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Entry limitations and heterogeneous tolerances in a Schelling-like segregation model

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ABSTRACT

In this paper we consider a Schelling-type segregation model with two groups of agents that differ in some aspects, such as religion, political affiliation or color of skin. The first group is identified as the local population, while the second group is identified as the newcomers, whose members want to settle down in the city or country, or more generally a system, already populated by members of the local population.

The members of the local population have a limited tolerance towards newcomers. On the contrary, some newcomers, but not all of them, may stand the presence of any amount of members of the local population. The heterogeneous, and partially limited, levels of tolerance trigger an entry and exit dynamics into and from the system of the members of the two groups based on their satisfaction with the number of members of the other group into the system. This entry/exit dynamics is described by a continuous piecewise-differentiable map in two dimensions. The dynamics of the model is characterized by smooth bifurcations as well as by border collision bifurcations. A combination of analytical results and numerical analysis are the main tools used to describe the quite complicated local and global dynamics of the model. The investigation reveals that two factors are the main elements that preclude integration. The first one is a low level of tolerance of the members of the two populations. The second one is an excessive and unbalanced level of tolerance between the two populations. In this last case, to facilitate the integration between members of the two groups, we impose an entry-limitation policy represented by the imposition of a maximum number of newcomers allowed to enter the system. The investigation of the dynamics reveals that the entry-limitation policy is useful to promote integration as it limits the negative effects due to excessive and unbalanced levels of tolerance.

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1. Introduction

In real-world situations, the integration of people who differ for religion, color of skin, political opinions and any other element of diversity is a complicated aspect that has many implications and affects all aspects of the human being's life and of the global society in general, such as personal relations, social relations, economics, politics, and the like. The main cause of non-integration (or segregation) is the limited level of tolerance that groups of individuals who share ideals, or are characterized by common features, have towards individuals that do not belong to their cluster. Moreover, the assumption that residential segregation observable in many U.S. cities, see, e.g. [1], is the output of a free interaction of agents guided by their own discriminatory individual choices, leads someone to think that individuals are totally intolerant. Nevertheless, other ones can be the causes leading

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to segregation. As underlined earlier by Schelling, see [2] and [3], and more recently in [1], [4], [5] and [6], a deep investigation of the real situation reveals that the segregation in many U.S. cities does not reflect the desire of the people but is the result of sets of integration preferences of the members of the different groups that are limited and mutually incompatible.

In his seminal contribution, see [2], Schelling proposes (sketches) two models to represent and describe the issue. The first model is a primeval example of agent-based modeling[1] that takes into account the point of view and the decisions of every single individual involved. This model has been extended and analyzed in many contributions, see e.g. [7,8] and [9]. The second model is a two-dimensional dynamical system that describes the entry/exit dynamics of the members of two populations in a city or a country or more generally a system. This model considers individuals as members of the two groups and describes the aggregate dynamics to result from the interaction of the two groups and based on adaptive mechanisms. Recently, see [10,11]–[12], this second model has been proposed as a nonlinear two-dimensional map. Compared to the agent-based models, this second setup allows us to base the findings of the dynamics of segregation on a solid mathematical ground and to use the last developments of the bifurcation theory, especially border collision bifurcation theory, to describe the mechanisms that either lead to segregation or promote integration. Nevertheless, the second setup does not have the flexibility and the possibility to detail the preferences and the differences, especially in terms of level of tolerance, of each single agent. However, it can be used as a solid mathematical validation of the results of the more general agent-based models and can offer a valid interpretation of some of the phenomena, at first sight unexplainable, that can result due to the nonlinearity of the entry/exit dynamics.

These Schelling-type models are mainly based on the simple assumption of homogeneous distributions of tolerances of members of different groups. However, this is not always the case in real-world situations where the heterogeneity of the distributions of tolerances is a crucial aspect of the segregation dynamics. An empirical analysis conducted in the U.S.A. to study the propensity of individuals of different ethnic groups to live together in the same neighborhood reveals distributions of tolerance of different shapes for the different ethnic groups, see [1]. The main difference in the distributions of tolerance among ethnic groups is related to the maximum number of agents of the other groups that are tolerated. In particular, from the empirical results reported and commented in [1], it emerges that some ethnic groups are characterized by a small fraction of individuals that can stand the presence of any number of individuals of the other groups, while some other ethnic groups can stand only a limited number of individuals of the other groups.

With the aim of capturing and describing the effect of this heterogeneity, we imagine a city or a country populated by two groups of individuals. One group is the local population, which is characterized by a limited level of tolerance and the second group are newcomers, which are characterized by a subgroup of members that tolerate the presence of any number of members of the other group. We normalize to one the number of individuals of the local population and we assume that the newcomers are in fewer numbers than the individuals of the local population. The resulting tolerance distributions and the adaptive dynamics describing the entry/exit flows of the members of the local population and of the members of the newcomers are similar to the one proposed in [10].

The analysis of the model reveals that for both low levels and large levels of tolerances the segregation equilibria represent the only asymptotically stable fixed points of the model. On the contrary, for intermediate levels of tolerance an equilibrium of non-segregation can be asymptotically stable. However, this equilibrium always coexists with at least another asymptotically stable equilibrium of segregation.

The results can partially appear counter-intuitive, especially the fact that the dynamic investigation of the model reveals that segregation can be caused by an excess of tolerance. Nevertheless, this phenomenon has a simple and straightforward explanation in terms of mutually incompatible sets of preferences as suggested by Schelling. Indeed, the high levels of tolerance of newcomers, which combined with the high, but in any case limited, tolerance levels of the individuals of the local population, boost the first ones to enter in a massive way and force the last ones to leave the city or the country where they live.

In order to provide a valid solution to the segregation caused by large levels of tolerances, we introduce entry-limitation constraints which apply to the newcomers. These entry restrictions represent an entry-limitation policy imposed by regulators that turns out to promote integration between individuals of the two populations. Indeed, such an exogenous control reduces the risk of massive entry and exit dynamics, typical of emotional or impulsive reactions, resulting from unbalanced levels of tolerance between members of the local population and newcomers, that threaten the possibility to have integration. For obvious reasons, the entry-limitations can be imposed only to the newcomers. Indeed, it is difficult to imagine that a regulator can force part of the local population to leave the region in which it lives and moves to another place for the sake of integration.

Due to the introduction of the entry-limitations a new asymptotically stable equilibrium of integration (or non-segregation) can appear through a border collision bifurcation. Moreover, the entry-limitations have the effect of reducing the amount of chaos in the dynamics of the system. This occurs through a sequence of border collision bifurcations. Indeed, the entry-limitations have the effect of introducing a further curve of non-differentiability in a map that is already piecewise differentiable.

This characteristic of the map makes the model interesting also from a mathematical point of view. Indeed, the investigation reveals the existence of *border collision bifurcations*, see e.g. [13–30] and [31] for theory and applications in economics and social sciences, both of codimension-one and codimension-two, which combined with smooth bifurcations of different types (as saddle-node bifurcations and

[1] As suggested by an anonymous referee, Schelling's contribution is defined by Epstain and Axtell, see [7], as "an early and prescient example of agent-based modeling in the social sciences".

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