A Schelling model with immigration dynamics

Linda Urselmans

University of Essex

Abstract. The Schelling model of segregation since its first appearance in 1969 has enjoyed widespread popularity for its ability to generate patterns of segregation akin to those found in the many cities over the world to this day. This paper builds on this model to evaluate the effects of migration on segregation levels and segregating behaviour. In the wake of current political events such as the large-scale influx of refugees into Europe, I investigate how the scale of migration impacts the ethnic makeup of existing populations and how the overall satisfaction is affected. The results show that size and scale can impact a population differently, but that the crucial explanatory factor is the population density.

The Schelling model in its current form was published in 1971 by Thomas Schelling in a bid to understand how individual decisions of agents to relocate could lead to a macro pattern of segregation [10]. In the context of widespread racial segregation in the US, the model could demonstrate that for segregation to occur on a macro scale, no deeply entrenched racism was required- even slight preferences to reside with people of ones' own colour could lead to segregated areas. The model has since been adapted and advanced in multiple ways and is a well-known model of self-sorting behaviour. A recent adaptation by Hatna and Benenson [6] incorporates assumptions of a heterogeneous society in which preferences for friendly neighbours would vary. This paper builds on their model and tests in how far the rules can simulate patterns of migration in segregated cities. The literature on migration has not featured a Schelling model implementing external migration onto the existing grid (rather, already existing agents migrate within the grid). Contrary to usual models of migration, this paper does not offer an explanation as to why immigration occurs; this is treated as a given. Rather, the size, rate and composition of migration are the crucial variables that are under investigation.

The migration literature has enjoyed a host of agent-based approaches (see [7] for an overview), but mostly in order to explain why migration occurs. In the scenarios that this paper considers, migration is taken as a given, but its intensity (how often does it occur, and how many migrants arrive) and the makeup of incoming migrants differs. The goal of this paper is two-fold. Firstly, it seeks to add to the theoretical insights that the Schelling model can give us, not just for migration but for general behaviour under conditions of sudden external shocks. Secondly, it seeks to evaluate whether and how the group of newly arriving agents affect the future pattern of the population. In order to simplify replicating experiments, the model is based on the aforementioned Hatna and Benenson study. Based on their description of the model details, I recreate their model and then proceed to adapt the model in order to test for my hypothesis.

The structure of this paper is as follows. In the following section, I summarise previous research done in the areas of migration and ethnic segregation. In Section 2, I describe Schelling's model of segregation and some of its variants. In Section 3, I describe how the Schelling model can be adapted to study migration, and the experimental set up and methodology. In Section 4, I discuss the results of the simulations. In Section 5, I discuss an additional variant of the model which can be used to further analyse the importance of population density and composition. Finally I conclude in Section 6.

1 Migration and ethnic segregation in the existing literature

The combination of migration and ethnic (residential) segregation has an intuitive appeal. Immigrants tend to cluster spatially [3], and so do ethnic groups [12]. Migration is usually defined as the movement of people from one place to another. These can be countries, regions, boroughs, cities or neighbourhoods. The type of migration that is of interest to this paper is international migration of people from their country of origin to another country (host country). When migrants enter a country, their point of entry is not random. Cities such as London have distinct areas that are well-known for accommodating newly arrived migrants [5]. International migration is still increasing [1] and affects the ethnic makeup of global cities such as New York or London. Ethnic segregation, occurs when people perceive a group of other people as different based on ethnicity and subsequently seek to live in closer proximity to people more like themselves. Migrants are an obvious group that can be singled out as different since they are foreign to the country. This can, but must not, be linked to differences in ethnicity. Visually poignant features such as skin colour make it easy for people to distinguish between those alike and those that are different. Studies on migration and ethnic diversity are widespread. Putnam [9] finds that migration can increase the social costs of cooperation if the resulting society is more diverse. The proposed link between high diversity and low social capital has since been tested, yielding contradictory results, most likely due to differences in operationalisation of the social variables (see [2] for more discussion).

Migration is likely to make a difference to patterns of segregation. In a separate literature that is primarily concerned with international migration, a subject of interest oftentimes are diasporas: pre-existing communities of foreigners that exert a form of attraction to fellow countrymen and women to move to the diaspora [4]. Diasporas thus grow larger and faster after forming, until a point is reached at which the host population grows weary of its size and spread, and political measures are employed to reduce the growth of diasporas. Diaspora growth has been linked to the gravity model of migration: migrants are pulled towards already existing migrants, even in the absence of pre-existing family ties [7].

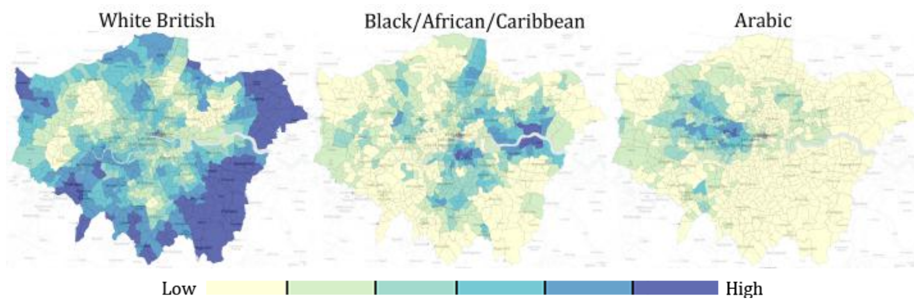

Fig. 1. The ethnic makeup of London in percentages, based on 2011 Census Data.

It is thus an intuitive conclusion that the rate of flow of migrants is at least in part a function of the existing "map": what country they move to and how the ethnic make-up of a country is shaped. Countries without diasporas are less attractive to migrants [8]. Equally, the ethnic makeup of a country or city is (in part) a function of the rate and flow of incoming migrants.

2 The Schelling Model

The basic idea of the Schelling model is that there exist two groups of people (usually represented through different colours) in a two-dimensional world (in this case a torus, i.e. there are no edges). In every group, the people (agents) have different preferences as to how many friends they tolerate in their vicinity. Friends are people of their own colour. In Schelling's original model, all agents share the same preference. The preference f (friend) is the fraction of like-coloured agents that is preferred. The model shows critical thresholds at $f = 0.3$ and $f = 0.7$, the former leading to a complete dispersal of greens and blues, the latter leading to distinct groups of segregated agents. Schelling's model showed that people do not need to be extremist in order to live in segregated neighbourhoods- in fact, even when people prefer mixed neighbourhoods, the aggregate pattern still tends towards segregation. For example, a person that tolerates mixed neighbourhoods, but wishes to be part of the majority (i.e. $f = 0.5$), the aggregate pattern tends towards segregation: if everyone wants to be in the majority, it is not possible to live in a mixed neighbourhood and have people satisfied. Recent studies interviewing migrants confirm the preferences [12].

Hatna and Benenson [6] allow for agents to have different preferences, which is more realistic than Schelling's assumption that everyone has the same minimum threshold. They are able to show that with two preference groups the setup can generate patterns of both integrated and segregated areas on the grid, which is in line with real-word census data of US cities 2010 that they cite; usually cities consist of both segregated and integrated areas [6].

3 Schelling and migration: the experimental setup

The model is an adaptation of the Schelling model by Hatna and Benenson [6] with several additions. Agents can be of either blue or green colour, can be either happy or unhappy, and have a preference for how big a fraction of friends (like-coloured) they want in their vicinity. If this preference is satisfied (i.e. at least the minimum is met), the agent is happy. Happiness gets re-evaluated at each turn. The neighbourhood consists of 24 tiles. Friend preference values can therefore range from 0 to 24. An F value of 17 means that 17 out of 24 neighbouring tiles should be of their own colour. This is roughly 71% of the neighbourhood.

All starting agents are green (the "natives"), all incoming agents are blue (the "migrants"). At the start, the count of greens is 1250, the count of blues is 0. At the end, the count of greens is 1250 and the count of blues is 1200. Unhappy agents will try to move to a better location. They chose from a maximum of 30 empty available tiles and select one with a satisfying friend-ratio. Just as in the Hatna and Benenson study, agents move to a tile with the same ratio, if no better one is available. Equally, agents have a 10^{-2} probability of moving even if they are happy. The intuition is that agents in the real world will also move due to reasons that do not relate to their neighbourhood preferences [6].

	Green	*Blue*
$F1 = 0$	25%	24%
$F2 = 0$	25%	24%

Table 1. Population at the end of each round.

The following settings were applied, unless mentioned otherwise:

1. Agents have one colour; either green or blue.
2. Agents have one of two possible preferences: $F = 0$ or $F = 17$ (see Table 1).
3. The grid size is $50 \times 50 = 2500$ tiles.
4. The starting population density is 50%, and the final density is 98%.
5. When moving, agents consider 30 randomly-chosen empty tiles to move to.
6. The probability of relocating randomly (if happy) is 10^{-2}.
7. The model runs for 10^5 time steps.
8. Every treatment is repeated 30 times.

Each round, every agent gets the chance to act upon their preferences. At first, an agent determines whether they are happy. It does so by collecting the information of their neighbourhood, and then evaluating whether their segregation preferences are matched. If not, the agent will move. In other words, unhappy agents will always seek to relocate, whereas happy agents will remain at their current location.

In order to make way for incoming migrants, the assumption that urban neighbourhoods operate at a near-full capacity (i.e. nearly 100% of the grid is covered with agents) needs to be relaxed. In the real world, cities can accommodate new citizens either by expanding in size (presuming that policy allows for expansion) or by creating new developments in already existing areas. In addition, current citizens can leave (due to various reasons). Lastly, the death of citizens can result in vacated properties. In this model, migration happens after a number of ticks depending on the experiment. The migrants will settle in densely populated areas,[1] and then proceed to follow the same rule-set as the "native" agents.

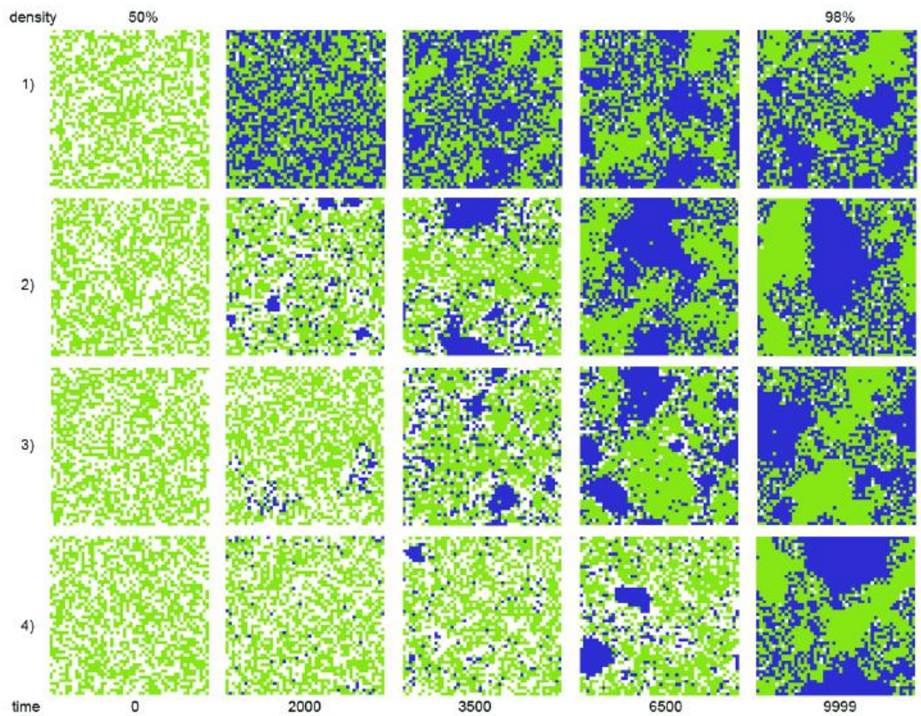

Fig. 2. The model over time (left to right). Each row represents one experiment. 1) influx of 1200 migrants once; 2) influx of 300 migrants four times; 3) influx of 80 migrants 50 times; 4) influx of 12 migrants 100 times.

4 Discussion

Five experimental setups are compared. For every experiment, the influx size and rate is changed. See Table 2 for an overview. The control experiment does not contain migration and starts with a 98% board density and mixed agent groups.

[1] For a detailed description of the settlement mechanism, see the Appendix.

Treatment	Influx	Influx rate	Influx size
Control	No	n.a.	n.a.
Treatment 1	Yes	1	1200 agents
Treatment 2	Yes	4	300 agents
Treatment 3	Yes	15	80 agents
Treatment 4	Yes	100	12 agents

Table 2. All experiment parameters.

The influx experiment with a rate of 1 will insert 1200 migrants all at once, one time only. The experiment with influx rate of 100 inserts 12 migrants at once, 100 times etc.. The experiments compare migration happening at a large scale, as a shock to the existing population, as opposed to the piecemeal variant with very few migrants arriving but at a continuous rate.

In order to evaluate the impact that influxes of new agents have on the existing population and the differences between different sizes of incoming groups, data from the model are sampled every 10 ticks. Thus, a simulation lasting for 10^5 ticks has 10^4 data points. The variables collected are:

1. Global happiness: the number of all happy agents divided by the total number of agents.
2. Moran's I index of colour

The global happiness metric is collected to ease the comparison to many Schelling models that use the agent's happiness as the primary goal of the simulation. Oftentimes when all agents are happy, the simulation terminates (this is not the case for this model. The simulation will terminate after 10^5 ticks). It can demonstrate the upheaval that a new influx can cause. The Moran's Index of spatial auto-correlation is a measure of how clustered the agents are. High levels of Moran's I indicate high levels of segregation.

Figure 3 and 4 compare all treatments to the control. They visualise the different impact that each influx setting has. The one-off influx results in large shocks of happiness (dropping from 95% to 53% within one turn, see Fig.3) and equally pushes both colour and friend-threshold segregation upwards. The control treatment has consistently higher values of both segregation and happiness, but towards the end, the values of both control and one-shock-treatment converge to very similar levels. The 4, 15 and 100 influx treatments show the same pattern: every time an influx occurs, the system experiences an overall shock relative to the size of the influx. The small and large step-like increases are very visible in the segregation patterns. However, as with the one-off treatment, all values eventually converge on very similar and oftentimes overlapping levels, showing no distinct difference over the long term. In other words, how often and how big migration happens does not change the circumstances in the long run. As soon as the density of 98% is approached, the model outcomes are virtually indistinguishable.

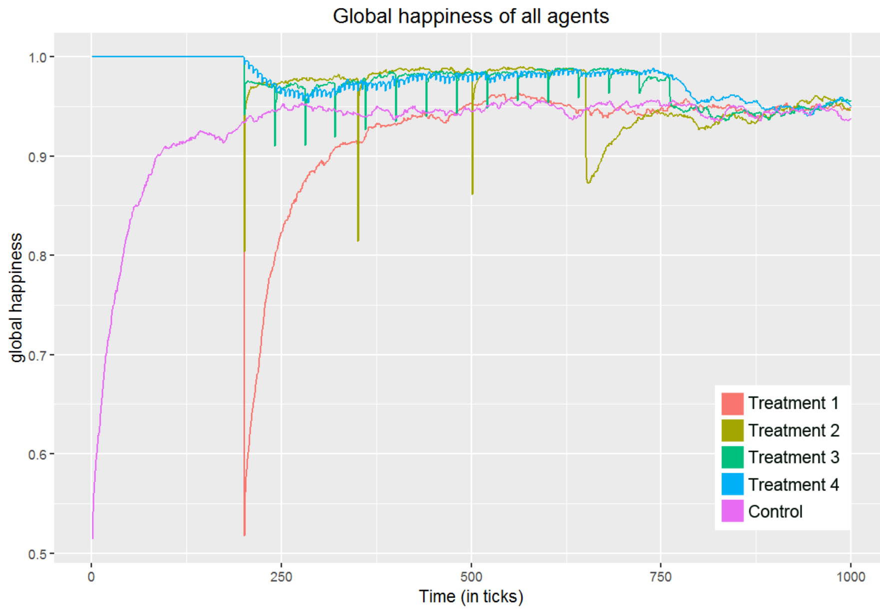

Fig. 3. The global happiness over time, comparing all four influx variations and the control.

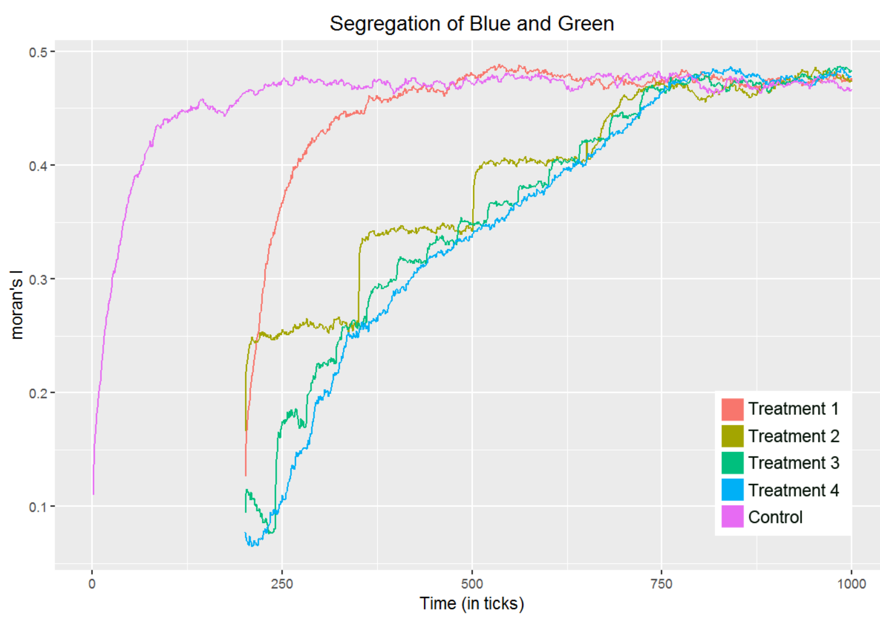

Fig. 4. The Moran's I of spatial auto-correlation over time, comparing all four influx variations and the control. Higher values indicate higher levels of segregation of green and blue agents.

In the short term however, differences are big; in particular, the one-influx experiment stands out. In that setting, the target density is reached in an instant, and thus the behaviour converges to similar levels of the no-influx density of 98%. The results indicate that the size and rate of migration in this model does not alter segregating behaviour or outcomes[2]. The Schelling-esque model patterns emerge as soon as critical densities are reached.

Because the convergence of behaviour occurred in the latter stages of the experiments, it was important to find out exactly when the convergence occurs. Fig 5 shows a close-up view of the global happiness under Treatment 4, 100 small influxes of 12 migrants. The happiness is plotted against the board density at the time. The breaking point occurs after 94% density. If the target density is lower

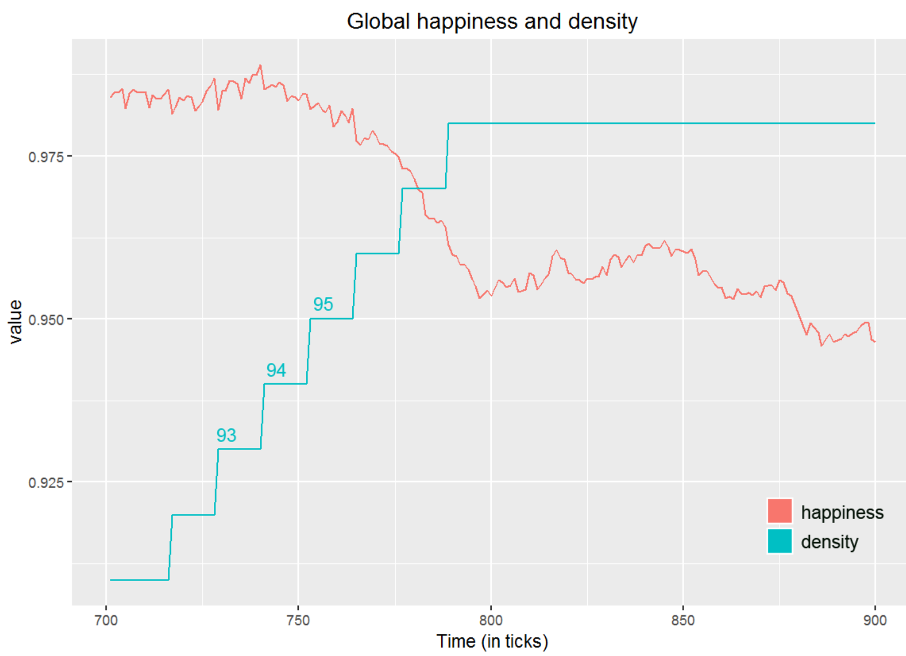

Fig. 5. Global happiness values between 91% and 98% density

than 94%, the convergence of behaviour would not occur. For that reason, the density warranted further investigation. The restrictions of the Schelling model have been investigated to some extent (see [11]) but the density and composition of groups are of particular interest in the case of migration. Migration can be interpreted to be an increase in population density; there needn't be a displacement of existing people, but rather an addition to an existing population.

[2] The same experiments were repeated using single F thresholds, as is standard for Schelling models. The convergence patterns remain.

5 Investigating population density and ethnic composition

To inspect the importance of density and composition, the model was revised: instead of migrants settling throughout the run, every migration is treated as a new initial condition. The amount of empty space that agents have in Schelling's model is significant: the more space there is for intolerant agents to "free" themselves from unsatisfactory neighbourhoods, the more likely they are able to avoid dissatisfaction. In general, more agents can be happy and much quicker in situations of empty space.

Crowded places on the other hands introduce friction, as agents are not able to escape as quickly (if at all). Instead of focusing on the migration of blues and greens throughout, migrants are implemented at the start of the simulation as part of the initial setup (since it doesnt matter when they come in). In the previous model, both green and blue as well as $F1$ and $F2$ ratios were uniformly distributed, so that roughly half of the population was green (or blue), and half of each group would have $F = 0$ (or $F = 17$). These parameters are now altered.

What if the existing population consisted of both tolerant and intolerant agents, but all new agents are hardliners (or vice versa)? This could be reminiscent of a real situation in which there are groups of migrants that are culturally too distant to integrate; or equally, newly arriving migrants are met by a very hostile crowd not willing to engage with the new people. I test different ratios of green and blue and $F = 0$ and $F = 17$ under different densities to see whether they affect the long term outcomes. Table 3 summarises the treatments A-D.

Treatment	Ratio Green-Blue	Ratio Green F1/F2	Ratio Blue F1/F2	Density
Treatment A	50% - 50%	50% - 50%	50% - 50%	88%, 96%
Treatment B	70% - 30%	50% - 50%	50% - 50%	88%, 96%
Treatment C	50% - 50%	90% - 10%	10% - 90%	88%, 96%
Treatment D	50% - 50%	90% - 10%	90% - 10%	88%, 96%

Table 3. All experiment parameters of population density and composition

Treatment A uses the same even split that was employed in the earlier stages of the analysis; treatment B retains the even split of moderates and hardliners, but features a larger native population (70% of all agents). Treatment C has an evenly split native-migrant population, but of all the natives, only 10% are hardliners whereas among the migrants, 90% are. The final treatment differs from C only in that migrants feature few hardliners just as the natives do, with 10%. Every treatment is repeated under conditions of 88% and 96% density. The densities were chosen because they lie below and above the critical threshold of convergent behaviour, respectively (see Fig. 5). Both global happiness and the Moran's I are collected again.

The results for this experiment are shown in Fig. 6 and Fig. 7.

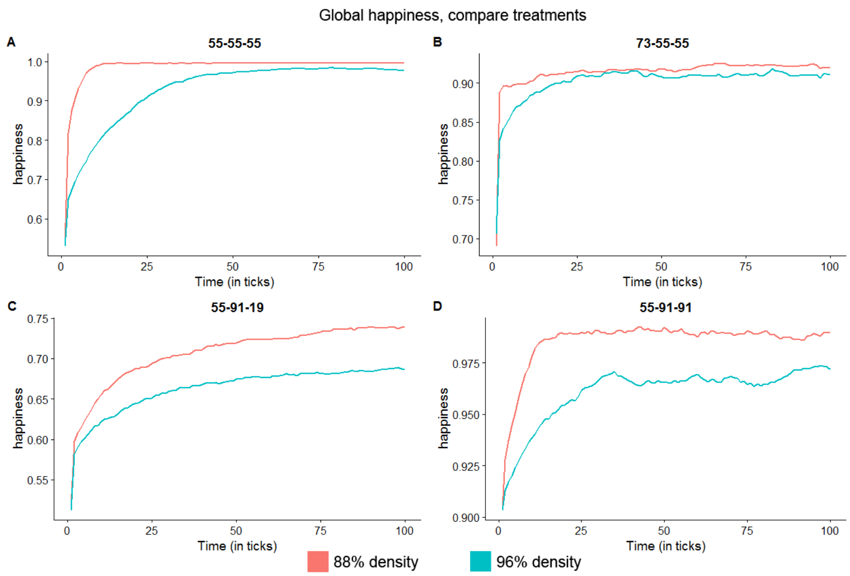

Fig. 6. The global happiness comparing 88% and 96% density levels. Treatments A, B, C and D (see Table 3).

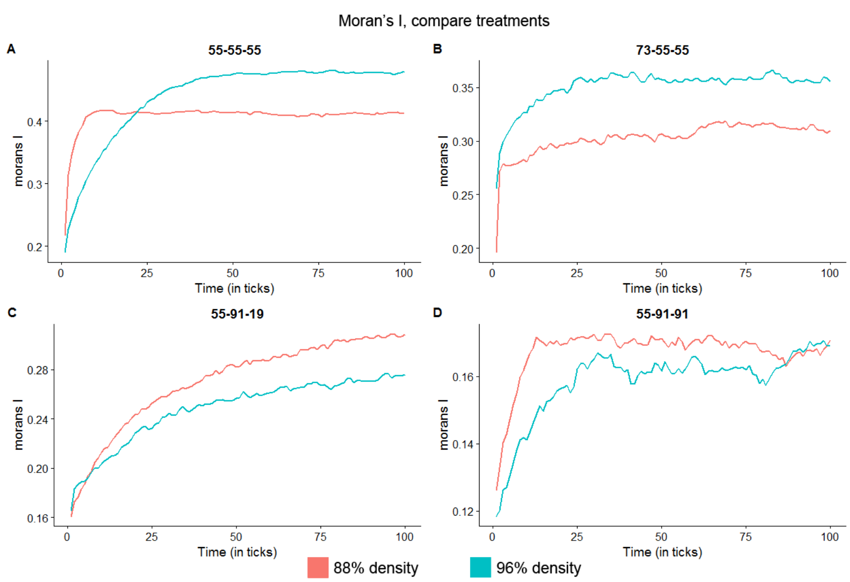

Fig. 7. The Moran's I of spatial auto-correlation, comparing 88% and 96% density levels. Treatments A, B, C and D (see Table 3).

As a general rule, the global happiness values show the same converging pattern, although under conditions of higher density, it takes longer to reach these values. In treatment A, for a global happiness of at least 97% to be reached, agents in a densely populated environment need 70 time steps- the same agents on 88% board density need a mere 20 time steps and retain their high happiness throughout. Overall, lower density results in higher happiness levels compared to the higher density setup. However, there are distinct trends of note: the relative difference is higher (and significant) in treatments C and D. Density becomes an important driver of happiness if the F-values are not evenly split. The C treatment, unique in its setup of 90% hardliner migrants, has the lowest levels of absolute happiness, never reaching 75% overall, even under conditions of lower density. This is intuitive given that much more hardliner preferences have to be accommodated, and they are unlikely to settle happily.

The segregation between blue and green agents (Moran's I) follows a different pattern. Conditions of higher density result in higher levels of segregation, but only if the number of tolerant agents and hardliners is evenly split (A and B). Intuitively, with fewer migrants than natives (B), overall segregation levels are lower. The size and occurrence of clusters is not as big, and thus, the Moran's I peaks at around 35% segregation compared to 47% in treatment A. Treatment C and D have large tolerant native populations, resulting in much less segregation. Having 90% migrant hardliners (C) drives segregation up, but not above 30%.

It seems that the hardliners are well-compensated by the large tolerant crowd. The trend is further downwards when almost all agents are tolerant (D). What is interesting here is that both C and D treatments, the effect of density is reversed. Higher density leads to lower levels of segregation (although this pattern is only robust in the C treatment). This is intuitive given that less dense populations offer more room to escape, encouraging clustering through freedom of movement. Although hardliners are more unhappy in dense settings, they also have less room to maneuver and are less likely to find a sufficiently segregated neighbourhood.

The two sets of graphs show that different composition of "migrants" and "natives" account for up to 5% of the variation in outcome, but the impact of varying the density is far greater.

To summarise, the density of the population amplifies segregation on both levels and impacts the happiness of agents in general. The composition of the population; how many are green or blue, tolerant or hardliners, is important but to a lesser extent. How well a population copes with a sudden influx of new people that are different along some cleavage (such as being a migrant) thus is largely a function of how crowded the place is in the first place. Short term differences between large and small migration flows can be explained by the variation in density that exists in the short term. More densities and composition combinations might shed more light on the tipping points which, according to the current state of this analysis, lie between 86% and 96% population density.

6 Conclusion

The results indicate that using a Schelling-model, the size and rate of migration of a new set of agents into an existing population have no long-term impact on segregation and happiness levels of agents. Any short term variation that may exist between large and small migration flows can be explained by the differences in population density. Further investigation of the model parameters showed that higher levels of density correspond to lower levels of happiness, but the segregation levels are more sensitive to the composition of agents.

When the number of arriving agents is low, agents have, on average, more empty space to use. Intolerant agents thus seek to belong to groups of their own colour, and if they are on the edge of a group, they are usually surrounded by empty space. Visually, this results in white buffer zones between groups. These zones do not appear if the population covers 98% of the map. Thus, agents on the fringe of a group will likely neighbour agents of a different colour, causing unhappiness and more movement. Because the space to move is so limited, constant friction keeps agents less happy and in a perpetuated state of seeking better places.

The research question of how the scale and size of migration affects segregating behaviour needs slight readjustment: scale and size of migration only matters under conditions of lower density, where overcrowding is less likely to cause constant friction. With more space available, differences in migrant and native population are more visible. It should be noted that the terminology of 'low' and 'high' density levels is relative. Whether a figure of 88% density translates into a highly or lowly populated population in the real world will shape any conclusions drawn.

The model shows that using the simple rules of Schelling, some conclusions can be drawn from migration setups; more crowded places will suffer more negative consequences of migration. However, I intend to conduct further analysis of the specific tipping points of population density and segregation behaviour.

References

1. UK Data Explorer Census 2011: Wards in London. `http://ukdataexplorer.com/census/london/`, [Online; accessed 4/1/2016]
2. Ariely, G.: Does diversity erode social cohesion? Conceptual and methodological issues. Political Studies 62(3), 573–595 (2014)
3. Bushi, M.: Rethinking Heterolocalism: The Case of Place-Making among Albanian-Americans (2014)
4. Collier, P.: Exodus. Immigration and Multiculturalism in the 21st Century. Penguin Books (2014)
5. Hall, S.: Super-diverse street: a 'trans-ethnography' across migrant localities. Ethnic and Racial Studies 00(00), 1–14 (2013)
6. Hatna, E., Benenson, I.: Combining segregation and integration: Schelling model dynamics for heterogeneous population. Journal of Artificial Societies and Social Simulation (JASSS) 18(4), 1–22 (2015)

7. Klabunde, A., Willekens, F.: Decision-Making in Agent-Based Models of Migration: State of the Art and Challenges. European Journal of Population 32(1), 73–97 (2016)
8. Novotny, J., Hasman, J.: The Emergence of Regional Immigrant Concentrations in USA and Australia: A Spatial Relatedness Approach. Plos One 10(5), e0126793 (2015)
9. Putnam, R.D.: E Pluribus Unum? Diversity and community in the twenty-first century. Scandinavian Political Studies 30(2), 137–174 (2007)
10. Schelling, T.C.: Dynamic Models of Segregation. Journal of Mathematical Sociology 1, 143–186 (1971)
11. Singh, A., Vainchtein, D., Weiss, H.: Schelling's segregation model: Parameters, scaling, and aggregation. Demographic Research 21, 341–366 (2009)
12. Søholt, S., Lynnebakke, B.: Do Immigrants' Preferences for Neighbourhood Qualities Contribute to Segregation? The Case of Oslo. Journal of Ethnic and Migration Studies 41(14), 2314–2335 (2015)