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## Segregation and the Perception of the Minority

Florent Dubois  
Christophe Muller

# Segregation and the Perception of the Minority\*

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## Abstract

In his seminal work, Schelling (1971) shows that even individual preferences for integration across groups may generate high levels of segregation. However, this theoretical prediction does not match the decreasing levels of segregation observed since the 1970s. We construct a general equilibrium model in which preferences depends on the number of peers and unlike individuals, but also on the benefit (or loss) they attribute to the economic and social life that a minority member brings with him, which we call their “perception of the minority”. In this framework, there always exists a structure of the preferences for which integrated equilibria emerge and are stable. Even when individuals are all prejudiced against other groups, there is still a level of the perception of the minority for which integration is a stable outcome. We then propose an econometric specification in which the structural preference parameters can be identified. In the case of South Africa, our estimates of preferences provide evidence for a dynamics toward increasing

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integration as the effect of the perception of the minority is found positive and significant, and overcome both racism and homophily by between roughly one and four times.

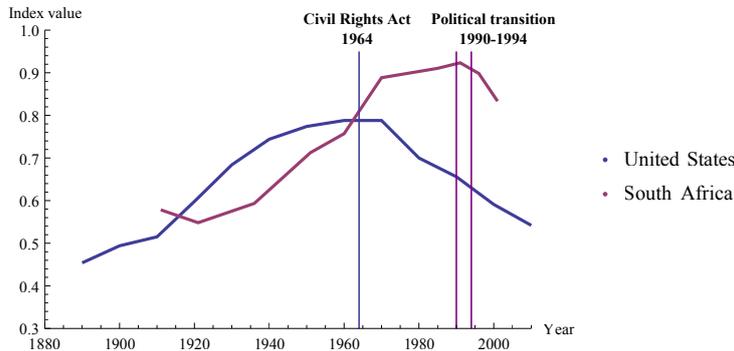
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## 1 Introduction

In his seminal contribution, Schelling[55] demonstrates that even though individuals may exhibit preferences for living in a mixed neighborhood, complete segregation is the most likely outcome. However, the trend observed in the United States since the 1970s is declining and has almost returned to the levels observed before the Jim Crow Era.<sup>1</sup> In South Africa, a similar trend can be observed since the end of the Apartheid in 1994 (see Figure 1). In this paper, we propose a theoretical model which can account for both segregationist and integrationist patterns. We then provide a structural econometric analysis of the dynamics of segregation in post-Apartheid South Africa.

Figure 1: Evolution of segregation in the United States and South Africa



This graph plots the Black-White segregation for the United States and South Africa, as measured by the dissimilarity index (Duncan and Duncan[30]). Data for the United States come from Glaeser and Vigdor[38]. Data for South Africa come from Christopher[19][20][21]. In both cases, segregation is an average of the main metropolitan areas.

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<sup>1</sup>The Jim Crow Era is the period of legal segregation in the United States. It starts with the end of the American Civil War and ends in 1964 with the Civil Rights Act. Even if Black-White segregation is declining, Hispanics and Asians are still as segregated as before in the United States (Charles[18], De la Roca et al.[25]).

We argue that people may perceive some benefits from living in integrated neighborhoods and, as a consequence, may choose to relocate in more desirable locations than where they currently reside. In the United States Zhang and Zheng[64] find that individuals are willing to pay at least \$300 for less segregation. Or people may simply value diversity (Aldrich et al.[2], and Wong[60]). The benefits perceived from integrated neighborhoods may be of different types. We might think for instance to complementarities in the job market as different groups specialize in different tasks,<sup>2</sup> may have distinct skills and endowments, or to risk-sharing opportunities due to the different assets held by different groups.<sup>3</sup> Obviously, these effects depend on the size of the minority in the neighborhood and are not purely racial or prejudicial attitudes. The magnitude of these effects relies on the tendency of individuals to perceive this externality generated by social and economic factors involving the minority, which is why we talk about “perception of the minority”.

We construct a location choice model in which we include this complementary externality in the utility function of the individuals, next to prejudicial attitude effects. We assume that the utility function depends on the number of individuals of the different groups living in the neighborhood, as in the work of Schelling and the following literature.<sup>4</sup> Our innovation, as compared to the literature, is this new attribute added in the utility function, which aims at capturing their perception of the minority.

We find that integration can emerge as a stable outcome although individuals have homophilic preferences. In this case, the perception of the minority needs to be sufficiently high to circumvent the effect of homophilic preferences. But this situation is also dependent from the initial conditions. Namely, if the minority is too small in both locations, then each minority prefers to relocate in the location where their own group is the majority rather than keep on living in the minority. As a consequence, segregation emerges despite a large positive benefit of integration. Moreover, segregation is not robust anymore, contrary to the literature. A shock strong enough will now displace the society into a stable integrated state. The situation described by Schelling appears to be a special case of our model. We find also cases of non-convergent dynamics.

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<sup>2</sup>We draw a parallel with the migration literature here. By specializing in different tasks, migrants and natives first avoid competition (Peri and Sparber[51]). Then, they may also increase wages and production due to complementarities in the tasks performed. Borjas[11] estimates the gain between \$7 and \$25 billion in the United States while Ottaviano and Peri[49] find an increase of 0.6% on average of the wage of natives.

<sup>3</sup>Bramoullé and Kranton[14] show that if there are risk-sharing relationships across communities, those who are linked (respectively are not) (directly or indirectly) across neighborhoods have a higher (respectively lower) welfare, and the aggregate welfare is higher.

<sup>4</sup>See Schelling[54][55][56], Pans and Vriend[50], Zhang[63][62], or Grauwil et al.[40]

Previous theoretical papers mainly try to explain the persistence of segregation. In these models, individuals look at their close neighborhood on a grid and move when dissatisfied by the racial mix.<sup>5</sup> In this context, even strict preferences for integration may lead to complete segregation due to space constraints. Similarly, our model is related to the bounded-neighborhood model (Schelling[55]) in which individuals look at the racial mix of the broad area where they live. However, except in the case of Miyao[47], the models in the literature retain a flavour of partial equilibrium models in that individuals are assumed to account only for changes in one precise location. Thus, integration can be stable in one location while segregation may increase as a whole. We follow Miyao[47] by specifying a general equilibrium framework. Note however that stable integrated equilibria in Miyao’s setting may arise because preferences are sufficiently weak so that individuals move almost at random in the absence of another mechanism of location selection. We also depart from the threshold utility function assumed after Schelling[55], because the linear form has some empirical supports (Bruch and Mare[15], and Easterly[32]). Moreover, it can also theoretically generate higher level of segregation than the threshold utility function in some cases (Van de Rijt et al.[59], and Bruch and Mare[16]). Finally, it will allow us explicit solutions for the equation system incorporating “perception of the minority” terms.

We then propose an empirical strategy to recover structural estimates of the perception of the minority and other preference parameters. In the case of post-Apartheid South Africa with two ethnic groups only, we use the asymmetric impact of the perception of the minority between locations dominated by Whites and those dominated by Blacks to identify our parameters of interest. We then recover the structural parameters in a two-stages procedure. First, we estimate the dynamics derived from the theoretical model. Then, by imposing theoretical restrictions on the econometric specification, we implement a least-square solution of the overidentified system.

We address the heteroscedasticity concern by using robust covariance matrices, and the endogeneity of the racial mix with instrumental variables. For the latter, we exploit the spatial dependence between group’s locations. If a location is inhabited by many Whites, neighboring locations are likely to be inhabited by Whites too, and so on for neighboring locations of neighboring locations. At the same time, unobserved factors are likely to be correlated only locally. Therefore, there is a certain distance from which the number of individuals in the neighboring locations is still correlated with populations in the origin but no longer with the unobserved factors.<sup>6</sup> We thus use the average number of group members in the

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<sup>5</sup>See Schelling[54][55], Miyao[47], Granovetter and Soong[39], and Dokumaci and Sandholm[27].

<sup>6</sup>Kasy[41] use a similar argument by using the average number of group members in neigh-

neighboring rings at order 2 and 3.

The data are taken from the South African censuses of 1996, 2001, and 2011 to avoid the Apartheid era and moves that would be induced by political factors. The data are harmonized at the 2001 subplace level to get consistent and stable geographic definitions throughout the three waves. Our different estimations yield similar results. In all specifications, we find that the perception of the minority exceeds racists preferences in absolute value. While there are studies estimating preferences for the United States<sup>7</sup> or Singapore<sup>8</sup>, we are, to the best of our knowledge, the first to study it for South Africa. Moreover, the type of data used is really important as different aggregation levels may produce contrasting pictures of segregation. A city may look integrated while all its neighborhoods may be completely segregated. However, rich disaggregated data are difficult to find. Thus, most researchers have employed public use micro areas (PUMAs) for city level analyses.<sup>9</sup> On the other hand, a few social scientists were able to avail of more detailed data, usually of a particular city, for neighborhood-based analyses.<sup>10</sup> Our study is based on data of the latter kind. However, our dataset is not limited to a particular city as we have detailed information for the whole country.

Our paper contributes to the literature on the estimation of preferences for neighborhoods.<sup>11</sup> However, our methodology differs from this literature in several respects. First, the authors in this literature estimate preferences from the equilibrium relationship of a location choice model, we use instead the dynamics of such model to estimate preferences. Because it takes time for individuals to adjust their location choices, estimating an equilibrium relationship at a particular time may not reflect the true preferences.<sup>12</sup> Second, only two papers estimate a preference parameter for diversity (Wong[60], and Zhang and Zheng[64]). Besides, we use a totally different identification strategy for such parameter.<sup>13</sup> Wong[60] interprets the significantly negative sign of the squared number of Chinese, Indians, or Malays as a taste for other-group members, but the turning points from which other-groups are desired are not precisely estimated. Zhang and Zheng[64] insert a segregation component directly in the formula of the utility function. They

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boring units that are 3kms away from the origin.

<sup>7</sup>See Bajari and Kahn[5], Bayer et al.[8], Kasy[41], and Zhang and Zheng[64].

<sup>8</sup>See Wong[60].

<sup>9</sup>PUMAs are areas constructed to have at least 100 000 individuals. See Bajari and Kahn[5], and Zhang and Zheng[64].

<sup>10</sup>See Bayer et al.[8], Wong[60], and Kasy[41].

<sup>11</sup>See Bajari and Kahn[5], Bayer et al.[8], Wong[60], Kasy[41], and Zhang and Zheng[64].

<sup>12</sup>Bayer et al.[9] provide a similar argument and formal evidences of this problem.

<sup>13</sup>Bajari and Kahn[5] find some preference for integration for Whites using a three-stage approach estimating first a hedonic price function, then household preferences parameters for house characteristics, and finally individual preferences. But they restrict their sample only to working migrants which is likely to bias the estimates of such preferences.

are then able to estimate the willingness-to-pay for a decrease in segregation as a taste for diversity. However, they cannot distinguish the effect of own-group and other-group preferences. Instead, we specify a structure for the perception of the minority which allows us to explicitly distinguish between all preference parameters. The asymmetry of the perception of the minority allows us to identify the effect. Finally, our goal is different from previous papers as we do not restrain ourselves to estimating preferences. Not only, we assess if the estimated preferences are compatible with stable integration, but also we characterize potential dynamic patterns of spatial changes.

The paper is organized as follows. Section 2 describes the model. We then characterize the necessary conditions for uniqueness and stability of an equilibrium. We analyse three relevant structures of preferences in the following subsection, namely "Mutual reject", "White segregation versus Black integration", and "Acting White". Finally, we provide an extension of our framework, giving the basis for our identification strategy at the end of the section. In Section 3, we describe the data and our empirical methodology. Then, we present our reduced form and structural estimates. Finally, we discuss our results in the Section 4. All proofs are given in the appendix Section 5.

## 2 A Model of Racial Integration

### 2.1 The model

Let be a city, or a country,<sup>14</sup> divided into two identical locations indexed on  $i \in I = \{1; 2\}$ . Two groups live in this city. Each individual is identifiable by his type  $k \in K = \{W; B\}$ , which he cannot hide.<sup>15</sup> The number of members of group  $k$  living in location  $i$  is denoted by  $N_i^k$  and the total number of individuals of type  $k$  in the city is  $L^k$ . Any number of individuals can live in the two locations. There are no spatial arrangements inside the neighborhoods. Individuals are either in or out. Thus, each location constitutes a bounded neighborhood, *i.e.* all individuals inside the location are neighbors with everyone else inside.

Individuals of type  $k$  have a utility function  $U^{ki}$  for living in location  $i$ .  $U^{ki}$  is composed of a deterministic part<sup>16</sup>  $u^{ki}$  and a stochastic part  $\varepsilon^{ki}$ , which may represent unobserved idiosyncratic characteristics:

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<sup>14</sup>Hereafter, we will stick to the interpretation of the model describing a city to keep the message simple. However, we can understand it as describing a country as well.

<sup>15</sup>We refer to W and B as Whites and Blacks as the racial dimension of segregation is one of the most salient feature in the United States or in South Africa. However, we could have chosen any other dichotomy, such as the young and the old, the rich and the poor, girls and boys...

<sup>16</sup>Which can be interpreted as the representative utility of the group  $k$  for the location  $i$  (McFadden[45] and Miyao[47]).

$$U^{ki} = u^{ki} + \varepsilon^{ki}. \quad (1)$$

Following Schelling, we assume that individuals care about the racial mix of the location where they reside. In contrast to previous works, individuals also care about the presence of a sizable minority. Recent empirical works have shown the existence of such effect.<sup>17</sup> This takes the following form:

$$\begin{cases} u^{Wi}(N_i^W, N_i^B) = aN_i^W + bN_i^B + \gamma_W \text{Min}[N_i^W; N_i^B] \\ u^{Bi}(N_i^W, N_i^B) = cN_i^W + dN_i^B + \gamma_B \text{Min}[N_i^W; N_i^B] \end{cases}, \quad (2)$$

with  $a, b, c, d, \gamma_W, \gamma_B$  real parameters describing respectively the White taste for Whites, the White taste for Blacks, the Black taste for Whites, the Black taste for Blacks, and the White and Black perceptions of the minority. The choice of a linear form is debated in the literature.<sup>18</sup> Card et al.[17] show that tipping points<sup>19</sup> occur locally when the minority share exceeds a threshold ranging from 5% to 20%. However, globally there do not seem to be any tipping point features (Bruch and Mare[15], Easterly[32]).

The interpretation of the last term, with the operator “Min”, on the right-hand side of (2), is twofold. First, the Min term can be seen as explicitly modelling what Schelling[54][55][56] calls the minority status; that is: the fact that individuals have a preference on whether they live in the minority or not. Depending on the sign of the  $\gamma$  coefficients, it expresses the taste for living in the minority if the considered individual belongs to the minority, on the one hand; and it reflects the perception of the minority of the individual if he belongs to the majority, which is also equivalent to minority status, on the other hand.

Then, this Min function echoes intuitions about economic and social complementarity between the groups. For instance, think about a rich White community which needs some poor Blacks in order to do some jobs that they do not want to do themselves, like cleaning the sewers or picking up the trashes. This argument is supported by the literature on the impact of migration on natives as mentioned previously. The underlying hypothesis is that if someone wants something that the other group has (a specific good or service, an insurance against shocks ...), he should tolerate at least some of its members.

Individuals choose where they want to live according to a best response rule. Consequently, individuals of type  $k$  select location  $i$  with probability  $P^{ki}$  such that

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<sup>17</sup>See Aldrich et al.[2], Wong[60], or Zhang and Zheng[64].

<sup>18</sup>Grauwin *et al.*[40] also provide an analytical solution of the Schelling model with potential functions in the case of similar linear utility functions. However, the necessary condition for the existence of a potential function is the symmetricity of the externality, which is not the case for us with the introduction of this “min” term.

<sup>19</sup>Tipping points refer to the minority share above which Whites start to flee from a particular location.

the location they have chosen is the one that maximizes their utility:

$$P^{ki} = Pr(U^{ki} > U^{kj}, \forall j \neq i \text{ and } i, j \in I). \quad (3)$$

We assume that individuals do not move if they are indifferent, which is why the inequality is strict. Consequently, the Nash equilibrium of the game is an allocation of individuals across locations such that all players live in the location which maximizes their utility. This allows us to define the number of individuals of each type in each location.

$$N_i^{k*} = P^{ki} L^k, \quad \forall i \in I, k \in K \quad (4)$$

with

$$\sum_{i \in I} N_i^k = L^k > 0. \quad (5)$$

## 2.2 Existence

**Proposition 1.** *Under the above model, there exists a Nash equilibrium.*

As our model has only two locations, it is possible to only study the situation in one location, say location 1, as the situation in the other location is complementary. This allows us to define formally the different states in which the system may end.

**Definition 1.** *An equilibrium is said to be **integrated** if all locations match the racial mix of the society (i.e. if  $N_1^B = \frac{L^W}{L^B} N_1^W$ ) and **segregated** otherwise.*

*Moreover, it is said to be **completely integrated** if each location is equally populated (i.e. if  $N_1^k + N_1^{-k} = N_2^k + N_2^{-k} = \frac{L^k + L^{-k}}{2}$ ,  $\forall k \in K$ , where  $-k$  denotes the types different from  $k$ ).*

*Segregation is **complete** if the two groups live entirely in a separate location.*

The definition of the different states can be generalized to the case of multiple groups. In the literature, it is said that a state is integrated if all locations are equally populated by the two groups.<sup>20</sup> Nevertheless, this definition does not take into account the possible unbalance in the size of the two groups, especially when one group is clearly assumed to be the minority. In our case, an integrated state

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<sup>20</sup>See Schelling[55], Zhang[63], or Pancs and Vriend[50]. Even in surveys of preferences such as Farley et al.[34] or Clark and Fosset[22], the 50-50 racial mix is often the most frequent choice among respondents.

reflects the relative size of the two groups in the society.<sup>21</sup> We fall back to the standard case used in the literature if both groups are of equal size. This discrepancy in the vocabulary used in the literature is mostly a matter of considering local versus global integration. If we are interested in only one location (or in a relative neighborhood), there is no point in considering other mixtures than the 50-50 racial mix as integrated. But if we want to evaluate the level of segregation of the whole city, we should then acknowledge that an integrated state should reflect the city relative sizes of the groups in each location.

### 2.3 Uniqueness and stability

Before analyzing the properties of an equilibrium in this model, we have to make another assumption about the distribution followed by the stochastic part. In order to keep the model simple, we assume that  $\varepsilon^{kj} - \varepsilon^{ki}$  follows a uniform distribution on the interval  $[\alpha; \beta]$  with  $\alpha < 0$  and  $\beta > 0$ . This assumption reduces the model to a linear probability model that is well-known in the discrete choice theory (Anderson et al.[3]). Because we are focusing only on location 1, we can simplify the notations by replacing  $N_1^W$  by  $W$  and  $N_1^B$  by  $B$ . We obtain the following system:

$$\begin{cases} W = \frac{\Delta u^{W1} - \alpha}{\beta - \alpha} L^W \\ B = \frac{\Delta u^{B1} - \alpha}{\beta - \alpha} L^B \end{cases} \quad (6)$$

with

$$\Delta u^{ki}(N_i^k, N_i^{-k}) = u^{ki}((N_i^k, N_i^{-k})) - u^{kj}(N_i^k, N_i^{-k}) \quad (7)$$

. Let us denote the size of the support of the uniform distribution  $\theta \equiv \beta - \alpha$ .

At this stage, it is convenient to assume equal population sizes,  $L^W = L^B \equiv L$ , to alleviate computations. In this case, we can compute the equilibrium as an explicit function of the parameters of the model:

$$\begin{cases} W^* = \frac{L[L(2b + \gamma_W)(\alpha + L(c + d + \gamma_B)) - (\alpha + L(a + b + \gamma_W))(2dL + L\gamma_B - \theta)]}{L^2(2b + \gamma_W)(2c + \gamma_B) - (2aL + L\gamma_W - \theta)(2dL + L\gamma_B - \theta)} \\ B^* = \frac{L[L(2c + \gamma_B)(\alpha + L(a + b + \gamma_W)) - (\alpha + L(c + d + \gamma_B))(2aL + L\gamma_W - \theta)]}{L^2(2b + \gamma_W)(2c + \gamma_B) - (2aL + L\gamma_W - \theta)(2dL + L\gamma_B - \theta)} \end{cases} \quad (8)$$

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<sup>21</sup>As mentioned by Fossett[35], and Clark and Fossett[22]

We have now to specify how the dynamic adjustment takes place if the initial distribution of types across locations is out of equilibrium. We assume that individuals move according to their observation of the configuration of the society in the previous period. Deriving from the system (6), we have the following dynamic adjustment process:

$$\begin{cases} \dot{W} = \frac{((2a + \gamma_W)L - \theta)W_t + (2b + \gamma_W)LB_t - L^2(a + b + \gamma_W) - \alpha L}{\theta} \\ \dot{B} = \frac{(2c + \gamma_B)LW_t + ((2d + \gamma_B)L - \theta)B_t - L^2(c + d + \gamma_B) - \alpha L}{\theta} \end{cases} \quad (9)$$

with  $\dot{W} = \frac{\partial W_t}{\partial t}$  and  $\dot{B} = \frac{\partial B_t}{\partial t}$ .<sup>22</sup> At this stage, we may note that the perception of the minority plays a role of offsetting the racial preferences. It will strengthen or dampen the preferences for like and unlike individuals. We then have the following properties:

**Proposition 2.** *Under the dynamic adjustment process (9), an integrated equilibrium is unique if and only if it is stable.*

The link between uniqueness and stability is a consequence of the linearity of this specification. Let us define what a structure of preferences is in this framework.

**Definition 2.** *A **structure of preferences** is a set of restrictions on the preference parameters for the own group and the other group:  $a, b, c$ , and  $d$ .*

**Proposition 3.** *For all  $a, b, c, d, \theta, L$  such that  $\frac{\theta}{L} \neq 2(d - c)$ ,  $a \neq b$ , and  $c \neq d$ :*

*There always exists a combination of the two perceptions of the minority ( $\gamma_W^*$ ;  $\gamma_B^*$ ) such that the city will end as being integrated without any policy intervention, no matter the initial configuration, if the trajectory does not hit the boundary of the domain.*

*Moreover, there also always exists a combination of perceptions of the minority ( $\gamma_W^P$ ;  $\gamma_B^P$ ) for which the city can become integrated through a relocation policy<sup>23</sup> if it were segregated in the first place.*

<sup>22</sup>The system can be solved analytically, which is done in appendix. However, the explicit solution of this system has little interest for us.

<sup>23</sup>A relocation policy consists in relocating individuals of a certain type from a location to another location.

The dynamic system behaves, in some case, as a spiral sink. Thus, all trajectories should converge to the integrated equilibrium. However, as there cannot be a negative number of individuals (or more than a hundred percent of a group) in a location, some trajectories are constrained to converge toward a segregated state. Hence, this imposes the restriction of not hitting the boundary of the domain. We will illustrate this property in the “mutual reject” case. Moreover, graphical illustrations of the Proposition 3 will be presented in the next subsection.

## 2.4 Exploring different structures of preferences

Despite many possible structures of preferences, we restrict our analyses to three cases that we think to be relevant. All these structures have in common to keep the attitude of Whites constant. In each situation, Whites will tend to segregate by seeking peers and rejecting the other group. Although there are signs of greater tolerance over time from Whites, we believe that this is still the main attitude in both the United States (Krysan et al.[44]) and South Africa (Duckitt et al.[29], and Dixon et al.[26]). So, we want to explore the dynamics of segregation given the attitude of Whites with respect to three possible attitudes that the discriminated group may adopt.

As we are studying a dynamic linear system on a bounded domain, some trajectories might end stuck at a point on the boundary of the domain. Such points are not equilibria but they are remarkable attractors in which the society might be trapped forever, without a policy intervention. Thus, we will call such situation *a state* to emphasize the difference with a proper stable equilibrium as defined in Section 2. We will consider these states as, at least, locally stable.

### 2.4.1 Mutual reject

When both groups are racist ( $b$  and  $c < 0$ ), we say that both groups are rejecting each other. Moreover, as discussed in the proof of the Proposition 3, antisocial behaviors are unlikely to be representative of a large share of the population. Thus, we also restrain individuals to have homophilic preferences as well ( $a$  and  $d > 0$ ). Sakoda[53] describes a similar situation in his “segregation” case. It also portrays the relationship between Afrikaaners and Africans (Duckitt et al.[29]). To fix ideas in graphical illustrations, we use the following parameter values:  $a = 10$ ,  $b = -8$ ,  $c = -2$ ,  $d = 6$ . For the sake of simplicity, we fix  $\theta = 6$ ,  $\alpha = -3$  and  $L = 1$  for the rest of the section.

Figure 2 depicts the bifurcation diagram and the associated dynamics. The bifurcation diagram shows which type of dynamics is at play depending on the values taken by the perceptions of the minority  $\gamma_B$  and  $\gamma_W$ . Each general category of dynamics is located by a number in the  $(\gamma_B, \gamma_W)$ -plane. The associated phase

diagrams are depicted just beside the bifurcation diagram. In the latter, the lines  $Tr(J_f)$  and  $|J_f|$  indicates respectively when the trace and the determinant of the Jacobian matrix of the dynamic system are null. The curve labelled “Complex roots” indicates when the dynamic system will oscillate. For all phase diagrams in the paper, the percentage of Blacks living in Location 1 are depicted on the abscissae while the percentage of Whites living in Location 1 are on the ordinate. If the axes are read in the opposite direction, the interpretation would be in percentages of each group living in Location 2. Finally, the curves  $\dot{B} = 0$  and  $\dot{W} = 0$  represents the nullclines of the dynamic system. Crossing these lines changes the dynamics of the group of which the nullcline has just been crossed.

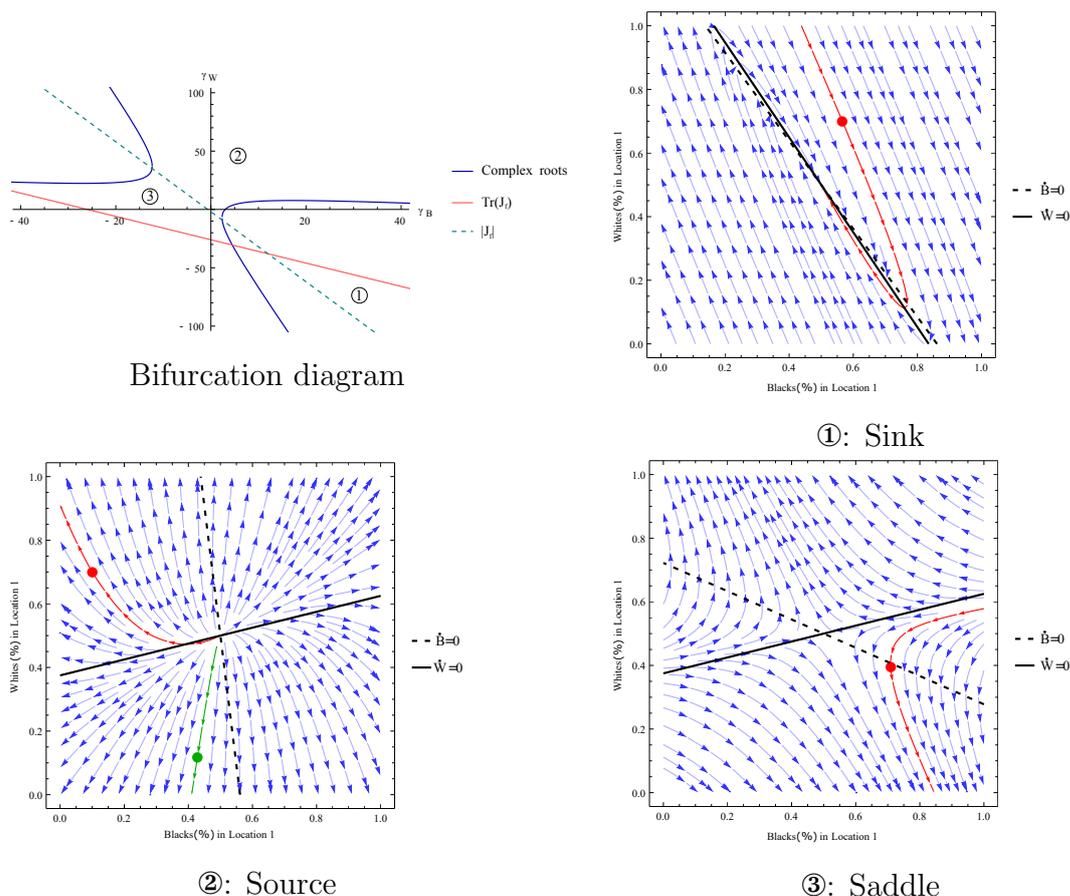


Figure 2: Mutual reject

From these graphics, we can see that integration can arise and be stable both with and without any intervention. This directly comes from Proposition 3. For a couple  $(\gamma_B^*; \gamma_W^*)$  lying in Area 1, the integrated equilibrium is stable. This occurs for a positive value of the Black perception of the minority and a negative value

of the White perception of the minority.

With such values of perception parameters, if the city starts in a configuration in which Whites dominate the most populated location, then Whites will move in the location dominated by Blacks, if the number of Blacks in this location is sufficiently large. Whites in the location they dominate benefit from a large number of peers but endure a consequent Black minority as well. So, the negative impact of the Black presence is amplified by the negative perception of the minority Whites have. In the other location, Whites suffer from living in the minority but this effect is attenuated by living with some peers and by the small number that constitute the White minority. They also suffer from the size of the local Black majority. Whites face then a trade-off between a location with a lot of peers but with a too high Black minority and a location with few peers but with a Black majority. Since they strongly reject the association with Blacks through their strong negative perception of the minority, the utility differential is in favor of the location dominated by Blacks as soon as the Black minority is large enough.

The fact that Whites would abandon a location where they dominate for a location where they constitute the minority in the first place seems to be counter-intuitive. However, consider a situation in which at least some Whites would have (in addition to their preferences for the racial mix) eugenic preferences<sup>24</sup> concerning mating and marriages.<sup>25</sup> Then, as the number of Whites in the location grows, it would be more difficult for these White eugenicists to influence their peers toward homogamous relationships. Thus, even if they hate Blacks, they might move in a location where they are the minority in order to insure their eugenic goal. Punishment of defectors would be easier and would increase the average utility of the White minority (Boyd et al.[13]). Bisin and Verdier[10] also describe such segregation norms in the marriage markets of French aristocrats, or Orthodox Jews. In South Africa, leaders of the Great Trek made clear that the racial lines would not be crossed in any compartment of life (although they were mostly angered by the abolition of slavery).<sup>26</sup> During the Apartheid, the enforcement of eugenic

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<sup>24</sup>Eugenic preferences refer to the desire of individuals to control mating strategies with the goal of “improving” the human species such that only “good” characteristics persist in the population. Such improvement and the good characteristics to preserve are obviously subjective. This type of preferences was widespread in all European societies and their colonies during the Colonialism era, and, in particular, in South Africa (Kirk[43]). Later, this kind of reasoning was largely used to justify the White supremacy and helped to establish firmly the racist and authoritarian regime that the Apartheid was (Rich[52], and Dubow[28]).

<sup>25</sup>This eugenic preferences could directly be the perception of the minority. Indeed, if Blacks are the minority in a location, they constitute the pervasive threat for these eugenicists, whereas if Whites constitutes the minority, it is easier for them to control the mating strategies of their members. In both case, it reflects the way they perceive the life with a minority, either as a threat or a beneficial control tool.

<sup>26</sup>Piet Retief declared: ”We are resolved, wherever we go, that we will uphold the just principles

preferences was established by the Immorality Act (1950) and the Prohibition of Mixed Marriage (1949)(Thomson[58]).

On the other hand, Blacks will be more reluctant to enter a location dominated by Whites. In this location, they will benefit from a small share of peers but this effect is positively reinforced by the complementarity with Whites. However, they will suffer from a large number of Whites. In the location dominated by Blacks, they will enjoy many of their peers and the few Whites will cause them only minor discomfort. But they will benefit only moderately from the complementarity with Whites. This might be the case if Whites possess the factors of production while Blacks mainly compose the labor force, which was the case during the Apartheid. Still today, this situation persists despite some redistribution policies. As Blacks value strongly the complementarity with Whites, the location dominated by Blacks is not as desirable as it seems compared to the one dominated by Whites. So, the utility differential between the two locations is lower than for Whites. It is also in favor of the location dominated by Whites as Blacks want to live with the biggest minority possible.

Whites want to live with the lowest minority possible while Blacks desire the largest minority possible. So, both groups are initially drifting apart as they prefer different locations. In the location dominated by Whites, a lot of Whites move out while a few more Blacks move in. While in the location dominated by Blacks, a lot of Whites move in and few Blacks move out. These two dynamics increase the utility differentials in the same direction. The location dominated by Whites becomes more attractive for Blacks as the minority increases and the number of Whites diminishes. While in the location dominated by Blacks, the minority increases but is still lower than the minority in the other location. Also, the Black majority decreases, which makes the Black dominated location more attractive for Whites. At some point, the number of Whites will be equal between the two locations. But as long as the number of Blacks is different in the two locations, Whites will continue to choose the location with the lowest minority while Blacks will choose the one with the largest minority even if the minority changed its color. This dynamic motion can continue to a completely segregated state.

However, after the minority changed color in both locations, there is a point from which the Blacks' preferred location changes. This switch occurs because the Black minority in the initially Black-dominated location is sufficiently large compared to the White minority in the other location. Thus, the positive effect for

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of liberty; [...] it is our determination to [...] preserve proper relations between masters and servants". His niece, Anna Steenkamp pursued later: "It is not so much their freedom that drove us to such lengths, as their being placed on an equal footing with Christians, contrary to the laws of God and the natural distinction of race and religion, so that it was intolerable for any decent Christian to bow down beneath such a yoke; wherefore we rather withdrew in order thus to preserve our doctrines in purity." (Thomson[58], p.88)

Blacks of being in a Black minority offsets the negative impact of the large White majority and the benefit they would get from peers and a small White minority in the other location. Then Blacks will move in the White-dominated location. Still, Whites are very sensitive to Black variations in their number. So, the Black minority will increase so much that even if Whites are all in the same location, they will evacuate this location. This process will move as described before until the city will reach the perfectly integrated equilibrium.

At this point, both Blacks and Whites do not want to move anymore because deviation will be harmful for both groups. Imagine that 1% of the Whites deviates from the equilibrium, then one location will have a 51% White majority but a 50% Black minority. As Whites do not like Blacks and Black minorities even more, they will face a strong penalty to live in this location. In the other location, 49% of the Whites will reside with 50% of the Blacks. However, the minority is lower than in the location dominated by Whites and, as it is a White minority, homophily weakens the negative perception of the minority. Thus, 1% of the Whites will move back to the Black-dominated location. If 1% of the Blacks deviates, the equilibrium will be restored because homophily strengthens the Black positive perception of the minority.

As mentioned before, even if for some trajectories the city will converge toward the perfectly integrated equilibrium, there are some initial configurations for which the city ends up completely segregated. In this case, a government willing to build an integrated city could achieve its goal by implementing a relocation policy. However, the number of displaced people has to be sufficiently large in a one-shot movement to bring back the city on an integration path. If the policy is not properly calibrated, then people may move back to their previous location(s), or others will enter and offset their departure. This “big push” policy is similar in spirit to programs like the Moving To Opportunity experiment in the United States. Our analysis could help to calibrate the proper size of the program if it would be generalized.<sup>27</sup>

Now, if a government would like to obtain an integrated city, it could also design a policy aiming at promoting positive perceptions of the minority for both groups. Thus, we would be in the first quadrant of the  $(\gamma_B; \gamma_W)$ -plan, and more generally in Area 2 of Figure 2. The city behaves as a source, and can end in a locally stable segregated or integrated state depending on the initial conditions. However, the government will be able to restore integration if the city was segregated in the first place by a sufficiently large relocation policy. Once again, the type of policy advocated is a “big push” story.

If the city starts in a configuration where both locations are not too unbalanced, then the city will converge toward an integrated state where all individuals gather

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<sup>27</sup>See Katz et al.[42] for details about the experiment

in the initially most populated location. If both groups perceive positively the minority, their utility will be larger in the location where the minority is the largest. If Whites dominates this location, they will also benefit from the large White majority through their homophilic preferences. If they constitute the minority, their positive perception of the minority will amplify their homophilic preferences. This effect will do more than compensate the large Black majority if the White minority is large enough. In the least populated location, Whites will benefit less from both their majority status and from the Black minority. Thus, the utility differential will be in favor of the most populated location for both groups. Thus both the minority and the majority groups will be larger as people moves from the least to the most populated location which widen further the utility differential.

If the city is initially unbalanced enough, the positive perceptions of the minority are not sufficiently large to compensate homophilic effects. Complete segregation would then occur. Whites in the location they dominate benefit largely from a large majority and benefit only a little from the small Black minority. In the other location, Whites will suffer from the large Black majority and gain only few from their minority status. The situation is symmetric for Blacks. So, both groups will have a utility differential in favor of the location dominated by their peers. Thus, Whites will move in the White dominated location, while Black will move out, which broaden the utility differential. However, in this example, relocating more than 30% of Blacks (or more than roughly 45% of Whites) at once will bring back the city on an integration path.

Finally, if the social context is such that both groups perceive negatively the minority, then we are almost completely in the third quadrant of the  $(\gamma_B; \gamma_W)$ -plan. More generally, the Area 3 of the Figure 2 exhibits the same type of saddle dynamics, only segregated states will emerge. In this situation, the perceptions of the minority reinforce the segregation forces of homophily and racism. Both groups want to live with the smallest minority possible. Whites living with a Black majority suffer both from being with a large number of Blacks and to live in the minority. While in the other location, their disutility of being associated with a Black minority is softened by the large peer presence they enjoy. So, as long as the unlike minority is not too large, the utility differential for each group will be in favor of the location dominated by their peers. Thus, the two groups will drift apart and a completely segregated city will emerge.

There are also initial configurations in which the city may at first sight converge to the perfectly integrated equilibrium but finally collapse in a segregated state. If Blacks dominate the most populated location, the large White minority generates a lot of discomfort for them. In the other location, Whites constitute the majority but suffer moderately from the small Black majority. Then at first, both Blacks and Whites will prefer the location dominated by Whites and start moving in,

which pulls the city toward more integration. However, at some point for Blacks, the racism effect of the growing White majority overcomes the homophilic effect of the growing Black minority (which is also counterbalanced by their negative perception of the minority). Then, the utility differential between the two locations changes. Whites still prefer the White dominated location whereas Blacks move in the Black dominated one. Finally, the two groups will drift apart until the city will be completely segregated as described earlier.

Once again we were in a situation in which a group, despite being largely dominating one location, will choose to leave this location. As a way to rationalize the Blacks' behavior, imagine that the White dominated location is the most affluent location. Then Blacks would move in to benefit from the higher standard of life in this affluent location. However, acculturation and status concerns may bring back Blacks in their previous location.

#### 2.4.2 White segregation versus Black integration

Blacks may oppose to the White segregationist preference structure a desire to live with both Blacks and Whites. This translates into a positive taste for both Blacks and Whites. We also choose to study the case of a stronger homophilic preference than the taste for the other group due to the homophilic bias already discussed earlier. Farley et al.[34] find such structure of preferences in the Detroit area in the late 1970s. In South Africa, Blacks have such preferences toward English-speaking Whites, however English-speaking Whites have also a friendly attitude toward Blacks (Duckitt et al.[29]). Our parameterization is set as follows:  $a = 10$ ,  $b = -8$ ,  $c = 5$ ,  $d = 7$ . Figure 3 represents the associated bifurcation diagram.

In this context, a completely integrated equilibrium can emerge from two negative perceptions of the minority. More generally, integration can be generated by any combination of perceptions that lies inside the Area 1 of Figure 3. However, the mechanism is similar to the one described in the "mutual reject" case. The main difference is that a relocation policy is not necessary in this case as the smallest level of integration is always preferred by Blacks. Assume that the city is completely segregated. Then, all Whites live in their most desirable location as they do not like Blacks and minority status. If 1% of Whites move out from this location, they will suffer from a number of Blacks, and constituting a small White minority. Compared to the all Whites location, they will choose to move back to their previous location, restoring the completely segregated state. On the other hand, if 1% of Blacks move in the all Whites location, they will benefit both from the maximum number of Whites, from the small presence of their peers, and from being in the minority. Compared to the all-Black location, they will prefer to stay where they are. Thus the utility differential for Blacks shifts in favor of the location dominated by Whites. Integration will increase as both groups will favor

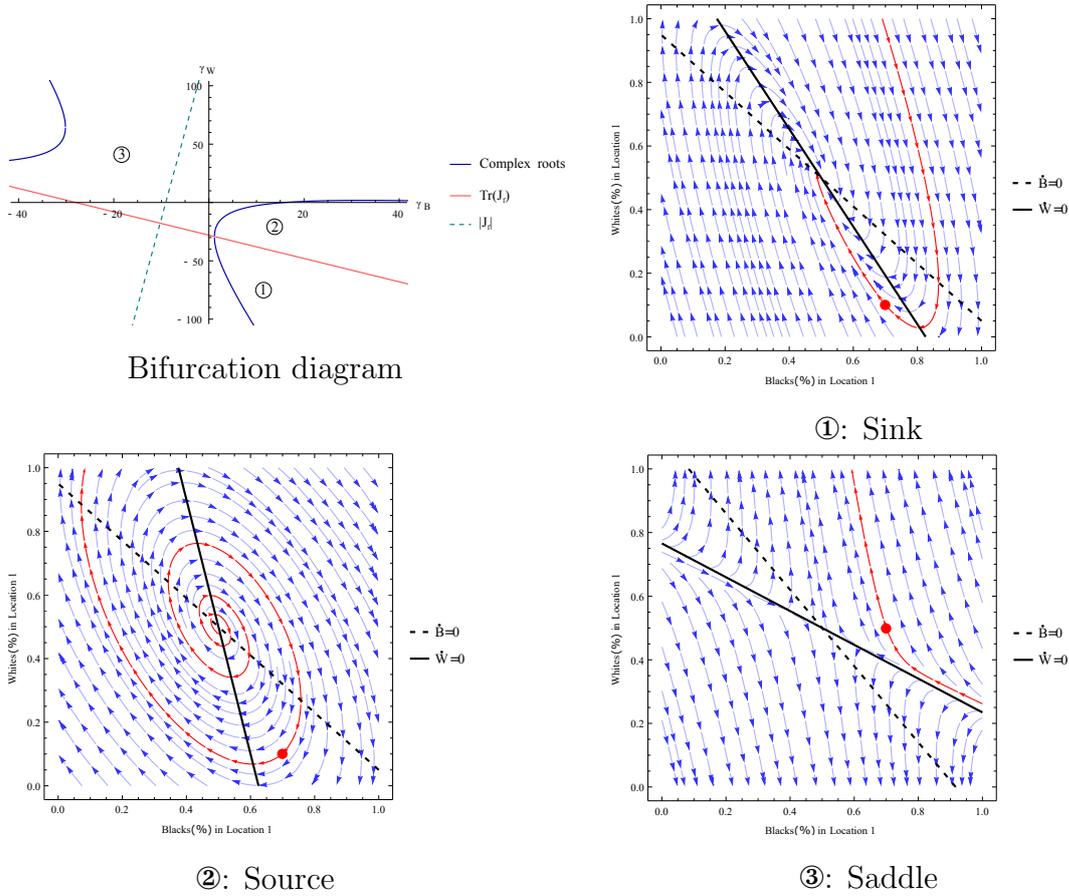


Figure 3: White segregation vs Black integration

the same location. Then, when the Black minority will be large enough, Whites will prefer to move out of this location. A completely integrated equilibrium will thus emerge as a stable outcome as described earlier.

Source dynamics can also arise in this context, but with this structure of preferences, we want to emphasize that all source dynamics might not be desirable. For perceptions of the minority lying in Area 2 of Figure 3, the source dynamics is spiralling. When the city is in this situation, neither the completely segregated states nor the integrated ones are stable anymore as one group will chase the other indefinitely in a limit cycle. Imagine that the city starts in the integrated state in which all individuals live in location 2. Then, Whites will move in the deserted location because they actually suffer a lot from the largest minority possible (no matter the color of the minority), and from the largest group of Blacks possible. On the other hand, they will enjoy living alone in the other location as there is no Black minority at all despite the limited peer presence. Thus the utility differential

for Whites is in favor of the deserted location. For Blacks, the deserted location is not interesting as they would be alone only benefiting from the small number of peers while complementarity with a large number of Whites, and a large Black majority is strongly beneficial for them. Thus, the utility differential for Blacks is in favor of the most populated location. At some point, the White minority becomes too small compared to the benefit of a small Black minority living in the all White location. Then both groups will favor the same location until the point where the Black minority will grow too large. The dynamics will continue as described previously but for a different location, hence completing the cycle.

Finally, the saddle dynamics that can occur lead to a segregated state as previously. However, segregation is not complete in this case as a small number of Blacks will live within the location dominated by Whites.

### 2.4.3 Acting White

Some individuals of the discriminated group may reject their own group and embrace the culture of the dominant group. This phenomenon is known as “acting Whit” or more generally as the oppositional culture hypothesis. It has been used to explain the different performances of Blacks and Whites in school tests (Ainsworth-Darnell and Downey[1], Austen-Smith and Fryer[4], Fryer and Torelli[36]) or on the job market (Battu et al.[6]) in the United States. This behavior is much less studied in South Africa, only partial evidences could be found in the literature (McKinney[46]). In our framework, this behavior translates into the following parameters set:  $a = 10$ ,  $b = -8$ ,  $c = 5$ ,  $d = -7$ . Figure 4 portrays the associated bifurcation diagram.

Compared to the previous structures of preferences, a stable completely integrated equilibrium can emerge for a larger subset of the  $(\gamma_B; \gamma_W)$ -plan (both with and without spiralling). Usually, completely integrated equilibria will not require a policy intervention in this case. Integrated states will occur also more frequently despite a reduced subset for source dynamics because some saddle dynamics will lead to integrated states rather than completely segregated states. Moreover saddle dynamics will usually not produce completely segregated states when deviating from an integrated one.

In the first quadrant of the  $(\gamma_B; \gamma_W)$ -plan, saddle dynamics have almost replaced the source dynamics. For some combinations of perceptions of the minority, the saddle dynamics will lead only to integrated states as for the example illustrated in Figure 4. If the city starts in a highly segregated configuration, Whites benefit a lot from their large majority and their racism is compensated by their positive perception of the minority in the location they dominate. In the other location, they benefit only a little from their small peer presence and consequently gain only little from their complementarity with Blacks, but they suffer a lot from

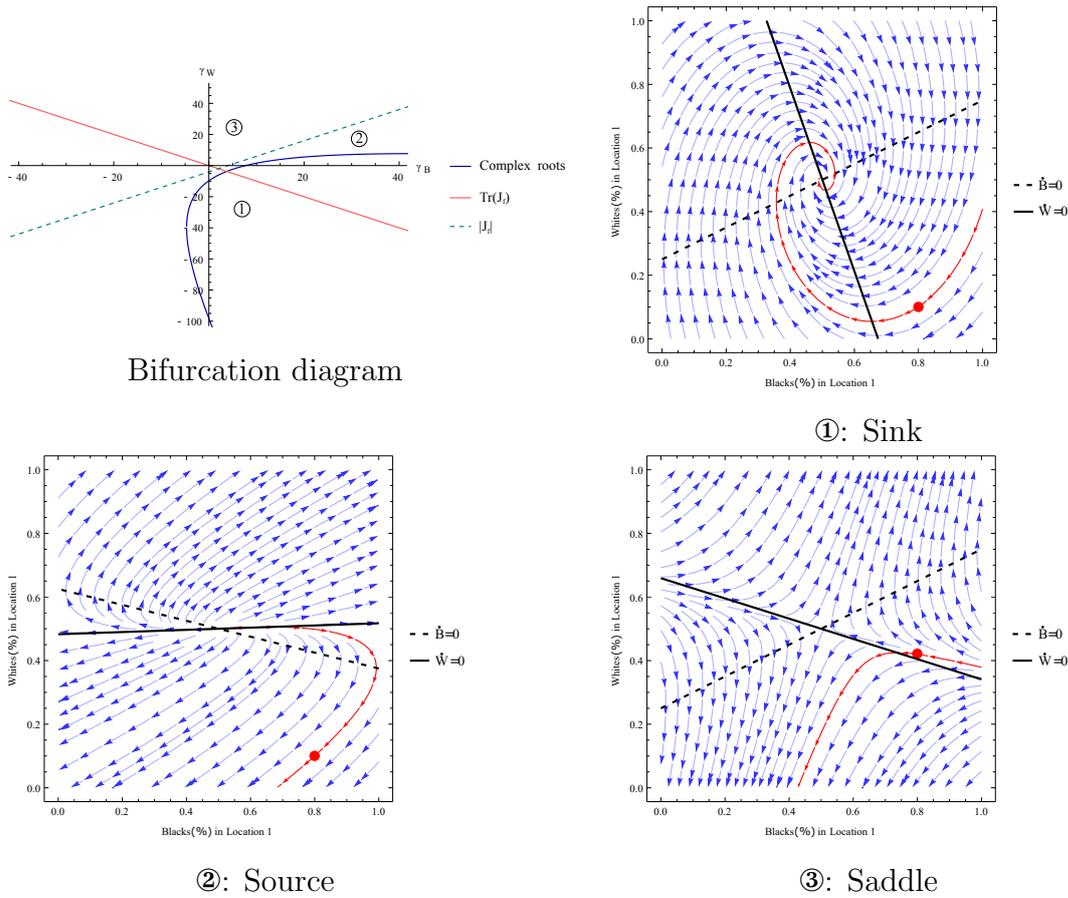


Figure 4: Acting White

the large Black majority. So, the utility differential is in favor of the location dominated by Whites. Besides, Blacks in the location dominated by Whites are benefiting from a large White majority, and both the small number of Blacks and living in the minority weaken the negative effect of a peer presence. In the other location, Blacks endure a large peer presence and benefit only a little from the small White minority. Hence, the utility differential is also in favor of the White dominated location. Then both Blacks and Whites will gather in the same location pushing the city into an integrated state.

Imagine now that Whites are initially close to an equal distribution in the two locations while Blacks are not. As Whites perceive positively the minority, they will move in the location dominated by Blacks because the White minority already living in the location is sufficiently large to compensate the large Black majority. On the other hand, Blacks will prefer to move out of this location at first as they can join a White majority and a small peer presence in the other

location. As both groups move, the utility differential increases for Whites but diminishes for Blacks. The White majority is decreasing while the Black minority is increasing while in the other location, the White minority is increasing and the Black majority is shrinking. Thus when the White minority has grown sufficiently large, Blacks come back in their initially dominated location.

From the description of the above example, we can see that saddle dynamics are sensitive to the perceptions of the minority. For instance, let us assume that Blacks have a negative perception of the minority and the city starts in an integrated state in which Location 1 is deserted. Blacks suffer a lot in this location as there is the largest Black community possible. No matter the identity of the minority, Blacks have a negative pay-off in this location while it is actually null in the other location as there is nobody. So, Blacks have an incentive to move out of this neighborhood. On the other hand, living with all their peers ensures Whites to have positive pay-off in this location, as the complementarity with Blacks compensate sufficiently their racist preference for the homophilic effect to dominate. Thus, Blacks destroy the integrated state of the city. However, Blacks do not want to live with peers. Consider a completely segregated state, Blacks would have an incentive to move in the location dominated by Whites as they can benefit a lot from the large number of Whites whereas they endure the largest Black community. So, there should be a point in between the completely segregated state and the integrated one with Location 1 deserted. The city thus reaches a stable state when the benefit of the White majority minus the cost of living in a Black minority is equal to the cost of living only with Blacks. This state is neither completely segregated nor completely integrated as one the group will be present in both locations while the other will live in only one location.

If the city follows a saddle dynamics, no relocation policy would restore an integrated state. The only possible policy would be to act on the perceptions of the minority to bring back the city either in a source dynamics (where a relocation policy can be implemented) or in a sink dynamics. In the latter scenario, usually no intervention would be required. The sink dynamics is similar to the one described in the previous structure of preference. The source dynamics (without spiralling) differs only from before in the reduced number of trajectories leading to a segregated state (which will usually not be complete).

## 2.5 Different population sizes

Now, we relax the assumption of equal population sizes. At the city level, one group overwhelms the other, say  $L^B > L^W$  which is the South African case.<sup>28</sup> The

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<sup>28</sup>Note that the reverse assumption  $L^W > L^B$  is the American situation while the case of equality  $L^W = L^B$  describes the Brazilian case approximately.

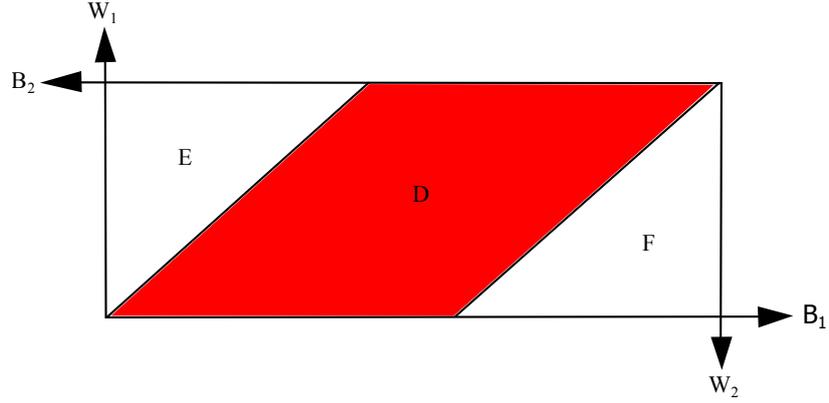


Figure 5: Representation of the different subsets of the city.

particularity of this situation resides in the apparition of a subset of racial mixes in which the minority group at the global level is also a minority at the local level for all the locations. When populations are equal this situation is impossible as a minority group in one location is, by complementarity, the majority in the other location.

There are two domains in which the society can be. The first domain is denoted  $D$ , where the minority group at the city level is also a minority at the local level.<sup>29</sup> The remainder domain can be split in two subsets, denoted  $E$  and  $F$ , which are the sets where the minority group in one location is the majority group in the other location.

The utility function, and therefore the difference in utility between two locations can be rewritten as:

$$\Delta u^{W1}(B, W) = \begin{cases} 2(a + \gamma_W)W + 2bB - (a + \gamma_W)L^W - bL^B & \forall (B; W) \in D \\ (2a + \gamma_W)W + (2b + \gamma_W)B - (a + \gamma_W)L^W - bL^B & \forall (B; W) \in E \\ (2a + \gamma_W)W + (2b + \gamma_W)B - aL^W - (b + \gamma_W)L^B & \forall (B; W) \in F \end{cases} \quad (10)$$

and

<sup>29</sup>The red diamond in Figure 5 is the set of all points where  $\min[W; B] = W$  and  $\min[L^W - W; L^B - B] = L^W - W$ .

$$\Delta u^{B1}(B, W) = \begin{cases} 2(c + \gamma_B)W + 2dB - (c + \gamma_B)L^W - dL^B & \forall (B;W) \in D \\ (2c + \gamma_B)W + (2d + \gamma_B)B - (c + \gamma_B)L^W - dL^B & \forall (B;W) \in E \\ (2c + \gamma_B)W + (2d + \gamma_B)B - cL^W - (d + \gamma_B)L^B & \forall (B;W) \in F \end{cases} \quad (11)$$

Then, the corresponding dynamics is:

$$W_{t+1} = \begin{cases} \frac{2(a + \gamma_W)W_t L^W + 2bB_t L^W - (a + \gamma_W)L^{W^2} - bL^B L^W - \alpha L^W}{\theta} & \forall (B;W) \in D \\ \frac{(2a + \gamma_W)W_t L^W + (2b + \gamma_W)B_t L^W - (a + \gamma_W)L^{W^2} - bL^B L^W - \alpha L^W}{\theta} & \forall (B;W) \in E \\ \frac{(2a + \gamma_W)W_t L^W + (2b + \gamma_W)B_t L^W - aL^{W^2} - (b + \gamma_W)L^B L^W - \alpha L^W}{\theta} & \forall (B;W) \in F \end{cases} \quad (12)$$

and

$$B_{t+1} = \begin{cases} \frac{2(c + \gamma_B)W_t L^B + 2dB_t L^B - (c + \gamma_B)L^B L^W - dL^{B^2} - \alpha L^B}{\theta} & \forall (B;W) \in D \\ \frac{(2c + \gamma_B)W_t L^B + (2d + \gamma_B)B_t L^B - (c + \gamma_B)L^W L^B - dL^{B^2} - \alpha L^B}{\theta} & \forall (B;W) \in E \\ \frac{(2c + \gamma_B)W_t L^B + (2d + \gamma_B)B_t L^B - cL^W L^B - (d + \gamma_B)L^{B^2} - \alpha L^B}{\theta} & \forall (B;W) \in F \end{cases} \quad (13)$$

These last two systems of equations are the basis of our empirical application. Depending on the subset in which the city is, we are able to identify all the parameters, and notably the parameters for the perceptions of the minority  $\gamma_W$  and  $\gamma_B$ . We present this application in the next section.

## 3 Racial Preferences in Post-Apartheid South Africa

### 3.1 Identification of the structural parameters

In our application, the locations will be South African subplaces, which we discuss in subsection 3.2. In order to identify the different subsets of the previous section, we divide the sample in two subsamples. The first subsample is composed by the districts in which Whites constitute the majority, whereas the second subsample is composed by the districts in which Blacks constitute the majority. Running regressions on a particular subsample will deliver the effect for this particular subset. For instance, if we estimate using the White-dominated subsample, we are considering that Location 1 is dominated by Whites. In that case, Location 2 is dominated by Blacks. Therefore, we are currently located in the subset E. Similarly, if we estimate using the Black-dominated subsample, we are considering that Location 1 is dominated by Blacks. In that case, Location 2 is dominated by Whites. Therefore, we are currently located in the subset F.<sup>30</sup> Thus, the empirical counterpart of the dynamic equation (12), for Whites in E, is a linear autoregressive model:

$$\begin{aligned}
 W_i(t+1) = & \delta + \beta_1 W_i(t) * L_i^W(t) + \beta_2 B_i(t) * L_i^W(t) + \beta_3 L_i^{W^2}(t) + \beta_4 L_i^W(t) * L_i^B(t) \\
 & + \beta_5 L_i^W(t) + \mathbf{X}_i(t)\boldsymbol{\beta} + \epsilon_{wi}(t+1)
 \end{aligned}
 \tag{14}$$

where  $\delta$  is a constant term,  $\mathbf{X}_i(t)$  is a set of location-specific control variables expressing the attractiveness of the locations,<sup>31</sup> and  $\epsilon_{wi}$  is an idiosyncratic shock that is specific to the subplace  $i$  and to whites (materialized by the subscript  $w$ ).

We estimate separately equation (14) for each group and each location using OLS. The obtained system of four equations is overidentified and we have to turn to a least-squares solution.

Recalling equation (12) for Whites in the subset E, we have:

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<sup>30</sup>Note that being in the subset E is equivalent to being in the subset F as E and F are symmetric. Thus, it is just a matter of notations and how you define Location 1 and Location 2. Moreover, the construction of our subsamples insures that we cannot be in the subset D as each subsample is dominated by a different group. For the rest of the paper, we will adopt the convention that Location 1 is the location dominated by Whites, whereas Location 2 is the location dominated by Blacks.

<sup>31</sup>Throughout this, boldface characters denote column vectors and matrices.

$$W_{1_{t+1}} = \frac{(2a + \gamma_W)W_t L^W + (2b + \gamma_W)B_t L^W - (a + \gamma_W)L^{W^2} - bL^B L^W - \alpha L^W}{\theta} \quad (15)$$

By identification with equation (14), we obtain the following linear system of five equations and four unknown parameters  $(a, b, \alpha, \gamma_W)$ :

$$\begin{cases} \beta_1 = 2a + \gamma_W \\ \beta_2 = 2b + \gamma_W \\ \beta_3 = -(a + \gamma_W) \\ \beta_4 = -b \\ \beta_5 = -\alpha \end{cases} \quad (16)$$

The minimum-distance solution results from the following minimization programme:

$$\min_{a, b, \gamma_W, \alpha} (\beta_1 - 2a - \gamma_W)^2 + (\beta_2 - 2b - \gamma_W)^2 + (\beta_3 + a + \gamma_W)^2 + (\beta_4 + b)^2 + (\beta_5 + \alpha)^2 \quad (17)$$

We obtain:

$$\begin{cases} \hat{a} = \frac{7\beta_1 - 3\beta_2 + 4\beta_3 - 6\beta_4}{10} \\ \hat{b} = \frac{2\beta_1 + 2\beta_2 + 4\beta_3 + -6\beta_4}{10} \\ \hat{\gamma}_W = \frac{\beta_2 - \beta_1}{2} + \beta_4 - \beta_3 \\ \hat{\alpha} = -\beta_5 \end{cases} \quad (18)$$

Finally, the standard errors of all the estimators of the structural parameters are calculated using the delta method.

### 3.2 Data description

The data used in the empirical application comes from the Community Profiles associated with the Census waves conducted in South Africa between 1996 and 2011. Community Profiles are cross-tabulations of the full counts aggregated by geographic areas. They are available up to the enumeration area level for the 1996 and 2011 censuses, and to the subplace level for the 2001 Census. As our statistical unit is a geographic subdivision, we are facing two problems. First, we would like

to have large sample sizes to conduct a statistical analysis. Second, as segregation measures are sensitive to changes in boundaries, we would like to have a stable geographic layer. Unfortunately, over the 1996-2011 period, no geographic layer remained unchanged. Thus, we have chosen to work at the subplace level adjusted to the 2001 boundaries. To adjust the data, we use the freeze history approach.<sup>32</sup> The overlap between the “source” and the “target” polygons serves as areal weight to adjust the data of the “source” layer to the targeted layer. See Appendix 5.5 for more details. This procedure leads to a sample of 21243 subplaces in each of the three Census waves. Subplaces are the lowest South African administrative division, except enumeration areas which are used only for censuses. In average, 2000 individuals live in a subplace. Moreover, the subplace has a concrete meaning for individuals as it is the broad area by which they locate their living place in a city. Real estate agencies also use this layer for their advertisements, which suggests that they correspond to local housing markets.

According to our equations above, our dependent variable should be the number of Whites<sup>33</sup> in a subplace at a particular census wave. However, we use instead the logarithm of the share of Whites (plus 1) in a subplace to avoid the effect of population size disparity between subplaces.

The main independent variables are the number of Whites and Blacks in a subplace at the previous census waves, transformed in the same way as for the dependent variable. We interact these covariates with a measure of the total size of the group at the province level. This measure is the logarithm of one plus the share of Whites at the province level. This variable also appears on its own and squared.

The set of control variables includes subplace-specific variables of basic socio-economic characteristics (mean age, mean income level, unemployment rate, mean education years). They are either measured in logarithm, or as the logarithm of one plus the share. More details about the construction of these variables can be found in the appendices.

### 3.3 Endogeneity

We use the Huber-White’s heteroscedastic-robust estimates of the covariance matrix as a correction.

Our estimator is likely to suffer from endogeneity issues for several reasons. First, in autoregressive models, the error term at a period  $t$  is often correlated to the autoregressive regressor because the latter is correlated with the error term at

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<sup>32</sup>See Norman et al.[48] for a more detailed description.

<sup>33</sup>We detail data construction only for Whites in the text for the sake of brevity. But the same transformations apply also for Blacks.

the previous period  $t - 1$ , and errors may be autocorrelated. In our context, forced displacements during the Apartheid can still possibly explain part of the current local racial composition, even conditionally on the previous Census information. Second, we might have omitted important factors. For instance, discriminatory practices in housing or mortgage markets might have an impact on racial compositions. Thus discriminatory practices would be correlated with the number of Whites in the previous period and the serially correlated error term at  $t$ . Finally, data contamination may be an issue as censuses usually suffer from under- or over count, which may be persistent over time. According to Statistics South Africa, undercount might be partly due to lack of accessibility, which is correlated with race.

Following Kasy[41], we construct instruments using the spatial structure of the White population. We average the number of Whites in contiguous subplaces using queen contiguity<sup>34</sup> of order 1, 2, and 3. On the one hand, if a subplace is dominated by Whites, neighboring subplaces are more likely to be populated by Whites as individuals exert homophilic behaviors. On the other hand, discriminatory practices in a subplace are less likely to be correlated with the number of Whites in adjacent subplaces. Kasy[41] argues that neighboring areas three kms away from the origin are likely to be valid instruments. Accordingly, we exclude the first ring of neighboring subplaces and use only 2nd and 3rd order contiguous subplaces as instruments. We estimate the model with GMM.

We test for endogeneity using the augmented regression approach of Wu[61] as the assumption of homoscedasticity of the Hausman’s test is not verified here.<sup>35</sup> It leads to systematically reject the null hypothesis of exogeneity. The P-values are almost always zero, except for an estimated P-value of 0.32 for Whites in F. The results of the Hansen’s J test for overidentifying conditions, as shown in Table 5, provide mixed support for our instrumentation strategy.

## 4 Discussion

### 4.1 What controls control for

Let us start with the preliminary GMM estimates in Table 1 and 2, then we will move on to the structural estimates. Two control variables are pretty straightforward to interpret, age and income. Age is always positive and significant for

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<sup>34</sup>“queen contiguity” comes from the rules of chess in which the queen can move in every direction.

<sup>35</sup>In all cases, the estimates of the P-values of the Breusch-Pagan tests are almost zero for all groups and location. The results of this test are shown in Table 6 for the Breusch-Pagan test for heteroscedasticity. See Table 4 for tests of endogeneity.

Whites, no matter the specification. This is not surprising as Whites are in average older than Blacks. Thus, older subplaces at the previous period are also those with the larger share of Whites at the current period. For Blacks, the effect is always negative and significant, except for the IV estimates of 2011 for which it is positive but insignificant. In the first case, it is just the opposite effect of Whites. Blacks are younger in average than Whites. Thus, older subplaces at the previous period are also indicative of a lower share of Blacks at the current period.

For income, the coefficient is always positive and significant for Whites, except in subplaces dominated by Blacks in 2011. Once again, the positive correlation is in line with the South African context. Whites are richer than Blacks in average, although the richest Black is richer than the poorest White. Hence, in subplaces dominated by Whites, the more affluent subplaces at the previous period are also those with the larger share of Whites at the current period. For Blacks in the subplaces dominated by Whites, the reverse relation occurs logically. On the other hand, in the subplaces dominated by Blacks, the relation is positive and significant for Blacks while it is positive for Whites but insignificant in 2011 and significant in 2001. These correlations indicate that sorting by income seems to occur in subplaces dominated by Whites. Thus, it seems likely that decentralized racism incentivizes Whites to pay higher prices in the housing market to live in more homogeneous locations.<sup>36</sup> This result might also come from the dominance of traditional dwellings in rural areas and homelands or informal dwellings in townships in the African real estate market during the Apartheid. Thus, most of the South African market is still unattractive to Whites despite the efforts made for improving living conditions of Africans.<sup>37</sup> On the other hand, the positive correlation in the subplaces dominated by Blacks, for both Blacks and Whites, may suggest a different pattern. It indicates that the richest subplaces are those with the largest share of Blacks. This is consistent with wealthy Black ghettos having formed in South African cities.<sup>38</sup> Moreover, the emergence of an educated Black middle class might also play a role in the formation of such ghettos.

The effect of education is rather puzzling. It is positive and significant for all specifications for Blacks, whereas it is almost always negative and significant for Whites. Thus, the more educated a subplace at the previous period, the higher (respectively lower) the share of Blacks (Whites) in this subplace at the current period. Moreover, except for Blacks in subplaces where they constitute the majority, education and income have an opposite effect on segregation. This result seems to reinforce our hypothesis that rich ghettos have formed following the emergence of an educated Black middle class, while it does not help us to interpret

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<sup>36</sup>See Cutler et al.[24] for a similar mechanism in the United States.

<sup>37</sup>See Thomson[58]

<sup>38</sup>See Bayer et al.[7] for a description of this mechanism for the United States.

the effects. It may be that more educated individuals are more tolerant and thus the more educated subplaces are also the less segregated. Another alternative explanation is some persistence of the occupational segregation generated by the Apartheid. Whites were predominant in the best jobs due to racial discriminations of the regime, even if they were not really qualified for the job.<sup>39</sup> This situation may have persisted in the form of active discrimination if recruiters prone to perpetuate such racial dominance were already those in charge during the Apartheid. Or it might just be stereotyping that constrains Blacks to be overqualified compared to Whites for a similar job.

The effect of unemployment on segregation is also not obvious. In subplaces dominated by Blacks, the effect is positive and significant for Blacks, and negative and significant for Whites. Thus, subplaces with more (less) unemployment at the previous period are those with the larger share of Blacks (Whites) at the current period. Hence, Blacks are the most affected by unemployment in the subplaces where they are the majority. In the subplaces dominated by Whites, the effect for Whites (when significant) is also negative which points to the same interpretation as before. The effect for Blacks seems negative. Then, subplaces with higher unemployment rates are those with the lower share of Blacks. It could be either that Blacks living in those places are mostly employed in domestic jobs with a living place on the property of Whites as part of the salary. Or it could be that Blacks living in those subplaces are very successful economically and can manage to live in a dwelling in these affluent subplaces. Thus, the effect would be driven by special selection effects for the Blacks. We now turn to our main interest: the estimates of the structural preference parameters.

## 4.2 Structural preferences estimates

Structural estimates are reported in Table 3. First, we note that the estimated parameters associated with the perceptions of the minority ( $\gamma_W$  and  $\gamma_B$ ) are always strongly significant. Moreover, they are always sizable in absolute value, as compared to homophily (a and d) and racism (b and c). They range between 116% and 456% of the effect of racism, and 31% and 451% of the effect of homophily in 2001 and 2011. Moreover, the perception of the minority is always positive except for Whites when they are the majority in each year.

Then, despite differences in magnitude, we observe for all years and racial groups a strong homophilic preference, no matter the subsample. The parameters a and d, respectively for Whites and Blacks, are always positive and strongly significant. When we look at the attitude toward the other group, Blacks are always

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<sup>39</sup>“Whites, however mediocre their talents, had a near monopoly on middle- and upper-level jobs in the bureaucracy and the private sector.” (Thomson[58], p.242).

characterized by racism, as the parameter  $c$  is always negative and strongly significant. For Whites, the results are ambiguous, as Whites living in Black-dominant subplaces exhibit racism ( $b$  is negative), whereas, in White-dominant subplaces, they have a positive attitude toward Blacks ( $b$  is positive). However, Durrheim et al.[31] find that both White groups (English-speaking and Afrikaaners) still express a negative attitude toward all the other Black groups (Africans, Coloureds, Indians), despite some attenuation over time. Duckitt et al.[29] find racism between Africans and Afrikaaners but no negative attitude from English-speaking Whites toward Africans. This is at odds with our findings concerning the attitude of Whites in the subplaces that they dominate. Thus, if we follow the findings in the literature, our estimates might support the "Mutual reject" scenario. Finally, if we abstract from the potentially biased coefficients, the perceptions of the minority are both positive and larger than racism effects, thus we might be in a Source dynamics. Hence, South Africa seems to be on an integration path.

### 4.3 What we have learned and what remains unsettled

In this paper, we have shown that integration among social or ethnic groups can always emerge when we introduce an externality for the economic and social life an unlike individual brings with him when settling in a community: the perception of the minority. When estimating this effect for South Africa, we find a strong impact of this externality, which is always more powerful than the effect of racism, and has a magnitude at least a third of that of homophily. This advocate for more integration to come in South Africa.

However, our analysis suffers from several caveats. First, an endogenous selection bias problem coming from the partition of the population we have made should be further studied, theoretically and statistically. Whites in the subplaces they dominate may have specific characteristics. Second, we do not control for other potential determinants of segregation such as crime or the housing market. Third, the simple model that has been proposed could be made more sophisticated. Among the restrictive features that could be relaxed stand the linearity of the functional form, or preference parameters that are assumed to be constant over time and the same for all individuals. However, studying complex nonlinear dynamics is usually done by linearizing locally, and the complexity of time varying heterogeneous parameters might have rendered intractable the study of the dynamics of the model.

Finally, the main message of this paper is that the perception of the minority is an important factor of the impact of the preferences on the dynamics of residential segregation. It may have even more impact than homophily and racism combined. A second message is that segregation is not a fatality, contrary to the findings of the literature after Schelling. But governments have to take an active part in

fighting segregation, either by relocating people as in the Moving To Opportunity program in the United States or by promoting diversity and the economic and social benefits that it brings to individuals.

## 5 Appendix

### 5.1 Proof of Proposition 1

*Proof.* Consider a simplex  $S$  defined by  $N_i^k \geq 0$  and  $\sum_k \sum_i N_i^k = L > 0$ . Let us first study the differentiability of the function  $\Delta u^{ki}(W, B)$ . As the two populations are equal, we can explicit the behavior of the min term. If  $W < B$  then  $\min[W, B] = W$  and  $\min[L^W - W, L^B - B] = L^B - B$ . If  $W > B$  then  $\min[W, B] = B$  and  $\min[L^W - W, L^B - B] = L^W - W$ . If  $W = B$  then  $\min[W, B] = W$  and  $\min[L^W - W, L^B - B] = L^W - W$  by convention. Then by simple algebra, we can deduce that the function  $\Delta u^{ki}$  can be expressed finally for Whites as:

$$\Delta u^{W_i}(W, B) = \begin{cases} (2a + \gamma_w)W + (2b + \gamma_w)B - L(a + b + \gamma_w) & \text{if } W \neq B \\ (a + b + \gamma_w)(2W - L) & \text{otherwise} \end{cases} \quad (19)$$

Then, the function  $\Delta u^{ki}(W, B)$  is differentiable on a domain if both the partial derivatives exist and if it has a total differential in each point of its domain. First, let us look at the case  $W = B$ . Thus,  $\Delta u^{ki}(W, B)$  reduces to a function of a single variable and we can easily check that  $\Delta u^{ki}(W, B)$  is effectively differentiable. When  $W \neq B$  we can easily see that the two partial derivatives exists, and, with a bit of algebra, that for an arbitrary  $(W_0, B_0)$  with  $W \neq B, W_0 \neq B_0$ :

$$\lim_{\substack{(W, B) \rightarrow (W_0, B_0) \\ W \neq B}} \frac{\Delta u^{ki}(W, B) - \Delta u^{ki}(W_0, B_0) - \left[ \frac{\partial \Delta u^{ki}}{\partial W}(W_0, B_0) \right] (W - W_0) - \left[ \frac{\partial \Delta u^{ki}}{\partial B}(W_0, B_0) \right] (B - B_0)}{|(W - W_0)^2 + (B - B_0)^2|} = 0 \quad (20)$$

Then  $\Delta u^{ki}(W, B)$  is differentiable for all  $W \neq B$  and *in fine* differentiable for all  $(W, B)$ . Then  $P^{ki}L^k$  is a continuous function which maps from  $S$  (which is a convex and compact set) into itself. Hence, the existence of a fixed point  $N_i^{k*} \geq 0$  such that  $N_i^{k*} = P^{ki}(u^{ki}(N_i^{k*}, N_i^{-k*}), u^{kj}(N_j^{k*}, N_j^{-k*}))L^k, \forall k \in K, \forall i, j \in I$  is ensured by Brouwer's fixed point theorem.  $\square$

## 5.2 Proof of Proposition 2

*Proof.* Let us first provide the conditions for uniqueness and the ones for stability, then let us show that uniqueness implies stability, and finally that stability implies uniqueness. Define two vectors

$$\begin{aligned} N &\equiv (N_1^W, N_2^W, N_1^B, N_2^B), \\ f &\equiv (f^{1W}, f^{2W}, f^{1B}, f^{2B}) \end{aligned} \tag{21}$$

with  $f^{ki} \equiv N_i^k - P^{ki}(\cdot)L^k \quad \forall k \in K$ . Hence, solving the system  $f(N) = 0$  gives us the equilibrium. As shown in the proof of proposition 1, the function  $\Delta u^{ki}(W, B)$  is differentiable which implies that  $f$  is a differentiable mapping from  $\Omega$  into  $\mathbb{R}^4$ , with  $\Omega$  a closed rectangular region  $\Omega = \{N | 0 \leq N_i^k \leq L^k\}$ . The Jacobian matrix is thus:

$$J_f = \frac{1}{\theta} \begin{pmatrix} \theta - (2a + \gamma_W)L & -(2b + \gamma_W)L \\ -(2c + \gamma_B)L & \theta - (2d + \gamma_B)L \end{pmatrix} \tag{22}$$

if  $W \neq B$ , and is equal to  $\text{diag}\{\theta - 2(a + b + \gamma_W)L, \theta - 2(d + c + \gamma_B)L\}$  otherwise. Then according to the theorem 4 of Gale and Nikaidô[37], the mapping  $f$  is univalent if the Jacobian matrix is a P-matrix (*i.e.* a matrix with all its principal minors positive). Thus in our case, as  $\frac{1}{\theta} > 0$ ,<sup>40</sup> we have the following sufficient conditions:

$$\begin{cases} \theta > (2a + \gamma_W)L, \\ \theta > (2d + \gamma_B)L, \\ (\theta - (2a + \gamma_W)L)(\theta - (2d + \gamma_B)L) > (2c + \gamma_B)(2b + \gamma_W)L^2. \end{cases} \tag{23}$$

If this conditions are satisfied, the uniqueness of the equilibrium is implied by the univalence of the mapping  $f$ .

Let us now examine the stability conditions considering the dynamic adjustment process in equation (9). We can remark that the right-hand side of the dynamic system is equal to  $-f(N)$  leading to the same Jacobian matrix multiplied by  $-1$ :

$$J_f = \frac{1}{\theta} \begin{pmatrix} (2a + \gamma_W)L - \theta & (2b + \gamma_W)L \\ (2c + \gamma_B)L & (2d + \gamma_B)L - \theta \end{pmatrix}. \tag{24}$$

Then, by classical arguments, the equilibrium is stable if the two eigenvalues of our system have a negative real part which can be viewed by conditions on the trace and the determinant:

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<sup>40</sup>Because of the assumption  $\alpha < 0$  and  $\beta > 0$ .

$$\begin{cases} 2(a+d)L + (\gamma_W + \gamma_B)L - 2\theta < 0, \\ ((2a + \gamma_W)L - \theta)((2d + \gamma_B)L - \theta) - (2c + \gamma_B)(2b + \gamma_W)L^2 > 0, \end{cases} \quad (25)$$

which is easily seen by simple algebra to be the same conditions as for the uniqueness which completes the proof.  $\square$

### 5.3 Proof of Proposition 3

*Proof.* We solve the equation  $Tr_{J_f} = 0$  for  $\gamma_W$  as a function of  $\gamma_B$  which leads to

$$\gamma_W = \frac{\theta}{L} - 2(a+d) - \gamma_B \quad (26)$$

Then, solving  $|J_f| = 0$  for  $\gamma_W$  as a function of  $\gamma_B$  leads to

$$\gamma_W = \frac{\gamma_B[(2b-2a)L + \theta]L + 4(cb-ad)L^2 + ((2a+2d)L - \theta)\theta}{((2d-2c)L - \theta)L} \quad (27)$$

These two lines are defined on  $\mathbb{R}$ . We can also characterize when the system will oscillate by solving  $Tr_{J_f}^2 - 4|J_f| = 0$  for  $\gamma_W$  as a function of  $\gamma_B$ . This gives us the following solutions:

$$\gamma_W = -2a - 4c + 2d - 3\gamma_B \pm \sqrt{S} \quad (28)$$

with

$$\begin{aligned} S \equiv & (4c - 2d)^2 + a(4 + 16c - 8d) - (2(a+d)L - 2\theta)^2 - 8aL\theta - 8dL\theta - 4\theta^2 \\ & + 16adL^2 - 16cdL^2 + \gamma_B(16a - 8b + 24c - 16d) + 8\gamma_B^2 \end{aligned} \quad (29)$$

Then, a sink will be characterized by a negative trace and a positive determinant. These conditions are fulfilled somewhere in  $\mathbb{R}^2$  for a certain couple  $(\gamma_B^*, \gamma_W^*)$  if the two lines (equations (26) and (27)) intersect. But they are also fulfilled if the two lines are parallel with different intercepts. They might have also been fulfilled when the two lines are the same but this case is not interesting as it will become clear by the end of the proof.

The two lines are parallel if they have the same slope coefficient. Thus, let us solve the following equation:

$$\frac{((2b-2a)L + \theta)L}{((2d-2c)L - \theta)L} = -1 \quad (30)$$

Note that we need to have  $2(d - c) \neq \frac{\theta}{L}$  in order for the line (27) to exist. After computations, we obtain:

$$b - a = c - d \quad (31)$$

If this condition is not satisfied, the two lines where the trace and the determinant are null are not parallel. Thus they intersect somewhere in the  $(\gamma_B, \gamma_W)$  plan.

Now, if they are parallel, they are mingled if they have the same intercept. Thus, let us solve the following equation:

$$\frac{\theta}{L} - 2(a + d) = \frac{4(cb - ad)L^2 + ((2a + 2d)L - \theta)\theta}{((2d - 2c)L - \theta)L} \quad (32)$$

After computations, we get:

$$(2d - 2c)L\theta + 2c(2a - 2b)L^2 + 2d(2c - 2d)L^2 = 0 \quad (33)$$

From this equation, we see that if  $a = b$  and  $c = d$  then the two lines are the same as they will have the same slope and intercept coefficients. However, this situation means that both groups like (or dislike) equally the two groups. This is not really credible as people have often a homophilic bias in their interactions (Currarini et al.[23], and Skvoretz[57]). Moreover, antisocial behaviors will be punished in environment where you have frequent or long lasting interactions(Bowles[12]). In the context of segregation, you are precisely in a situation where you are going to have these kinds of interactions with your neighbors. Thus antisocial behaviors will not characterize a substantive share of individuals in the population.

Now, if  $a \neq b$  and  $c \neq d$ , we can rewrite the previous equation as:

$$\begin{aligned} L(2d - 2c)(\theta - 2dL) + 2c(2a - 2b)L^2 &= 0 \\ \Leftrightarrow (2d - 2c)(\theta - 2dL) &= -2c(2a - 2b)L \\ \Leftrightarrow \theta - 2dL &= \frac{-2c(2a - 2b)L}{2d - 2c} \\ \Leftrightarrow \frac{\theta}{L} &= 2(d - c) \end{aligned} \quad (34)$$

The last equation comes from the assumption that the two lines are parallel (*i.e.*  $b - a = c - d$ ). However, this condition implies that the line (27) does not exist.

So, if we exclude unlikely structures of preferences (*i.e.*  $a = b$  and  $c = d$ ), and if the line (27) exists, then the line (26) and (27) either intersect once or are parallel with different intercepts. Then there exist parameters regions  $(\gamma_B^*; \gamma_W^*)$

where the trace will be positive while the determinant will be negative. Thus, the equilibrium will be a sink, integrated and stable.

Moreover, there also exists parameters regions  $(\gamma_B^P; \gamma_W^P)$  where the trace and the determinant will be both positive. Thus the system will be dynamically a source. In this case, the equilibrium will not be stable anymore but the system will end in one of the corner of the edgeworth box depicting our city. Then if the city is in the basin of attraction of an integrated state,<sup>41</sup> there is no need for a public policy as the system will converge by itself toward an integrated state. On the contrary, if the city is in the basin of attraction of a completely segregated state, then a relocation policy that will displace a sufficient number of members of the local majority to the other location will replace the city on an integration path. Hence, the proof is complete.  $\square$

## 5.4 Analytic solution of the first-order differential system

*Proof.* Recalling the system (9):

$$\begin{cases} \dot{W} = \frac{((2a + \gamma_W)L - \theta)W_t + (2b + \gamma_W)LB_t - L^2(a + b + \gamma_W) - \alpha L}{\theta} \\ \dot{B} = \frac{(2c + \gamma_B)LW_t + ((2d + \gamma_B)L - \theta)B_t - L^2(c + d + \gamma_B) - \alpha L}{\theta} \end{cases} \quad (35)$$

we can rewrite it in a more tractable form:

$$\begin{cases} \dot{W} = AW_t + PB_t - K_w \\ \dot{B} = CW_t + DB_t - K_b \end{cases} \quad (36)$$

$$\text{with } A \equiv \frac{(2a + \gamma_W)L - \theta}{\theta}, P \equiv \frac{(2b + \gamma_W)L}{\theta}, C \equiv \frac{(2c + \gamma_B)L}{\theta}, D \equiv \frac{(2d + \gamma_B)L - \theta}{\theta}, \\ K_w \equiv \frac{-L^2(a + b + \gamma_W) - \alpha L}{\theta}, K_b \equiv \frac{-L^2(c + d + \gamma_B) - \alpha L}{\theta}.$$

Then, we can get the following system by expressing  $B_t$  as a function of  $W_t$  and its differentials:

$$\begin{cases} B_t = \frac{\dot{W} - AW_t - K_w}{P} \\ \dot{B} = CW_t + DB_t - K_b \end{cases} \quad (37)$$

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<sup>41</sup>See definition 3 for the precise meaning of what we call a state.

Deriving an expression of  $\dot{B}$  from this first equation, we obtain:

$$\dot{B} = \frac{\ddot{W} - A\dot{W}}{P} \quad (38)$$

We can then rewrite the second equation of the system (37) as:

$$\frac{\ddot{W} - A\dot{W}}{P} = CW + D\frac{\dot{W} - AW_t - K_w}{P} + K_b \quad (39)$$

which can be rearranged as:

$$\ddot{W} - \frac{(A+D)}{P}\dot{W} + \left(A - \frac{C}{P}\right)W_t = K_b - \frac{D}{P}K_w \quad (40)$$

We solve first the homogeneous equation related to equation (40):

$$\ddot{W} - \frac{(A+D)}{P}\dot{W} + \left(A - \frac{C}{P}\right)W_t = 0 \quad (41)$$

which has the characteristic equation:

$$r^2 - \frac{(A+D)}{P}r + \left(A - \frac{C}{P}\right) = 0 \quad (42)$$

with  $r$  a generic term. Depending on the sign of the discriminant of equation (42), we get the following general solutions denoted by the superscript  $g$ :

$$\left\{ \begin{array}{l} \text{If } \Delta > 0, \quad \text{Then } W_t^g = k_1 e^{r_1 t} + k_2 e^{r_2 t} \quad \text{with } r_1, r_2 = \frac{A+D}{2P} \pm \frac{\sqrt{\Delta}}{2} \\ \text{If } \Delta = 0, \quad \text{Then } W_t^g = k_1 e^{rt} + k_2 t e^{rt} \quad \text{with } r = \frac{A+D}{2P} \\ \text{If } \Delta < 0, \quad \text{Then } W_t^g = e^{\xi t} (k_1 \cos \varphi t + k_2 \sin \varphi t) \quad \text{with } \xi = \frac{A+D}{2P} \text{ and } \varphi = \frac{\sqrt{\Delta}}{2} \end{array} \right. \quad (43)$$

For a particular solution (denoted by the superscript  $p$ ), as the forcing term is a constant, let us assume that  $y(t)$  is a constant, then the first differential is null while the second differential does not exist which implies that a particular solution for  $W_t$  is:

$$W_t^p = \frac{PK_b - DK_w}{PA - C} \quad (44)$$

As the solution of a differential equation is the sum of a general solution and a particular solution, we know the form of the solution for  $W_t$ . Therefore we can compute the solution for  $B_t$ . First, if  $\Delta > 0$ , then we have:

$$W_t^* = k_1 e^{r_1 t} + k_2 e^{r_2 t} + \frac{PK_b - DK_w}{PA - C} \iff \dot{W}^* = r_1 k_1 e^{r_1 t} + r_2 k_2 e^{r_2 t} \quad (45)$$

Finally, substituting into the first equation of (37), we get:

$$B_t^* = (r_1 - A)k_1 e^{r_1 t} + (r_2 - A)k_2 e^{r_2 t} - A \frac{PK_b - DK_w}{PA - C} \quad (46)$$

□

## 5.5 Freezing history

The idea of this method of adjustment for spatial data is simple. First, we have to choose a geographical basis that will serve as the reference for adjustment. Then, we need to keep tracks of the changes of boundaries. By identifying where the two layers intersect, we are able to compute an adjustment weight depending on the share of the area of the new polygons lying in the boundaries of each of the reference polygons.

Imagine a fictitious city divided into four equivalent parts (Figure 6a). After a political decision, the boundaries are changed to a new configuration (Figure 6b). By "freezing the history" to the initial boundaries, we use the first demarcation as our geographical basis and adjust the new boundaries to the previous one. With the intersection of the two sets of boundaries (Figure 6c), we can identify that the districts A and B are equivalent to the union of half of the district A' and B', when the districts C and D are equivalent to union of half of the district C' and D'. Then, the (counterfactual) population that would have been in district A in the next period if the boundaries were still those of the initial period can be recovered by assigning half of the population of A' and B' to A.

There are some limitations to this method. First, it makes the assumption that individuals are uniformly distributed inside each area, so that cutting half of an area transfers half of the population as well. This is kind of a heroic assumption to make but it is the simplest possible adjustment. Moreover, the more disaggregated the geography, the more uniformly distributed the population.<sup>42</sup> As long as you increase the number of areas, the population inside each area becomes more and more uniform in terms of characteristics but also in terms of distribution. If you can disaggregate your geography up to a block of houses, for instance, then assuming

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<sup>42</sup>Echenique and Fryer[33] use a similar argument.

that taking half of the population when cutting the area by half is much less heroic. In our application, we use the subplace level in 2001 as our geographical basis and we use the information of the enumeration areas in 1996 and 2011 to adjust each census waves to the geography of 2001. Enumeration areas constitute the lowest geographical level available in a census, just below subplaces. This also helps mitigating the strength of this uniformity assumption.

Finally, this method presents the disadvantage of having a geography basis less and less relevant as boundaries change. However, in our case, this is not a serious problem. First, because we are considering census waves that are just preceding and succeeding our geographical basis. Then, we are interested in residential segregation. So, it is essential to keep the boundaries constant, even if it means losing relevance, because we do not want to measure changes in segregation due to changes in boundaries. Finally, our analysis is much less concerned about this loss of relevance of the geographical basis than a study of elections could be.

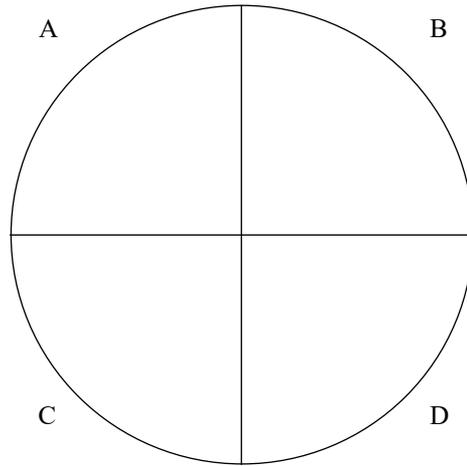
## 5.6 Details of the variables

Table 1 and 2: GMM preliminary estimations

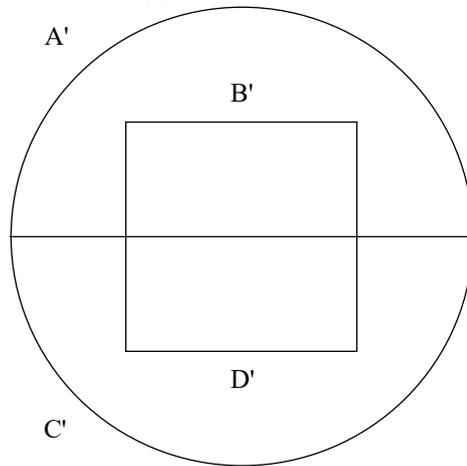
- $B * L^W$  represents the interaction between  $B$  and  $L^W$  which are respectively  $\ln(1 + b)$  and  $\ln(1 + L^w)$ , with  $b$  the share of Blacks in a district in 1996, and  $L^w$  is the share of Whites in a province in 1996. It is equivalent to the term  $B_t L^W$  in the theoretical model.
- $W * L^W$  represents the interaction between  $W$  and  $L^W$  which are respectively  $\ln(1 + w)$  and  $\ln(1 + L^w)$ , with  $w$  the share of Whites in a district in 1996, and  $L^w$  is the share of Whites in a province in 1996. It is equivalent to the term  $W_t L^W$  in the theoretical model.
- $L^B * L^W$  represents the interaction between  $L^B$  and  $L^W$  which are respectively  $\ln(1 + L^b)$  and  $\ln(1 + L^w)$ , with  $L^b$  the share of Blacks in a province in 1996, and  $L^w$  is the share of Whites in a province in 1996. It is equivalent to the term  $L^B L^W$  in the theoretical model.
- $L^{W^2}$  represents the square of  $L^W$  which is  $\ln(1 + L^w)$ , with  $L^w$  the share of Whites in a province in 1996. It is equivalent to the term  $(L^W)^2$  in the theoretical model.
- $L^W$  represents  $\ln(1 + L^w)$  with  $L^w$  the share of Whites in a province in 1996. It is equivalent to the term  $L^W$  in the theoretical model.
- $B * L^B$  represents the interaction between  $B$  and  $L^B$  which are respectively  $\ln(1 + b)$  and  $\ln(1 + L^b)$ , with  $b$  the share of Blacks in a district in 1996, and

$L^b$  is the share of Blacks in a province in 1996. It is equivalent to the term  $B_t L^B$  in the theoretical model.

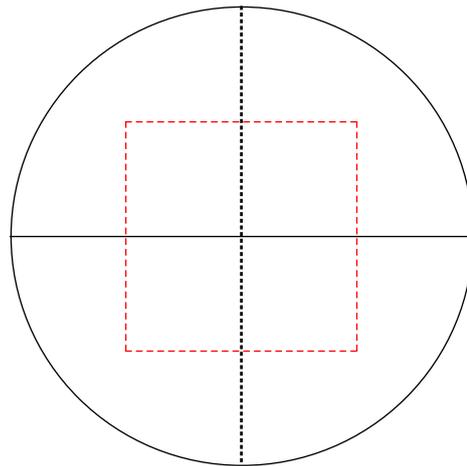
- $W * L^B$  represents the interaction between  $W$  and  $L^B$  which are respectively  $\ln(1 + w)$  and  $\ln(1 + L^b)$ , with  $w$  the share of Whites in a district in 1996, and  $L^b$  is the share of Blacks in a province in 1996. It is equivalent to the term  $W_t L^B$  in the theoretical model.
- $L^W * L^B$  represents the interaction between  $L^W$  and  $L^B$  which are respectively  $\ln(1 + L^w)$  and  $\ln(1 + L^b)$ , with  $L^b$  the share of Blacks in a province in 1996, and  $L^w$  is the share of Whites in a province in 1996. It is equivalent to the term  $L^B L^W$  in the theoretical model.
- $L^{B^2}$  represents the square of  $L^B$  which is  $\ln(1 + L^b)$ , with  $L^b$  the share of Blacks in a province in 1996. It is equivalent to the term  $(L^B)^2$  in the theoretical model.
- $L^B$  represents  $\ln(1 + L^b)$  with  $L^b$  the share of Blacks in a province in 1996. It is equivalent to the term  $L^B$  in the theoretical model.
- **Mean years of education (1996)** represents the natural logarithm of the mean number of years of schooling in a subplace in 1996.
- **Mean age (1996)** represents the natural logarithm of the mean age in a subplace in 1996.
- **Mean income (1996)** represents the natural logarithm of the mean income in a subplace in 1996. The income is computed as the center of the class in which the individual has declared to be. Incomes of other year are deflated to 1996 Rands.
- **Unemployment rate (1996)** represents the natural logarithm of 1 plus the unemployment rate in a subplace in 1996. The unemployment rate is computed as the number of individuals aged 15 or older declaring that they are unemployed and looking for a job over the sum of the individuals aged 15 or older currently employed and of the individuals declaring being unemployed.



(a) Initial configuration



(b) New boundaries



(c) Intersection of the two layers

Figure 6: Freezing history

Table 1: GMM Preliminary estimation 2001

	GMM 2001			
	Blacks (E)	Whites (E)	Blacks (F)	Whites (F)
1996 $B * L^B$	3.074*** [0.189]		1.582*** [0.030]	
1996 $W * L^B$	-0.775** [0.301]		0.287** [0.112]	
1996 $L^{B^2}$	-1.183*** [0.339]		-1.912*** [0.089]	
1996 $L^W * L^B$	-0.259 [0.189]	0.049 [0.284]	-0.029 [0.050]	-0.380*** [0.140]
1996 $L^B$	1.182*** [0.274]		1.235*** [0.090]	
Mean age (1996)	-0.084*** [0.024]	0.064*** [0.024]	-0.020** [0.009]	0.046*** [0.007]
Mean years of education (1996)	0.402*** [0.064]	-0.271*** [0.065]	0.005*** [0.002]	-0.009*** [0.001]
Unemployment rate (1996)	-0.344*** [0.104]	0.045 [0.083]	0.019** [0.008]	-0.057*** [0.005]
Mean income (1996)	-0.102*** [0.013]	0.066*** [0.012]	0.002*** [0.001]	0.004*** [0.001]
1996 $B * L^W$		-3.622*** [0.683]		0.204** [0.103]
1996 $W * L^W$		6.750*** [0.650]		4.076*** [0.269]
1996 $L^W$		-3.819*** [0.655]		0.291*** [0.065]
1996 $L^{W^2}$		2.939* [1.775]		-1.635*** [0.246]
Observations	3143	3143	17258	17258
$R^2$	0.341	0.455	0.792	0.360

Standard errors in brackets computed with heteroscedastic-robust covariance matrices. All variables are expressed in natural logarithm.

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Table 2: GMM Preliminary estimation 2011

	GMM 2011			
	Blacks (E)	Whites (E)	Blacks (F)	Whites (F)
2001 $B * L^B$	2.409*** [0.132]		1.681*** [0.037]	
2001 $W * L^B$	-0.661*** [0.225]		-0.302** [0.128]	
2001 $L^{B^2}$	-0.906** [0.388]		-1.582*** [0.104]	
2001 $L^W * L^B$	-0.415** [0.174]	0.531 [0.328]	-0.335*** [0.070]	-0.606*** [0.195]
2001 $L^B$	0.916*** [0.332]		0.858*** [0.103]	
Mean age (2001)	0.012 [0.028]	0.065*** [0.024]	0.014 [0.009]	0.048*** [0.006]
Mean years of education (2001)	0.300*** [0.051]	-0.277*** [0.050]	0.012*** [0.003]	-0.011*** [0.002]
Unemployment rate (2001)	-0.105 [0.076]	-0.229*** [0.063]	0.002 [0.009]	-0.066*** [0.005]
Mean income (2001)	-0.056*** [0.008]	0.036*** [0.007]	0.007*** [0.001]	0.001 [0.001]
2001 $B * L^W$		-2.312*** [0.699]		0.404*** [0.141]
2001 $W * L^W$		7.145*** [0.510]		7.089*** [0.366]
2001 $L^W$		-5.030*** [0.628]		0.390*** [0.074]
2001 $L^{W^2}$		6.434*** [2.246]		-2.428*** [0.311]
Observations	2555	2555	15580	15580
$R^2$	0.370	0.552	0.693	0.436

Standard errors in brackets computed with heteroscedastic-robust covariance matrices. All variables are expressed in natural logarithm.

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Table 3: Structural parameters

	GMM 2001				GMM 2011			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Blacks (E)	Whites (E)	Blacks (F)	Whites (F)	Blacks (E)	Whites (E)	Blacks (F)	Whites (F)
a		6.957*** (1.096)		1.685*** (0.165)		7.950*** (1.110)		2.713*** (0.203)
b		1.771** (0.825)		-0.251* (0.145)		3.221*** (0.974)		-0.629*** (0.188)
c	-0.859*** (0.284)		-0.374*** (0.044)		-0.807*** (0.257)		-0.156*** (0.060)	
d	1.066*** (0.179)		0.274*** (0.041)		0.728*** (0.193)		0.835*** (0.049)	
gamma	1.001*** (0.294)	-8.075*** (2.081)	1.235*** (0.073)	0.681*** (0.255)	1.043*** (0.301)	-10.631*** (2.408)	0.256*** (0.084)	1.520*** (0.313)

Standard errors in parentheses

\*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$

Table 4: Augmented regression tests for endogeneity

	2001			2011				
	Blacks (E)	Whites (E)	Blacks (F)	Whites (F)	Blacks (E)	Whites (E)	Blacks (F)	Whites (F)
GMM C statistics	66.84	25.11	9.63	2.27	68.48	33.53	59.22	31.34
P-value	0.00	0.00	0.01	0.32	0.00	0.00	0.00	0.00

Table 5: Hansen's J test for overidentifying conditions

	2001			2011				
	Blacks (E)	Whites (E)	Blacks (F)	Whites (F)	Blacks (E)	Whites (E)	Blacks (F)	Whites (F)
J statistics	1.44	0.49	8.94	7.94	1.50	6.82	1.65	5.40
P-value	0.49	0.78	0.01	0.02	0.47	0.03	0.44	0.07

Table 6: Breusch-Pagan's test for heteroscedasticity

	2001			2011				
	Blacks (E)	Whites (E)	Blacks (F)	Whites (F)	Blacks (E)	Whites (E)	Blacks (F)	Whites (F)
F-statistics	47.67	34.62	2124.90	1194.54	16.26	24.72	202.52	882.67
P-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Assumption of the normality of the residuals is not used to compute these tests. Arguments against the normality of the residuals can be obtained from authors upon request.

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