the same homophily threshold as the ethnicity-oriented agents, $\theta^{\mathrm{E}} = \theta^{\mathrm{V}}$. Further~~on,~~, using panels, we also show ~~in panels~~ how segregation changes when one ~~ethnic~~ group is in a majority condition ~~with increasing size up~~ and one in a minority condition. We report the range from equal sizes, included, to 90% majority, included. The thick lines ~~show~~ denote ethnic segregation ($\Theta^{\mathrm{E}}$ in magenta) and value segregation ($\Theta^{\mathrm{V}}$ in ~~blue). Focusing on equal size~~ green). Examining equally sized ethnic groups and low homophily thresholds of $\theta^{\mathrm{E}} = \theta^{\mathrm{V}} = 0.3$, we observe that the emergent ethnic and value segregation for all agents in the population are almost equal and lower than in Schelling's original model $\Theta^{\mathrm{E}} = 0.62 \approx 0.61 = \Theta^{\mathrm{V}}$. ~~For the interpretation of the~~ To interpret the degree of ethnic and value segregation in our model, it is important to note that only half of all ~~the~~ agents consider the ethnic or value segregation of their local neighborhood as important for their happiness. ~~That means, the computed value segregation for all agents is an average over agents of which one half is~~ Thus, half of the agents over which value segregation is computed as average are ethnicity-oriented and ~~does not~~ do not actually care about values~~; vice-versa for ethnic segregation~~. Vice versa, half of the agents over which ethnic segregation is computed are value-oriented and do not care about ethnicity of other agents. Nevertheless, even if we ~~look specifically at~~ specifically look at only the ethnic segregation of ethnicity-oriented agents ~~only~~ ($\Theta^{\mathrm{E}} = 0.69$) or solely the value segregation of value-oriented agents ~~only ($\Theta^{\mathrm{E}} = 0.62$~~($\Theta^{\mathrm{V}} = 0.62$), we find that both are lower than in Schelling's original model (numbers are ~~not~~ shown in Fig. ~~?? but in Fig.~~ **??**C).

Higher homophily thresholds in Fig. **??** show an increase ~~of segregation, in particular~~ in segregation, particularly for value segregation. The sudden drop ~~of~~ in segregation for homophily thresholds beyond $\theta^{\mathrm{E}} = \theta^{\mathrm{V}} = 0.7$ ~~comes together~~ correlates with a drop ~~of~~ in the fraction of happy agents from 100% to almost zero. The reason is that, for such strong homophily preferences, the system is not able to find an equilibrium through random moves of unhappy agents. It is important to keep ~~the existence of~~ this order-disorder transition in mind ~~for the interpretation of the~~ when interpreting the following results.

Fig. **??** also shows that changes ~~of~~ in the size of the majority ethnic group leaves value segregation almost ~~unchanged and changes~~ unaffected. Moreover, it influences ethnic segregation in a simple way: ~~in~~

| Static agent variable | Range |
|---|---|
| Ethnicity $E(i)$ (`color`) | Ethnicity 1 (~~red~~blue), Ethnicity 2 (~~green~~orange) |
| Value orientation $V(i)$ (`shape`) | ethnicity-oriented (`square`), value-oriented (`circle`) |

| Parameters for setup of initial conditions | Range | Parameter sweep |
|---|---|---|
| Population density (`density`) | 0.5–0.99 | 0.7 |
| Fraction of majority ethnicity (`fraction_majority`) | 0.5–1 | $0.5, \overset{+0.1}{\ldots}, 0.9$ |

| Global parameters for simulation run | Range | Parameter sweep |
|---|---|---|
| Ethnic homophily threshold $\theta^{\mathrm{E}}$ (`ethnic_homophily`) | [0,1] | $0, \overset{+0.1}{\ldots}, 1$ |
| Value homophily threshold $\theta^{\mathrm{V}}$ (`value_homophily`) | [0,1] | $0, \overset{+0.1}{\ldots}, 1$ |

| Dynamic variables for agents | Computation | Range |
|---|---|---|
| Ethnic similarity in neighborhood $\Theta_i^{\mathrm{E}}$ | $\#\{j \in N(i) \vert E(j) = E(i)\}/\#N(i)$ | [0,1] |
| Value similarity in neighborhood $\Theta_i^{\mathrm{V}}$ | $\#\{j \in N(i) \vert V(j) = V(i)\}/\#N(i)$ | [0,1] |
| Happiness of $i$ (`happy?`) | $\Theta_i^{\mathrm{E}} \geq \theta^{\mathrm{E}}$ if $V(i) =$ ethnicity-oriented, $\Theta_i^{\mathrm{V}} \geq \theta^{\mathrm{V}}$ if $V(i) =$ value-oriented | TRUE, FALSE |
| Neighborhood density $d_i$ | $d_i = \frac{\#N(i)}{8}$ | [0,1] |

| Global output measures | Computation |
|---|---|
| Fraction of happy agents | # happy agents / # agents |
| Ethnic segregation $\Theta^{\mathrm{E}}$ | mean ethnic segregation |
| ... of all agents | (Figs. **??**, **??**, and **??**) |
| ... of ethnicity-oriented agents | (Figs. **??**, and Fig. **??**) |
| ... of value-oriented agents | |
| ... of ethnicity-oriented agents from majority ethnicity | (Fig. **??**) |
| ... of ethnicity-oriented agents from minority ethnicity | |
| ... of value-oriented agents from majority ethnicity | |
| ... of value-oriented agents from minority ethnicity | |
| Value segregation $\Theta^{\mathrm{V}}$ | mean value segregation |
| ... subgroups as above | (Figs. as above) |
| Neighborhood density $d$ | mean neighborhood |
| ... subgroups as above as above | (only Figs. **??**, **??**, and **??**) |

Table 1: Tables of static agent variables, parameters, parameter sweep values for simulation experiments, and output measures. Typewriter font is a reference to names used in NetLogo code [@PaolilloLorenz2018ValueSegregation].

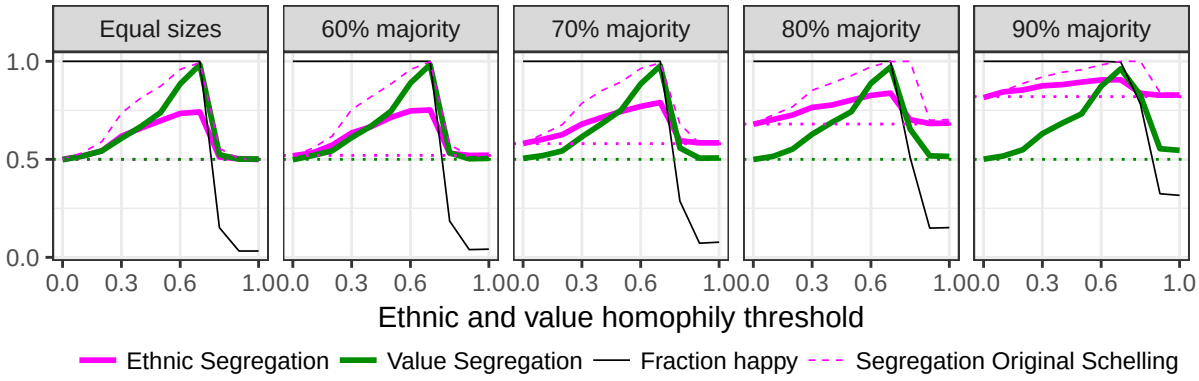


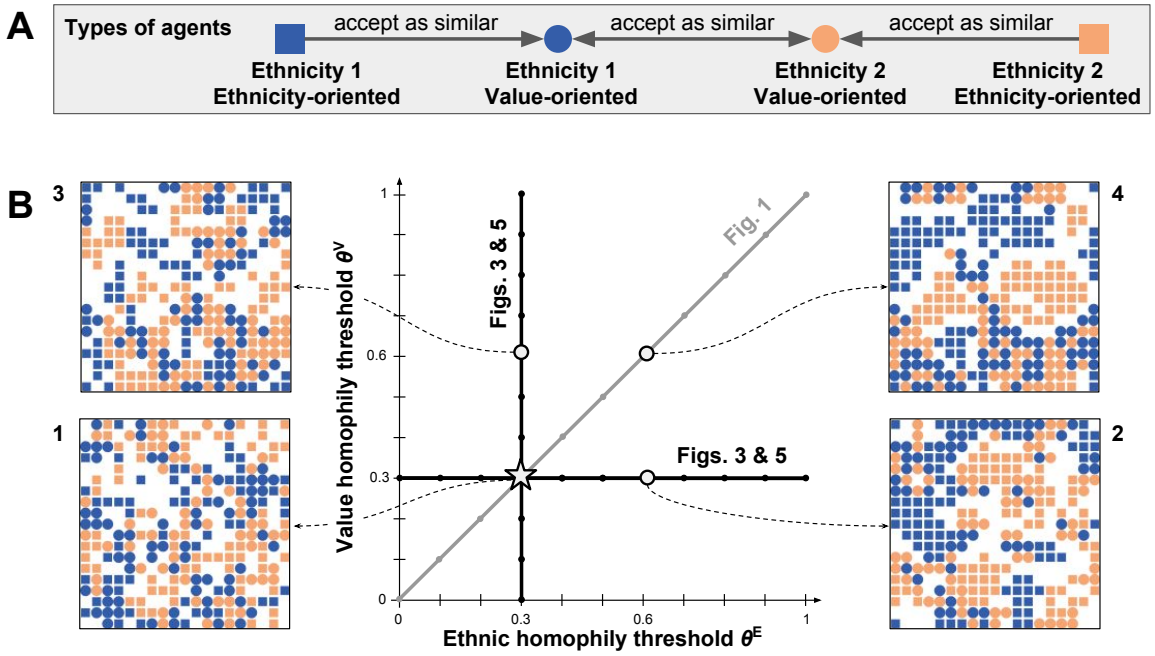

Figure 1: Ethnic and value segregation $(\Theta^{\mathrm{E}}, \Theta^{\mathrm{V}})$ for equal ethnic and value homophily thresholds $\theta^{\mathrm{E}} = \theta^{\mathrm{V}}$ in comparison to ethnic segregation in Schelling's original model. Results for societies with different sizes of ~~the two~~ each ethnic ~~groups~~group. Dotted lines ~~show~~ denote the baseline segregation in random initial conditions.

In a society where the majority ethnicity is a fraction of $x$ the baseline ethnic segregation in random initial conditions is $x \cdot x + (1-x) \cdot (1-x)$ .(Example: 80% of agents have an ethnic segregation of 0.8 and 20% have 0.2.) Thus, baseline ethnic segregation under 60%, 70%, 80%, and 90% majorities is 0.52, 0.58, 0.68, and 0.82. ~~The segregation above~~ Segregation above the baseline changes proportionally ~~to~~ with the distance between the baseline segregation and 1.

Fig. **??**B ~~shows how~~ illustrates emergent equilibrium configurations~~look like. Examples~~. As in Fig. **??**B, examples 1 and 4 show ~~examples~~ cases with equal ethnic and value homophily thresholds~~as in Fig. ??.~~. For low homophily thresholds $(\theta^{\mathrm{E}}, \theta^{\mathrm{V}}) = (0.3, 0.3)$, some clustering is visible, but still we continue to see areas in which all four types of agents are mixed. For high homophily thresholds $(\theta^{\mathrm{E}}, \theta^{\mathrm{V}}) = (0.6, 0.6)$, areas of almost exclusively value-oriented agents are clearly visible, as well as areas of ethnicity-oriented agents ~~in~~ for both ethnicities. Fig. **??** ~~also~~ extends the analysis to societies with ~~low value-oriented and higher~~ a lower value-orientation and a greater ethnic-orientation and ~~the other way round~~vice versa.

In particular, we focus on the effects of cross-contagion ~~of strengthening the~~ in strengthening homophily preferences on increases ~~of~~ in segregation. To that end, let us consider a society with low ethnic and ~~low~~ value homophily preferences, as in Examples 1 ~~and 2~~ from Fig. **??** (~~check~~ see Sections B and C). When the ethnicity-oriented agents change to a high homophily threshold $\theta^{\mathrm{E}} = 0.6$, as in Example 2, we observe that not only ~~ethnic segregation increases~~ does ethnic segregation increase, as in Schelling's original model, but also value segregation $\Theta^{\mathrm{V}}$ increases from 0.61 to 0.69. The ~~other way round~~ opposite occurs in Example 3: When the value-oriented agents increase their homophily threshold to $\theta^{\mathrm{V}} = 0.6$~~they do not only increase value segregation~~, not only value segregation increases, but also ethnic segregation increases from 0.62 to 0.67. ~~In this case, the increase~~ This scenario is entirely due to a strong increase in

ethnic segregation in the group of the ethnicity-oriented agents. Thus, by increasing their value homophily preferences, the value-oriented agents have not changed their ethnic segregation, but rather increased the ethnic segregation of the ethnicity-oriented agents, with whom they do not share values~~with. The~~. This increase is substantial, from 0.69 to 0.81. This new outcome is the main new emergent effect in our extended Schelling model.




**C**

**3 Low ethnic, high value homophily**

| $\theta^E = 0.3$, $\theta^V = 0.6$ | Total | Ethnicity-oriented | Value-oriented |
|---|---|---|---|
| Ethnic Segreg. $\Theta^E$ | 0.67 | 0.81 | 0.52 |
| Value Segreg. $\Theta^V$ | 0.78 | 0.76 | 0.80 |
| Neighbor density $d$ | 0.72 | 0.60 | 0.85 |

**1 Low ethnic, low value homophily**

| $\theta^E = 0.3$, $\theta^V = 0.3$ | Total | Ethnicity-oriented | Value-oriented |
|---|---|---|---|
| Ethnic Segreg. $\Theta^E$ | 0.62 | 0.69 | 0.54 |
| Value Segreg. $\Theta^V$ | 0.61 | 0.59 | 0.62 |
| Neighbor density $d$ | 0.72 | 0.66 | 0.78 |

| Measures in a initial distribution (baseline) | |
|---|---|
| Ethnic Segreg. $\Theta^E$ | 0.5 |
| Value Segreg. $\Theta^V$ | 0.5 |
| Neighbor density $d$ | 0.7 |

**Cell color: Emergent segregation / density**

| |
|---|
| baseline [-0.15, -0.05] |
| baseline [-0.05, +0.05] |
| baseline [+0.05, +0.15] |
| baseline [+0.15, +0.25] |
| baseline [+0.25, +0.35] |
| baseline [+0.35, +0.45] |

**4 High ethnic, high value homophily**

| $\theta^E = 0.6$, $\theta^V = 0.6$ | Total | Ethnicity-oriented | Value-oriented |
|---|---|---|---|
| Ethnic Segreg. $\Theta^E$ | 0.73 | 0.95 | 0.51 |
| Value Segreg. $\Theta^V$ | 0.88 | 0.88 | 0.89 |
| Neighbor density $d$ | 0.75 | 0.67 | 0.83 |

**2 High ethnic, low value homophily**

| $\theta^E = 0.6$, $\theta^V = 0.3$ | Total | Ethnicity-oriented | Value-oriented |
|---|---|---|---|
| Ethnic Segreg. $\Theta^E$ | 0.73 | 0.90 | 0.56 |
| Value Segreg. $\Theta^V$ | 0.69 | 0.68 | 0.70 |
| Neighbor density $d$ | 0.74 | 0.70 | 0.77 |

Figure 2: (A) Types of agents and ~~whom~~ who they consider similar. (B) The $(\theta^E, \theta^V)$-space of different combinations of ethnic and value homophily thresholds. The gray diagonal ~~refer~~ refers to the parameters in Fig. 1. The black lines refer to the parameters analyzed in Figs. 3 and 5. Further~~on~~, four examples of simulation outcomes for $(\theta^E, \theta^V) = (0.3, 0.3), (0.3, 0.6), (0.6, 0.3), (0.6, 0.6)$. (C) Numeric values for ethnic segregation, value segregation, and neighborhood density for the four examples in equal group size conditions. Numbers are computed once for the total population and separately for the half-groups ~~of~~ comprising the ethnicity-oriented and the value-oriented agents. The numbers ~~come~~ derive from the simulation analysis~~where~~, whereby each number is the average over ten runs. A separation with respect to ethnicity is not of interest, since the condition that is presented is for equal group size, ~~and~~ meaning the numbers would ~~be~~ essentially be the same for both ethnicities.

Fig. **??** ~~shows~~ demonstrates how ethnic and value segregation changes with respect to one homophily threshold ~~while~~ when the other is ~~hold~~ held constant at a low homophily threshold, as shown by the black lines in Fig. **??**B. The blue lines in Fig. **??** emphasize the cross-contagion effect. Further~~on, the figure shows~~, this figure illustrates that ethnic segregation stays relatively close to the baseline level of 0.5 for the group of the value-oriented agents in all simulations. ~~Instead, ethnic~~ Ethnic segregation reaches very high levels for the group ~~of~~ comprising the ethnicity-oriented agents. In contrast, the value segregation of the ethnicity-oriented agents is only slightly below the value segregation of the value-oriented agents in all simulations.

Another aspect of interest is how homophily preferences affect the density of agents in their neighborhoods. In all our simulations, the baseline density in initial conditions is 0.7, meaning that~~on average~~, on average, 70% of the eight neighboring patches are occupied by others. The panels at the bottom of Fig. **??** ~~show~~ illustrate that the total neighborhood density is only slightly above baseline. Value-oriented agents usually live with substantially more agents in their neighborhood than ethnicity-oriented agents. For a ~~low value~~ low-value homophily threshold ($\theta^{\mathrm{V}} = 0.3$), this result holds for almost all ethnic homophily thresholds (see panel on the left-hand side), except for $\theta^{\mathrm{E}} = 0.7$, which is the highest ethnic homophily threshold for which an equilibrium of all happy agents can be reached (cf. Fig. **??**). For a low ethnic homophily threshold ($\theta^{\mathrm{E}} = 0.3$), the difference between the neighborhood densities of the value-oriented and the ethnicity-oriented agents is ~~at~~ the largest for intermediate value homophily thresholds (see panel on the right-hand side of ~~fig~~Fig. **??**).

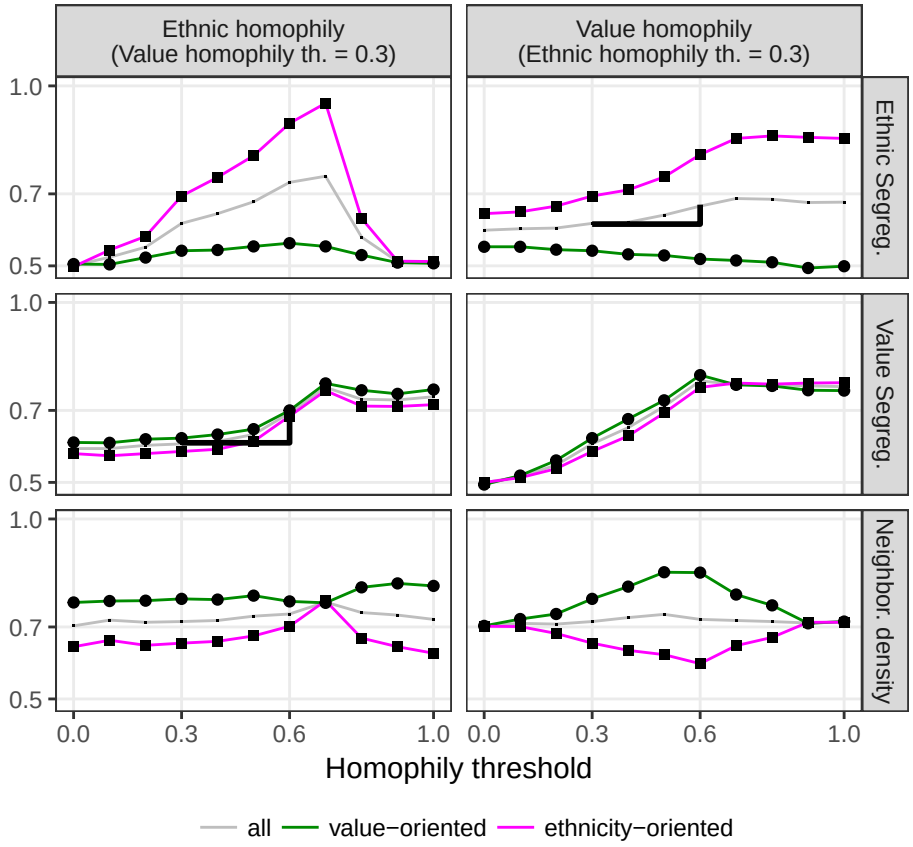
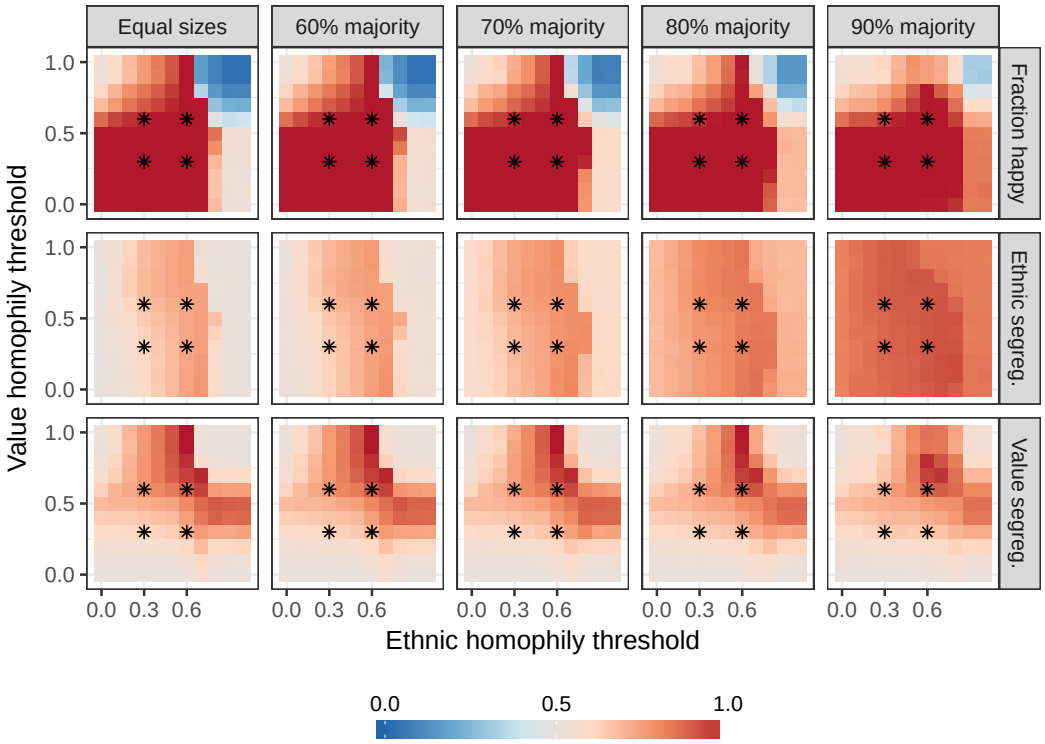



Figure 3: Ethnic segregation, value segregation, and neighborhood density ($\Theta^{\mathrm{E}}$, $\Theta^{\mathrm{V}}$, and $d$) as a function of the ethnic and value homophily thresholds ($\theta^{\mathrm{E}}$ and $\theta^{\mathrm{V}}$) with $\theta^{\mathrm{V}} = 0.3$ and $\theta^{\mathrm{E}} = 0.3$ respectively (cf. Fig. **??**) in equal sizes condition. Computation of segregation and density separated for ethnicity-oriented and value-oriented agents. In all underlying simulations both ethnicities have equal sizes. The thick black lines show effects of cross-contagion: The emergent ethnic segregation through higher value homophily thresholds and the emergent value segregation through higher ethnic homophily thresholds.

Fig. ?? ~~shows~~ illustrates the fraction of finally happy agents, and ethnic and value segregation for the whole society as a heatmap in the $(\theta^{\mathrm{E}}, \theta^{\mathrm{V}})$-plane (cf. Fig. ??B). Results for different sizes of the majority ethnicity are shown in different panels. The panels ~~about~~ concerning the fraction of happy agents show some ~~interesting~~ fascinating insights about the border of the order-disorder transition. Dark red areas mark the ordered region, ~~where the~~ in which society reaches a configuration ~~with all~~ whereby all are agents happy. Interestingly, this result is possible for all value homophily thresholds when the ethnic homophily preference of the ethnicity-oriented agents is relatively high at $\theta^{\mathrm{E}} = 0.6$. Under these conditions, happiness for all agents can be reached even when value-oriented agents do not tolerate any ethnicity-oriented ~~agent~~ agents in their neighborhood ($\theta^{\mathrm{V}} = 1$). ~~Surprisingly, this is~~ This outcome is surprisingly not possible when these ethnicity-oriented agents ~~have only~~ only have low ethnic homophily preferences~~of~~, e.g. $\theta^{\mathrm{E}} = 0.3$. In this case, some value-oriented agents remain unhappy and ~~not~~ unable to find a place to be happy~~, nor they~~. And they do not temporarily build a configuration ~~which~~ that makes other agents move which could create ~~some~~ space for them to form or join a cluster of happy value-oriented agents. ~~The other way round~~For the highest ethnic homophily threshold, there is no value homophily ~~threshold~~ theshold for which it is possible to reach happiness for all~~for the highest ethnic homophily threshold~~.

With respect to the size of the majority ethnicity, the results are relatively similar with one notable further insight. For larger majorities the fraction of happy agents does not drop to zero in the disordered region ($\theta^{\mathrm{E}} \geq 0.8, \theta^{\mathrm{V}} \geq 0.8$). In a society with a 90% majority, half of the agents ~~is~~ are happy. These are mostly the ethnicity-oriented agents from the majority ethnicity (45% of the population). ~~They~~ These agents are easily happy ~~just~~ because of the low fraction of agents from the other ethnicity.




~~Heatmap of the fraction of happy agents, ethnic segregation $\Theta^{\mathrm{E}}$, and value segregation $\Theta^{\mathrm{V}}$ with respect to the space of the ethnic and value similarity thresholds $(\theta^{\mathrm{E}}, \theta^{\mathrm{V}})$ (cf. Fig. ??). Panels columns show simulation results for different sizes of the two ethnic groups.~~

For societies with ethnic groups of unequal size, it makes sense to ~~also look at differences in~~ separately examine the differences in the emergent ethnic or value segregation separately for the different ethnic groups. This task was not of interest in Fig. ?? because ethnic groups of equal size are formally identical and thus reach the same numeric values of segregation. Fig. ?? reproduces Fig. ?? for societies with an 80% majority of ethnicity 1 (~~red~~blue). In contrast to Fig. ??, Fig. ?? ~~shows~~ separately illustrates the emergent ethnic and value ~~segregation~~ segregations and the neighborhood densities for all four ~~different~~ types of agents (cf. Fig. ??A) separately. ~~Roughly summarized~~To roughly summarize,

increased ethnic segregation, value segregation ~~or neighborhood density appear~~ and population density in the neighborhood appear to be more drastic for the minority ethnicity. In particular, the difference in the emerged ethnic segregation for value-oriented agents and ethnicity-oriented agents of the minority condition is striking.

It is important to ~~notice~~ note that all the ~~quantitative results presented~~ presented quantitative results hold only for societies with densities of 0.7 and ~~also~~ only for the given world of $51 \times 51$ patches with periodic boundary conditions (torus). Nevertheless, results would ~~turn out~~ be similar for larger and not ~~too~~ slightly smaller worlds. Higher densities would affect the location of the order-disorder transition. Under higher densities it is generally more difficult for a society to reach happiness for all agents because of the limited space to move.

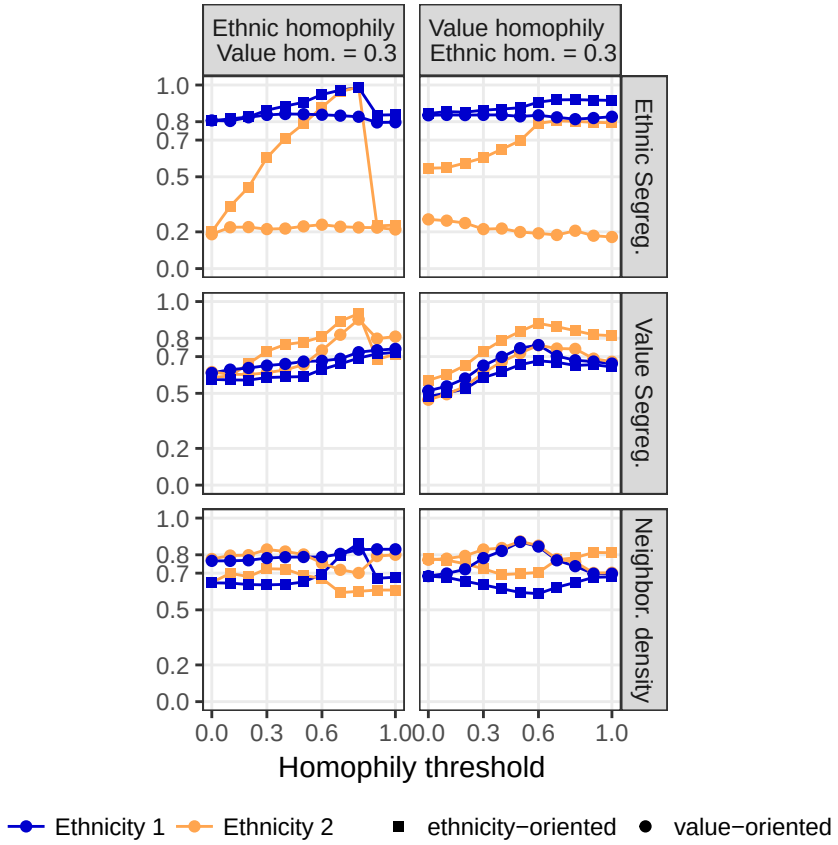



Figure 4: Same panel structure as Fig.?? but for societies with an 80% majority of ~~Ethnicity~~ ethnicity 1 and a 20% minority of ~~Ethnicity~~ ethnicity 2. Ethnic segregation, value segregation, and neighborhood density are computed separately for the ethnicity-oriented majority (40% of the population), the value-oriented majority (40%), the ethnicity-oriented minority (10%), and the value-oriented minority (10%). The horizontal ~~guideline are set to show~~ guidelines illustrate the baseline value segregation (50%) the baseline ethnic segregation of the minority and the majority (20% and 80%), and the baseline density (70%).

# 4 Conclusions and Discussion

In a population of individuals from two ethnic groups of which half are value-oriented and define similarity ~~based on~~ as shared values of ethnic tolerance, ethnic segregation is generally reduced ~~compared to the~~ when compared to Schelling's original model. This result is because the value-oriented people of both ethnic groups tend to ~~segregate~~ separate from ethnicity-oriented people in ethnically mixed regions, while ~~the~~ ethnicity-oriented people tend to ~~segregate in regions separated~~ situate in regions divided by ethnicity. ~~Interestingly, the~~ The ethnically mixed region ~~show~~ interestingly shows a higher neighborhood density.

~~Maybe,~~ It is possible that we have identified ~~some driving force which~~ a driving force that could provide an explanation for the empirical phenomenon that ethnic diversity as well as ethnic tolerance is higher in densely populated areas (e.g. cities), while regions with low population density often show both less ethnic diversity and less ethnic tolerance. We do not claim ~~,~~ that the mechanisms in our model are the only ~~explanation for~~ explanations for the differences in diversity and tolerance values between cities and rural areas, but we think their emergence in such a simple model is ~~worth mentioning~~notable.

Further on, our results ~~show some~~ suggest interesting cross-contagion effects which can shed some light on the unintended consequence of individuals strengthening their homophily preferences. When tolerant people increase their homophily preferences ~~, e.g. through aggregation with tolerant people and rejection of nontolerant attitudes, this might create more~~ with rejection of intolerant attitudes, we observe an increase in ethnic segregation over time~~, mostly in the areas left by tolerant where ethnicity-oriented people would live. This~~. This finding is remarkable because ~~the increase of~~ this increase in ethnic segregation is neither ~~through any change of preferences of~~ due to any preference changes in the people who care about ethnicity, nor is it intended by the promotion of tolerance. When ~~, instead,~~ ethnicity-oriented people instead increase their homophily preferences, e.g. through an increase ~~of racist sentiments(for whatever reason)~~in racist sentiments, this creates~~over time more~~, over time, greater value segregation for all subpopulations. This result is remarkable, because ethnicity-oriented agents would accept tolerant others of the same ethnicity in their neighborhood, but end up with ~~less of them~~fewer of these individuals. In general, value segregation makes perception bias about the value distribution ~~in~~ across the whole society more likely. In particular, ethnicity-oriented people ~~extrapolating~~ who extrapolate from their neighborhoods (with no or few tolerant people) might severely underestimate or not even believe the degree of ethnic tolerance in ~~the~~ society. Of course, this ~~also holds the other way round~~ argument also similarly holds for tolerant people, who might underestimate the degree of ethnic homophily preferences in ~~the~~ society. In the ethnic minority, cross-contagion effects are more drastic. This result demonstrates that relative group sizes~~plays a role in Schelling-type dynamics in~~, in addition to homophily preferences and spatial constraints~~. In the condition of minority , aggregation of~~, play a role in Schelling-type dynamics. For the minority group, aggregating value-oriented agents ~~turn ethnically mixed neighborhood~~ render ethnically mixed neighborhoods more attractive to ethnicity-oriented agents of their group, so to ethnically segregate. ~~The~~ This result also offers an alternative to ~~the assumption of~~ assuming the inevitable assimilation of minority groups as suggested by Esser (~~Esser~~ 2010).

We recognize some areas ~~of~~ for further modeling work. First, the attribution of values could be more realistically defined as a continuous and not ~~just~~ only a categorical state variable. This ~~can also~~ shift can facilitate comparison with real-world data~~. Theoretically, it~~, and it theoretically means to explore if such heterogeneity of agents leads to qualitatively new phenomena. ~~In the same direction, agents could pursue ethnic or value homophily in parallel~~ Agents could similarly pursue both ethnic and value homophily with different importance. In general, a better empirical understanding of ~~the cognition of agents with respect to their actual formation of~~ how agents form their homophily preferences is fundamental to judge the implications of our model's results for ~~empirical~~ practical application. The regular grid might be a reasonable approximation of the real world for many purposes, but human settlement shows much ~~higher variation of~~ greater variation in local population density ~~then~~ than can be modeled in ~~the~~ a grid with only one resident per patch. Multiple residents per patch might be a fruitful route to more realistically model this variation ~~more realistically~~ (Gargiulo, Gandica, and Carletti 2017).

Despite these and other potential extensions and robustness tests, we think that different and overlapping definitions of similarity ~~is a very useful extension~~ are useful extensions to Schelling's model ~~to describe~~ as they can aid in describing complex and apparently contradicting ~~scenarios of residential segregation in modern~~ segregation scenarios. In modern, multi-ethnic ~~societies.~~

~~Further on, in multi-ethnic~~ societies ~~resulting from migration, the constraints where the "interplay of individual choices" (Schelling 1969, 488) occur are likely to not to happen only in physical space, but also with respect to attitudes, social classes and cultural identities, meaning that also these, not only the place of residence, are subject to change. The heterogeneity of people in attributing importance to one dimension over the others and define similarity processes contribute to the complexity of such scenarios. This is especially of interest form an inter-generational perspective. The~~ people segregate not only along ethnic boundaries, but many dimensions, but many dimensions, e.g from social class to cultural norms, which can increase or decrease the distance between ethnic groups (Wimmer 2009). From an intergenerational perspective, the degree of adaptation of previous generations ~~might constitute the basic option~~ from minority groups along such boundaries constitutes the antecedent for the successful investment of new generations in the receiving ~~societies context~~ society (Esser 2010). ~~We can adapt this to emerging segregation and the chance it implies for interaction between ethnic groups (Massey and Denton 1988; Clark 2015). While the influence of residential segregation on societal integration is~~

~~acknowledged, the underlying processes and causality directions are still not (Bolt, Sule Özüekren, and Phillips 2010)~~This has clearly implications for the cohesion of societies itself. We believe that the complex system perspective and agent-based ~~modelling~~ modeling can support empirical research in this field and~~in particular~~ , in particular, that the extension of value-oriented tolerant agents in Schelling's model will find future applications in this direction.

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