

# A Social Network Analysis of Occupational Segregation\*

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## Abstract

We develop a social network model of occupational segregation between different social groups, generated by the existence of positive inbreeding bias among individuals from the same group. If network referrals are important for job search, then expected homophily in the contact network structure induces different career choices for individuals from different social groups. This further translates into stable occupational segregation equilibria in the labor market. We derive the conditions for wage and unemployment inequality in the segregation equilibria and characterize first and second best social welfare optima. Surprisingly we find that socially optimal policies involve segregation.

**JEL codes:** A14, J31, Z13

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# 1 Introduction

Occupational segregation between various social groups is an enduring and pervasive phenomenon, with important implications for the labor market. Richard Posner recently pointed out that “a glance of the composition of different occupations shows that in many of them, particularly racial, ethnic, and religious groups, along with one or the other sex and even groups defined by sexual orientation (heterosexual vs. homosexual), are disproportionately present or absent”<sup>1</sup>. There are countless empirical studies within sociology and economics that document the extent of occupational segregation. Most studies investigating the causes of occupational segregation agree that ‘classical’ theories such as taste or statistical discrimination by employers cannot alone explain occupational disparities and their remarkable persistence. While several meritorious alternative theories were to date considered, scientists with long-standing interest in the area, such as Kenneth Arrow (Arrow, 1998), particularly referred to modeling the social network interactions as a very promising avenue for further research in this context.

In this paper we consider a simple social interactions model in order to investigate occupational segregation and wage inequality in the labor market. Although the bulk of studies on social interaction in labor markets remains largely ‘descriptive empirical’, significant progress has been lately achieved in modeling labor market phenomena by means of social networks. Recent articles have for instance investigated the effect of social networks on employment, wage inequality, and labor market transitions.<sup>2</sup> This work points out that individual performance on the labour market crucially depends on the position individuals takes in the social network structure. However, this work typically does not focus on the role that networks play in the persistent patterns of occupational segregation and inequality between races and gender.<sup>3</sup> To the best of our knowledge, this is the first attempt of a social network analysis that focuses primarily on occupational segregation and inequality between social groups.

We construct a four-stage model of occupational segregation between two homogeneous, exogenously given, mutually exclusive social groups, acting in a two-job labor market. In the first stage each individual chooses one of two specialized educations to become a worker. In the second stage individuals randomly form “friendship” ties with other individuals, with a tendency to form relatively more ties with members of the same social group, what is known

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<sup>1</sup>The quote is from a post in “The Becker-Posner Blog”, see <http://www.becker-posner-blog.com>. Posner goes on by giving a clear-cut example of gender occupational segregation: “a much higher percentage of biologists than of physicists are women, and at least one branch of biology, primatology, appears to be dominated by female scientists. It seems unlikely that all sex-related differences in occupational choice are due to discrimination”

<sup>2</sup>Such recent papers include Arrow and Borzekowski (2003), Calvó-Armengol and Jackson (2004, 2006), Fontaine (2007), Lavezzi and Meccheri (2004), Bramoullé and Saint-Paul (2006), Ioannides and Soutevent (2006).

<sup>3</sup>Calvó-Armengol and Jackson (2004) find that two groups with two different networks may have different employment rates due to endogenous decision to drop out of the labour market. However, their finding requires that the groups are initially unconnected and that the initial employment state of the two groups is unequal as well.

in the literature as “(*inbreeding*) *homophily*”, “*inbreeding bias*” or “*assortative matching*”.<sup>4</sup> In the third stage workers use their networks of friendship contacts to search for jobs. In the fourth stage workers earn a wage and spend their income on a single consumption good.

In this model we obtain the following results. First and not surprisingly, we show that with inbreeding homophily within social groups, a complete polarization in terms of occupations across the two groups arises as a stable equilibrium outcome. This result follows from standard arguments on network effects. If a group is completely segregated and specialized in one type of job, then everyone in that group has many more job contacts if it sticks to their specialization. Therefore sticking to the specialization ensures good job opportunities to the group members, and these incentives stabilize segregation.

We next extend the basic model by allowing for “good” and “bad” jobs, to analyze equilibrium wage and unemployment inequality between the two social groups. We show that with large differences in job attraction (wages), the main outcome of the model is that one group fully specializes in the good job, while the other group mixes over the two jobs. The group that specializes in the good job always has a higher payoff and a lower unemployment rate in this partial segregation equilibrium. Furthermore, with a sufficiently large intra-group homophily, the ‘fully specializing’ group also has a higher equilibrium employment rate *and* a higher wage rate, thus being doubly advantaged. Our model is therefore able to explain typical empirical patterns of gender, race or ethnical labor inequality. The driving force behind this result is the fact that the fully specialized group, being homogenous, is able to create a denser job contact network than the group that is mixed. Therefore, the fully specialized is group has a clear advantage against the other group.

We then consider the question whether society benefits from a integration policy, such that inequality between social groups disappears. We therefore analyze a social planner’s first and second-best policy choice. Surprisingly, segregation is the preferred outcome in the first-best analysis, while a *laissez-faire* policy leading to segregation shaped by individual incentives is maximizing social welfare in the second-best case. The main reason for this result is that much denser and efficient networks can be formed when groups are segregated then when they are mixed. Thus overall employment is higher with segregation. On the other hand, *laissez-faire* inequality remains sufficiently constrained, such that segregation is an overall socially optimal policy. Our social welfare analysis points out important policy issues typically ignored by proponents of anti-segregation legislature.

The paper is organized as follows. The next section shortly overviews empirical findings on occupational segregation by race, gender and ethnicity. We review empirical evidence on the relevance of job contact networks and extent of social group homophily in Section 3; we set up our model of occupational

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<sup>4</sup>Homophily measures the relative frequency of within-group versus between-group friendships. There exists inbreeding homophily or an inbreeding bias if the group’s homophily is higher than would have been expected if friendships are formed randomly. See Currarini, Jackson and Pin (2007) for formal definitions.

segregation in Section 4, and we discuss key results on the segregation equilibria in Section 5. Section 6 analyses the social welfare outcome. We summarize and conclude the paper in Section 7.

## 2 The extent of occupational segregation

A few examples of studies that review and/or present detailed statistics on the occupational segregation<sup>5</sup> and wage inequality patterns by gender, race or ethnicity are Beller (1984), Albelda (1986), King (1992), Padavic and Reskin (2002), Charles and Grusky (2004). All these studies agree that, despite substantial expansion in the labor market participation of women and affirmative action programs aimed at labor integration of racial and ethnic minorities, women typically remain clustered in female-dominated occupations, while blacks and several other races and ethnic groups are over-represented in some occupations and under-represented in others; these occupations are typically (though not always) of lower 'quality', meaning they are paying less, on average, which explains part of the fact that women compared to men and blacks and several ethnical groups compared to whites typically experience wage penalties<sup>6</sup>.

King (1992) offers for instance detailed evidence that throughout 1940-1988 there was a persistent and remarkable level of occupational segregation by race and sex, such that "approximately two-thirds of men or women would have to change jobs to achieve complete gender integration", with some, but not a lot of, changes throughout time, particularly for some subgroups; the occupational segregation between white and black women appears to have diminished most during the 60's and the 70's, although the occupational segregation between white and black males or that between males and females in general remained remarkable stable. Several studies by Barbara Reskin and her co-authors, see for instance the references and discussion in Padavic and Reskin (2002), document the extent of occupational segregation by narrow race-sex-ethnic cells and find that segregation by gender remains extremely prevalent and that within occupations segregated by gender, racial and ethnic groups are also aligned along stable segregation paths. Although most these studies were done for the USA, there is also considerable international (particularly from Europe and for segregation by gender) evidence that, albeit some variations, similar patterns of segregation hold, e.g. Pettit and Hook (2005).

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<sup>5</sup>Some of these papers, eg. Sorensen (2004), discuss in detail the extent of general labor market segregation between social groups, at the workplace, industry and occupation levels. Here we shall be concerned with modeling segregation by occupation alone (known also as "horizontal segregation"), which appears to be dominant at least relative to segregation by industry. Weeden and Sorensen (2001) convincingly show that occupational segregation in the USA is much stronger than segregation by industries and that if one wishes to focus on one single dimension, "occupation is a good choice, at least relative to industry".

<sup>6</sup>The other prominent side of the 'labor market segregation explaining the wage differential' story is that women relative to men and, respectively, blacks vis-a-vis whites might experience wage differentials within the same occupation, when located in different workplaces; then we deal with the so-called *vertical segregation* dimension. As stated above we shall be concerned in this paper only with the occupational dimension, the *horizontal segregation*.

## 3 Evidence on job contact networks and homophily

### 3.1 Importance of job contact networks

The ‘personalization’ of the interaction between individuals in an otherwise anonymous market, such as making use of job contact networks, was inherited in economics from other fields, with sociology being the primary source. There is by now a well established set of stylized facts that show the importance of the informal job networks in matching job seekers to firm vacancies. For instance, it is known that on average about 50 percent of the workers obtain jobs through their personal contacts. Evidence in this regard starts a long time ago and covers multiple countries e.g. Rees (1966), Granovetter (1995), Holzer (1987), Montgomery (1991), Topa (2001); Bewley (1999) enumerates two dozen studies published between until the 1990’s, where the fraction of jobs obtained via friends or relatives ranges between 30 and 60 percent. It was also found that, on average, 40-50 percent of the employers actively use social networks of their current employees (i.e. they hire recommended applicants) to fill their job openings and the acceptance rate of such offers is higher, e.g. Holzer (1987). Furthermore, employee-employer matches obtained via contacts appear to have certain common characteristics. Those who found jobs through personal contacts were more satisfied with their job, eg. Granovetter (1995); less likely to quit, e.g. Datcher (1983), Devine and Kiefer (1991), Simon and Warner (1992), Datcher Loury (2006); but not necessarily having higher wages, cf. Granovetter (1995), Ioannides and Datcher Loury (2004), Datcher Loury (2006). For a more detailed overview of studies on job information networks, Ioannides and Datcher Loury (2004) is a more recent reference.

We further single out one finding that relates to differences in the use of informal job networks among professions. Mark Granovetter (1995) pointed out that although personal ties seem to be relevant in job searching and matching for all professions, their incidence is higher for blue-collar workers (50 to 65 percent) than for white-collar categories such as accountants or typists (20 to 40 percent). However, especially interesting in Granovetter’s report is that for certain other white-collar categories such as academics, the use of social connection in job finding is as high as 77 percent (informal ties being the dominating job search strategy also for high-school teachers at 54 percent). Corroborated with Richard Posner’s observation in the introductory paragraph of this paper and with the evidence on occupational segregation across the academic fields, discussed in the previous section, these observations have the potential to make our framework especially (but not exclusively) relevant for explaining occupational disparities within the *academe*. Our modeling assumption of individuals choosing one specialized education that can only give them access to one specific job further reinforces this academic connotation, as will become more clear once our theoretical framework has been introduced.

## 3.2 Intra-group homophily

There is considerable empirical evidence in the (multi-disciplinary) literature on the existence of the so-called social “homophily”<sup>7</sup>, also referred to as “assortative matching” or “inbreeding social bias”, that is, there is a higher probability of establishing links among people with similar characteristics.

Early studies by Rees (1966) and Doeringer and Piore (1971) showed that workers who had been asked for references concerning new hires, were in general very likely to refer people with ‘similar’ features to them. While these similar features can be anything, such as ability, education, age, race and so on, the focus on our paper shall be on groups stratified along exogenous features (ie. one is born in such a group and cannot alter his/her group membership) such as those divided along the lines of gender, race or ethnicity. Indeed, most subsequent empirical evidence on homophily dealt with such groups. Hence, Marsden (1987) finds, using the U.S. General Social Survey, that personal contact networks tend to be highly segregated by race, while other studies such as Brass (1985) or Ibarra (1992), using cross-sectional single firm data, find significant gender segregation in personal networks. More recent evidence is given by Mayer and Puller (2007) and Currarini et al. (2007).

Yet more direct evidence comes from the tabulations in Montgomery (1992), which unambiguously document the existence of large gender homophily within job contact networks: over all occupations in a US sample from the National Longitudinal Study of Youth, 87 percent of the jobs obtained through contacts by men were based on information received from other men and 70 percent of the jobs obtained informally by women were based on information from other women. This is true also for occupations and industries that are highly segregated. Importantly, Montgomery (1992) shows that these outcomes hold even when looking at each narrowly defined occupation categories or one-digit industries<sup>8</sup> separately, including traditionally male or female dominated occupations where job referrals for the minority group members were still obtained with a very strong assortative matching via their own gender group. For example, in male-dominated occupations such as machine operators, 81 percent of the women who found their job through a referral, had a *female* reference. Such figures are in fact surprisingly large and- even more surprising- they are likely to be lower bounds for magnitudes of the inbreeding biases within other exogenous social groups<sup>9</sup>. Montgomery (1992) provides more in depth discussion and gives

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<sup>7</sup>The “homophily theory” of friendship was first introduced and popularized by the sociologists Paul F. Lazarsfeld and Robert K. Merton, cf. Lazarsfeld and Merton (1954).

<sup>8</sup>Weeden and Sorensen (2001) estimate a two-dimensional model of gender segregation, by industry *and* occupation, using a data sample generated from the 1990 Equal Employment Opportunity Supplemental Tabulations File. They find much stronger segregation across occupations than across industries: 86% of the total association in the data is explained by one dimensional model with only occupational segregation; this increases to about 93% once industry segregation is also accounted for. See also footnote 2.

<sup>9</sup>The gender homophily is likely to be smaller than the assortative mixing within social groups differentiated along race or ethnicity because of the frequent close-knit relationships between men and women. This is de facto verified for instance by Marsden (1988) who finds strong inbreeding biases in the contacts between individuals of the same race or ethnicity but

further references on the evidence on the gender homophily.

Perhaps the most recent addition to the pile of evidence here is an empirical study by Fernando and Sousa (2005) on a unique dataset documenting both *the recruitment* and *the hiring* stages for an entry-level job at a call center of a large US bank. This study finds unambiguously that contact networks contribute to the gender skewing of jobs and in addition documents directly that there is strong evidence of gender homophily in the refereeing process of the contacts: referees of both genders tend to strongly produce same sex referrals.

Indirect pieces of evidence come from other research areas. Extensive research on homophily in general shows that people tend to be friends with similar others, see for instance McPherson et al (2001) for a review, with 'exogenous' characters such as race, ethnicity or gender, being essential dimensions of homophily. The literature also shows that friendship patterns are more homophilous than would be expected by chance or availability constraints, even after controlling for the unequal distribution of races or sexes through social structure, e.g. Shrum, Cheek and Hunter (1988). There is furthermore a considerable body of evidence pointing towards "pure" same race preferences in marrying or dating (eg. the "mating taboo" in Wong, 2003 or the speed dating preferences in Fishman et al, 2006), among very young kids (e.g. Hraba and Grant, 1970), among audiences of television shows (Dates, 1980, Lee, 2006) etc.

Finally, we address shortly the relative importance of homophily within 'exogenously given' versus 'endogenously created' social groups. As already mentioned, assortative matching happens along a great variety of dimensions. However, the empirical literature so far documents that, within the society as a whole, the importance of the 'natural' homophily within exogenous groups such as those divided by race, ethnicity, gender, and- to a certain extent- religion, seems to outweigh assortative matching within endogenously formed groups such as those stratified by educational, political or economic lines. For example, using US data, Marsden (1988) finds, inter alia, strong inbreeding bias in contacts between individuals of the same race or ethnicity and, less pronounced homophily by education level. Another study by Tampubolon (2005), using UK data, finds that the dynamics of friendship is strongly affected by gender, marital status and age, but not by education, and only marginally by social class. These facts justify why we focus our discussion on homophily within such "naturally" arising social groups, such as gender, racial or ethnic ones, although, as will become clear in the modeling, assuming assortative matching by education, *in addition to inbreeding homophily by social group*, does not in any way affect our results.

## 4 A model of occupational segregation

Based on the stylized facts mentioned in Section 3, we build a parsimonious theoretical model of social network interaction, able to explain stable occupational

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less pronounced inbreeding bias within gender categories.

segregation, employment and wage gaps without a need for alternative theories. The model is a variant of the segregation model of Benabou (1993).<sup>10</sup>

Let us consider the following setup. A continuum of individuals with measure 1 is equally divided into two social groups, Reds ( $R$ ) and Greens ( $G$ ). The individuals are ex ante homogeneous apart from their social color. They can work in two occupations,  $A$  or  $B$ . Each occupation requires a corresponding thorough specialized education (career track), such that a worker cannot work in an occupation if she is not qualified to do so by having followed the educational track corresponding to that occupation. We assume that it is too costly for individuals to follow both educational tracks. Hence, individuals have to choose their education before they enter the labor market.<sup>11</sup>

Consider now the following order of events:

1. Individuals choose one education in order to specialize either in occupation  $A$  or in occupation  $B$ ;
2. Individuals randomly establish “friendship” relationships, thus forming a network of contacts;
3. Individuals participate in the labor market. Individual  $i$  obtains a job with probability  $s^i$ .
4. Individuals produce a single good for their firms and earn a wage  $w^i$ . They obtain utility from consuming goods that they buy with their wage.

We proceed here with an elaboration of these events.

#### 4.1 Education strategy and equilibrium concept

The choice of education in the first stage involves strategic behavior. Workers choose the education that maximizes their expected payoff given the choices of other workers, and we therefore look for a Nash equilibrium in this stage. This can be formalized as follows.

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<sup>10</sup>Benabou (1993) considers a social interactions model of two neighborhoods and the choice between high and low education, similar to our two social groups and two different education tracks. Whereas in Benabou it is assumed that educational spillovers create network externalities, in our model this role is taken by the formation and function of job contact networks. However, Benabou assumes that only highly educated individuals create education spillovers to neighbors, thus specifying a particular form of network externalities that simplifies his analysis considerably. In contrast, in our model the education tracks are assumed to be symmetric, which leads to a more complicated patterns of network externalities than in Benabou. Moreover, in contrast to Benabou we focus on unemployment and wage inequality as well. Overall, Proposition 1 on the stability of segregation is similar to Proposition 2 in Benabou, but the rest of the analysis differs substantially.

The precursor of studies on segregation is the seminal work by Schelling (1971) on the emergence of high levels of neighborhood racial segregation from tiny differences in the tolerance threshold levels of members of each race group, regarding the presence of the other race.

<sup>11</sup>For example, graduating high school students may face the choice of pursuing a medical career or a career in technology. Both choices require several years of expensive specialized training, which makes it unfeasible to follow both career tracks.

Denote by  $\mu_R$  and  $\mu_G$  the fractions of Reds and respectively Greens that choose education  $A$ . It follows that fraction  $1 - \mu_X$  of group  $X \in \{R, G\}$  chooses education  $B$ . The payoff will depend on these strategies, thus the payoff of a worker of group  $X$  that chooses education  $A$  is given by  $\Pi_A^X(\mu_R, \mu_G)$ , and similarly  $\Pi_B^X(\mu_R, \mu_G)$ . Define  $\Delta\Pi^X \equiv \Pi_A^X - \Pi_B^X$ . The functional form of the payoffs is made more specific later in subsection 4.4.

In a Nash equilibrium each worker chooses the education that gives her the highest payoff, given the education choices of all other workers. Since workers of the same social group are homogenous, a Nash equilibrium implies that if some worker in a group chooses education  $A$  ( $B$ ), then no other worker in the same group should prefer education  $B$  ( $A$ ). This implies that a pair  $(\mu_R, \mu_G)$  is an *equilibrium* if and only if, for  $X \in \{R, G\}$ , the following holds:<sup>12</sup>

$$\Delta\Pi^X(\mu_R, \mu_G) \leq 0 \text{ if } \mu_X = 0 \quad (1)$$

$$\Delta\Pi^X(\mu_R, \mu_G) = 0 \text{ if } 0 < \mu_X < 1 \quad (2)$$

$$\Delta\Pi^X(\mu_R, \mu_G) \geq 0 \text{ if } \mu_X = 1. \quad (3)$$

To strengthen the equilibrium concept, we restrict ourselves to *stable equilibria*. We use a simple stability concept based on a standard myopic adjustment process of strategies, which takes place before the education decision is made. That is, we think of the equilibrium as the outcome of an adjustment process. In this process, individuals repeatedly announce their preferred education choice, and more and more workers revise their education choice if it is profitable to do so, given the choice of the other workers.<sup>13</sup> Concretely, we consider stationary points of a dynamic system guided by the differential equation  $\dot{\mu}_X = k\Delta\Pi^X(\mu_R, \mu_G)$ . This implies that  $\mu \equiv (\mu_R, \mu_G)$  is a stable equilibrium if it is an equilibrium and (i) for  $X \in \{R, G\}$ :  $\partial\Delta\Pi^X/\partial\mu_X < 0$  if  $\Delta\Pi^X = 0$ ; (ii)  $\det(D\Delta\Pi(\mu)) > 0$  if  $\Delta\Pi^R = 0$  and  $\Delta\Pi^G = 0$ , where  $D\Delta\Pi(\mu)$  is the Jacobian of  $(\Delta\Pi^R, \Delta\Pi^G)$  with respect to  $\mu$ .

## 4.2 Network formation

In the second stage the workers form a network of contacts. We assume this network to be random with homophily; that is, we assume that the probability for two workers to create a tie is  $p \geq 0$  when the two workers are from different social groups and follow different education tracks; when the two workers are

<sup>12</sup>The question whether the equilibrium is in pure or mixed strategies is not relevant, because the player set is a measure of identical infinitesimal individuals (except for group membership). Our equilibrium could be interpreted as a Nash equilibrium in pure strategies; then  $\mu_X$  is the measure of players in group  $X$  choosing pure strategy  $A$ . The equilibrium could also be interpreted as a symmetric Nash equilibrium in mixed strategies; in that case the common strategy of all players in group  $X$  is to play  $A$  with probability  $\mu_X$ . A hybrid interpretation is also possible.

<sup>13</sup>One could think of such a process as the discussions students have before the end of the high school about their preferred career. An alternative with a longer horizon is an overlapping generations model, in which the education choice of each new generation partly depends on the choice of the previous generation.

Table 1: The probability of a tie between two individuals, depending on the group membership and education choice.

		Education	
		same	different
Social group	same	$p + \kappa + \lambda$	$p + \lambda$
	different	$p + \kappa$	$p$

from the same social group, the probability of creating a tie increases with  $\lambda > 0$ . Similarly, if two workers choose the same education, then the probability of creating a tie increases with  $\kappa \geq 0$ . Hence, we fully allow for assortative matching also by education, in addition to the "primary", intra social group, type of homophily. We do not impose any further restrictions on these parameters, other than securing  $p + \lambda + \kappa \leq 1$ . This leads to the tie formation probabilities given in Table 1. We will refer to two workers that create a tie as "friends"

We assume that the probability that an individual  $i$  forms a tie with individual  $j$  is exogenously given and constant. In reality establishing a friendship between two individuals typically involves a rational choice from the part of those individuals considered. It is therefore plausible that individuals try to optimize their job contact network in order to maximize their chances on the labor market.<sup>14</sup> In particular, individuals from the disadvantaged social groups should have an incentive to form ties with individuals from the advantaged group.

While the above argument is probably true, we decided not to incorporate this aspect of network formation in our model. The harsh reality is that strategic network formation does not appear to dampen the inbreeding bias in social networks significantly; in Section 3 we provided an abundance of evidence that strong homophily exists even within groups that have strong labor market incentives *not* to preserve such homophily in forming their ties. The reason could be that, even though individuals decide rationally on the friendships they make, the payoff of forming a tie is mainly determined by various social and cultural factors, and only for a smaller part by benefits from the potential transmission of valuable job information.<sup>15</sup> On top of that, studies such as, for instance, Granovetter (2002) also notes that many people would feel exploited if they find out that someone befriends them for the selfish reason of obtaining job information. These elements might hinder the role of labor market incentives when forming ties. Hence, while we do not doubt that incentives play a role when forming ties, we believe that such incentives are not sufficient to undo the effects of the

<sup>14</sup>See Calvó-Armengol (2004) for a model of strategic network formation in the labor market.

<sup>15</sup>Currarini et al. (2007) discuss a model of network formation in which individuals form preferences on the number and mix of same-group and other-group friends. In this model inbreeding homophily arises endogenously.

significant homophily. In order to keep the model simple, we therefore assume network formation exogenous in this paper.

### 4.3 Job matching and social networks

The third stage we envision for this model is that of a dynamic labor process, in which information on vacancies is propagated through the social network, as in Calvó-Armengol and Jackson (2004), Calvó-Armengol and Zenou (2005), Ioannides & Soetevent (2006) or Bramoullé and Saint-Paul (2006). Workers who randomly lose their job are initially unemployed, because it takes time to find information on new jobs. The unemployed worker receives such information either directly, through formal search, or indirectly, through employed friends who receive the information and pass it on to her (in the particular case where all her friends are also unemployed, only the formal search method can get a job for an unemployed worker). As the specific details of such a process are not important for our purposes, we do not consider these dynamic models explicitly, but take a "reduced form" approach. In particular, we assume that unemployed workers have a higher propensity to receive job information when they have more friends with the *same job background*, that is, with the *same choice of education*.

This assumption is, on the one hand, based on the result of Ioannides & Soetevent (2006) that in a random network setting the individuals with more friends have a lower unemployment rate.<sup>16</sup> On the other hand, the assumption is based on the conjecture that workers are more likely to receive information about jobs in their own occupation. For example, when a vacancy is opened in a team, the other team members are the first to know this information, and are also the ones that have the highest incentives to spread this information around. Formally, denote the probability that individual  $i$  becomes employed by  $s^i = s(x_i)$ , where  $x_i$  is the measure of friends of  $i$  with the same education as  $i$  has. We thus assume that  $s(x)$  is differentiable,  $0 < s(0) < 1$  (there is non-zero amount of direct job search) and  $s'(x) > 0$  for all  $x > 0$  (the probability of being employed increases in the number of friends with the same education).

It is instructive to show how  $s^i$  depends on the education choices of  $i$  and the choices of all other workers. Remember that  $\mu_R$  and  $\mu_G$  are the fractions of Reds and respectively Greens that choose education  $A$ . Given the tie formation probabilities from Table 1 and some algebra, the employment rate  $s_A^X$  of  $A$ -workers in group  $X \in \{R, G\}$  will be given by:

$$s_A^X(\mu_R, \mu_G) = s((p + \kappa)\bar{\mu} + \lambda\mu_X/2) \quad (4)$$

and likewise, the employment rate  $s_B^X$  of  $B$ -workers in group  $X$  will be

$$s_B^X(\mu_R, \mu_G) = s((p + \kappa)(1 - \bar{\mu}) + \lambda(1 - \mu_X)/2) \quad (5)$$

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<sup>16</sup>This result is not trivial as the unemployed friends of employed individuals tend to compete with each other for job information. Thus if a neighbor of a jobseeker has more friends, the probability that this neighbor passes information to the jobseeker decreases. In fact, in a setting in which everyone has the same number of friends, Calvó-Armengol and Zenou (2005) show that the unemployment rate is non-monotonic with the (common) number of friends.

where  $\bar{\mu} \equiv (\mu_R + \mu_G)/2$ .

Note that  $s_A^X > s_A^Y$  and  $s_B^X < s_B^Y$  for  $X, Y \in \{R, G\}$ ,  $X \neq Y$ , if and only if  $\mu_X > \mu_Y$  and  $\lambda > 0$ . We will see in Section 5.1 that the ranking of the employment rates is crucial, as it creates a group-specific network effect. That is, keeping this ordering, if only employment matters (jobs are equally attractive), then individuals have an incentive to choose the same education as other individuals in *their* social group. Importantly, it is straightforward to see that this ordering of the employment rates depends on  $\lambda$ , but it does not depend on  $\kappa$ . Therefore, only the homophily among members of the same social group- and not the eventual assortative matching by education- is relevant to our results.

#### 4.4 Wages, consumption and payoffs

The eventual payoff of the workers depends on the wage they receive, the goods they buy from that wage, and the utility they derive from consumption. Without loss of generality we assume that an unemployed worker receives zero wage. However, the wages of employed workers are not exogenously given, but they are determined by supply and demand.

When firms offer wages, they take into account that there are labor market frictions and that it is impossible to employ all workers simultaneously. Thus what matters is the effective supply of labor as determined by the labor market process in stage 3. Let  $L_A$  be the total measure of employed  $A$ -workers and  $L_B$  be the total measure of employed  $B$ -workers. Hence,

$$L_A(\mu_R, \mu_G) = \mu_R s_A^R(\mu_R, \mu_G)/2 + \mu_G s_A^G(\mu_R, \mu_G)/2 \quad (6)$$

and

$$L_B(\mu_R, \mu_G) = (1 - \mu_R) s_B^R(\mu_R, \mu_G)/2 + (1 - \mu_G) s_B^G(\mu_R, \mu_G)/2. \quad (7)$$

Given (4) and (5) from above, it is easy to check that  $L_A$  is increasing with  $\mu_R$  and  $\mu_G$ , whereas  $L_B$  is decreasing with  $\mu_R, \mu_G$ .

As in Benabou (1993), consumption, prices, utility, the demand for labor and the implied wages are determined in a 1-good, 2-factor general equilibrium model. All individuals have the same utility function  $U : R_+ \rightarrow R$ , which is strictly increasing and strictly concave with  $U(0) = 0$ . The single consumer good sells at unit price, such that consumption of this good equals wage and indirect utility is given by  $U_i = U(w_i)$ .

Firms put  $A$ -workers and  $B$ -workers together to produce the single good at constant returns to scale. Wages are then determined by the production function  $F(L_A, L_B)$ . As usual, we assume that  $F$  is strictly increasing and strictly concave in  $L_A$  and  $L_B$  and  $\partial^2 F / \partial L_A \partial L_B > 0$ . Writing the wage as function of education choices and using (6) and (7), the wages of  $A$ -workers and  $B$ -workers,  $w_A$  and  $w_B$ , are given by

$$w_A(\mu_R, \mu_G) = \frac{\partial F}{\partial L_A}(L_A(\mu_R, \mu_G), L_B(\mu_R, \mu_G)),$$

and

$$w_B(\mu_R, \mu_G) = \frac{\partial F}{\partial L_B}(L_A(\mu_R, \mu_G), L_B(\mu_R, \mu_G)).$$

It is again easy to check that  $w_A$  is strictly decreasing with  $\mu_R$  and  $\mu_G$ , whereas  $w_B$  is strictly increasing.

We can now define the payoff of a worker as his expected utility at the time of decision-making. The payoff function of an  $A$ -educated worker from social group  $X \in \{R, G\}$  is thus

$$\Pi_A^X(\mu_R, \mu_G) = s_A^X(\mu_R, \mu_G)U(w_A(\mu_R, \mu_G)). \quad (8)$$

Similarly,

$$\Pi_B^X(\mu_R, \mu_G) = s_B^X(\mu_R, \mu_G)U(w_B(\mu_R, \mu_G)). \quad (9)$$

If we do not impose further restrictions, then there could be multiple equilibria, most of them uninteresting. To ensure a unique equilibrium in our model (actually: two symmetric equilibria), we make the following two assumptions.

**Assumption 1** For the wage functions  $w_A$  and  $w_B$

$$\lim_{x \downarrow 0} U(w_A(x, x)) = \lim_{x \downarrow 0} U(w_B(1-x, 1-x)) = \infty.$$

**Assumption 2** For  $X \in \{R, G\}$ , and for all  $\mu_R, \mu_G \in [0, 1]$

$$\left| \frac{\partial s_A^X / s_A^X}{\partial \mu_X / \mu_X} \right| < \left| \frac{\partial U / U}{\partial w_A / w_A} \right| \left| \frac{\partial w_A / w_A}{\partial \mu_X / \mu_X} \right|$$

and

$$\left| \frac{\partial s_B^X / s_B^X}{\partial \mu_X / \mu_X} \right| < \left| \frac{\partial U / U}{\partial w_B / w_B} \right| \left| \frac{\partial w_B / w_B}{\partial \mu_X / \mu_X} \right|.$$

Assumptions 1 and 2 guarantee the uniqueness of our results. Assumption 1 implies that the wage for scarce labor is so high that at least some workers always find it attractive to choose education  $A$  or respectively  $B$ ; everyone going for one of the two educations cannot be an equilibrium. In Assumption 2 we assume that the education choice of an individual has a smaller marginal effect on the employment probability within a group than on the wages and overall utility. Note that the assumption implies that for  $X \in \{R, G\}$

$$\frac{\partial \Pi_A^X}{\partial \mu_X} < 0 < \frac{\partial \Pi_B^X}{\partial \mu_X},$$

and it is this feature that guarantees the uniqueness of our results. The assumption is not restrictive as long as there is sufficient direct job search, because the employment probability of each individual in our model is bounded between  $s(0) > 0$  and 1, with  $s(0)$  capturing the employment probability in the absence

of any ties and thus induced only by the exogenously given direct job finding rate. Hence, a higher  $s(0)$  implies less of an impact of the network effect on the employment rate.

It should be noted that we make these assumptions above only in order to focus our analysis on segregation outcomes. The assumptions are not necessary. For example, in the calibration of Section 6.2 Assumption 2 is violated, but there are still (two) unique equilibria.

## 5 Equilibrium results

We now present the results on the analysis of our model. The formal proofs of all propositions are relegated to the Appendix. Without loss of generality we suppose throughout the section that  $w_A(1, 0) \geq w_B(1, 0)$ , thus the  $A$ -occupation is weakly more attractive than the  $B$ -occupation when effective labor supply is equal. We call  $A$  the “good” job, and  $B$  the “bad” job.

### 5.1 Occupational segregation

We are in particular interested in those equilibria in which there is segregation. For clarity, we say that there is *complete segregation* if  $\mu_R = 0$  and  $\mu_G = 1$ , or, vice versa,  $\mu_R = 1$  and  $\mu_G = 0$ . On the other hand, there is *partial segregation* if for  $X \in \{R, G\}$  and  $Y \in \{R, G\}$ ,  $Y \neq X$ :  $\mu_X = 0$  but  $\mu_Y < 1$ , or, vice versa,  $\mu_X = 1$  but  $\mu_Y > 0$ .

Our first result is that segregation, either complete or partial, is the only stable outcome:

**Proposition 1** *Suppose Assumptions 1 and 2 hold. Define  $s_H \equiv s((p + \kappa + \lambda)/2)$  and  $s_L \equiv s((p + \kappa)/2)$ .*

(i) *If*

$$1 \leq \frac{U(w_A(1, 0))}{U(w_B(1, 0))} \leq \frac{s_H}{s_L}, \quad (10)$$

*then there are exactly two stable equilibria, both with complete segregation.*

(ii) *If*

$$\frac{U(w_A(1, 0))}{U(w_B(1, 0))} > \frac{s_H}{s_L}, \quad (11)$$

*then there are exactly two stable equilibria, both with partial segregation, in which either  $\mu_R = 1$  or  $\mu_G = 1$ .*

We first note that a non-segregation equilibrium cannot exist, even in the case of a tiny amount of homophily ( $\lambda$  very small). The intuition is that homophily in the social network among members of the same social group creates a group-dependent network effect. Thus, if slightly more Red workers choose  $A$  than Greens do, then the value of an  $A$ -education is higher for the Reds than

for the Greens, while the value of a  $B$ -education is lower in the Reds' group. Positive feedback then ensures that the initially small differences in education choices between the two groups widen and widen until at least one group segregates completely into one type of education.

Second, if the wage differential between the two jobs (for equal numbers of  $A$ -educated and  $B$ -educated workers) is not "too large" vis-a-vis the social network effect (condition 10), complete segregation is the only stable equilibrium outcome, given a positive inbreeding bias in the social group. Thus one social group specializes in one occupation, and the other group in the other occupation. On the other hand, the proposition makes clear that complete segregation cannot be sustained if the wage differential is "too large" vis-a-vis the social network effect (condition 11). Starting from complete segregation, a large wage differential gives incentives to the group specialized in  $B$ -jobs to switch to  $A$ -jobs.

Interestingly, the "unsustainable" complete segregation equilibrium is then replaced by a partial equilibrium in which one group specializes in the "good" job  $A$ , while the other group has both  $A$  and  $B$ -workers. Partial segregation in which one group, say  $G$ , specializes in the "bad" job  $B$  is unsustainable, as that would lead to an oversupply of  $B$ -workers and an even larger wage differential. This would provide the  $B$ -workers in the  $R$ -group with strong incentives to switch en masse to the  $A$ -occupation.

## 5.2 Inequality

The discussion so far ignored eventual equilibrium differentials in wages and unemployment between the two types of jobs. We now take on those issues. We continue assuming that  $w_A(1, 0) \geq w_B(1, 0)$  and, in light of the results of Proposition 1, without loss of generality we will focus on the equilibrium in which  $\mu_R = 1$ . Thus the Reds specialize in the "good" job  $A$ , and the "bad" job  $B$  is only performed by Green workers.

We first consider the case in which wage differentials are small enough so that complete segregation is an equilibrium ( $\mu_R = 1$  and  $\mu_G = 0$ ). In this case, it is straightforward to see the implications. Since both groups specialize in equal amounts, the network effects are equally strong, and the employment rates are equal. Given that employment rates are equal, the effective labor supply is also equal, and therefore the wage of "good" job is weakly higher. We thus have the following result:

**Proposition 2** *Suppose Assumptions 1 and 2 hold. Define  $s_H \equiv s((p + \kappa + \lambda)/2)$  and  $s_L \equiv s((p + \kappa)/2)$  and suppose that  $1 \leq \frac{w_A(1,0)}{w_B(1,0)} \leq \frac{s_H}{s_L}$ . Suppose  $(\mu_R, \mu_G) = (1, 0)$  is a stable equilibrium. In that equilibrium*

$$w_A \geq w_B,$$

$$s_A^R = s_B^G > s_B^R = s_A^G,$$

and

$$\Pi_A^R \geq \Pi_B^G \geq \Pi_A^G \geq \Pi_B^R. \quad (12)$$

The above result is not very surprising, thus we turn next to the case in which wage differentials are large. In that case there is a partial equilibrium in which  $(\mu_R, \mu_G) = (1, \mu^*)$  where  $\mu^* \in (0, 1)$ . First note that, according to (2), this implies the following condition:

$$\Pi_A^G(1, \mu^*) = \Pi_B^G(1, \mu^*),$$

or equivalently

$$s_A^G(1, \mu^*)U(w_A(1, \mu^*)) = s_B^G(1, \mu^*)U(w_B(1, \mu^*)).$$

Thus, whereas workers in group  $R$  prefer the  $A$ -job, the workers in group  $G$  make an individual trade-off: lower wages should be exactly compensated by higher employment probabilities, and vice versa.

We are particularly interested in the question whether this individual trade-off between unemployment and wages also translates into a similar trade-off at the macro-level, in which an inter-group wage gap is compensated by a reversed employment gap. We have the following proposition.

**Proposition 3** *Suppose Assumption 1 and 2 hold. Define  $s_H \equiv s((p+\kappa+\lambda)/2)$  and  $s_L \equiv s((p+\kappa)/2)$  and suppose that  $\frac{w_A(1,0)}{w_B(1,0)} > \frac{s_H}{s_L}$ . Define  $\hat{\mu} \in (0, 1)$ , such that*

$$w_A(1, \hat{\mu}) = w_B(1, \hat{\mu}), \quad (13)$$

and let  $(\mu_R, \mu_G) = (1, \mu^*)$  be a stable equilibrium. In that equilibrium

$$\Pi_A^X > \Pi_B^Y = \Pi_A^Y > \Pi_B^X. \quad (14)$$

Moreover,

(i) if  $\hat{\mu} < \frac{\lambda}{2(p+\kappa+\lambda)}$ , then

$$s_A^R > s_B^G > s_A^G > s_B^R,$$

and

$$w_A(1, \mu^*) > w_B(1, \mu^*);$$

(ii) if  $\hat{\mu} > \frac{\lambda}{2(p+\kappa+\lambda)}$ , then

$$s_A^R > s_A^G > s_B^G > s_B^R,$$

and

$$w_B(1, \mu^*) > w_A(1, \mu^*).$$

The main implication of this proposition is that an inter-group wage gap is not compensated by a reversed employment gap. On the contrary, it is possible that the group specializing in the good job, the Reds, both earn a higher wage and have higher employment probabilities than the Greens. This is in particular

the case when the group homophily bias  $\lambda$  is large relative to  $p$  and  $\kappa$  (in fact  $p + \kappa$ ) and there is a big difference between the good and the bad jobs (case (i) above).

This result can be understood by the following observation: the workers in the specializing group  $R$  have a higher employment probability than *all* workers in group  $G$ . This is always the case, independent of the question whether the individual in  $G$  is an  $A$  or a  $B$  worker, or whether  $s_B^G > s_A^G$  or not. The intuition behind this result is very simple. As all members of group  $R$  choose the same occupation, the Reds remain a strong homogenous social group. Our assumptions on network formation with homophily then implies that they are able to create a lot of ties, and hence, they benefit the most from their social network. On the other hand, the Greens are dispersed between two occupations. This weakens their social network, and this decreases their chances on the labor market both for the  $A$  and  $B$ -workers in group  $G$ .

Whether the wage differential between the workers in the two groups is positive or negative hinges on the relative size of  $\lambda$  relative to  $p + \kappa$ , in the term  $\frac{\lambda}{2(p+\kappa+\lambda)}$  from the inequality conditions in Proposition 3. It is interesting to go beyond the theoretical aspect and highlight the practical relevance of this result. First, as seen from the stylized facts from Section 3, the assortative matching by education,  $\kappa$ , is typically found to be much lower relative to racial, ethnical or gender homophily. The second interesting situation is a scenario where the probability of making contacts in general,  $p$ , were already extremely high relative to the intra-group homophily bias. However, given the surprisingly large size of intra-group inbreeding biases in personal networks of contacts found empirically, this is also unlikely. Hence, the likelihood is very high that in practice  $\lambda$  would dominate the other parameters in the cutoff term  $\frac{\lambda}{2(p+\kappa+\lambda)}$ .

We sum up the findings from the last proposition. The fully specializing group is always being better off in terms of unemployment rate and payoff, independent of either relative or absolute sizes of  $\lambda$ ,  $p$  and  $\kappa$  (as long as  $\lambda > 0$ ), as shown in Proposition 3. Furthermore, given the observed patterns of social networks discussed in Section 3, the condition of  $\lambda$  dominant relative to  $p$  and  $\kappa$  is likely to be met. This ensures that the group fully specializing in the good job always has a higher wage in the equilibrium than the group mixing over the two jobs, as proved in Proposition 3. Note that this partial segregation equilibrium is in remarkable agreement with observed occupational, wage and unemployment disparities in the labor market. This suggests that our simple model offers a plausible explanation for major empirical patterns of labor market inequality.

## 6 Social welfare

### 6.1 First best social optimum

In the previous section we observed that individual incentives lead to complete segregation and inequality. This suggests that a policy that reduces segregation may reduce inequality as well, and in fact may be socially beneficial. This is

argument is often used by proponents of positive discrimination. We therefore set out to analyze the implications of our model from a social planner's point of view.

We consider a utilitarian social welfare function:

$$W(\mu_R, \mu_G) = \mu_R \Pi_A^R / 2 + (1 - \mu_R) \Pi_B^R / 2 + \mu_G \Pi_A^G / 2 + (1 - \mu_G) \Pi_B^G / 2, \quad (15)$$

where  $\Pi_A^X \equiv \Pi_A^X(\mu_R, \mu_G)$  and  $\Pi_B^X \equiv \Pi_B^X(\mu_R, \mu_G)$  are given by equations (8) and (9). Since unemployed workers obtain zero utility, we can also write the welfare function as

$$W(\mu_R, \mu_G) = L_A U \left( \frac{\partial F}{\partial L_A}(L_A, L_B) \right) + L_B U \left( \frac{\partial F}{\partial L_B}(L_A, L_B) \right), \quad (16)$$

where  $L_A \equiv L_A(\mu_R, \mu_G)$  and  $L_B \equiv L_B(\mu_R, \mu_G)$  were introduced by (6) and (7). The formulation in (16) is useful, because it shows that what matters for social welfare is the effect of a policy on its effective labor supply.

We consider a first-best social optimum, that is, the social planner is able to fully manage  $\mu_R \in [0, 1]$  and  $\mu_G \in [0, 1]$  and therefore the social optimum  $\mu^S = (\mu_R^S, \mu_G^S)$  is defined as

$$\mu^S = \operatorname{argmax}_{\mu_R \in [0, 1], \mu_G \in [0, 1]} W(\mu_R, \mu_G).$$

We obtain the following result:

**Proposition 4** *If for all  $x \in [0, (p + \kappa + \lambda)/2]$ :*

$$s''(x) > -\frac{4}{\lambda} s'(x). \quad (17)$$

*then any social optima involves complete or partial segregation.*

Thus a segregation policy is socially preferred, as long as  $s(x)$ , the employment probability of having  $x$  friends with the same education, is "not too concave". This proposition can be understood as follows. Suppose that there is no segregation, and  $0 < \mu_G < \mu_R < 1$ . In that case the Reds obtain a higher employment probability in an  $A$ -occupation,  $s_A^R > s_B^R$ , whereas the Greens have a higher employment rate as  $B$ -workers,  $s_B^G > s_A^G$ . Now consider the effect on segregation, wages and employment when a social planner forces a Red individual choosing a  $B$ -occupation and a Green individual choosing an  $A$ -occupation to *switch their occupation choice*. In that case  $\mu_R$  slightly increases, whereas  $\mu_G$  slightly decreases.

The result of this event is, first, that segregation increases; the gap between  $\mu_R$  and  $\mu_G$  becomes larger. Second, the total fraction of individuals that choose occupation  $A$ ,  $\mu_R + \mu_G$ , does not change. So the ratio of  $A$ -workers versus  $B$ -workers does not change much, and therefore the ratio of wages does not change much either. Thus the effect on wage inequality is only marginal. Third, by switching occupations, the Red worker can now benefit from a denser network,

and have an employment probability  $s_A^R$  instead of  $s_B^R$ . The same is true for the Green worker switching from  $B$  to  $A$ . Thus the combined payoffs of the two workers increases as they are more likely to become employed.

Finally, we need to consider the externality on the employment rates of the workers not involved in the occupation switch. In particular, the switch of occupations increases the network effects of the other Red  $A$ -workers and Green  $B$ -workers, whereas it decreases the network effects of Red  $B$ -workers and Green  $A$ -workers. The restriction on the concavity of  $s(x)$  ensures that the switch of occupations on average puts a positive externality on the employment probabilities of other workers. We conclude that the switch of occupations of the two workers hardly affects wage inequality, while it increases the labor supply of both  $A$  and  $B$ . Therefore, social welfare increases.

The general message of this result is that an integration policy can have detrimental effects on employment, effects that are often ignored by advocates of positive discrimination. Integration might weaken employment chances of individuals, because the network effects are weaker in mixed networks. In the case of complete segregation, individuals are surrounded by similar individuals during their education. Therefore, by our assumptions on network formation, they are easily able to make many friends that they can rely on when searching on the job market. Consequently, employment probabilities are very high. On the other hand, if educations are mixed, then individuals have more difficulties in creating useful job contacts, and therefore their employment probabilities are lower.

The result that integration weakens network effects and decreases labor market opportunities has empirical support in related literature on segregation. For example, Currarini et al. (2007) find clear evidence that larger (racial) minorities create more friendships, and Marsden (1987) finds a similar pattern in his network of advise. Therefore, it is for a worker more beneficial to choose an education in which she is only surrounded by similar others, instead of an education in which racial groups are mixed, let alone in which she is a small minority. Also, Alesina and La Ferrara (2000, 2002) find that participation in social activities is lower in racially mixed communities and so is the level of trust. These and our results suggest that one should not only focus on inequality when suggesting integration policies, but that one should also take into account possible negative impact of integration on social network effects.

Our result on the first-best social optimum hinges for a large part on the fact that the social planner is able to increase employment by increasing segregation, while still controlling wage inequality. In reality, though, a social planner may not have this amount of control. Perhaps a more feasible policy is a policy in which the social planner enforces and stabilizes integration, but where the exact allocation of workers to occupations is determined by individual incentives. In the case of segregation there would be a potentially large inequality in payoffs between the social groups, whereas in the case of integration there may be complete payoff equality, but employment may be lower.

This suggests a second-best analysis of social welfare, in which there is a potential trade-off of segregation between network benefits and inequality. Such

an analysis is unfeasible without further specifying the parameters, hence we will perform the analysis subsequent to calibrating the model for reasonable parameters and functional forms.

## 6.2 Second best social optimum

### 6.2.1 Numerical simulation

As often done in such models, e.g. Fontaine (2007), we calibrate the parameters of the model in order to perform a small numerical simulation of the model. The purpose of this simulation is to get a better feeling on the mechanisms of the model, the restrictiveness of our assumptions, and the magnitude of the wage gap that it can generate. The simulation also allow us to get some insights about a second-best welfare policy.

We first specify functional forms for  $s(x)$ , the employment probability as function of the number of friends with the same education,  $F(L_A, L_B)$ , the production function and thus the derived wage functions, and  $U(x)$ , the utility function. Regarding the employment function, we consider the function that follows from a dynamic labor process, in which employed individuals become unemployed at rate 1, and in which unemployed individuals become employed at rate  $c_0 + c_1x$ . Thus  $c_0$  is the rate at which unemployed workers directly obtain information on job vacancies, and  $c_1$  measures the strength of having friends. This leads to the employment function

$$s(x) = \frac{c_0 + c_1x}{1 + c_0 + c_1x}.$$

As we had defined  $s_0 = s(0)$  as the employment probability when only direct search is used, it follows that  $s_0 = c_0/(1 + c_0)$ .

For the production function we assume the commonly used Cobb-Douglas function with constant returns to scale,

$$F(L_A, L_B) = \theta L_A^\alpha L_B^{1-\alpha}.$$

For the utility function we consider a function with constant absolute risk aversion, where  $\rho$  is the coefficient of absolute risk aversion. That is

$$U(x) = 1 - e^{-\rho x}.$$

We calibrate the parameters as follows. We first calibrate  $s_0$ ,  $c_1(p + \kappa)$ , and  $c_1\lambda$  from three equations that are motivated by the empirical evidence given in Section 2 and 3. This parametrization is sufficient to perform the simulation, and it is thus not necessary to identify  $c_1$ ,  $p$ ,  $\kappa$  and  $\lambda$  in more detail. The first equation is obtained by imposing the restriction that 50% of the workers find their job through friends, as suggested in Section 2. This restriction implies that the direct job arrival rate  $c_0$  should equal the indirect job arrival rate through friends  $c_1x$ . The indirect job arrival rate differs, depending on the choices of the

individuals, but if we focus on the case complete segregation, in which  $\mu_R = 1$  and  $\mu_G = 0$ , then we can impose the following restriction:

$$c_0 = c_1(p + \kappa + \lambda)/2.$$

Next, we calibrate the amount of inbreeding homophily in the social group. This amount typically differs depending on the group defining characteristic. For example, analyzing data on Facebook participants at Texas A&M, Mayer and Puller (2007) find that two students living in the same dorm are 13 more likely to be friends than two random students, two black students 17 more likely, but two Asian students 5 times more likely and two Hispanic students twice as likely to be friends. We decide to keep the amount of inbreeding homophily in the simulation modest, and we therefore impose that  $\lambda = 3(p + \kappa)$ .

We then impose that the employment rate is 95% in case of complete segregation. Given the above, we solve

$$\frac{2c_0}{1 + 2c_0} = 0.95,$$

which implies that

$$s_0 = \frac{c_0}{1 + c_0} = \frac{19}{21} \approx .9048.$$

Finally, this implies values of  $c_1(p + \kappa) = 4.75$  and  $c_1\lambda = 14.25$ .

We now consider the productivity parameter,  $\theta$  and the coefficient of absolute risk aversion,  $\rho$ . The coefficient of absolute risk aversion has been estimated between  $6.6 \times 10^{-5}$  and  $3.1 \times 10^{-4}$  (Gertner, 1993; Metrick, 1995; Cohen and Einav, 2005). We set the risk aversion at  $1.0 \times 10^{-4}$ , which means a coefficient of relative risk aversion of 4 at a wealth level of \$ 40,000, or indifference at participating in a lottery of getting \$ 100.00 or losing \$ 99.01 with equal probability.

The productivity parameter,  $\theta$ , is chosen such that average income equal \$ 40,000 in the case of complete segregation,  $(\mu_R, \mu_G) = (1, 0)$ , and  $\alpha = .5$ .<sup>17</sup> Since in that situation  $w_A(1, 0) = w_B(1, 0) = \theta/2$ , we have  $\theta = 80,000$ .

We now look at payoffs, wages and employment in our model with  $s_0$ ,  $c_1(p + \kappa)$ ,  $c_1\lambda$ ,  $\rho$  and  $\theta$  as given Table 2, and in which  $\mu_R$ ,  $\mu_G$  and  $\alpha$  vary. Given the result of Proposition 1 that there is either a complete equilibrium or a partial equilibrium, in which one group specializes in the good job, we concentrate our attention to the parameter space in which  $\alpha \in [1/2, 1)$ ,  $\mu_R = 1$  and  $\mu_G \in [0, 1)$ . Thus occupation  $A$  is “good”, and group  $R$  specializes in  $A$ .

We first show a plot of  $\Delta\Pi^G(1, \mu_G)$  as a function of  $\mu_G$  for different values of  $\alpha$ . This function illustrates the payoff evaluation that a Green individual makes when deciding on its occupation. If  $\Delta\Pi^G(1, \mu_G) > (<)0$ , then the Green individual prefers  $A$  ( $B$ ) if she believes that all Reds choose  $A$  and fraction  $\mu_G$  of Greens choose  $A$ . Clearly, in an equilibrium it should hold that either  $\Delta\Pi^G(1, 0) < 0$  or  $\Delta\Pi^G(1, \mu_G) = 0$ .

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<sup>17</sup>GDP per capita was \$ 44,190 in the U.S. in 2006 according to figures from the IMF.

Table 2: Chosen parameter values in the simulation and the sensitivity with respect to  $\hat{\alpha}$  and the maximum wage gap.

Parameter	Value	Elasticity of $\hat{\alpha}$ $\hat{\alpha} = .5904$	Elasticity of wage gap $G(1, 0) = .306$
$s_0$	.9048	-1.71	-9.47
$c_1(p + \kappa)$	4.75	-.04	-.23
$c_1\lambda$	14.25	.08	.46
$\rho$	$1.0 \times 10^{-4}$	.38	2.09
$\theta$	80,000	.38	2.09

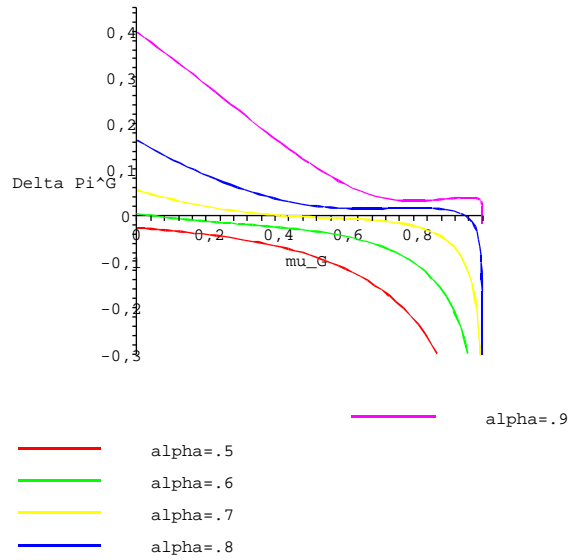


Figure 1:  $\Delta\Pi^G(1, \mu_G)$  as a function of  $\mu_G$  for different values of  $\alpha$ .

The plot is shown in Figure 1. The plot illustrates the workings of the model. First, note that for  $\alpha = .5$ ,  $\Delta\Pi^G(1, \mu_G)$  is clearly negative, so given that the Reds choose  $A$  the Greens prefer  $B$  and complete segregation is an equilibrium. However,  $\Delta\Pi^G(1, \mu_G)$  increases with  $\alpha$ , such that for  $\alpha > .5904 \equiv \hat{\alpha}$ , we have that  $\Delta\Pi^G(1, 0) > 0$  and complete segregation is not an equilibrium anymore. In that case, there is a unique partial equilibrium. Note that  $\Delta\Pi^G(1, \mu_G)$  is not monotonically decreasing for very large  $\alpha$ , which implies that Assumption 2 is violated. Nonetheless, there is still a unique equilibrium for all values of  $\alpha$ .

If  $\alpha < .5904$  we have complete segregation as an equilibrium. In that case Proposition 2 gives us employment rates and wages. The employment rates are thus for  $\alpha < .5904$ :

$$s_A^R = s_B^G = .95 \text{ and } s_B^R = s_A^G = .9223.$$

The wages have a particular simple form in the case of complete segregation, being  $w_A(1, 0) = \theta\alpha$  and  $w_B(1, 0) = \theta(1 - \alpha)$ . Therefore, if we define the wage gap as  $G(\mu_R, \mu_G) = 1 - w_B(\mu_R, \mu_G)/w_A(\mu_R, \mu_G)$ , then the wage gap under complete segregation is  $G(1, 0) = 2 - 1/\alpha$ . Note that at  $\alpha = \hat{\alpha} = .5904$ , we have

$$w_A(1, 0) = 47,233 \text{ and } w_B(1, 0) = 32,767$$

and the wage gap is thus  $G(1, 0) = .306$ . Thus a small employment gap of .9223 versus .95 is only just compensated by a wage gap of 30%! The reason of this tenfold magnification is risk aversion of individuals. Individuals try to avoid the (small) risk of unemployment and even accept major losses in income to accomplish that.

We would like to know whether an even larger wage gap can be sustained in a partial segregation equilibrium when  $\alpha > .5904$ . We therefore plot the equilibrium wages,  $w_A(1, \mu^*)$  and  $w_B(1, \mu^*)$ , and equilibrium employments,  $s_A^R(1, \mu^*)$ ,  $s_B^R(1, \mu^*)$ ,  $s_A^G(1, \mu^*)$  and  $s_B^G(1, \mu^*)$ , as function of  $\alpha$ . Remember that the equilibrium  $\mu^*$  equals zero when  $\alpha \leq \hat{\alpha}$ , and solves  $\Delta\Pi^G(1, \mu^*) = 0$  when  $\alpha > \hat{\alpha}$ . These plots are shown in Figure 2 and 3. The pictures confirm Propositions 2 and 3. Moreover, for the chosen parameters we also observe that the wage gap  $G(1, \mu^*)$  is maximized at  $\alpha = \hat{\alpha}$ . When  $\alpha$  becomes larger than  $\hat{\alpha}$  the wage of  $A$  declines and the wage of  $B$  increases until the wage gap is reversed.

We next look at the sensitivity of  $\hat{\alpha}$  with respect to its parameters, as we saw that at  $\alpha = \hat{\alpha}$  the wage gap is maximized. We do this by computing the elasticities of  $\hat{\alpha}$  and of the implied wage gap  $G(1, 0)$  at the chosen parameters. That is we look at the percentage increase of  $\hat{\alpha}$  and the maximum wage gap change when a parameter 1% increases. The elasticities are shown in columns 2 and 3 of Table 2. We see that  $\hat{\alpha}$  and the implied maximum wage gap are most sensitive to  $\rho\theta$ , the coefficient of relative risk aversion. A 1% increase in this coefficient leads to a 2% increase in the maximum wage gap. On the other hand, our calibration seems least sensitive to the network parameters  $c_1(p + \kappa)$  and  $c_1\lambda$ . The maximum wage gap seems to be close to linear with respect to  $1 - s_0$ , the unemployment rate if a worker only consider direct search techniques. That is, if we chose  $s_0 = .95$  instead of  $s_0 = .90$ , it would roughly half the maximum wage gap.

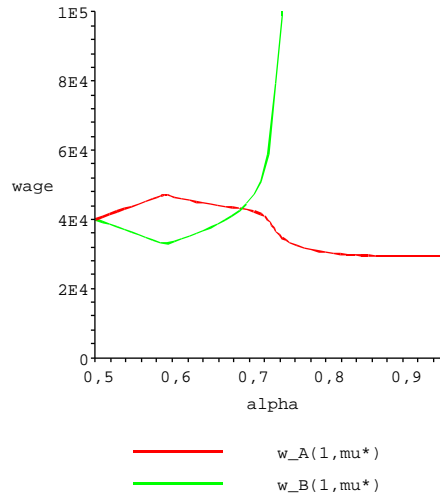


Figure 2: Equilibrium wages as function of  $\alpha$ .

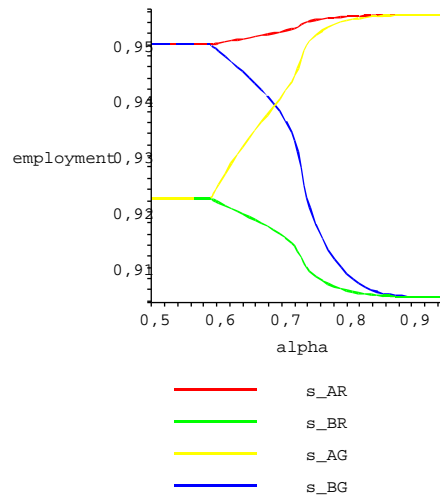


Figure 3: Equilibrium employment rates as function of  $\alpha$ .

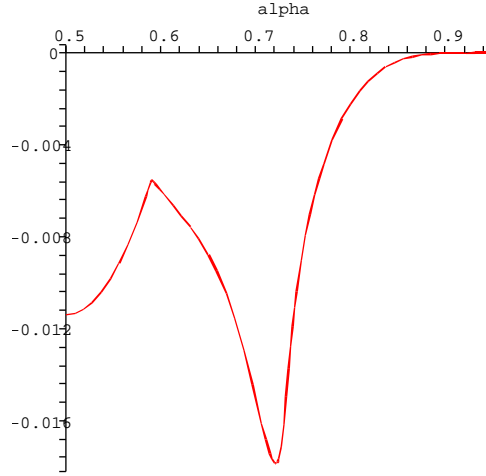


Figure 4: The percentage increase in welfare of a policy that enforces perfect integration.

### 6.2.2 Implications for the second-best welfare outcome

We now consider a second-best optimum. We suppose that government does not have the institutions to completely control  $\mu_R$  and  $\mu_G$ , but that it is able to stabilize a symmetric equilibrium, such that  $\mu_R = \mu_G = \mu^S$ .<sup>18</sup> Should the government do this? In case the government stabilizes integration, we still impose the equilibrium condition, which is in this case symmetric. Therefore

$$\Pi_A^R(\mu^S, \mu^S) = \Pi_B^R(\mu^S, \mu^S) = \Pi_A^G(\mu^S, \mu^S) = \Pi_B^G(\mu^S, \mu^S).$$

Thus in the symmetric case, there is complete equality. On the other hand, in the case of segregation, we consider the equilibrium allocation  $(\mu_R, \mu_G) = (1, \mu^*)$ , such that Reds obtain a higher payoff than Greens. Therefore, we might face a trade off when assessing an integration policy. It wipes out inequality, but it might decrease employment.

We therefore show a plot of the increase in social welfare from such an integration policy,  $I = W(\mu^S, \mu^S)/W(1, \mu^*) - 1$  as function of  $\alpha$ . Figure 4 shows this plot. We observe that  $I$  is always negative for all values of  $\alpha$ . So for the chosen parameters we see that the integration policy is never preferred. People are better off segregated.

<sup>18</sup>In the proof of Lemma 1 we show that there exists a symmetric equilibrium, but that it is unstable, that is, after a small deviation from the equilibrium individual incentives drive education choices to segregation.

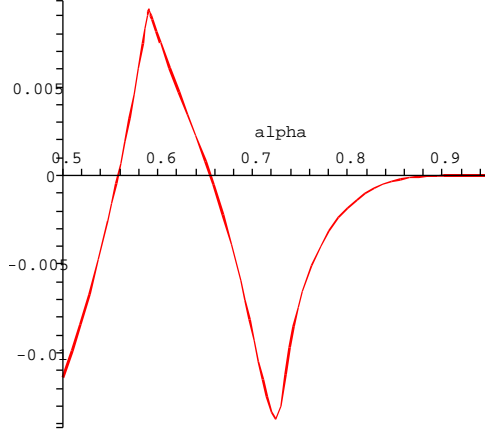


Figure 5: The percentage increase in payoffs for Green workers of a policy that enforces perfect integration.

Our results are very clear; a second best policy involves a “laissez-faire” policy, such that society becomes segregated. The intuition behind this result is twofold. First, in the case of partial segregation the equilibrium is determined by the Green workers. They trade off a benefit in wage against a loss in employment. Their individual incentives therefore already put a limit on the amount of wage inequality that can be sustained in equilibrium. Second, an integration policy would lead to lower employment rates. In a society with risk-averse individuals, society puts large emphasis on unemployment, and therefore prefers to allow for some inequality in order to obtain these higher employment rates.

We finally note that an integration policy is only beneficial when society has *additional* distributional concerns that are not incorporated by the concavity of the individual utility function. For example, consider the case of a maximin social welfare function:  $W_{\min} = \min_i \Pi_i$ . In the integrated case,  $\mu_R = \mu_G = \mu^S$ , everyone obtains the same payoff, whereas in the segregated case workers from group  $G$  are worst off. Therefore,  $W_{\min}(1, \mu^*) = \Pi_B^G(1, \mu^*)$  and  $W_{\min}(\mu^S, \mu^S) = \Pi_B^G(\mu^S, \mu^S)$ . We show a comparison of these two payoff  $\Pi_B^G(\mu^S, \mu^S)/\Pi_B^G(1, \mu^*) - 1$  in Figure 5. We observe that the Green workers would benefit from an integration policy for values of  $\alpha$  around  $\hat{\alpha}$  where the wage gap is particularly large. Thus in that case, strong distributional concerns would justify integration.

## 7 Summary and conclusions

We have investigated a parsimonious social network framework where jobs are obtained through a network of contacts formed stochastically, after career decisions had been made. We have shown that even with a very small amount of homophily within each social group, dynamically stable occupational segregation equilibria will arise. If the wage differential across the occupations is not too large, complete segregation will always be sustainable. If the wage differential is large, complete segregation cannot be sustained, but a partial segregation equilibrium in which one of the group fully specializes in one education while the other group mixes over the career tracks, is sustainable. Furthermore, our model is able to explain sustained unemployment and wage differences between the social groups.

We also analyze the implications of our model from a social planner's point of view. In the first best social welfare optimum, we find that segregation is the socially preferred outcome. Subject to proper calibration of our model parameters, a second best social welfare analysis supports a laissez-faire policy, where society also becomes segregated, shaped by individual incentives. Both these conclusions are valid in light of 'reasonable' concavity features of the individual utility function. Our social welfare conclusions cast some doubts on an "always integration" policy choice; if job referrals through contact networks are relevant in matching workers to vacancies, and if the mechanisms of our model are the correct ones, an 'integration approach' would only be justified under strong additional distributional concerns, not reflected in the individual utility functions.

We assumed that individuals first choose an education, and then form a network of job contacts. As a consequence, individuals have to make *expectations* about the network they could form, and base their education decisions on these expectations. This is in contrast to earlier work on the role of networks in the labor market. In former research, the network was supposed to be already in place, or the network was formed in the first stage (Montgomery, 1991; Calvó-Armengol, 2004; Calvó-Armengol & Jackson, 2004).

Our departure from the earlier frameworks raises questions about the assumed timing of the education choice. Are crucial career decisions made before or after job contacts are formed? One might be tempted to answer: both. Of course everyone is born with family ties, and in early school and in the neighborhood children form more ties. It is furthermore known that peer-group pressure among children has a strong effect on decisions to, for instance, smoke or engage in criminal activities and, no doubt, family and early friends do also form a non-negligible source of influence when making crucial career decisions. However, we argue that most job-relevant contacts (so called 'instrumental ties') are made later, for instance at the university or early at the workplace or simply when starting to look for a suitable job, hence after a specialized career track has been chosen. Even if those ties are typically not as strong as family ties, they are more likely to provide relevant information on vacancies to job seekers. Granovetter (1973, 1985) provides convincing evidence that job seekers more of-

ten receive crucial job information from acquaintances ("weak ties") instead of family or close friends ("strong ties"). If the vast majority of such instrumental ties are formed after the individual embarked on a (irreversible) career, then it is justified to consider a model in which the job contact network is formed after making a career choice.

While our social interaction model can describe empirical patterns of occupational segregation and wage inequality between gender, racial or ethnical groups, other factors are also documented to play a significant role in this context. This model should thus be seen as complement to alternatives such as taste discrimination or rational bias by employers, which are still present in the market despite their (predicted) erosion over time, due to both competitive pressure and institutional instruments. It is therefore pertinent to directly investigate how relevant are the mechanisms described in this paper and to assess their relative strength in explaining observed occupational segregation, vis-à-vis other proposed theories. Another avenue for future research is to extend this framework to issues such as the position of minority versus majority groups, by looking at the interaction between social groups of unequal sizes.

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## A Proofs

The proof of Proposition 1 uses the following lemma:

**Lemma 1** *Suppose Assumptions 1 and 2 hold. A weakly stable equilibrium  $(\mu_R^*, \mu_G^*)$ , in which  $0 < \mu_R^* < 1$  and  $0 < \mu_G^* < 1$ , does not exist.*

**Proof.** Suppose  $(\mu_R^*, \mu_G^*)$  is a stable equilibrium, and  $\mu_R^* \in (0, 1)$  and  $\mu_G^* \in (0, 1)$ . By condition (2)

$$\Pi_A^R(\mu_R^*, \mu_G^*) = \Pi_B^R(\mu_R^*, \mu_G^*) \text{ and } \Pi_A^G(\mu_R^*, \mu_G^*) = \Pi_B^G(\mu_R^*, \mu_G^*) \quad (18)$$

Substituting (8)-(9) into (18) and rewriting, these equations become

$$\frac{U(w_A(\mu_R^*, \mu_G^*))}{U(w_B(\mu_R^*, \mu_G^*))} = \frac{s_B^R(\mu_R^*, \mu_G^*)}{s_A^R(\mu_R^*, \mu_G^*)} = \frac{s_B^G(\mu_R^*, \mu_G^*)}{s_A^G(\mu_R^*, \mu_G^*)}. \quad (19)$$

Since  $\lambda > 0$ ,  $\mu_R^* > \mu_G^*$  implies  $s_A^R > s_A^G$  and  $s_B^R < s_B^G$ . But this means that if  $\mu_R^* > \mu_G^*$ , then

$$\frac{s_B^R(\mu_R^*, \mu_G^*)}{s_A^R(\mu_R^*, \mu_G^*)} < \frac{s_B^G(\mu_R^*, \mu_G^*)}{s_A^G(\mu_R^*, \mu_G^*)}.$$

which contradicts (19). The same reasoning holds for  $\mu_R^* < \mu_G^*$ . Hence, it must be that  $\mu_R^* = \mu_G^*$ .

However  $(\mu_R^*, \mu_G^*)$  with  $\mu_R^* = \mu_G^*$  cannot be a stable equilibrium. To see this, suppose that  $(\mu^*, \mu^*)$  with  $\mu^* \in (0, 1)$  is a stable equilibrium. Hence  $\Pi_A^X(\mu^*, \mu^*) = \Pi_B^X(\mu^*, \mu^*)$  for  $X \in \{R, G\}$  and  $\frac{\partial \Delta \Pi^X}{\partial \mu^X} < 0$  at  $\mu_R = \mu_G = \mu^*$ , and  $\det(G(\mu^*, \mu^*)) > 0$ , where  $G(\mu) = D\Delta \Pi(\mu)$  is the Jacobian of  $\Delta \Pi \equiv (\Delta \Pi^R, \Delta \Pi^G)$  with respect to  $\mu \equiv (\mu_R, \mu_G)$ .

Since  $\lambda > 0$ , it must be that

$$\frac{\partial s_A^X}{\partial \mu_X} > \frac{\partial s_A^X}{\partial \mu_Y} > 0 \quad (20)$$

and

$$\frac{\partial s_B^X}{\partial \mu_X} < \frac{\partial s_B^X}{\partial \mu_Y} < 0 \quad (21)$$

for  $X, Y \in \{R, G\}$  and  $Y \neq X$ . Furthermore, if  $\mu_R = \mu_G = \mu^*$ , then  $s_A^X = s_A^Y$ ,  $\frac{\partial L_A}{\partial \mu_X} = \frac{\partial L_A}{\partial \mu_Y}$ ,  $\frac{\partial L_B}{\partial \mu_X} = \frac{\partial L_B}{\partial \mu_Y}$ , and therefore,

$$\frac{\partial w_A}{\partial \mu_X} = \frac{\partial w_A}{\partial \mu_Y} \quad (22)$$

and

$$\frac{\partial w_B}{\partial \mu_X} = \frac{\partial w_B}{\partial \mu_Y}. \quad (23)$$

From (20)-(23) and Assumption 2, it follows that, at  $\mu_R = \mu_G = \mu^*$ ,

$$\frac{\partial \Delta \Pi^X}{\partial \mu_Y} < \frac{\partial \Delta \Pi^X}{\partial \mu_X} < 0.$$

for  $X, Y \in \{R, G\}$ ,  $X \neq Y$ . But then it is straightforward to see that  $\det(G(\mu^*, \mu^*)) < 0$ . This contradicts stability. ■

**Proof of Proposition 1.** (i) If (10) holds, then

$$\Pi_A^R(1, 0) > \Pi_B^R(1, 0) \text{ and } \Pi_A^G(1, 0) < \Pi_B^G(1, 0).$$

Hence,  $(\mu_R, \mu_G) = (1, 0)$  is clearly a stable equilibrium. The same is true for  $(\mu_R, \mu_G) = (0, 1)$ . Lemma 1 and Assumption 2 ensure that these are the only two equilibria.

(ii) If (11) is true, then

$$\Pi_A^G(1, 0) > \Pi_B^G(1, 0). \quad (24)$$

Furthermore, from Assumption 1 we know that  $\frac{\partial \Delta \Pi^G(1, \mu_G)}{\partial \mu_G} < 0$  for all  $\mu_G \in [0, 1]$ . It follows from Assumption 1, equation (24) and continuity of  $F$ ,  $U$  and  $s$ , that there must be a unique  $\mu^*$ , such that

$$\Pi_A^G(1, \mu^*) = \Pi_B^G(1, \mu^*).$$

Moreover,  $s_A^R(1, \mu^*) > s_A^G(1, \mu^*)$  and  $s_B^G(1, \mu^*) > s_B^R(1, \mu^*)$ , so we have at  $(\mu_R, \mu_G) = (1, \mu^*)$

$$\Pi_A^X > \Pi_B^Y = \Pi_A^Y > \Pi_B^X. \quad (25)$$

It is therefore clear that  $(\mu_R, \mu_G) = (1, \mu^*)$  is a stable equilibrium. The same is true for  $(\mu_R, \mu_G) = (\mu^*, 1)$ .

To show that there is no other equilibrium, note that by (11)  $\Pi_A^R(1, 0) > \Pi_B^R(1, 0)$ . Assumption 2 then implies that  $\Pi_A^R(\mu, 0) > \Pi_B^R(\mu, 0)$  for all  $\mu \in [0, 1]$ . Hence,  $(\mu, 0)$  and, similarly,  $(0, \mu)$  cannot be an equilibrium. By Lemma 1 we also know that there is no mixed equilibrium. ■

**Proof of Proposition 2.** The equations follow almost directly. We have

$$s_A^R(1, 0) = s_B^G(1, 0) = s_H > s_L = s_B^R(1, 0) = s_A^G(1, 0).$$

Further, by assumption  $w_A \geq w_B$  at  $(\mu_R, \mu_G) = (1, 0)$ . Finally, at  $(\mu_R, \mu_G) = (1, 0)$

$$U(w_A)s_A^R \geq U(w_B)s_B^G \geq U(w_A)s_A^G \geq U(w_B)s_B^R,$$

and this is equivalent to (12). ■

**Proof of Proposition 3.** Consider the stable equilibrium at  $(1, \mu^*)$ . Since it is an equilibrium we know that

$$\Pi_A^G(1, \mu^*) = \Pi_B^G(1, \mu^*).$$

In the proof of Proposition 1, equation (25), we already demonstrated the inequality (14). Further, by Assumption 2 we know that  $\Delta\Pi^G(1, \mu_G)$  is strictly monotonically decreasing in  $\mu_G$ .

(i) If  $\hat{\mu} < \frac{\lambda}{2(p+\kappa+\lambda)}$ , then  $s_A^G(1, \hat{\mu}) < s_B^G(1, \hat{\mu})$ . As  $w_A(1, \hat{\mu}) = w_B(1, \hat{\mu})$  it must be that

$$\Pi_A^G(1, \hat{\mu}) < \Pi_B^G(1, \hat{\mu}).$$

But then it also must be that  $\mu^* < \hat{\mu}$ . As we consider a partial equilibrium, we know that  $\mu^* > 0$ . Hence,  $0 < \mu^* < \hat{\mu}$  and  $w_A(1, \hat{\mu}^*) > w_B(1, \hat{\mu}^*)$ , as  $w_A(\mu_R, \mu_G)$  is a decreasing function, whereas  $w_B(\mu_R, \mu_G)$  is increasing.

(ii) If  $\hat{\mu} > \frac{\lambda}{2(p+\kappa+\lambda)}$ , then  $s_A^G(1, \hat{\mu}) > s_B^G(1, \hat{\mu})$  and  $\Pi_A^G(1, \hat{\mu}) < \Pi_B^G(1, \hat{\mu})$ . But then  $\mu^* > \hat{\mu}$ . By Assumption 1 we know that  $\mu^* < 1$ . Hence,  $\hat{\mu} < \mu^* < 1$ , and therefore  $w_A(1, \hat{\mu}^*) < w_B(1, \hat{\mu}^*)$  ■

We next continue with the proof of Proposition 4. This proof uses the following lemma:

**Lemma 2** *Suppose that for all  $x \in [0, (p + \kappa + \lambda)/2]$*

$$s''(x) > -\frac{4}{\lambda} s'(x). \quad (26)$$

(i) *If  $\mu_X > \mu_Y$  for  $X, Y \in \{R, G\}$ , then*

$$\frac{\partial L_A}{\partial \mu_X}(\mu_R, \mu_G) > \frac{\partial L_A}{\partial \mu_Y}(\mu_R, \mu_G) > 0, \quad (27)$$

and

$$\frac{\partial L_B}{\partial \mu_Y}(\mu_R, \mu_G) < \frac{\partial L_B}{\partial \mu_X}(\mu_R, \mu_G) < 0. \quad (28)$$

(ii) If  $\mu_R = \mu_G = \mu$ , then

$$\frac{\partial^2 L_A}{(\partial \mu_X)^2}(\mu, \mu) > \frac{\partial^2 L_A}{\partial \mu_X \partial \mu_Y}(\mu, \mu), \quad (29)$$

and

$$\frac{\partial^2 L_B}{(\partial \mu_X)^2}(\mu, \mu) > \frac{\partial^2 L_B}{\partial \mu_X \partial \mu_Y}(\mu, \mu). \quad (30)$$

**Proof.** (i) It is easy to derive that for  $X \in \{R, G\}$ :

$$\frac{\partial L_A}{\partial \mu_X} = \frac{1}{2} \left( s_A^X + \mu_R \frac{\partial s_A^R}{\partial \mu_X} + \mu_G \frac{\partial s_A^G}{\partial \mu_X} \right) > 0 \quad (31)$$

$$\frac{\partial L_B}{\partial \mu_X} = \frac{1}{2} \left( -s_B^X + (1 - \mu_R) \frac{\partial s_B^R}{\partial \mu_X} + (1 - \mu_G) \frac{\partial s_B^G}{\partial \mu_X} \right) < 0 \quad (32)$$

at  $(\mu_R, \mu_G)$ . From (31) and (32), we find that for all  $X, Y \in \{R, G\}$ :  $\partial L_A / \partial \mu_X > \partial L_A / \partial \mu_Y$  is equivalent to

$$s_A^X + \mu_X \left( \frac{\partial s_A^X}{\partial \mu_X} - \frac{\partial s_A^X}{\partial \mu_Y} \right) > s_A^Y + \mu_Y \left( \frac{\partial s_A^Y}{\partial \mu_Y} - \frac{\partial s_A^Y}{\partial \mu_X} \right). \quad (33)$$

With the definition of  $s_A^X$  in (4) we can write out

$$s_A^X + \mu_X \left( \frac{\partial s_A^X}{\partial \mu_X} - \frac{\partial s_A^X}{\partial \mu_Y} \right) = s((p + \kappa)\bar{\mu} + \lambda\mu_X/2) + \frac{\mu_X \lambda}{2} s'((p + \kappa)\bar{\mu} + \lambda\mu_X/2) \quad (34)$$

when  $X \neq Y$ . Therefore  $\mu_X > \mu_Y$  is equivalent to (33), whenever (34) is strictly monotone increasing with  $\mu_X$ , where we can treat  $\bar{\mu} = (\mu_X + \mu_Y)/2$  as a constant. It is easy to check that this is indeed the case under condition (26). We conclude that hypothesis (27) holds whenever  $\mu_X > \mu_Y$ . With a similar derivation one can show that condition (26) implies (28) as well.

(ii) The second derivatives of  $L_A$  and  $L_B$  with respect to  $\mu_X$  and  $\mu_Y$  are

$$\frac{\partial^2 L_A}{\partial \mu_X \partial \mu_Y} = \frac{1}{2} \left( \frac{\partial s_A^X}{\partial \mu_Y} + \frac{\partial s_A^Y}{\partial \mu_X} + \mu_R \frac{\partial^2 s_A^R}{\partial \mu_X \partial \mu_Y} + \mu_G \frac{\partial^2 s_A^G}{\partial \mu_X \partial \mu_Y} \right) \quad (35)$$

$$\frac{\partial^2 L_B}{\partial \mu_X \partial \mu_Y} = \frac{1}{2} \left( -\frac{\partial s_B^X}{\partial \mu_Y} - \frac{\partial s_B^Y}{\partial \mu_X} + (1 - \mu_R) \frac{\partial^2 s_B^R}{\partial \mu_X \partial \mu_Y} + (1 - \mu_G) \frac{\partial^2 s_B^G}{\partial \mu_X \partial \mu_Y} \right). \quad (36)$$

Taking the second derivatives of  $s_A^X$ , evaluating at  $\mu_R = \mu_G = \mu$  and reordering, we get that (29) is equivalent to

$$s''((p + \kappa + \lambda)\mu/2) < -\frac{4}{\lambda\mu} s'((p + \kappa + \lambda)\mu/2). \quad (37)$$

Inequality (37) clearly holds if condition (26) holds, which proves (29). In a similar fashion, (26) implies (30) ■

**Proof of Proposition 4.** Suppose that  $W(\mu_R, \mu_G)$  is maximized at  $(\mu_R, \mu_G) = (\tilde{\mu}_R, \tilde{\mu}_G)$ , where  $\tilde{\mu}_R \in (0, 1)$  and  $\tilde{\mu}_G \in (0, 1)$ . Define  $c \equiv L_A(\tilde{\mu}_R, \tilde{\mu}_G)/L_B(\tilde{\mu}_R, \tilde{\mu}_G)$ , and consider the constrained maximization problem:

$$\max_{\mu_R \in [0,1], \mu_G \in [0,1]} W(\mu_R, \mu_G) \text{ s.t. } L_A(\mu_R, \mu_G) = cL_B(\mu_R, \mu_G). \quad (38)$$

Because by definition of  $c$ , the solution  $(\tilde{\mu}_R, \tilde{\mu}_G)$  satisfies the restriction

$$g(\mu_R, \mu_G) = cL_B(\mu_R, \mu_G) - L_A(\mu_R, \mu_G) = 0, \quad (39)$$

it actually solves the maximization problem (38).

Define the feasible set  $C = \{\mu_R \in [0, 1], \mu_G \in [0, 1] | g(\mu_R, \mu_G) = 0\}$ . By the assumption of constant returns to scale, we have that for all  $(\mu_R, \mu_G) \in C$ :  $w_A(\mu_R, \mu_G)$  and  $w_B(\mu_R, \mu_G)$  are constant, and therefore, at all  $(\mu_R, \mu_G) \in C$ , the welfare function (16) can be written as

$$W(\mu_R, \mu_G) = L_A(\mu_R, \mu_G)(U(\bar{w}_A) + U(\bar{w}_B)/c),$$

which is monotone increasing with  $L_A(\mu_R, \mu_G)$ . Therefore, the solution  $(\tilde{\mu}_R, \tilde{\mu}_G)$  also solves the following maximization problem:

$$\max_{\mu_R \in [0,1], \mu_G \in [0,1]} L_A(\mu_R, \mu_G) \text{ s.t. } L_A(\mu_R, \mu_G) = cL_B(\mu_R, \mu_G). \quad (40)$$

We verify that  $(\tilde{\mu}_R, \tilde{\mu}_G)$  indeed satisfy the first- and second-order conditions of problem (40). The Langrangian is given by

$$\mathcal{L}(\mu_R, \mu_G, \psi) = (1 - \psi)L_A(\mu_R, \mu_G) + \psi cL_B(\mu_R, \mu_G).$$

Since  $(\tilde{\mu}_R, \tilde{\mu}_G)$  is supposed to be interior, the following first order constraints should hold:

$$\frac{\partial \mathcal{L}}{\partial \mu_R}(\tilde{\mu}_R, \tilde{\mu}_G, \psi) = (1 - \psi) \frac{\partial L_A}{\partial \mu_R}(\tilde{\mu}_R, \tilde{\mu}_G) + \psi \frac{\partial L_B}{\partial \mu_R}(\tilde{\mu}_R, \tilde{\mu}_G) = 0 \quad (41)$$

$$\frac{\partial \mathcal{L}}{\partial \mu_G}(\tilde{\mu}_R, \tilde{\mu}_G, \psi) = (1 - \psi) \frac{\partial L_A}{\partial \mu_G}(\tilde{\mu}_R, \tilde{\mu}_G) + \psi \frac{\partial L_B}{\partial \mu_G}(\tilde{\mu}_R, \tilde{\mu}_G) = 0. \quad (42)$$

The first part of Lemma 2 implies that  $\psi \in (0, 1)$  and that under condition (26):  $\mu_R > \mu_G$  if and only if  $\partial \mathcal{L} / \partial \mu_R > \partial \mathcal{L} / \partial \mu_G$ . Therefore, condition (26) and the first-order conditions imply that  $\tilde{\mu}_R = \tilde{\mu}_G \equiv \tilde{\mu}$ .

Since  $\tilde{\mu}_R = \tilde{\mu}_G$  defines a unique point in  $C$ , the second-order condition should hold at  $\tilde{\mu}_R = \tilde{\mu}_G$ , which says that the Hessian of the Langrangian with respect to  $(\mu_R, \mu_G)$  evaluated at the social optimum,  $D_{\mu_R, \mu_G}^2 \mathcal{L}(\tilde{\mu}, \tilde{\mu}, \psi)$ , is negative definite on the subspace  $\{z_R, z_G | z_R(\partial g / \partial \mu_R) + z_G(\partial g / \partial \mu_G) = 0\}$ . The second order condition is thus that at  $(\mu_R, \mu_G) = (\tilde{\mu}, \tilde{\mu})$ :

$$2 \frac{\partial g}{\partial \mu_R} \frac{\partial g}{\partial \mu_G} \frac{\partial^2 \mathcal{L}}{\partial \mu_R \partial \mu_G} - \left( \frac{\partial g}{\partial \mu_R} \right)^2 \frac{\partial^2 \mathcal{L}}{(\partial \mu_G)^2} - \left( \frac{\partial g}{\partial \mu_G} \right)^2 \frac{\partial^2 \mathcal{L}}{(\partial \mu_R)^2} > 0. \quad (43)$$

Because  $\frac{\partial g}{\partial \mu_R}(\tilde{\mu}, \tilde{\mu}) = \frac{\partial g}{\partial \mu_G}(\tilde{\mu}, \tilde{\mu})$ , and  $\frac{\partial^2 \mathcal{L}}{(\partial \mu_G)^2}(\tilde{\mu}, \tilde{\mu}) = \frac{\partial^2 \mathcal{L}}{(\partial \mu_R)^2}(\tilde{\mu}, \tilde{\mu})$ , the second order condition (43) simplifies to  $\frac{\partial^2 \mathcal{L}}{\partial \mu_R \partial \mu_G}(\tilde{\mu}, \tilde{\mu}) > \frac{\partial^2 \mathcal{L}}{(\partial \mu_R)^2}(\tilde{\mu}, \tilde{\mu})$ , or equivalently

$$(1-\psi) \frac{\partial^2 L_A}{\partial \mu_R \partial \mu_G}(\tilde{\mu}, \tilde{\mu}) + \psi \frac{\partial^2 L_B}{\partial \mu_R \partial \mu_G}(\tilde{\mu}, \tilde{\mu}) > (1-\psi) \frac{\partial^2 L_A}{(\partial \mu_R)^2}(\tilde{\mu}, \tilde{\mu}) + \psi \frac{\partial^2 L_B}{(\partial \mu_R)^2}(\tilde{\mu}, \tilde{\mu}). \quad (44)$$

By the second part of Lemma 2, inequality (44) cannot hold under condition (26). Therefore we have a contradiction and the non-segregation allocation  $(\tilde{\mu}_R, \tilde{\mu}_G)$  cannot be a social optimum. Since a social optimum exists by continuity of  $W$  and compactness of  $[0, 1]^2$ , the social optimum necessarily has to involve complete or partial segregation. ■