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Overlooked Implications of Ethnic Preferences for Residential Segregation in Agent-based Models

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Summary. We investigate the impact of preferences for co-ethnic contact on residential segregation and find support for the Schelling hypothesis that modest preferences can have significant consequences for segregation under certain conditions. Our findings temper and in some instances contradict Laurie and Jaggi's claim that expanding 'vision', the size of the immediate neighbourhood households consider when evaluating residential ethnic mix, makes stable integration a likely outcome in Schelling-like models with weak-to-moderate preferences. We note several reasons why our results differ from Laurie and Jaggi's. The most important of these is that Laurie and Jaggi underestimate the segregation-producing potential of weak-to-moderate preferences because they overlook a powerful interaction between preferences and ethnic demography and perform their simulations using the optimal ethnic mix for achieving integration. We show that the preferences Laurie and Jaggi describe as compatible with stable integration generate high levels of segregation in their model under settings for ethnic demography common in real cities.

In a recent paper in this journal, Laurie and Jaggi (2003) reported research that, in their view, requires that standard interpretations of Schelling's (1969, 1971, 1978) agent-based model of residential segregation be reconsidered and revised. If correct, their conclusions may have significant implications as the Schelling model is one of the most influential and celebrated agent-based models. It is seen as a valuable tool for investigating how micro-level residential choice behaviour can produce aggregate-level patterns of ethnic residential segregation and it is routinely cited as an exemplar of how relatively simple, micro-level behaviour can produce non-obvious emergent structure in spatial networks (Macy and Willer, 2002). Clark (1991), Krugman (1996), Young (1998), Epstein and Axtell (1996) and Wasserman and Yohe (2001) are among the many scholars and researchers who have explored different aspects of Schelling's model and endorsed his conclusions that integration tends to be an unstable condition in model systems and that high levels of segregation can occur even when no individual in the population wishes to reside in the type of ethnically homogeneous neighbourhood found in highly segregated cities.

Laurie and Jaggi extend Schelling's model by investigating how 'vision', a parameter governing the size of the immediate 'neighborhood' surrounding a residential location, affects segregation behaviour. They report that vision interacts with preferences to

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produce 'non-simple segregation behaviour' that includes *stable integration* under model specifications they view as relevant for residential segregation in urban areas. Accordingly, Laurie and Jaggi (2003, p. 2689) contend that their study provides evidence against "claims of inevitability of segregation in Schelling-like models" and claim to have "discovered that there is a large region of the parameter space" for preferences and vision "where integrated communities remain stable for arbitrarily long times" (p. 2690). They stress that this "stable regime does not correspond to some unrealistic, Gandhian levels of racial preferences/tolerances of the agents" but is consistent with "non-zero and quite substantive values" of preferences and can serve "to generate an optimistic outlook for the future of neighbourhood integration" (Laurie and Jaggi, 2003, pp. 2690–2691). Thus, they assert that "contrary to popular belief, rather modest decreases in xenophobia and/or preferences for one's own kind, *when coupled with increased vision*, can lead to stable and integrated neighbourhoods" and they suggest that

> The education community and other social agents who work to lower preference for one's own kind and to increase tolerance for the 'other', can take strong encouragement from this study (Laurie and Jaggi, 2003, p. 2703; original emphasis).

We commend Laurie and Jaggi on a number of counts. First, unlike some critics of the Schelling model, they show great respect for Schelling's contributions and the depth of his original insights. Even as they question conventional assessments of Schelling's theories, they note that Schelling himself was careful to recognise the limits of his contributions and showed subtle understanding of the complexity of the issues. Thus, where many have studiously ignored Schelling's work or dismissed it without engaging it in a direct way, Laurie and Jaggi take his model seriously; they seek to extend and refine it with the goal of gaining a better understanding of the potential linkages between individual preferences and segregation.

Secondly, Laurie and Jaggi display a welcome appreciation for the value of developing theory from the ground up by exploring models that are purposefully kept simple, at least initially, in order to gain a better understanding of the implications of the model. They resist the urge to introduce excessive 'realism' in their model before the complex behaviour manifest in simpler versions of the model are well understood. Instead, they are guided by the view that theoretical development is served well by elaborating established models in incremental steps to minimise problems in establishing cause and effect relations.

Thirdly, Laurie and Jaggi provide clear descriptions of how they implement and modify Schelling's model. The broader literature on residential segregation is replete with discussions of the relationship between preferences and segregation that offer strong conclusions without outlining a model that supports them or providing a basis for evaluating the conclusions in a rigorous way. In contrast, Laurie and Jaggi are clear and explicit about the components of their model and the key mechanisms that drive their findings. They give precise descriptions of how they implement preferences, urban structure, ethnic demography and agent behaviour involved in housing search and residential choice. In short, they provide the essential ingredients for cumulative scientific inquiry; a clearly specified model that facilitates replication and extension.

Fourthly, they show a nuanced understanding of how segregation in real urban systems is the product of many factors. They avoid contrived arguments pitting one factor against another when there is no basis for portraying them as mutually exclusive or competing explanations. Thus, while they recognise the role of factors such as economic inequality, housing discrimination and institutional forces in segregation dynamics, they pursue an intentionally restricted analysis aimed at gaining a better understanding of the linkages between preferences and segregation. This leads them to suggest policy options for reducing segregation—namely, enhancing available information about neighbourhood ethnic composition and promoting increased tolerance of residential contact with out-groups and reduced preferences for in-group contact—that would not necessarily be highlighted in analyses focusing on other factors contributing to segregation (such as mortgage loan discrimination, realtor steering, minority economic disadvantage).

We applaud the Laurie and Jaggi study for the reasons just enumerated and for the care of their analysis and the clarity of their exposition. However, we believe that close scrutiny of their implementation of Schelling's model leads to the conclusion that their findings must be interpreted more narrowly than their discussion suggests. Specifically, we conclude that, while Laurie and Jaggi's results are correct in most technical respects, the broad substantive implications they draw from their analyses must be discounted. First, their central findings hinge on very low settings for 'vision' that have limited relevance for *residential* segregation. Secondly, they adopt idiosyncratic model settings for ethnic demography and search that lead them to *underestimate* seriously the impact of preferences on segregation and the magnitude of the changes in preferences that may be needed to reduce segregation in real cities.

We establish the basis for our conclusions as follows. First, we introduce SimSeg, the simulation model we use to perform our analyses, and highlight points of similarity and difference between it and the model used by Laurie and Jaggi. Secondly, we replicate key findings from the Laurie and Jaggi study to show that the SimSeg model produces similar segregation behaviour when implementing model specifications that correspond closely with those used by Laurie and Jaggi. Thirdly, we introduce variations in the specification of search and of 'vision' to show how they influence model-generated segregation patterns. Fourthly, and finally, we introduce other variations in model specification to document that preferences and ethnic demography interact in a complex way that is both central to determining segregation behaviour in agent-based models *and* highly relevant to understanding *residential* segregation in real cities.

The SimSeg Model

The SimSeg programme is an agent-based model written by the senior author of this paper for the purpose of conducting simulation experiments exploring segregation dynamics (Fossett, 2003, 2004, 2005a). The characteristics and capabilities of the SimSeg programme have been outlined elsewhere (Fossett, 1998; Fossett and Senft, 2004), however, only a few are relevant to the analyses presented in this paper.[1] In this section of the paper, we briefly review the key points of similarity and difference between the agent-based model Laurie and Jaggi describe and SimSeg, the model we use. We then use the SimSeg model to replicate key findings from the Laurie and Jaggi study and show that our contradiction of their findings cannot be attributed to technical differences between the two models.

The first concept we consider is that of the 'agent'. In both models, agents are virtual households with the ability to search in a virtual housing market and make residential choices. Households possess binary ethnic status. Following Laurie and Jaggi, they are labelled either White or Black. Of course, these labels are arbitrary. Households have preferences for co-ethnic contact specified in terms of the percentage of co-ethnic households found in the 'neighbourhood' in which the household lives or to which it is considering moving. In the Laurie and Jaggi model, ethnic preferences are homogeneous within and across groups. In the SimSeg model, preferences may vary by ethnic group, a feature on which we draw in later analyses.

Households reside in housing units at fixed locations in a virtual city landscape. Housing units have no qualities other than occupancy status and neighbourhood ethnic composition. Searching households can only move to unoccupied housing units. When they move, they leave their origin housing unit unoccupied and it becomes 'available'. Their destination housing unit becomes occupied and 'unavailable'. In both models, housing units are arranged in a virtual 'city landscape'. In the Laurie and Jaggi model, the landscape consists of a 50×50 square grid with 2500 housing units. There are no boundaries of any kind in the grid. The apparent east–west boundaries of the visual representation of the grid are analytically treated as 'wrapping around' to meet each other. The same is true with regard to the apparent north–south boundaries. Thus, their landscape forms an 'edgeless torus'. SimSeg can also generate a landscape of this type. However, as is evident in figures presented in this paper, we prefer to use an alternative landscape in which housing units are organised into a roughly circular city form. In this implementation, housing units are grouped into 112 'bounded areas' in a neighbourhood grid and each area is sub-divided into a square 7×7 housing grid. This yields 5488 housing units and a virtual city landscape which has outer boundaries or 'edges' analogous to those of real urban areas. Laurie and Jaggi describe their 'edgeless torus' landscape as attractive because it suppresses 'boundary effects'—but we find no evidence that effects of this nature are important for any result we investigate here.[2]

In both models, the initial condition is one of random assignment of households to locations in the city landscape with 10 per cent of housing units being left vacant. By definition, residential location is not systematically linked with racial status, so the city landscape is 'integrated' at initialisation based on the notion of 'even' distribution (Massey and Denton, 1988). Laurie and Jaggi quantify this dimension of segregation using '*S*', which they describe as the "ensemble averaged, von Neumann segregation coefficient".[3] Laurie and Jaggi do not cite methodological studies, of *S* but state that it varies between 0 and 1 and is "closely related to the dissimilarity index" (Laurie and Jaggi, 2003, p. 2693). Methodological analysis by Fossett (2005b) shows that *S* is equivalent to Bell's (1954) familiar revised index of isolation (*R*) and also is closely related to the well known eta-squared index (η^2). We also found that *S* exhibits a strong correlation with the index of dissimilarity (*D*) computed using an individual-level computing formula for site-centred areas given in Fossett (2005b).[4]

Our methodological analysis showed that the values of all three site-centred measures, *S*, η^2 and *D*, were higher when the size of the immediate neighbourhood used in segregation calculations was small. This raises a methodological question: does the choice of segregation measures influence substantive findings in agent-based models? Laurie and Jaggi measure segregation using *S* computed for minimal von Neumann neighbourhoods and do not report results for other measures or 'scales' of segregation. Happily, our methodological analysis found that: scores for D, *S* (R) and η^2 computed using the site-centred areas correlated closely with each other when computed at different spatial scales; and, these scores also correlated closely with scores computed using data for the 112 bounded areas in the city landscape.[5] In view of this, we report the index of dissimilarity (*D*) computed from data for bounded areas. The measure is familiar; it leads to identical substantive conclusions; and computing it for bounded areas reduces the computational burden in our simulations.

One final comment on measuring segregation, Laurie and Jaggi describe *S* as being normed against the expected value under random assignment. We draw on Winship (1977) to apply a transformation formula that norms *D* against its expected value under random assignment. Due to the norming procedures, both *S* and *D* can take on negative values. When this occurs, it indicates that the city is *more* integrated than would be expected under random assignment.

In both studies, the central variables in the analyses are the ethnic composition (*C*) of the city, the range of 'vision' (*R*) defining the size of immediate neighbourhoods and preferences for co-ethnic contact (*P*). Laurie and Jaggi characterise these as "the interesting, essential and dominant independent variables in this model" (p. 2703, note 6). Laurie and Jaggi set the city ethnic composition (*C*) to 50 per cent black ($C = 50$) in all of their analyses.[6] They offer several reasons for this choice. They state that "the model has been intentionally kept symmetrical between the two races" to further the study's goal of understanding the effect of vision (p. 2692) and "because it is the prototypical case and has been the focus of much earlier work" (p. 2693). Finally, they suggest that they chose this value "to concentrate on the *worst-case* scenario" (p. 2969; emphasis added). For purposes of replicating Laurie and Jaggi, we also set the city ethnic mix to 50/50. In later analyses, we vary ethnic mix. We do so for three reasons: to highlight the fact that it is a crucial factor conditioning the impact preferences for co-ethnic contact have on segregation outcomes; because imbalanced ethnic ratios are typical in real cities; and to show that the 50/50 ethnic mix, far from being the "worst-case" scenario, is *optimal* for obtaining stable integration.

Laurie and Jaggi specify 'immediate neighbourhoods' based on the value of R. 'R-neighbourhoods' are site-centred regions consisting of the housing units that can be reached by travelling R spaces by cardinal moves from a chosen point. These neighbourhoods assume the form of 'diamond-shaped' areas where the vertices of the diamonds extend out R units from the focal housing unit on the points of the compass. For the purposes of this paper, we also implement site-centred neighbourhoods in this way.[7] The approach yields neighbourhoods that are very small when R is 1 and that rapidly increase in size as R increases. We also implement vision using 'bounded areas', neighbourhoods with fixed boundaries, and find that results obtained using this specification are similar to those obtained using large-R site-centred neighbourhoods.

Laurie and Jaggi specify an agent's preference for co-ethnic contact (P) as the minimum percentage of same-race agents it must find among the residents of its immediate neighbourhood to be 'satisfied'. In their simulations, preferences are homogeneous and symmetrical; that is, the value of P is constant within and across ethnic groups. They vary the value of P from a minimum of 20 per cent to a maximum of 50 per cent. In our initial simulations replicating Laurie and Jaggi, we set the SimSeg model to implement ethnic preferences as they do. In later analyses, we vary the implementation of preferences in two ways: we allow P to vary over a much wider range and we allow P to take different values for different groups.

Laurie and Jaggi specify a search process that proceeds as follows. An agent is selected at random and it 'evaluates' the ethnic mix in its immediate neighbourhood (C_N). If the agent is 'satisfied' (if $C_N \geq P$) it does nothing. If the agent is not satisfied, it attempts to move by randomly selecting available housing units and evaluating them in the same manner. If the agent discovers an available unit with an immediate neighbourhood that would allow it to improve its satisfaction, it moves creating a vacancy at its origin location. This process continues until a static 'equilibrium' is reached; that is, until movement ceases because no household is able to improve their satisfaction by moving. This specification has two characteristics that we consider in more depth later in the paper. One is that it has no mechanism of population turnover; households are 'immortal' and thus a satisfied household can reside in the same location *for ever.* The other is that households move only to improve satisfaction and, in a given simulation, *may never move from their initially assigned locations.*

For purposes of replicating Laurie and Jaggi, we specify a similar search process using the SimSeg model. During a period of activity termed a 'cycle', households are selected at random and given the opportunity to evaluate their immediate neighbourhood and compare it with the immediate neighbourhoods for a set of a dozen vacant housing units selected at random. The household will move if it discovers a vacant housing unit that is more 'satisfying'. If more than one of the evaluated units is 'more' satisfying, the household will move to the one that is 'most' satisfying. The evaluation process continues until a number equalling 25 per cent of all households have been given the opportunity to move. This ends the 'cycle'. The process is repeated for a sufficient number of cycles to establish a static equilibrium.[8]

In the analyses featured in this study, we use a modified version of this search process. The modification is simple: households are required to move the first time they are selected for search even if the housing options they encounter are less 'satisfying' than their initially assigned location. This rule ensures that every household will move at least once during the simulation experiment and thus at the end of the simulation all households will reside in a location they identified and selected through search.[9] The modification is simple but, as we show below, has important consequences for segregation outcomes.

Replicating Laurie and Jaggi

The previous section noted many points of similarity between the Laurie and Jaggi model and the SimSeg model and also several differences. SimSeg's implementation of the city landscape corresponds more closely with real urban form, while Laurie and Jaggi's landscape hews closely to stylised forms used in agent-based modelling. Likewise, the measurement of segregation in SimSeg follows conventions in the demographic research literature on residential segregation while Laurie and Jaggi use the less well known '*S*'. In this section of the paper, we demonstrate that these differences do not appear to be consequential for our ability to replicate Laurie and Jaggi's central findings using the SimSeg model.

Figure 1 presents the results of three representative simulation experiments that replicate the first set of results in Laurie and Jaggi's study. Panel 1 shows the unsurprising result that when households have no preferences for co-ethnic contact, segregation does not emerge.[10] Panel 2 shows that, when households seek 50 per cent co-ethnic contact and vision is specified to the very low value of $R = 1$, the experiment produces what Laurie and Jaggi term 'small-domain' segregation characterised by dendritic

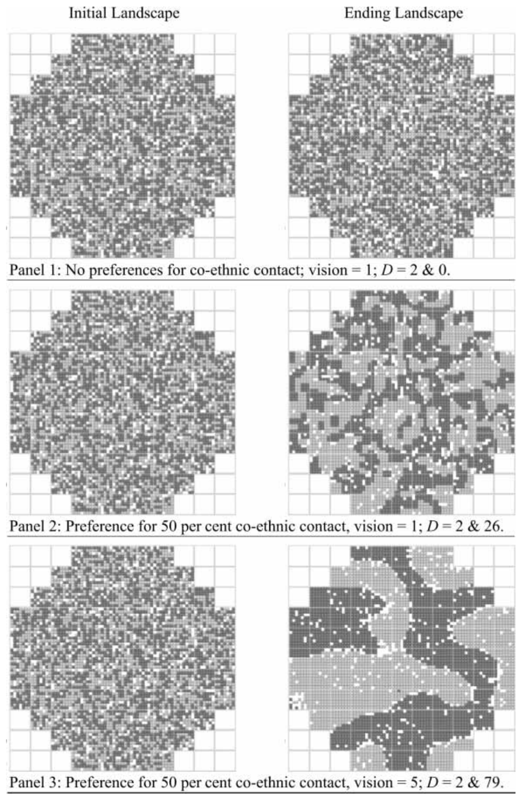

Figure 1. Initial and final landscapes from simulations replicating Laurie and Jaggi's analyses investigating how vision conditions the impact of preferences under 50/50 ethnic mix.

regions of ethnic homogeneity. Panel 3 shows that, if vision is changed to the higher value of $R = 5$, it produces a much higher level of segregation with extensive 'ghettos' (a term they use). These results correspond closely with results Laurie and Jaggi present (in their Figure 3). There is no indication here that our representation of the city landscape or our use of a modified search process causes results generated by the SimSeg model to differ in any important way from those reported by Laurie and Jaggi.

Figure 2 presents final landscapes from representative simulation experiments replicating the analyses that Laurie and Jaggi present (in their Figure 4). These analyses explore how preferences for co-ethnic contact interact with vision in their model. In all simulations, the initial landscape (not

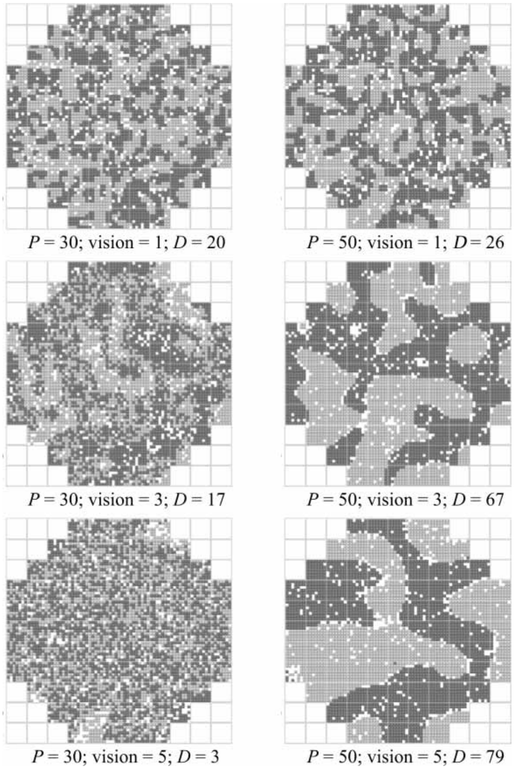

Figure 2. Ending landscapes from simulations replicating Laurie and Jaggi's analyses investigating the interaction of preferences for co-ethnic contact and vision.

shown in these figures) is characterised by segregation near 0.0. The results in column 1 show that, when households have low preferences for co-ethnic contact ($P = 30$), the level of segregation in the ending landscape *declines* as vision increases from $R = 1$ to $R = 3$ to $R = 5$. Furthermore, when vision reaches $R = 5$, the ending landscape has extremely low segregation. In contrast, the results in column 2 show that, when preferences for co-ethnic contact are set at a moderate level ($P = 50$), the level of segregation in the ending landscape *increases* as vision increases and stands at a very high level when vision reaches $R = 5$.

Note that the simulations presented in Figures 1 and 2 use our modification of the Laurie and Jaggi search process. In an expanded version of this paper (Fossett and Waren, 2004b), we also present results of simulations using Laurie and Jaggi's search rule. In the interests of economy of presentation, we omit these and many other results replicating Laurie and Jaggi's analyses and limit our discussion to the results we view as central to their substantive conclusions.

Laurie and Jaggi (2003) interpret their finding of an interaction between vision and preferences results as lending "theoretical support to two specific policy initiatives" for reducing segregation: one is to increase 'vision' by improving "the availability and the flow of housing market information" and the other is to encourage reductions in preferences for co-ethnic contact that would make home-seekers more willing to "consider alternative neighbourhoods where their own race is not concentrated" (2003, pp. 2697–2698). We do not strictly disagree with Laurie and Jaggi's findings or with their general policy recommendations. However, we argue that they should be qualified and placed in broader context.

We view their first policy recommendation as largely moot since households routinely use non-minimal vision in making location decisions. For example, households take account of the ethnic mix of sub-divisions, school districts, suburbs and a variety of other moderate to large-scale bounded and site-centred areas. We know of no basis for assuming otherwise.

Regarding the second policy recommendation, we go on to show that Laurie and Jaggi seriously underestimate the segregation-promoting potential of preferences and thus the magnitude of the social change needed to eliminate the impact of preferences for co-ethnic contact on segregation. We establish these and other points by exploring variations of the Laurie and Jaggi model. Our analyses lead us to conclude that Laurie and Jaggi's central findings and the interpretations they assign to them must be qualified in two important respects. One is that, when specifications of vision and search move away from idiosyncratic implementations used in the literature on agent-based modelling and towards forms consonant with substantive theory and research on residential segregation, the impact of preferences on segregation becomes stronger and more robust and interactions involving vision take on much less importance.

The other needed qualification we identify is that, when ethnic demography is varied to include values typical in real cities, it produces higher levels of segregation than Laurie and Jaggi suggest because they overlook an important fact—ethnic demography conditions the impact of preferences on segregation and causes the 50/50 ethnic mix they use in their simulations to yield the most *optimistic* results possible for integration.

Commentary and Critique of Laurie and Jaggi's Model Specifications

Researchers drawing on simulation methods must make many choices. One option is to strive for realism to enhance the ability to draw implications for empirical systems. Laurie and Jaggi follow an alternative strategy of making small changes to a simple but well understood model. They are clear about why they do so; it ensures that their model is similar to those used in previous studies in the literature on agent-based simulations. The benefit of this is that it makes clear what effects are produced by manipulating 'vision'. In this regard, Laurie and Jaggi's choices are reasonable and their conclusions about the consequences of varying vision are sound *in the context of the specific models they investigate*. However, Laurie and Jaggi do not limit their discussion of the consequences of varying vision to the context of the stylised models found in the literature on agent-based simulations. They explicitly suggest that their results have broader relevance for understanding residential segregation in real urban systems. When they do so, it leaves them open to criticism regarding whether their model specification choices are well-suited for the purpose of investigating residential segregation dynamics.

We note that Laurie and Jaggi, like most researchers who have used agent-based models to explore segregation, are not specialists in segregation. Their study is not anchored in substantive theory and research on residential segregation, but rather in previous research using agent-based models.[11] Accordingly, they give more attention to how their model compares with previous agent-based models and less attention to issues concerning the relevance their model may have for residential segregation. Consider—for example, Laurie and Jaggi's rationale for implementing the city landscape as a 'torus'. They defend this choice by stating that their goal is to understand the consequences of varying vision while "minimising computational artefacts" (Laurie and Jaggi, 2003, p. 2692). But their choice of the torus only makes sense if 'computational artefacts' are identified in terms of departures from previous research using agent-based models; not in terms of maximising model relevance for residential segregation. If 'edge' effects are in some way important for segregation outcomes, adopting the torus landscape may well *reduce* the relevance of the model for understanding segregation in real cities since they have 'edges'.

Happily, we do not find any evidence that this particular choice is crucial to the relationships that interest us.[12] But our point about the general orientation of their study stands as we can offer similar comments regarding their choices to implement a 50/50 ethnic mix; definitions of neighbourhood that are very small and do not consider bounded areas; and a search process where households can occupy the same housing unit forever, in some cases without ever moving based on search. These choices are not strongly grounded in the broader literature on residential segregation but instead follow practices in the literature on agent-based models.

We do not necessarily object to Laurie and Jaggi's model specification choices *so long as they place their model-generated results in proper perspective.* Thus, we do not criticise their findings regarding the complex interaction of vision (R) and preferences for co-ethnic contact (P). We can replicate these findings and note below that we believe they may be relevant to understanding segregation dynamics in certain situations; specifically, situations that are short in duration and involve *only* local spatial scales. We grow concerned, however, when Laurie and Jaggi offer their analyses as a basis for understanding patterns of *residential* segregation. In our view, the model settings they investigate limit their ability to speak to this subject. Indeed, their model specification choices *obscure* some of the Schelling model's most important implications for *residential* segregation. For example, in the 'real' world, cities have imbalanced ethnic mixes, population turnover is continuous and non-minimal neighbourhoods are relevant to location decisions. We now go on to show that model specifications crafted to reflect these patterns generate results that either diminish the relevance of Laurie and Jaggi's central findings or contradict them altogether by providing strong support for the view that moderate preferences for co-ethnic contact can produce high levels of segregation under a wide range of substantively plausible conditions.

Observations on the Laurie and Jaggi Search and Movement Process

The search and movement process in Laurie and Jaggi's model drives the city landscape to a static equilibrium where all household movement has ceased. The residential distribution 'freezes' for eternity for two reasons; households move *only* when they can improve their 'satisfaction' and households are 'immortal' and, if satisfied, can occupy the same residence *for ever*. This differs significantly from real residential systems which have continuous residential turnover and movement resulting from demographic processes of migration and household lifecycle dynamics. The absence of these basic population dynamics attenuates the creation of *random* vacancies in the Laurie and Jaggi model and suppresses movement. Consequently, their search process can generate 'equilibrium' residential patterns that are idiosyncratic and misleading with regard to segregation dynamics.

This can be seen by considering what happens when the Laurie and Jaggi model is run for a city with a $50/50$ ethnic mix, with vision set to $R = 7$ and with preferences for co-ethnic contact set to 0 ($P = 0$). Since households move only to improve their satisfaction and all are satisfied at initialisation, no residential movement will occur. The initial city landscape and the final city landscape will be one and the same because the city is in static equilibrium at initialisation. Superficially, the result is consistent with Laurie and Jaggi's conclusion that weak preferences for co-ethnic contact are compatible with integration. However, *their model also implies that weak preferences are compatible with complete segregation.* To see this, make one change to the above simulation: initialise the city landscape to be segregated rather than integrated by packing all households from one group into a single, circular 'ghetto' at the centre of the landscape.[13] Under the Laurie and Jaggi search process, no residential movement will occur. No household can improve its satisfaction by moving and the city will remain unchanged and perfectly segregated! Thus, preferences that obviously would permit complete integration to emerge under regular population movement will not be registered by the Laurie and Jaggi model.

This shows that Laurie and Jaggi's basis for optimism about the possibilities for integration under regimes of modest preferences for co-ethnic contact is tied in a crucial way to the initial conditions of their model. Under their specification of residential search and movement, integration thrives under modest preferences for co-ethnic contact *only if the city is initially integrated.* Their model provides no basis for optimism about the possibilities for reducing segregation in *real* cities. On the contrary, a literal interpretation of the implications of the Laurie and Jaggi model suggests that *pre-existing* segregation would not decline even if preferences for co-ethnic contact were eliminated entirely. We do not take this implication of their model as a meaningful basis for understanding segregation in real cities. We note it only to show that the Laurie and Jaggi search process is not a good choice for exploring segregation dynamics. A model that implies that segregation is an equilibrium state when all households are indifferent from neighbourhood ethnic mix is unsatisfactory. Segregation in such a situation is inherently unstable and will give way to integration if any demographic process is operating to produce household movement. We believe that a satisfactory model of segregation dynamics should be capable of revealing this fact.

The SimSeg model meets this requirement by implementing alternative search processes. As a general rule, we prefer a search process that represents demographic dynamics that produce the continuous population turnover and random vacancies seen in real residential systems.[14] For the purposes of this paper, however, we introduce only a small modification to the Laurie and Jaggi search process. Specifically, we require only that households move the first time they are selected for search. After their initial move, the households are then guided by the original logic of the Laurie and Jaggi search process and move again only to increase satisfaction. Under this process, the city landscape will move towards a static equilibrium in which movement ceases.

This alternative process has important implications for segregation patterns in many situations. Consider, for instance, the situation described above where households are indifferent from neighbourhood ethnic mix ($P = 0$) and the city is initialised as perfectly *segregated.* Under the original Laurie and Jaggi process, the city is in static equilibrium at initialisation and no households move. Under our process, every household moves once and the city undergoes a rapid and complete transition from segregated to integrated.[15] Under our search process, a household searching for the first time randomly surveys available vacancies and takes the first one it finds since all ethnic mixtures will be ‘satisfying’. Since moves are random with respect to ethnic mix, the process is strongly integration-promoting. Movement ceases when all households have been selected for search at least once. The final city landscape is integrated and, in contrast to Laurie and Jaggi’s model, the final distribution of households is determined by preference-guided search, not initial assignment by an outside entity. This modified search procedure yields a substantively sensible outcome in this situation and, as noted earlier, we can replicate Laurie and Jaggi’s central findings using this search procedure.[16] Thus, we conclude that it is a superior alternative for investigating the impact of preferences on residential segregation.

Implications of the Relevance of Non-minimal Neighbourhoods

Laurie and Jaggi’s findings about non-simple segregation behaviour deriving from the interaction of vision and ethnic preferences apply only in the restricted parameter space where agents consider ethnic mix in *only* small, immediate neighbourhoods. A fundamental condition must be met for this model parameterisation to have practical relevance for *residential* segregation: it must be plausible to assume that households consider ethnic mix *only* in relation to minimal, immediate neighbourhoods ($R \leq 2$). Laurie and Jaggi do not stress this point. They also do not provide any basis for assuming that real households will ‘restrict’ their vision in this way when taking account of ethnic concerns in residential decisions. In our view, this possibility is implausible. Casual and systematic observation alike suggest that households are sensitive to the ethnic mix of a variety of non-minimal neighbourhood contexts including ‘bounded areas’ such as city blocks, apartment complexes, sub-divisions, school districts and suburbs. We know of no accepted basis for viewing non-minimal neighbourhoods as irrelevant for residential location decisions and note that Schelling’s (1971) paper, which serves as a significant point of departure for the Laurie and Jaggi study, gives bounded neighbourhoods extended treatment.

On this basis, we conclude that the interaction between vision and preferences documented in Laurie and Jaggi’s study has little relevance for *residential* segregation. Note that this conclusion stands even if the ethnic mix of minimal, immediate neighbourhoods *is* salient in residential decisions. Residential decisions may involve considerations of ethnic mix in both small *and* large neighbourhoods; there is no need to portray the issue as involving an 'either–or' choice. But the segregation behaviour Laurie and Jaggi document under conditions of minimal vision is manifest *only* when non-minimal neighbourhoods are strictly irrelevant.

We hasten to note that this does not mean that Laurie and Jaggi's careful analysis of how segregation behaviour varies when vision is restricted to small immediate neighbourhoods is without value. Indeed, we believe their work may be relevant for understanding segregation in small, short-duration situations such as seating patterns in auditoriums and school lunch-rooms and conversation groups at social gatherings. The key is that it may be plausible in these situations to assume that non-minimal neighbourhoods are strictly irrelevant.

The Interaction of Preferences and Ethnic Demography

The previous section outlines our basis for concluding that, for residential segregation, the most important interaction in the Laurie and Jaggi model is *not* the interaction of vision and preferences. This section outlines our basis for a second conclusion: the most important interaction in agent-based segregation models is one that Laurie and Jaggi do not consider at all; it is the interaction between ethnic demography and preferences.

Schelling (1971) pointed out that the impact of preferences on segregation is conditioned by ethnic demography, but Laurie and Jaggi hold ethnic demography constant in their simulations. They characterise the 50/50 mix they use in their simulations as a 'worst-case' scenario for achieving integration.[17] In fact, this ethnic mix is *optimal*. To see this, assume that perfect integration is achieved by strategically arranging households to ensure that ethnic mix is uniform throughout the city landscape. In this situation, all households will experience the same ethnic mix. Since all households in the Laurie and Jaggi simulations are assigned the same preference for co-ethnic contact (P), universal satisfaction results when P is compatible with the ethnic mix of the city. Specifically, universal satisfaction occurs when $P \leq \min[C, (100 - C)]$.[18] The highest level of P that is compatible with universal satisfaction under integration is determined by the value of $\min[C, (100 - C)]$. This reaches its maximum value of 50 when the ethnic mix is 50/50.

Based on this, the 50/50 city is hardly a 'worst case'; it can sustain universal satisfaction with integration at higher levels of P than any other ethnic mix. This is a finding Schelling specifically noted (Schelling, 1971, pp. 148, 179). In contrast, consider a 90/10 ethnic mix which is not uncommon in real cities. Integration in a city with this ethnic mix can be universally satisfying only when preferences for co-ethnic contact are within the range of 0–10 per cent. If desired co-ethnic contact rises above 10 per cent, all households in the smaller group will be dissatisfied under integration. For example, if P is set at 50 in this city, there would be considerable *latent* potential for segregation to emerge since all members of the smaller group would be 40 points shy of attaining their preferred level of co-ethnic contact.

In the Laurie and Jaggi model, dissatisfaction occurs when co-ethnic representation falls short of preferred co-ethnic presence and it increases monotonically as the discrepancy increases. Consequently, integration produces dissatisfaction for all members of a group when the group's population percentage falls below their desired level of co-ethnic contact and the level of the dissatisfaction will vary directly with the magnitude of the discrepancy. Guided by the assumption that integration is less stable when it produces higher levels of dissatisfaction, we advance two hypotheses regarding segregation behaviour in agent-based models where groups hold symmetrical, homogeneous preferences, as they do in the Laurie and Jaggi study, and where households consider ethnic mix in non-minimal neighbourhoods.

H1. Segregation is likely to emerge when the relative size of any group falls below the prevailing preference for co-ethnic contact.

H2. The level of segregation should vary directly with the size of the discrepancy between the 'demand' for co-ethnic contact and the demographic 'supply' of co-ethnic neighbours under conditions of integration.

We present evidence supporting these hypotheses below. Before introducing these results, however, we first point out that these hypotheses cannot be adequately tested using the Laurie and Jaggi model because it can produce pathological results in simulations where city ethnic mix departs from 50/50. We discuss this point at length in an expanded version of this paper (Fossett and Waren, 2004b). In the interests of space, we present only a brief summary here.

In a nutshell, the Laurie and Jaggi model is unsatisfactory because it can yield integration as an 'equilibrium' outcome even when there is widespread dissatisfaction with neighbourhood ethnic mix and tremendous 'latent' potential for segregation-producing movement. The problem traces to the fact that the Laurie and Jaggi model provides inadequate opportunities for households to act on their residential preferences. Schelling (1971, p. 154) noted that "fair freedom of movement" is crucial to expression of segregation potential in simulations of the sort Laurie and Jaggi explore. The key to this is the availability of vacancies which would give households the opportunity to act on their preferences. Schelling recommended using a vacancy rate of 25–30 per cent to ensure this. Laurie and Jaggi implement a much lower vacancy rate of 10 per cent and provide no alternative mechanism for generating vacancies that would permit households to exercise choice. As a result, their model 'short circuits' segregation-promoting residential movement in a way that Schelling specifically warned against.

The nature of the pathology can be outlined with a simple example. Consider a simulation with the following characteristics: ethnic mix is set at 90/10, *P* is set at 50 (i.e. all households prefer 50 per cent co-ethnic presence), the vacancy rate is set at 10 per cent and vision (*R*) is set at 5 which yields neighbourhoods containing 60 housing units. Under initial random assignment, each neighbourhood will, on average, have 6 vacancies and 54 occupied units. Of the occupied housing units, 48–49 will be occupied by households from the larger ethnic group and 5–6 will be occupied by households from the smaller ethnic group.

Households from the larger ethnic group are all satisfied (their ethnic preference is met); they will not move unless the neighbourhood ethnic mix changes dramatically. Households from the smaller ethnic group are all dissatisfied; they are motivated to move to neighbourhoods where their group is better represented. Random variation in neighbourhood ethnic mix will create neighbourhoods that depart slightly from the 90/10 ratio. Households from the smaller group will systematically move to neighbourhoods where their group's representation is greater. But movement will quickly cease. The reason is simple. Neighbourhoods have only a few vacancies (6 on average), so the destination neighbourhoods quickly fill up with households from the smaller group (they are the only households moving). At that point, all movement ceases. neighbourhoods gaining population will have an ethnic mix around 80/20 and no vacancies; neighbourhoods losing population will have an ethnic mix of 100/0 and 20 per cent vacancies. No neighbourhood will have an ethnic mix that will satisfy households from the smaller ethnic group. Thus, all households from the smaller group will be dissatisfied, but they cannot move due to the absence of vacancies in the neighbourhoods they prefer. A static equilibrium obtains with low levels of segregation.[19]

This is a pathological outcome because it is obvious that the residential pattern is inherently unstable. Considerable latent potential for segregation exists (every household in the smaller group is unsatisfied and willing to move), but it is not expressed because movement is artificially restricted by the scarcity of vacancies. This limits the relevance of the Laurie and Jaggi search model for *residential* segregation. In real residential systems, households are not immortal and eternally immobile as households from the larger ethnic group are in the above example. On the contrary, basic demographic processes such as migration and household life-cycle dynamics generate steady population 'turnover' wherein some households exit the population and are replaced by new households. Significantly, these demographic processes produce *regular random vacancies in all areas of the city*. The occurrence of such vacancies is all that is needed to 'unleash' the latent potential for segregation in the situation just described.

Accordingly, simulation models of Schelling segregation dynamics must adopt one of two practices. They must hew closely to Schelling and implement vacancy rates sufficient to permit preferences to be exercised; or, they must provide a mechanism for the creation of vacancies that will accomplish the same objective. Laurie and Jaggi's model is unsatisfactory in this regard. The simple modification we introduce to the Laurie and Jaggi search algorithm is sufficient to unleash the latent potential for segregation in the situation described above. The modification requires all households to move on first search so that they will ultimately reside in a location they chose through search (not initial assignment). This creates vacancies throughout the city which in turn provide opportunities for households to act on their ethnic preferences. Significantly, it leads to a fundamentally different equilibrium landscape characterised by high levels of segregation.

In our view, the Laurie and Jaggi search process is inadequate for investigating the dynamics of *residential* segregation. It assumes away basic demographic events which are ubiquitous in real cities and which can be demonstrated to play an important role in segregation dynamics.[20] Households move for a host of reasons unrelated to ethnic concerns and thus *all* neighbourhoods experience regular, on-going population turnover. Research on ethnic succession establishes that this plays a crucial role in neighbourhood ethnic transitions; neighbourhoods undergo succession in large part because they lose their ability to fill regularly occurring vacancies with new entrants who reproduce the social characteristics of the households who are exiting.

In fairness to Laurie and Jaggi, we stress that our objection to their model centres on the crucial issue of whether it is adequate for modelling segregation dynamics in *residential* systems. We believe it is not. However, it may be entirely appropriate for modelling segregation in other situations. For example, seating patterns in a high school cafeteria or a basketball gymnasium are not necessarily subject to the regular creation of vacancies. As seats begin to fill up, agents settle into vacancies that offer 'satisfying' ethnic mixes among immediate neighbours. They may also have opportunities to move if they become dissatisfied with the ethnic mix of their neighbours. However, the seating arrangement will eventually 'freeze' into a stable equilibrium that will not be perturbed until the lunch hour or basketball game is over. Thus, it is possible that the segregation outcomes we view as implausible for residential systems may be relevant for other social contexts.

Central Analyses

We now turn to a more systematic investigation of segregation outcomes under varying conditions of ethnic demography and specifications of vision. To begin, Figures 3–5 present results from four sets of simulation experiments that lend preliminary support to our hypotheses. Preferences for co-ethnic contact are fixed at a low level of 30 per cent in all four sets of experiments. Within each set, the ethnic mix of the city is varied from 90/10 to 75/25 to 65/35 to 50/50. Each of the four sets implements a different specification of vision. The search process in all of the simulations is our modified version of the Laurie and Jaggi algorithm that requires households to move on first search and thereafter only to improve satisfaction.

We begin by considering the results obtained when vision is specified in terms of site-centred, immediate neighbourhoods where vision is set to $R = 5$. Experiments based on this specification are presented in Figure 3. The pattern is straightforward: the level of segregation is a function of the discrepancy between ethnic demography and preferences. Thus, the highest level of segregation is seen when the ethnic mix is 90/10 ($D = 72$) and segregation declines steadily as the ethnic mix moves closer to 50/50 ($D = 3$). This is exactly the pattern predicted by our hypothesis.

Figure 4 presents a set of experiments that implement a variant of vision where households evaluate housing choices based not on ethnic mix for site-centred immediate neighbourhoods, but on ethnic mix *within* bounded areas. We view this implementation of 'vision' as interesting for substantive reasons reviewed earlier and note that Schelling (1971) explicitly recognised the relevance of bounded areas in his writings on segregation dynamics. One impact of implementing vision in this way is that ethnic settlement patterns tend to follow the borders of bounded areas and thus area-to-area transitions in ethnic mix are sometimes abrupt. This kind of pattern is not uncommon in real cities where ethnic mix sometimes changes abruptly with sub-division or school district boundaries. Significantly, the findings for segregation obtained using this implementation of vision correspond closely with those obtained using Laurie and Jaggi's implementation of vision (with $R = 5$). Values of D are higher using the bounded area implementation of vision, but only because we calculate D from these very same fixed areas. The central pattern is the same: segregation levels decline as city ethnic mix declines from 90/10 to 50/50.

The results for the experiments shown in Figure 5 also manifest this pattern. These experiments use a variation in the implementation of vision where households evaluate housing choices based on both the ethnic composition of bounded areas and of *adjacent* bounded areas.[21] This implementation of

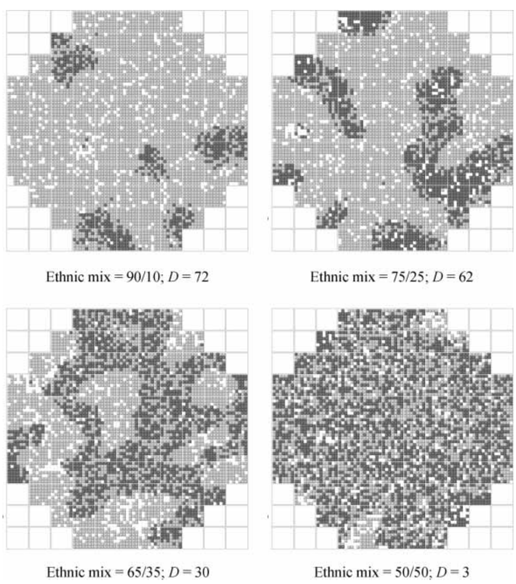

Figure 3. Ending landscapes from analyses where ethnic mix is varied with preferences for co-ethnic contact set at 30 per cent and vision set at $R = 5$.

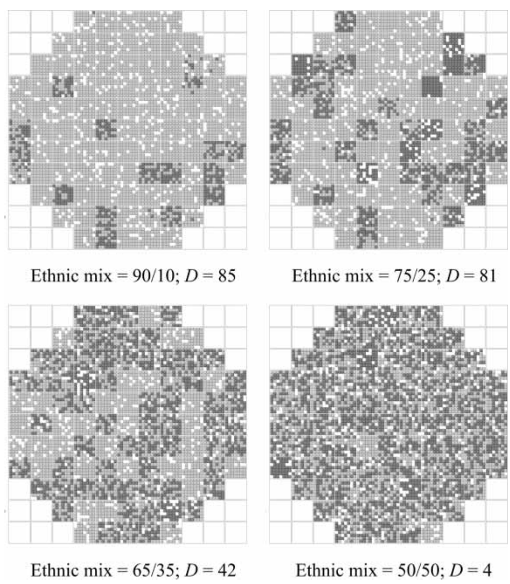

Figure 4. Ending landscapes from analyses where ethnic mix is varied with preferences for co-ethnic contact set at 30 per cent and vision uses bounded areas.

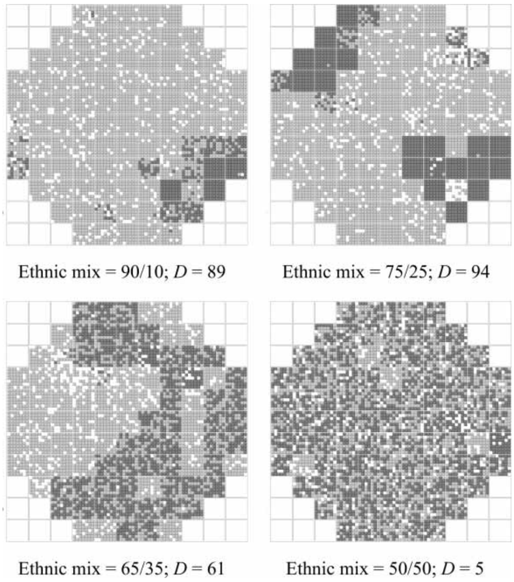

Figure 5. Ending landscapes from analyses where ethnic mix is varied with preferences for co-ethnic contact set at 30 per cent and vision uses bounded areas and adjacent areas.

vision produces the highest levels of segregation seen in these figures. It also produces strong patterns of clustering not unlike those seen in many cities.

The results in Figures 3–5 support a clear finding; when vision involves moderate-to-large spatial domains, segregation takes on high values whenever 'demand' for co-ethnic contact exceeds the demographic 'supply'. Implementing vision as site-centred, immediate neighbourhoods with a moderate R setting of 5 produces slightly lower levels of segregation and clear patterns of clustering.[22] Vision implemented in terms of bounded areas produces intermediate levels of segregation, but with 'chequerboarding' instead of clustering.[23] Implementing vision in terms of both bounded areas and adjacent bounded areas produces a similar pattern with higher levels of segregation and pronounced patterns of clustering.

The variations across these three specifications suggest that the impact of vision differs when 'bounding' is involved. Bounding refers to whether vision follows isolated fixed regions or is site-centred. This aspect of vision has implications for the dimension of segregation known as clustering. Implementing vision based on site-centred areas with $R = 5$ produces clustering in the simulations shown in Figure 3 as regions of ethnic homogeneity grow and connect to each other. In Figure 4, strict bounding, the limitation of vision to single bounded areas, produces visual evidence of 'chequering', a pattern where ethnic mix of adjacent bounded areas is uncorrelated. In Figure 5, implementing vision based on the hybrid combination of the bounded area *and* its adjacent bounded areas produces especially strong patterns of clustering. The principle appears to be that clustering emerges when vision is site-centred in some respect.[24]

In the simulations presented here, uneven distribution and clustering are most pronounced when vision is based on bounded areas and adjacent bounded areas. But, this is primarily due to the fact that the ring of adjacent bounded areas covers a large expanse of up to 392 housing units. Vision involving site-centred areas of this scale produces especially high levels of segregation when preferences are segregation-promoting (for example, with ethnic ratios of 90/10, 75/25 and 65/35). Thus, for example, in simulations not reported here, we found that equally high levels of uneven distribution and clustering were produced when vision was implemented using site-centred neighbourhoods delimited by large values of R (such as $R = 10–15$).[25] This points to the need to modify Laurie and Jaggi's findings regarding the interaction of vision and segregation. They correctly find that moving from minimal- to moderate-scale vision helps to retard segregation when preferences are compatible with integration. But movement from moderate- to wide-scale vision produces higher segregation when preferences are segregation-promoting.

The results shown in Figure 6 are based on experiments where vision is implemented as the minimal, four-unit, von Neumann neighbourhood ($R = 1$). They document a pattern that runs counter to the results obtained

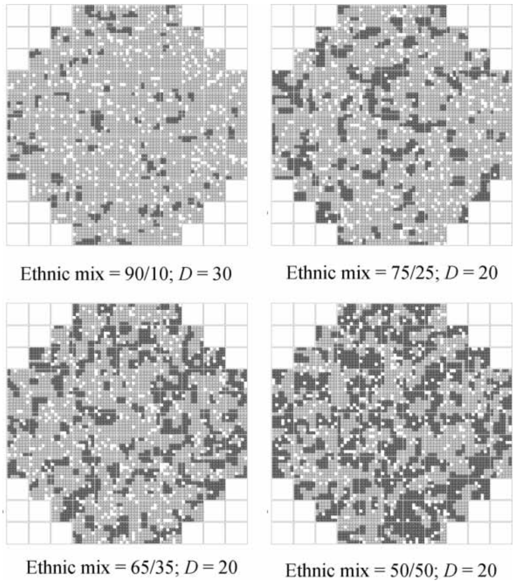

Figure 6. Ending landscapes from analyses where ethnic mix is varied with preferences for co-ethnic contact set at 30 per cent and vision set at $R = 1$.

using the three previous specifications for vision. When vision is specified this way, our hypotheses are not supported. As the example landscapes show, segregation changes little as city ethnic mix moves from 90/10 to 50/50.

The 'vision' implemented in these simulations is the minimum that can be specified and, in our view, should be seen as a special case.[26] As Laurie and Jaggi note, this setting for vision tends to produce small-domain segregation that forms a dendritic pattern with 'snaking' ribbons of ethnic homogeneity running randomly through the bounded areas of the SimSeg city landscape. This 'small-domain' segregation tends not to register at a high level when segregation is measured by computing the index of dissimilarity from data for bounded areas. The ribbons of darkly shaded households for the smaller group tend to increase in length, width and overall 'coverage' as ethnic mix moves from 90/10 towards 50/50.

This is an unsurprising function of the changing demography of the city, but it warrants mention because it accounts for the fact that the segregation scores are slightly higher when the ethnic mix is 90/10 compared with other ethnic mixes. In the 90/10 case, the availability of households from the smaller group is low and the 'ribbons' that arise are spread further apart in space and, due to the less extensive coverage, are less likely to join into long sections over the course of the simulation experiment. Because their average length is shorter, they are less likely to cross area boundaries and D computed for fixed neighbourhoods is slightly higher.

Table 1 summarises the dissimilarity scores for the experiments just reviewed. It also includes dissimilarity scores for several additional experiment sets we prepared to cover all ethnic mix combinations on five-point intervals from 95/5 to 50/50. These data lend further support to our hypotheses. When vision involves non-minimal spatial domains, ethnic demography conditions the impact of preferences on segregation such that high levels of segregation emerge when preferences for co-ethnic contact equal or exceed the smaller group's percentage in the population and the level of segregation increases with the magnitude of the discrepancy. Significantly, this pattern is seen whether vision is implemented using site-centred areas, as in the Laurie and Jaggi study, or using the variations involving bounded areas.

Table 1 also documents an interaction between ethnic demography and segregation when vision is implemented as the minimal, small-R formulation ($R = 1$). But we do not view this as support for our hypotheses. Instead, as we suggested previously, we believe it should be seen as an artefact of the fact that, when segregation is computed from fixed-area data, small segregation patterns tend to register better when ethnic mix is low.

The patterns seen in Table 1 are documented more systematically in Figure 7. This figure plots the index of dissimilarity from the final city landscapes of 1200 separate simulation experiments by the smaller group's percentage representation in the city population. Each graph in the figure depicts the results from 300 experiments conducted

Table 1. Scores for the index of dissimilarity for the simulations shown in Figures 3–6 plus scores for additional experiments

Ethnic demography	Site-centred vision $R = 1$	Moderate to large-domain vision: Site-centred vision $R = 5$	Bounded area only	Bounded area + adjacent region
95/5 mix	43	79	86	88
90/10 mix	30	74	85	89
85/15 mix	22	73	82	86
80/20 mix	24	68	84	87
75/25 mix	20	62	81	94
70/30 mix	20	60	67	96
65/35 mix	20	34	42	61
60/40 mix	21	22	14	35
55/45 mix	19	9	7	8
50/50 mix	20	3	4	5

implementing the four versions of vision used in the experiments reported in Figures 3–6 and Table 1. In each of these simulations, the preference for co-ethnic contact is set at 30 per cent and the size of the smaller group in the population is randomly varied from 5 to 50. The three graphs for non-minimal vision all show that the impact of preferences for co-ethnic contact for segregation are strongly conditioned by ethnic demography and in a manner consistent with our hypotheses. Segregation is low when ethnic preferences can be ‘easily’ satisfied under integration (on the right-hand side of the graphs). But when ‘demand’ for co-ethnic contact exceeds ‘supply’ under integration

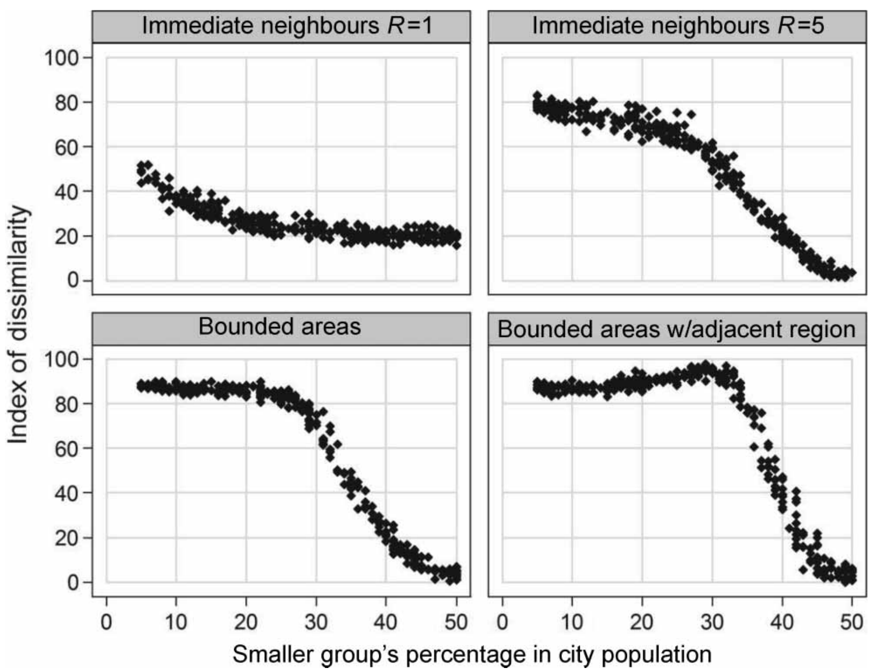

Figure 7. Index of dissimilarity by the smaller group’s percentage representation in the city population under four implementations of vision with preferences for co-ethnic contact at 30 per cent.

(on the left-hand side of the graphs), segregation emerges. The discrepancy between demand and supply increases moving from right to left on the graphs. As predicted by our hypotheses, segregation moves to high levels as this discrepancy increases.

Two interesting patterns are evident in Figure 7. One is that, once demand for co-ethnic contact approaches and exceeds supply, segregation climbs rapidly to high levels. The transition is less abrupt than a 'step' function, but the effect involves a region of rapid increase (running from right to left in the graphs) leading into a 'plateau' where segregation is at consistent high levels. Another pattern is that segregation begins to elevate well *before* demand exceeds supply. Thus, as documented in Table 1 as well as in Figure 7, a high level of segregation is generated under the 65/35 ethnic mix even though the percentage representation of the smaller group is a full 5 points *above* the relatively low preference for 30 per cent co-ethnic contact.

Fossett and Waren (2004a) provides insight into this result. They report that segregation outcomes in agent-based models are consistently higher than outcomes that can be achieved under planning and strategic placement. Under strategic placement, the 65/35 ethnic mix could easily sustain stable integration where all households are satisfied. However, in the simulations here, the initial household placements are random and many households are unsatisfied and move to achieve the co-ethnic contact they desire. Their moves are unco-ordinated, not strategic. Stable integration is logically possible, but the moves of individual households produce steady 'drift' towards ethnically polarised neighbourhoods and stable segregation.

Fossett (2003, 2005a) has termed the powerful interaction of preferences and ethnic demography documented in Table 1 and Figure 9, the "paradox of weak minority preferences". The essence of the paradox is that relatively weak preferences for co-ethnic contact can produce high levels of segregation when population groups are small. Of course, the broader principle involved is not paradoxical. If demand for co-ethnic contact cannot be met under integration, goal-directed moves by individual households will create a drift towards segregation that is self-reinforcing and unlikely to be reversed. When the preferences for co-ethnic contact are very high, this is unsurprising. But, it is not widely appreciated that the effect can be strong when relatively weak preferences combine with unbalanced ethnic ratios. Since such demographic conditions are typical, not rare, the paradox takes on particular substantive significance.

Varying Preferences for Co-ethnic Contact across Groups

The results to this point are consistent with a simple principle: segregation outcomes under voluntary choice by individual households are determined not by the absolute magnitude of the preference for co-ethnic contact, but by the *discrepancy* between the preferences individuals hold and the demographic supply that can satisfy these preferences under conditions of integration (i.e. even distribution). We explored this hypothesis in greater depth by performing several thousand experiments setting the SimSeg model to implement vision based on site-centred areas defined by $R = 5$ and using our specification for search. For these experiments, we sample the parameter space for the model as follows. We randomly vary Whites' preferences for co-ethnic contact from 0 to 90; we randomly vary Blacks' preferences for co-ethnic contact from 0 to 90; we randomly vary R from 1 to 7; and we randomly vary city ethnic mix from 95/5 to 5/95.

For each simulation experiment, we computed the maximum discrepancy between an ethnic group's supply and its percentage in the population. We then categorised this variable into five-unit intervals and plotted the distribution of scores on the index of dissimilarity as shown in Figure 8.[27] The results provide strong support for our hypothesis. The level of segregation resulting is always high when the co-ethnic preferences

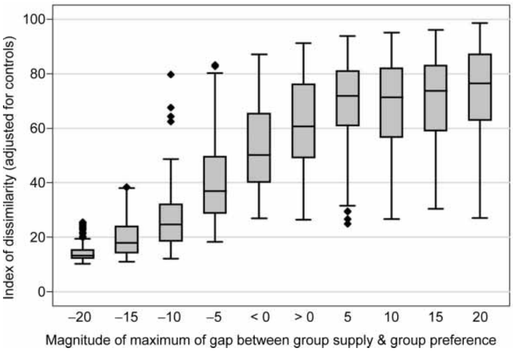

Figure 8. Box plot showing distribution of index of dissimilarity by the magnitude of the maximum difference between group supply and group demand for co-ethnic contact.

of at least one group equal or exceed the supply available in integrated neighbourhoods. As seen earlier in Figure 7, the level of segregation is distinctly elevated when the balance between supply and demand is merely ‘tight’. For example, in simulations where there is a surplus of supply but it is 5 points or less, the median value of the index of dissimilarity is about 50. Under these conditions, perfect integration is clearly feasible under planning and strategic placement, but it does not emerge under the unco-ordinated location decisions of individual households despite the fact that the city landscape is initially integrated. It is not until supply exceeds demand by a full 10 points that segregation levels fall away to levels that would be expected under random assignment!

Two outcomes in the parameter space for the model merit comment. One is that simulations with low levels of preference for co-ethnic contact for both groups produced high levels of segregation in cities with imbalanced ethnic mixes. This provides very strong support for the Schelling notion that high levels of segregation can emerge even when location decisions are not specifically motivated by the desire to live in ethnically homogeneous areas.[28] The other is that simulations where *one* group held a strong preference for co-ethnic contact sometimes produced low levels of segregation in cities with imbalanced ethnic mixes. This result occurs when the group holding the strong preference for co-ethnic contact is a demographic majority *and* the other group holds a low preference for co-ethnic contact. For example, segregation will be low in cities with an 80/20 ethnic mix, if the larger group’s preference for co-ethnic contact does not exceed 70 per cent *and* the smaller group’s preference for co-ethnic contact does not exceed 10 per cent. The key factor that permits stable integration in this situation is that both groups’ preferences can be easily met under conditions of even distribution. This provides further support for Schelling’s basic insight that the implications of preferences for segregation are complex and cannot be deduced based on knowledge of preferences alone.

Positive Preferences for Diversity: A Potential Basis for Optimism

Laurie and Jaggi characterised their study as providing a basis for ‘optimism’ regarding ethnic segregation. They interpreted their results as suggesting that policies aimed at expanding vision and promoting moderate preferences for co-ethnic contact could serve to lower segregation. The results we present here suggest that their optimism must be tempered. Laurie and Jaggi stated that preferences need not be ‘unrealistic’ or ‘Gandhian’ in order to achieve integration. But they did not take account of the interaction of preferences and ethnic demography and based their conclusions on results obtained using an ethnic mix that was optimal for producing integration. Our results show that, even with expanded vision, moderate and weak preferences for co-ethnic contact can produce high levels of segregation under ethnic demographic conditions that are typical in most cities.

This is an important and sobering finding. ‘Realistic’ reductions in preferences for co-ethnic contact may not necessarily be enough to drive existing segregation down and promote stable integration. But we do not believe that this finding implies that ethnic segregation is inevitable. Instead, we suggest that it means that additional directions in policy options concerning preferences need to be considered. One new direction that deserves attention is the potential role that positive preferences for ethnic diversity (or aversion to extreme ethnic homogeneity) may play in reducing ethnic segregation. Laurie and Jaggi follow the literature on agent-based modelling and focus exclusively on preferences for co-ethnic contact. But research on residential preferences indicates that people may simultaneously hold both positive preference for co-ethnic contact *and* positive preferences for contact with other groups.[29]

In the case of ethnic minority groups, this may reflect the mixture of desires to maintain connection with the ethnic community and at the same time achieve assimilation with the broader society, including greater contact with ethnic majority groups. The preference to seek significant levels of out-group contact may reflect instrumental motives for assimilation such as gaining access to the residential amenities available only in majority ethnic areas. Alternatively, it may reflect a willingness to relinquish ethnic bonds and seek full incorporation into primary social relationships with the majority group including friendship and kin networks. Or it may reflect some combination of these and other motives. In the case of ethnic majority groups, desires for out-group contact may reflect a willingness at least partially to embrace the diversity of ethnic culture in modern societies and especially urban areas and a desire to avoid living an 'insulated' life in 'bland', homogeneous, residential areas.

What role might such preferences play in segregation? We use the SimSeg model to implement simulation scenarios relevant to this question. First, we elaborate ethnic preferences to allow for positive preferences for co-ethnic contact and positive preferences for out-group contact. These must be constrained to be logically compatible, but otherwise can be implemented in a straightforward way. For example, if preferences for co-ethnic contact are set at 30 per cent, a preference for out-group contact can be specified at any value between 0 and 70 per cent. If it is set to 30 per cent, all households would be completely satisfied with neighbourhoods that range between 30 and 70 per cent Black and all households would be dissatisfied in some degree with neighbourhoods that were less than 30 per cent Black or more than 70 per cent Black.

Figure 9 presents results of experiments exploring the potential role of diversity preferences on segregation. Ethnic demography here is set to 70/30 and vision is implemented in the four variations used earlier. We implemented the diversity preference in a conservative way. We calculated satisfaction scores on out-group contact in the same way as satisfaction scores on co-ethnic contact but we gave them only *half* the weight given to the satisfaction scores for co-ethnic contact. This corresponds to a situation where households sincerely hold the goal of seeking diversity, but assign it less importance than the goal of seeking co-ethnic contact. These results suggest that positive preferences for ethnic diversity have the potential to dampen the segregation-promoting

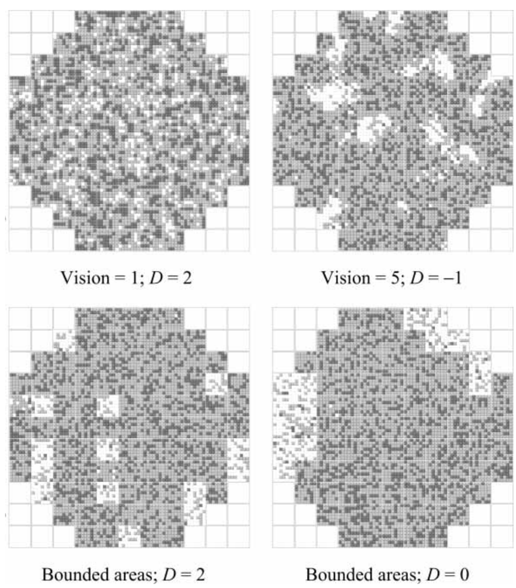

Figure 9. Ending landscapes from analyses where vision is varied with preferences for co-ethnic contact at 30 per cent, preferences for out-group contact at 30 per cent, and ethnic mix set to 70/30.

consequences of preferences for co-ethnic contact established in previous sections of this paper. Across the board, segregation is very low. Of particular interest, segregation is low in all three scenarios with non-minimal vision. As previously reported in Table 1, these same three scenarios produced high levels of segregation without diversity preferences. Thus, the introduction of positive preferences for diversity sharply reduced segregation. This finding, as so many others, is anticipated by Schelling (1971, pp. 165–166).[30]

We also performed a second set of experiments using a variation in preferences that was even more conservative. Specifically, we departed from Laurie and Jaggi's practice of maintaining symmetrical preferences for both groups and assigned stronger preferences for co-ethnic contact to the demographic majority group (Whites). We set the preference for co-ethnic contact for Whites at 50 per cent while keeping the similar preference for Blacks at 30 per cent and maintaining the preference for out-group contact at 30 per cent for both groups. Thus, Whites are not satisfied if they are a demographic minority, but also wish to live in ethnically diverse areas. The results for these experiments are shown in Figure 10. Segregation is low in all four experiments and again suggests that positive preferences for ethnic diversity have the potential to dampen the segregation-promoting consequences of preferences for co-ethnic contact established in previous sections of this paper.

In our view, these results provide a realistic basis for optimism regarding the possibilities for ethnic integration under unconstrained choice dynamics. The results are encouraging because preferences for out-group contact are assigned only half the weight of preferences for co-ethnic contact. Clearly, future research should direct attention to the question of how diversity preferences may serve to reduce segregation.

However, it is important to keep these exploratory results in perspective because the simulations implement conditions that are favourable to integration in two key respects. The first is that neither group's preference for co-ethnic contact exceeds its representation in the population. This makes it possible for White and Black households to meet their preferences for co-ethnic contact and diversity by residing in areas that mirror the city's 70/30 ethnic mix. This would not be possible in a city with a 90/10 ethnic mix. Future research should investigate that particular circumstance to assess the limits of the diversity preference effect seen in Figures 9 and 10.

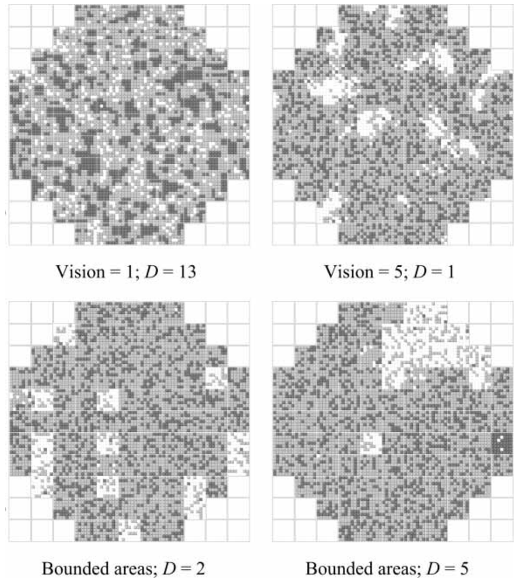

Figure 10. Ending landscapes from analyses where vision is varied with preferences for co-ethnic contact at 50 per cent for Whites and 30 per cent for Blacks, preferences for out-group contact at 30 per cent and ethnic mix set to 70/30.

The second way these scenarios specify conditions favourable to integration is by implementing preferences that depart substantially from those documented in surveys. In the case of Whites, surveys suggest that most White households prefer at least 80 per cent co-ethnic contact (Charles, 2000, 2001; Clark, 1991, 1992; Farley *et al.*, 2000). There is relatively little evidence to suggest that the average White household specifically seeks diversity and assigns this goal a high priority.[31] The more common 'optimistic' interpretation is that Whites 'tolerate' diversity and their level of 'tolerance' has increased appreciably over the past four decades. But, our earlier results suggested that mere 'tolerance' is not likely to be a powerful mechanism for *promoting* integration. That is, tolerance of out-group contact is *permissive* of greater integration, *but it does not specifically generate movement towards integration.* The models explored here show that, when preferences for co-ethnic contact exceed demographic supply under integration, neighbourhoods drift steadily towards ethnic polarisation via irreversible neighbourhood 'tipping' dynamics of the type considered by Schelling. The results presented in Table 1 and Figure 7 show that mere tolerance of diversity does not serve as a 'brake' on this dynamic.

We should stress that we are couching our assessment of the relative inconsequence of tolerance of diversity in the context of models that assess only the *direct* effects of preferences. In a broader view, the permissive role of tolerance may be more important. Residential choices are driven by non-ethnic residential goals such as seeking better municipal services, higher-quality housing and closer proximity to employment: all are influential factors in residential decisions. Tolerance of ethnic diversity allows households pursuing non-ethnic goals to consider a wider range of neighbourhood ethnic mixes. Thus, while tolerance of diversity may not directly counter the segregation-promoting effects of preferences for co-ethnic contact, it may still facilitate integration indirectly by allowing non-ethnic dynamics to undermine the 'drift' towards segregation seen in 'pure' preference-effect models.

Our analyses indicate that those who wish to *promote* integration via preference-related interventions should give attention not only to reducing desires for co-ethnic contact but also to educational efforts that would foster a meaningful desire for ethnic diversity. With respect to majority group preferences, this goal may be 'within reach' in cities with imbalanced ethnic mixtures such as the 90/10 and 75/25 scenarios used in the experiments presented earlier. Cities with ethnic mixtures along these lines are not uncommon. Surveys suggest that most Whites will 'tolerate' neighbourhoods with 90/10 to 75/25 ethnic mixes. If Whites actively *sought* such neighbourhoods with these ethnic mixes, it could help to promote large reductions in segregation. Considering the significant changes in attitudes that have taken place over the past four decades, it is not altogether unrealistic to imagine such changes are possible.

This scenario is more complicated, however, because surveys suggest that typical Black households have preferences for at least 50 per cent co-ethnic contact. These preferences are not compatible with stable integration in cities with 90/10 or 75/25 ethnic mixes due to the paradox of weak minority preferences. Blacks' preferences for co-ethnic contact are markedly *lower* than those held by Whites, but they are not integration-promoting relative to ethnic demographies found in most metropolitan areas. On a more encouraging note, survey evidence suggests that Blacks, more so than Whites, often hold positive preferences for non-trivial diversity. The paradox of weak minority preferences suggests that demographic minority groups may bear a disproportionate 'burden' in achieving integration. In most American metropolitan areas, integration requires Whites to embrace only moderate levels of out-group contact while still being able to maintain high levels of co-ethnic contact. In contrast, minority groups often must seek very high levels of out-group contact and accept low levels of co-ethnic contact, a point noted by Schelling (1971, p. 179). For minorities, spatial assimilation implies the potential demise of geographically based minority ethnic communities in urban areas. These issues are likely to be important and complex and thus deserve attention in future research.

Summary and Discussion

Our primary purpose in this paper has been to investigate the implications of a theoretical model of ethnic preference effects on segregation. As in the Laurie and Jaggi study, the crucial variables in the model are ethnic demography, ethnic preferences and 'vision'. Laurie and Jaggi stressed the interaction of vision and preferences. We conclude that this interaction may be relevant to understanding segregation found in small, short-duration settings such as lunch room and auditorium seating. However, we do not see it as important to understanding residential segregation since larger spatial domains are salient in residential choices in metropolitan areas and basic demographic processes generate random vacancies that unleash the full segregation-promoting potential of preferences.

Instead, we direct attention towards the interaction of ethnic preferences and ethnic demography. This interaction is powerful and in our view has clear relevance for understanding residential segregation in metropolitan areas. Because Laurie and Jaggi did not recognise this interaction, their study adopted a setting for ethnic demography that was optimal for achieving integration. We believe this helps to account for their premature willingness to question the Schelling model of segregation and offer conclusions about ethnic preferences and integration that were more optimistic than those advanced by previous researchers. We provide a more nuanced assessment of the implications of ethnic preferences under ethnic mixtures common in American metropolitan areas. Our analyses lead us to be more cautious about the possibilities for integration under unconstrained ethnic preferences. We find support for the hypothesis that preferences are segregation-promoting when demand for co-ethnic contact cannot be satisfied by demographic supply under integration. Based on this, we have a more sober view of the changes that may be needed to achieve dramatic reductions in segregation given prevailing preferences for co-ethnic contact and the ethnic demographies of most metropolitan areas.

We are able to end on a more optimistic note by pointing to the role that positive preferences for diversity can potentially play in reducing segregation. We distinguish 'diversity preferences' from the more passive 'tolerance' of diversity. Tolerance of diversity is not inconsequential and may play an important 'permissive' role in situations where factors other than ethnic considerations may promote residential integration. But in models that highlight the segregation- and integration-promoting effects of preferences, positive preferences for diversity appear to retard directly the segregation-promoting effects of preferences for co-ethnic contact to a much greater degree than mere tolerance of diversity.

Notes

1. Information about the programme can obtained at the senior author's website which can be found at http://sociweb.tamu.edu. A version of SimSeg geared to undergraduate teaching can be found at the website for Amber Waves Software of Lancaster, Pennsylvania (http://simseg.com).
2. Laurie and Jaggi do not suggest that the substance of their findings depends in any important way on using the edgeless torus urban form. Fossett and Dietrich (2005) undertake a methodological study investigating the impact of city form and neighbourhood shape on segregation outcomes. They report that results obtained using the edgeless torus form are similar to results obtained using the circular city form.
3. The computing formula is given in Laurie and Jaggi (2003, p. 2693). The properties of the measure are reviewed in Fossett (2005b).
4. In simulations with a 50/50 ethnic mix, we found that S and η^2 had high correlations with D ($r > 0.98$). However, when the ethnic mix departs from 50/50, Ds relationships with S and η^2 turn non-linear.
5. The zero-order correlations among the measures all exceeded 0.98.
6. While they state that C is restricted to the range $0.0 < C \leq 0.5$ (p. 2692), C does not take any value other than 0.5 in the analyses they report.
7. Fossett and Dietrich (2005) performed a methodological analysis using a variety of neighbourhood shapes including circles, diamonds and squares. They found that neighbourhood shape had no effect on segregation outcomes net of the impact of neighbourhood scale (i.e. the number of housing units delimited by the neighbourhood).
8. We run our simulations for 30 cycles. This is an arbitrary number, but it is sufficiently high to ensure that segregation patterns

have converged on an equilibrium. In most cases, the number of moves in a cycle will fall to zero or near zero well before cycle 30 because no households can improve their situation by moving.

9. Under the Laurie and Jaggi search specification, households can remain in their originally assigned location so long as they remain 'satisfied'. Thus, at the end of the simulation, they do not necessarily reside in a location that they chose through search.
10. Laurie and Jaggi do not present a similar result because under their search process no households would move in this simulation. In our search process, each household moves on first search.
11. See Charles (2003) for a recent review of the literature on residential segregation.
12. We also conducted simulations using the torus form and obtained similar findings.
13. We present results for simulation experiments implementing these settings in the expanded version of this paper (Fossett and Waren, 2004b, Appendix Figure 3).
14. See Fossett and Waren (2004b) for further discussion of this point.
15. This is is documented in Fossett and Waren (2004b, Appendix Figure 3).
16. This is documented in Fossett and Waren (2004b, Appendix Figure 1, Appendix Table 1 and Appendix Figure 2).
17. Laurie and Jaggi offer no rationale for this characterisation and we are unaware of any supporting theory.
18. The expression $\min[C, (100 - C)]$ represents the minimum value of percentage White and percentage Black.
19. We present simulation results documenting this outcome in Fossett and Waren (2004b).
20. We review this point in depth in Fossett and Waren (2004b).
21. It is similar to using a 'Moore' neighbourhood of bounded areas where satisfaction with ethnic mix in the bounded area is given priority. Specifically, satisfaction with the ethnic mix of the aggregated population in adjacent bounded areas counts half compared with satisfaction with the ethnic mix for the bounded area.
22. Laurie and Jaggi (2003, p. 2695) refer to larger clusters as 'ghettos'. We use the term cluster to link the pattern with measurement theory for segregation which identifies clustering as a 'dimension' of segregation (Massey and Denton, 1988).
23. Chequering occurs when areas are homogeneous but the ethnic mix of adjacent areas is uncorrelated.
24. The implementation of vision based on adjacent bounded areas is a type of site-centred spatial domain.
25. This significantly increases the 'computational' burden of the experiment and this may help to account for why most agent-based models consider low settings for *R*.
26. At least, it is the minimum, non-zero vision that can be specified when vision is uniform in all directions.
27. The plotted values are residuals from an analysis of variance that controls for categories of vision (1–7) and the continuous covariate for percentage Black.
28. In the interest of space, we do not systematically explore the effects of vision and percentage Black. The strongest effects in the analysis are those presented. As noted earlier in the paper, the level of segregation is low when vision is at its logical minimum (*R* is 1), but segregation increases dramatically as vision moves past 2. All effects considered are statistically significant at 0.001 or better. The adjusted R^2 for the analysis of variance is approximately 0.84.
29. See Charles (2003) for a good overview of the literature on ethnic preferences.
30. Schelling even anticipates the pattern of high vacancy rates in ethnically homogeneous areas seen in the three simulations that use non-minimal vision.
31. Our analysis of data on residential preferences taken from the Houston Area Surveys (Klineberg, 2003) provides some evidence that Whites in Houston, Texas, display a discernible preference for ethnic diversity. White respondents in this survey indicate they are more willing to move into neighbourhoods that are 10–20 per cent non-White than neighbourhoods that are all-white. At present, this is an isolated empirical result, but it bears closer examination.

References

CHARLES, C. Z. (2000) Residential segregation in Los Angeles, in: L. D. BOBO, M. L. OLIVER, J. H. JOHNSON, JR and A. VALENZUELA, JR (Eds) *Prismatic Metropolis: Inequality in Los Angeles*, ch. 4. New York: Russell Sage.

CHARLES, C. Z. (2001) Processes of racial residential segregation, in: A. O'CONNOR, C. TILLY, and L. D. BOBO (Eds) *Urban Inequality: Evidence from Four Cities*, ch. 4. New York: Russell Sage.

CHARLES, C. Z. (2003) The dynamics of residential segregation, *Annual Review of Sociology*, 29, pp. 167–207.

CLARK, W. A. V. (1991) Residential preferences and neighborhood racial segregation: a test of the Schelling segregation model, *Demography*, 28, pp. 1–19.

CLARK, W. A. V. (1992) Residential preferences and residential choices in a multi-ethnic context, *Demography*, 29, pp. 451–466.

EPSTEIN, J. M. and AXTELL, R. (1996) *Growing Artificial Societies: Social Science from the Bottom Up.* Cambridge, MA: MIT Press.

FARLEY, R., DANZIGER, S. and HOLZER, H. J. (2000) *Detroit Divided.* New York: Russell Sage.

FOSSETT, M. A. (1998) *SimSeg: a computer program to simulate the dynamics of residential segregation by social and ethnic status.* Race and Ethnic Studies Institute Technical Report and Program, Texas A&M University.

FOSSETT, M. A. (2003) *Ethnic preferences, social distance dynamics, and residential segregation: results from simulation analyses.* Paper presented at the *Annual Meetings of the American Sociological Association*, Chicago, August.

FOSSETT, M. A. (2004) *Racial preferences and racial residential segregation: findings from analyses using minimum segregation models.* Paper presented at the *Annual Meetings of the Population Association of America*, Boston, April.

FOSSETT, M. A. (2005a) Ethnic preferences, social distance dynamics, and residential segregation: results from simulation analyses, *Mathematical Sociology*, (forthcoming).

FOSSETT, M. A. (2005b) *Measuring segregation in agent-based simulation models.* SimSeg Technical Paper.

FOSSETT, M. A., and DIETRICH, D. (2005) *Effects of city and neighborhood size and shape on segregation outcomes in agent-based simulations.* Paper presented at the *Annual Meetings of the Southwestern Sociological Society*, New Orleans, Louisiana, March.

FOSSETT, M. A., and SENFT, R. (2004) *SimSeg and generative models: a typology of model generated segregation patterns.* Paper presented at *Agent 2004—Social Dynamics: Interaction, Reflexivity, and Emergence*, University of Chicago, Chicago, Illinois, October (http://agent2004.anl.gov/).

FOSSETT, M. A., and WAREN, W. (2004a) *Comparing predictions of minimum segregation models with results from agent-based simulation.* Paper presented at the *Annual Meetings of the Southwestern Sociological Society*, Corpus Christi, Texas, March.

FOSSETT, M. A., and WAREN, W. (2004b) *Overlooked implications for ethnic preferences in agent-based simulation models.* Paper presented at *Agent 2004—Social Dynamics: Interaction, Reflexivity, and Emergence*, University of Chicago, Chicago, Illinois, October (http://agent2004.anl.gov/).

KRUGMAN, P. (1996) *The Self-organizing Economy.* Oxford: Blackwell.

KLINEBERG, S. (2003) *Houston Area Survey, 1982–2003.* Rice University, Houston, Texas (www.houstonareasurvey.org).

LAURIE, A. J. and JAGGI, N. K. (2003) The role of 'vision' in neighbourhood racial segregation: a variant of the Schelling segregation model, *Urban Studies*, 40, pp. 2687–2704.

MACY, M. W. and WILLER, R. (2002) From factors to actors: computational sociology and agent-based modeling, *Annual Review of Sociology*, 28, pp. 143–166.

MASSEY, D. S. and DENTON, N. A. (1988) The dimensions of residential segregation, *Social Forces*, 67, pp. 281–309.

SCHELLING, T. C. (1969) Models of segregation, *American Economic Review, Papers and Proceedings*, 59, pp. 488–493.

SCHELLING, T. C. (1971) Dynamic models of segregation. *Journal of Mathematical Sociology*, 1, pp. 143–186.

SCHELLING, T. C. (1978) *Micromotives and Macrobehavior.* New York: Norton.

WASSERMAN H. and YOHE, G. (2001) Segregation and the provision of spatially defined local public goods, *The American Economist*, 45, pp. 13–24.

WINSHIP, C. (1977) A re-evalutation of indices of residential segregation, *Social Forces*, 55, pp. 1058–1066.

YOUNG, P. (1998) *Individual Strategy and Social Structure: An Evolutionary Theory of Social Structure.* Princeton, NJ: Princeton University Press.