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Urban spatial structure, employment and social ties[☆]

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ABSTRACT

Consider a model where workers from the majority and the minority group choose both their residential location (geographical space) and the intensity of their social interactions (social space). We demonstrate under which condition one group resides close to the job center while the other lives far away from it. Even though the two groups have the same characteristics and there is no discrimination in the housing or labor market, we show that the majority group can have a lower unemployment rate whenever it resides close to or far away from the workplace. This is because this group generates a larger and better-quality social network.

1. Introduction

Economists have long been interested in how the socio-economic outcomes of individuals are shaped by their interactions with others around them. This question is especially important in urban areas where cities provide the homes, workplaces, and social environments for most individuals and where there is a substantial stratification across ethnic groups. The aim of this paper is to show how the size and the quality of social networks can cause large outcome discrepancies between urban minority and majority groups.

We develop a simple urban model with labor market frictions and job search where jobs are only found through social networks. Indeed, to find a job, workers need to commute to other workers to benefit from their social networks and increase their frequency of interactions and urban trips to other social network members. They balance their chance of finding a job with the additional time and travel cost of meeting others. We consider a closed and linear city where all jobs are located in the job center.

There are two populations, the majority and the minority group, with the exact same characteristics except for the sizes of their populations.¹ We analyze two types of spatial equilibria. In the first equilibrium (Equilibrium 1), the majority group chooses to live close to the job center while the minority group prefers to reside far away from it. This may correspond to a European city (such as Paris, London, Rome, Stockholm, etc.) where ethnic minorities tend to reside in the suburbs far away from jobs while the white majority group tend to live close to the job center located in the center of the city (see e.g. Fieldhouse, 1999; Åslund et al., 2010; Gobillon et al., 2011). This equilibrium also corresponds to a “new” American city such as Los Angeles, Atlanta, Houston, Dallas, Miami where jobs are provided in the suburbs and ethnic minorities reside at the (historical) city-center away from job providers.² In this equilibrium, ethnic minorities face both *ethnic segregation* because they are spatially separated from the other group and *spatial mismatch* because they are physically separated from jobs.

In the second equilibrium (Equilibrium 2), the opposite occurs so that the minority group resides close to the job center while the

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¹ We could easily interpret our model in terms of income groups with rich and poor households.

² Indeed, Glaeser et al. (2000, 2008) differentiate between old and new cities in the United States. *Old cities* in the United States are cities that were among the ten most populous U.S. cities in 1900. On the contrary, *new cities* are cities that have much smaller populations in 1990 compared to today. Glaeser et al. (2000, 2008) show that, in *older cities*, downtowns are more established and employment is centralized. In *newer cities*, employment is much more decentralized.

majority group live far away from it. This suggests an “old U.S. city” urban configuration such as New York, Chicago, Philadelphia, Detroit, Boston or San Francisco. In this case, ethnic minorities (Afro-Americans and Hispanics) reside close to the job center located in the city center whereas the majority group (Whites) lives at the periphery of the city.³ In this equilibrium, minorities face only *ethnic segregation* since they reside close to jobs.

We show that the majority group experiences a lower unemployment rate than the minority group in *any of those two equilibria*. This is one of our key results: a large enough majority population (e.g. white American community) may reside far away from jobs and still experience a higher employment rate than the minority population (e.g. Black community) who resides closer to jobs. In our model, this result stems from the trade off between residing far way from jobs, which implies higher commuting costs and lower work net-benefits, residing away from one’s own network community, which raises costs of interacting with peers and thus lowers search activities, and belonging to a larger network community, which increases network-size effects and thus search activities. In other words, the workers of the majority group compensate their urban location disadvantage by their bigger population and larger social network. Their larger social network allows them to search more intensively for jobs and get hired more often than minority workers. In turn, they obtain stronger employment experiences, which raises the quality of their social network in terms of likelihood of obtaining relevant job information. This is not the case for minorities when they reside far away from the job center since their network cannot compensate for their location disadvantage.

This result is quite unique as it can explain the *low employment rates of ethnic minorities in different cities*, a well-documented stylized facts both in the United States and in Europe.⁴ As stated above, the main reason for this result is the fact that the social network of the majority group is *large* and of *high-quality* while the opposite is true for the minority-group network.

We then extend our model in two different directions. First, we endogenize the social network sizes by letting workers from one group to socially interact with workers from the other group. We highlight the conditions under which the two groups choose not to interact with each other. In other words, we show how *ethnic segregation* endogenously emerges in *both the spatial and social space*. Second, we allow workers to direct their search and decide without uncertainty with whom they want to socially interact more in the city. In contrast to the benchmark model with random search, this favors social interactions with closer individuals in order to reduce travel costs. We show that the majority group may still experience a lower unemployment rate, even when they reside far away from jobs. Indeed, even though the two populations are *identical* in terms of their characteristics, we can demonstrate under which conditions (ethnic) minorities experience higher unemployment rates, socially interact mostly with people from their own group and even interact less than the majority group does.

The paper unfolds as follows. The next section highlights our contribution with respect to the literature. [Section 3](#) presents the benchmark model where we determine the employment rate, workers’ search activities and location decisions. [Section 4](#) analyzes the urban equilibria with two populations. [Sections 5](#) and [6](#) extend the analysis to the cases where workers can mix their social networks and where they choose the intensity of ties to each member of their own population (directed

search). Finally, [Section 7](#) discusses the policy implications of our model. All proofs of the propositions can be found in the Appendix. In addition, in an Online Appendix ([supplementary material](#)), we develop our model when there is only one population, analyze spatial equilibria with heterogeneous neighborhoods and provide further discussions of the numerical examples.

2. Related literature

Our paper contributes to the literature on “social interactions and cities”, which is a small but growing field.

2.1. Urban economics and economics of agglomeration

There is an important literature in urban economics looking at how interactions between agents create agglomeration and city centers.⁵ It is usually assumed that the level of the externality that is available to a particular firm or worker depends on its location relative to the source of the external effect – the spillover is assumed to attenuate with distance – and on the spatial arrangement of economic activity. This literature (whose keystones include: Beckmann, 1976; Fujita and Ogawa, 1980; Lucas and Rossi-Hansberg, 2002; Helsley and Strange, 2014; Behrens et al., 2014) examines how such spatial externalities influence the location of firms and households, urban density patterns, and productivity. For example, Glaeser (1999) develops a model in which random contacts influence skill acquisition, while Helsley and Strange (2004) consider a model in which randomly matched agents choose whether and how to exchange knowledge. Similarly, Berliant et al. (2002) show the emergence of a unique center in the case of production externalities while Berliant and Wang (2008) demonstrate that asymmetric urban structures with centers and subcenters of different sizes can emerge in equilibrium. More recently, Using a social interaction framework, Mossay and Picard (2011, 2013) determine under which condition different types of city structure emerge. All these models are different from ours since the labor market is not explicitly modeled and therefore the impact of social interactions on the labor-market outcomes is not analyzed.

2.2. Peer effects, social networks and urbanization

There is a growing interest in theoretical models of peer effects and social networks (for overviews, see Jackson, 2008; Ioannides, 2012; Jackson and Zenou, 2015; Jackson et al., 2017). However, there are very few papers that explicitly consider the interaction between the social and the geographical space.⁶ Brueckner et al. (2002), Helsley and Strange (2007), Brueckner and Largey (2008), Zenou (2013) and Helsley and Zenou (2014) are exceptions but, in all these models either the labor market is not included or social interactions are exogenous. Sato and Zenou (2015) is the only paper that has both aspects but the focus is totally different since it mainly analyzes on the role of weak and strong ties in the labor market and explains why, in denser areas, individuals choose to interact with more people and meet more random encounters (weak ties) than in sparsely populated areas. Finally, Schelling (1971) is clearly a seminal reference when discussing social preferences and location. Shelling’s model shows that, even a mild preference against interaction with another community can lead to large differences in terms of location decision. In this framework, total segregation persists even if most of the population is tolerant about heterogeneous neighborhood composition. Our model is very different

³ Of course the reality is more complex but this gives a clear picture of these different cities. See e.g. Cutler and Glaeser (1997), Cutler et al. (1999), Glaeser et al. (2008) and Hellerstein et al. (2008).

⁴ For example, the unemployment rate in France is roughly 6 percentage points higher for African immigrants than for natives and, in the United States, the unemployment rate is approximately 9 percentage points higher for blacks than for whites (Gobillon et al., 2014). See also Decreuse and Schmutz (2012) and Rathelot (2014) who show that, in France, individuals of African origin have worse labor market outcomes than that of other groups.

⁵ See Fujita and Thisse (2013) for a literature review.

⁶ Recent empirical researches have shown that the link between these two spaces is quite strong, especially within community groups (see e.g. Topa, 2001; Bayer et al., 2008; Ioannides and Topa, 2010; Patacchini and Zenou, 2012; Del Bello et al., 2015). See also Ioannides (2012, Chap. 5), Ross (2012, Chap. 5) and Topa and Zenou (2015) who review the literature on social interactions and urban economics.

from models à la Schelling since we focus on the relationship between the labor market and social interactions.

To the best of our knowledge, this paper is the first one to explain urban structures and labor-market outcomes through the intensity and scope of social interactions.

2.3. Spatial mismatch

There is ample evidence showing that distance to jobs is harmful to workers, in particular, ethnic minorities. This is known as the “spatial mismatch hypothesis” (for overviews, see Ihlanfeldt and Sjoquist, 1998; Ihlanfeldt, 2006; Zenou, 2008). Indeed, first formulated by Kain (1968), the spatial mismatch hypothesis states that, residing in urban segregated areas distant from and poorly connected to major centers of employment growth, black workers face strong geographic barriers to finding and keeping well-paid jobs. There are, however, very few theoretical models explaining these stylized facts (for a survey see Gobillon et al., 2007 and Zenou, 2009b). The standard approach is to use a search model to show that distant workers tend to search less (due to lack of information about jobs or less opportunities to find a job) and thus stay longer unemployed (Coulson et al., 2001; Wasmer and Zenou, 2002).⁷ Zenou (2013) develops a different model where workers only find jobs through weak and strong ties (social networks). He shows that minority workers, residing far away from jobs, may experience adverse labor outcomes because they choose to mainly interact with other minority workers who are themselves more likely to be unemployed. In this literature, all models have to assume some discrimination against minority workers (usually in the housing market) to obtain the different outcomes for minority and majority workers.

Our main contribution to this literature is twofold. First, we propose a model where segregation in the urban and social space arises endogenously in equilibrium. Second, we explain why ex ante identical workers can end up with very different labor-market outcomes and different locations in the city. In particular, we are able to explain why (ethnic) minorities reside close to or far from jobs and experience a higher unemployment rate than the (white) majority group because of the smaller size and quality of their social networks.

3. The model

Consider a linear city with unit width and two working populations of exogenous size P_i , each residing on a geographical support (set) $D_i \subset \mathbb{R}$, $i = 1, 2$. All workers work in the job center, located at $x = 0$. Observe that the job center can either corresponds to a central business district if it is located in the center of the city or to a suburban business district if it is located at the periphery of the city. Our model encompasses both cases and, thus, we refer to the job or employment center as the business district. To highlight the forces in our model, there is no discrimination in the housing or labor market and we exclude any exogenous bias in workers' preferences and endowments. Workers then have exactly the same characteristics: they have the same productivity, the same exogenous wage w ,^{8,9} the same unit use of residential space and the same linear commuting costs t (per unit of distance) to commute to the job center.

⁷ See also Brueckner and Zenou (2003) for a model of spatial mismatch but without an explicit search model. In an efficiency wage model where, in equilibrium, no worker shirks, they show that housing discrimination can lead to adverse labor-market outcomes for black workers.

⁸ The wage is exogenous because we have in mind low-skilled jobs, where workers are paid a minimum wage.

⁹ In the presence of an unemployment benefit B , the wage w should be replaced by $w - B$, i.e. the gain over the unemployment benefit. For simplicity, we normalize B so that $B = 0$.

3.1. Utility and employment probability

Every individual socially interacts with other individuals residing in the city and decides on how often she wants to interact with them. Each social interaction allows the individual to acquire a piece of job information but implies a travel cost τ (per unit of distance), which is different from t , the commuting cost.¹⁰ This implies that workers can only communicate face to face and interaction cost is a function of geographic distance in the city. First, there is strong evidence that, indeed, social interactions decrease with geographical distance (Marmaros and Sacerdote, 2006; Büchel and von Ehrlich, 2017; Kim et al., 2017). Second, there is also evidence that individuals in cities prefer to communicate face to face rather than using electronic communication (Gaspar and Glaeser, 1998; Glaeser, 2000).

We initially consider that individuals only interact with individuals from the same population because of cultural differences and/or language barriers. The empirical literature widely support this assumption: ethnic minorities are known to extensively use their social networks for the purpose of finding a job (Battu et al., 2011) while majority and minority groups are reported not to interact much with each other, as it is the case between blacks and whites in the United States (Sigelman et al., 1996; Topa, 2001). Also, blacks are much likely to be employed at some types of jobs than others (Holzer and Reaser, 2000). For the main part of the paper, we focus on workers' interactions within their own community. In Section 5, we relax this assumption and consider the case when workers' socialization choice extends to the other community's members.

In this paper, we assume that social interactions are the main channel for finding employment.¹¹ As in Zenou (2009a), we also assume *risk neutral* individuals and perfect capital markets with a zero interest rate.¹² As a result, workers engage in income smoothing as they cycle in and out of unemployment: they save while employed and draw down their savings when out of work. Their consumption expenditure therefore reflects their average disposable incomes. Therefore, individuals choose their residence given their expected income and utility. This is in accordance with the recent history of the US labor market where the high unemployment level has not lasted more than half a decade and workers did not change their residential location when they become temporarily unemployed. It also in accordance with the European labor market conditions where moving costs are important due to differences in culture, language, qualification, pension and law. As a result, workers have fewer opportunities to change job location during their unemployment spells. In this context, the expected utility of an individual of population $i = 1, 2$ residing at location x is given by:

$$U_i(x) = e_i(x)(w - t|x|) - C_i(x) - R(x) \quad (1)$$

where $e_i(x)$ is her employment probability, $R(x)$ the land rent for the use of her residential space unit, and $C_i(x)$ the cost of her social interactions (see more details below).¹³ Given the unit city width and individuals' unit use of residential space, the total number of workers of each population i is given by $P_i = \int_{D_i} \lambda_i(y) dy$ where $\lambda_i(y)$ denotes the number of individuals residing at location y . The number of employed workers in population i is equal to:

¹⁰ There is strong evidence that many jobs are found through social interactions and networks. See, in particular, Calvó-Armengol and Jackson (2004), Ioannides and Loury (2004), Galenianos (2014) and Zenou (2015).

¹¹ There is strong evidence that firms mainly rely on referral recruitment (Mencken and Winfield, 1998; Pellizzari, 2010). It is also well documented that workers use a lot their social networks to find a job (Ioannides and Loury, 2004).

¹² When there is a zero interest rate, workers have no intrinsic preference for the present so that they only care about the fraction of time they spend employed and unemployed. Therefore, the expected utilities are not state dependent.

¹³ The unemployment benefit is normalized to zero so that there is no term with unemployment probability $1 - e_i(x)$ in (1). Interaction cost $C_i(x)$ and land rent $R(x)$ are independent of employment probability $e_i(x)$ because they are paid independently of worker i 's employment status.

$$E_i = \int_{D_i} \lambda_i(y) e_i(y) dy$$

while the number of unemployed individuals is simply:

$$P_i - E_i = \int_{D_i} [1 - e_i(y)] \lambda_i(y) dy$$

Workers are either employed or unemployed. When working, they may lose their job with an exogenous probability β (firm bankruptcy, restructuring, etc.). When they are unemployed, workers residing at location x search for a job with a success probability of $\pi_i(x)$. In a steady-state equilibrium, flows in and out unemployment must be equal so that $\beta e_i(x) = \pi_i(x)[1 - e_i(x)]$. This yields the following individual's employment rate:

$$e_i(x) = \frac{\pi_i(x)}{\pi_i(x) + \beta} \quad (2)$$

3.2. Job search and social interactions

In this paper, we focus on the relationship between social interactions and employment. The benefits of social interactions are through the information flows workers obtain about employment opportunities. Each social interaction with an employed individual is associated to a probability of finding a job in the job center. We initially assume that every individual *randomly* meets her population mates (*random search*). Specifically, each individual of population i residing at x chooses to meet and interact with $n_i(x)$ persons from her own population *without knowing in advance the residence and employment status of the visited persons*. This set-up has both probabilistic and deterministic interpretations about the social network. First, it corresponds to a random matching model where each individual chooses her residence location and then build up a permanent social network of random ties after her arrival in the city. Second, it can be interpreted as a repetition of time periods where each individual meets $n_i(x)$ different individuals whose identities are independently and randomly drawn within her own population. In that case, $n_i(x)$ is the *expected number of people* that individuals of population i meet over their lifetime. Finally, it can refer to the social interactions during the individual's lifetime in the city. In this case, each individual will meet all her population mates $n_i(x)$ times in a deterministic way during the period considered in the model (say 30 years). For example, if $n_i(x) = 0.4$, then individual i will meet her friends 40% of her time during her lifetime. In all these interpretations, $n_i(x)$ corresponds to the concept of *weak ties* introduced by [Granovetter \(1973\)](#) in which weak ties are generated through professional meetings, casual acquaintances, encounters in sport events, etc. This assumption of random search is made for analytical tractability and is relaxed in [Section 6](#).

Given the employment rate for workers of population i , E_i/P_i , the individual probability of finding a job for a worker of group i residing at x is given by:

$$\pi_i(x) = \alpha_i n_i(x) \frac{E_i}{P_i} \quad (3)$$

Because each worker searches randomly across the city, her probability to get a relevant piece of job information after an interaction depends on the employment rate E_i/P_i of her group i and her intensity of social interactions $n_i(x)$. The employment rate E_i/P_i will then reflect the “quality” of her social network in terms of job search efficiency. By contrast, the term $\alpha_i \equiv \alpha(P_i)$ captures the *population size or network size* effect on job search. It is an increasing and convex function of P_i (i.e. $\alpha(P_i) > 0$, $\alpha'(P_i) \geq 0$). As discussed in [Granovetter \(1973\)](#), larger network size leads to wider professional diversity in the social network, therefore broader job information and higher likelihood of finding a job. When there are no network size effects, then $\alpha_i = \alpha > 0$ and it is just a positive constant.

From (2), we can see that $e_i(x) = \pi_i(x)/[\pi_i(x) + \beta]$ or equivalently

$\pi_i(x) = \beta e_i(x)/[1 - e_i(x)]$. Plugging this value of $\pi_i(x)$ into (3), we obtain:

$$e_i(x) = \frac{\alpha_i n_i(x) E_i / P_i}{\beta + \alpha_i n_i(x) E_i / P_i} \quad (4)$$

or equivalently

$$e_i(x) = f(\alpha_i n_i(x) E_i / P_i) \quad (5)$$

where

$$f(z_i) \equiv \frac{z_i}{\beta + z_i} \quad (6)$$

with $f'(z_i) > 0 > f''(z_i)$, $f(0) = 0$ and $\lim_{z_i \rightarrow +\infty} f(z_i) = 1$ and where $z_i \equiv \alpha_i n_i(x) E_i / P_i$. Indeed, for a given location x , higher social contacts and/or higher employment rate in own population raises own probability of finding a job. In this case, the steady-state aggregate employment rate in population i is given by

$$E_i = \int_{D_i} e_i(x) dx = \int_{D_i} f_i(\alpha_i n_i(x) E_i / P_i) dx$$

Since social interactions require travel, they generate a cost that increases with the number of interactions and traveled distances. We assume that any worker residing at x pays a travel cost equal to $\tau|x - y|$ where y is the location of the visited person and τ is the unit travel cost. Given that workers randomly interact within their own group, the worker's probability of visiting that group member is equal to $\lambda_i(y)/P_i$, where $\lambda_i(y)$ denotes the number of group mates at location y . Her expected cost of each interaction can then be written as:

$$c_i(x) = \frac{1}{P_i} \int_{D_i} \tau|x - y| \lambda_i(y) dy \quad (7)$$

Finally, the worker's total interaction cost is equal to $C_i(x) \equiv n_i(x)c_i(x)$. Observe that the worker's social interaction cost crucially depends on her proximity to the spatial center of her population (more precisely, the barycenter of D_i). If she locates there, she would have access at equal cost to her group mates from her left and her right. Her average cost $c_i(x)$ would then be the lowest one. But, if she locates at the edge of her population's residential area, she would have to travel longer distances to meet her peers so that $c_i(x)$ will have the highest value.

3.3. Land rents

In the land market, land is offered to the highest bidders ([Fujita and Thisse, 2013](#)) and there is no discrimination so that workers, given their budget constraint, can reside anywhere in the city. Let u_i be the equilibrium (expected) utility obtained by an individual of type i . It should be clear that, in equilibrium, all individuals of population i have the same expected utility u_i . From (1), it is easily verified that the bid rent of a worker i located at x is given by:

$$\Psi_i(x, u_i) = e_i(x)(w - t|x|) - n_i(x)c_i(x) - u_i \quad (8)$$

where $e_i(x)$ and $c_i(x)$ are given by (5) and (7). We assume that $w - t|x| > 0$, $\forall x \in [0, b]$ so that workers always have incentives to search for a job.

3.4. Optimal search intensity and social interactions

The number of social interactions $n_i(x)$ is a choice variable. Thus, a worker i located at x chooses $n_i(x)$ that maximizes her expected utility (1) or equivalently her bid rent (8), i.e.

$$\Psi_i(x, u_i) = \max_{n_i(x)} [e_i(x)(w - t|x|) - n_i(x)c_i(x)] - u_i \quad (9)$$

where $e_i(x)$ is given by (5). The first-order condition is equal to:¹⁴

¹⁴ Given the concavity of $f(\cdot)$, there is a unique maximum given by $n_i^*(x)$.

$$\alpha_i (E_i/P_i) f'(\alpha_i n_i^*(x) E_i/P_i) = \frac{c_i(x)}{w - t|x|} \quad (10)$$

which solves for $n_i^*(x)$. When deciding her optimal intensity of social interactions, the worker trades off the increase in her chance of finding a job obtained by an additional social interaction (as shown by the LHS of (10) that is equal to $\partial e_i(x)/\partial n_i(x) > 0$) with the increase in the travel cost associated to this encounter, $c_i(x)$, compared to the net benefit of being employed, $w - t|x|$ (i.e. the RHS of (10)). Since $f(\cdot)$ is a decreasing function, the optimal number of interactions, $n_i^*(x)$, increases with this net income $w - t|x|$. Finally, observe that $n_i^*(x)$ decreases with x , the distance to the job center, if and only if the right-hand side (RHS) of (10) increases in x , for $x \geq 0$. By (5) the employment probability will then also fall with x .

To be more specific, we can use the definition of $f(\cdot)$ given in (6), to determine the solution of (10). We obtain:

$$[\beta + \alpha_i n_i^*(x)(E_i/P_i)]^2 = \frac{\alpha_i \beta (w - t|x|)(E_i/P_i)}{c_i(x)} \quad (11)$$

which using (4) can be written as:¹⁵

$$[1 - e_i^*(x)]^2 = \frac{\beta c_i(x)}{\alpha_i (w - t|x|)(E_i/P_i)} \quad (12)$$

Eq. (11) or (12) are well-defined if the right-hand side of (12) is lower than one. Otherwise, we have a corner solution: $e_i^*(x) = n_i^*(x) = 0$. In the sequel, we focus on the situation where $e_i^*(x) > 0$ and $n_i^*(x) > 0$ for all locations x in the city. For that, we impose that the right-hand side of (12) to be lower than one, which is equivalent to:

$$\frac{\alpha_i E_i}{\beta P_i} > \max_x \left[\frac{c_i(x)}{w - t|x|} \right] \quad (13)$$

We can discuss the basic properties of the employment probability $e^*(x)$ and the number of social interactions $n_i^*(x)$. First, when $c_i(x)/(w - t|x|)$ increases in x , both the employment probability $e_i^*(x)$ and the number of interactions $n_i^*(x)$ fall with the distance from the city center. This occurs for two reasons. On the one hand, the workers who live further away from the job center have a lower income net of commuting cost, $w - t|x|$, which reduces their incentives to search for a job. On the other hand, when $c_i(x)$ rises, workers reside further away from their social networks that are a source of job information. In this case, their job search efforts become more costly and workers have smaller incentives to search for a job.

Also, from (12), given the population size P_i and therefore $\alpha_i \equiv \alpha(P_i)$, it can be shown that the employment probability $e_i^*(x)$ increases with higher aggregate employment rate E_i/P_i . As workers have higher chance of obtaining information about job opportunities when the individuals in their own social networks are employed, they have higher incentives to search for a job and ultimately are less likely to stay unemployed. However, the impact of the aggregate employment rate E_i/P_i on the number of interactions $n_i^*(x)$ is ambiguous and depends on the shape of the function $f(\cdot)$. Indeed, one can show from (11) that the number of interactions $n_i^*(x)$ decreases with E_i/P_i if and only if

$$\frac{-zf''(z_i)}{f'(z_i)} > 1$$

evaluated at $z_i = n_i(x) E_i/P_i$. This reflects a *substitution effect* between social interactions and employment level in the population (see below). In particular, the impact of the employment rate on the number of interactions is not monotonic. It is easily checked that $n_i^*(x)$ falls with $\alpha_i E_i/P_i$ if and only if

¹⁵ Observing that (4) implies that

$$\alpha_i n_i(x) \frac{E_i}{P_i} = \frac{e_i(x) \beta}{[1 - e_i(x)]}$$

$$\frac{\alpha_i E_i}{P_i} > 4\beta \left[\frac{c_i(x)}{w - t|x|} \right] \Leftrightarrow e_i^*(x) > \frac{1}{2} \quad (14)$$

Hence, when the aggregate employment rate is not too low, workers react to an increase in aggregate employment rate by reducing their job searches amongst their social ties. Workers have indeed better chance to find a job and reduce their efforts in entertaining such social interactions. This substitution effect is more important for workers who bear low search costs and reside closer to the city center (low $c_i(x)/(w - t|x|)$). Applying the envelop theorem, we finally obtain the following land gradient for $x > 0$:

$$\Psi'_i(x, u_i) = -e_i^*(x) t [\text{sign}(x)] - n_i^*(x) c'_i(x) \quad (15)$$

So far, we have analyzed the properties of the model for any possible urban configuration. We would like now to study the possible urban configurations under such model.

4. Urban equilibria

Consider two populations ($i = 1, 2$) that are separated in the city space.¹⁶ As stated above, there is no discrimination in the housing or labor market so that all workers from these two populations are treated equally. Moreover, all workers have exactly the same characteristics. However, population 1 resides close to the job center, i.e. in the interval $[-b_1, b_1]$, while population 2 resides far away from the job center, i.e. at $[-b_2, -b_1) \cup (b_1, b_2]$, where $b_1 > 0$ is the border between populations 1 and 2 and b_2 is the city border ($b_2 > b_1$). For convenience, we label populations 1 and 2 respectively as the “central” and “peripheral” populations. The population sizes are now given by $P_1 = 2b_1$ and $P_2 = 2(b_2 - b_1)$ while the total population size is still equal to $P = 2b_2$. We assume a uniform distribution of individuals in the city. In that case, with workers’ unit land use, we have: $\lambda_1(y) = 1$ and $\lambda_2(y) = 0$ for $y \in [-b_1, b_1]$ while $\lambda_1(y) = 0$ and $\lambda_2(y) = 1$ for $y \in [-b_2, -b_1) \cup (b_1, b_2]$. We want to show under which conditions, this spatial configuration is an equilibrium.

In such an urban configuration, each population’s social network maps to a distinct geographical area. Segregation therefore implies the *separation of populations both in their social and spatial dimensions*. Also, according to Kain (1968), a *spatial mismatch* occurs when the minority group has higher unemployment and resides far from the jobs. In our setup, it takes place when the smaller population is at the periphery and experiences a lower aggregate employment rate. Hence, this urban setup fits two situations. First, when the central population is the “white” or “majority” group and the peripheral population is the “ethnic” or “minority” group, the equilibrium can lead to a *spatial mismatch* (see Equilibrium 1 in Section 2 on the spatial-mismatch literature). As stated in the Introduction, this equilibrium could correspond to a European city such as Paris or London where minority workers usually live in the suburbs and the majority workers reside close to the job center or to a “new” American city such as Los Angeles or Atlanta where jobs are often located far away from minorities workers. Second, when the central population consists of the “ethnic” or “minority” group and peripheral population is the “white” or “majority” group, then the equilibrium could correspond to an “old” American city such as New York or Chicago where blacks and Hispanics reside close to the job center while white workers live at the outskirts of the city (see Equilibrium 2).¹⁷

¹⁶ The Online Appendix discuss the cases of (i) urban equilibria with a single population (Online Appendix A) and (ii) urban equilibria with two populations that are spatially integrated, i.e. uniform spatial distribution across the city (Online Appendix B). The reader may refer to the former case for a simpler setup. The latter case is not presented in our main text because it is not immune to small perturbations of preferences and technologies. Such a spatial equilibrium indeed breaks down if one population earns slightly higher salaries than the other, needs slightly smaller land plots, has a slightly lower commuting or search cost, etc.

¹⁷ More generally, in American cities, black families tend to reside closer to city centers

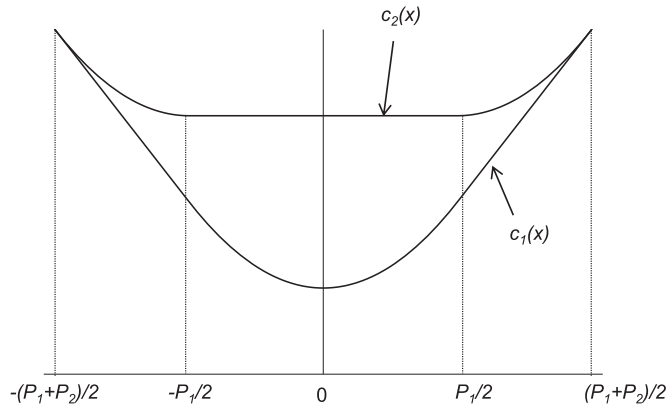


Fig. 1. Travel cost functions in the segregated city.

In this urban configuration, the expected costs of social interactions differ across populations and are given by:

$$c_1(x) = \begin{cases} \frac{\tau}{2b_1}(b_1^2 + x^2) & \text{if } |x| \leq b_1 \\ \tau|x| & \text{if } b_1 < |x| \leq b_2 \end{cases} \quad (16)$$

and

$$c_2(x) = \begin{cases} \frac{\tau}{2}(b_1 + b_2) & \text{if } |x| \leq b_1 \\ \frac{\tau}{2(b_2 - b_1)}(b_2^2 - 2b_1|x| + x^2) & \text{if } b_1 < |x| \leq b_2 \end{cases} \quad (17)$$

Fig. 1 displays these two cost functions. It can be checked that the cost $c_i(x)$ for each group of workers $i = 1, 2$ is a symmetric and a convex function of x . The social interaction costs increase as workers locate farther away from the city center. Furthermore, $c_1(x) < c_2(x)$ for all $|x| < b_2$ and $c_1(x) = c_2(x)$ at $|x| = b_2 = (P_1 + P_2)/2$. Finally, it is easily verified that the ratio of average travel costs $c_2(x)/c_1(x)$ is a monotonically increasing function of x if and only if $x > 0$.

From (12), we can readily conclude that the employment probability in each population decreases as workers reside further away from the city center and that the peripheral population has a disadvantage in terms of access to its own members and to jobs. This is mainly because the workers of the peripheral population are spread around in the city while the workers of the central population are concentrated at the vicinity of the job center and are geographically closer to their social network. Assuming zero opportunity of land outside the city, the urban equilibrium is then defined as follows:

Definition 1. Given that $c_1(x)$ and $c_2(x)$ are determined by (16) and (17), $P_1 = 2b_1$ and $P_2 = 2(b_2 - b_1)$, a closed-city competitive spatial equilibrium with two populations, where the central population 1 resides close to the job center while the peripheral population 2 lives far away from the job center, is defined by a 9-tuple $(R^*(x), e_1^*(x), e_2^*(x), E_1^*, E_2^*, n_1^*(x), n_2^*(x), u_1^*, u_2^*)$ satisfying the following conditions:

(i) Land rent (land-rent condition):

$$R^*(x) = \begin{cases} \max\{\Psi_1(x, u_1^*), \Psi_2(x, u_2^*), 0\} & \text{for } -b_2 < x < b_2 \\ \Psi_1(x, u_1^*) = \Psi_2(x, u_2^*) & \text{for } x = -b_1 \text{ and } x = b_1 \\ \Psi_2(x, u_2^*) = 0 & \text{for } x = -b_2 \text{ and } x = b_2 \\ 0 & \text{for } |x| > b_2 \end{cases} \quad (18)$$

(footnote continued)

than white families. For example, Hellerstein et al. (2008) report that 58% of black men and 27% of white men live in central city areas in the United States. In that case, our equilibrium 1 would correspond to a “typical” European city while our equilibrium 2 to a “typical” American city.

(ii) Spatial distribution of employment for type i workers:

$$e_i^*(x) = \frac{\alpha_i n_i^*(x) E_i^*/P_i}{\beta + \alpha_i n_i^*(x) E_i^*/P_i} \quad (19)$$

(iii) Aggregate employment (labor-market conditions):

$$\frac{E_1^*}{P_1} = \frac{2}{P_1} \int_0^{b_1} e_1^*(x) dx \quad (20)$$

$$\frac{E_2^*}{P_2} = \frac{2}{P_2} \int_{b_1}^{b_2} e_2^*(x) dx \quad (21)$$

(iv) Spatial distribution of social interactions for type i workers:

$$[\beta + \alpha_i n_i^*(x) (E_i^*/P_i)]^2 = \frac{\alpha_i \beta (w - t|x|) (E_i^*/P_i)}{c_i(x)} \quad (22)$$

where $\alpha_i = \alpha(P_i)$.

We look at equilibria for which $e_i^*(x) > 0$ and $n_i^*(x) > 0$ for all locations in the city. To guarantee that this is always true, we impose that

$$(E_i/P_i)(\alpha_i/\beta) > \frac{c_i(b_i)}{w - tb_i}, \quad i = 1, 2 \quad (23)$$

To obtain the labor market conditions for each population $i = 1, 2$, using (12), we can write (20) and (21) as follows (noticing that $b_1 = P_1/2$ and $b_2 = (P_1 + P_2)/2$):

$$\left(1 - \frac{E_i^*}{P_i}\right) \sqrt{\frac{E_i^*}{P_i}} = \Gamma_i(P_1, P_2) \quad (24)$$

where

$$\Gamma_1(P_1, P_2) \equiv \sqrt{\frac{\beta}{\alpha(P_1)}} \frac{2}{P_1} \int_0^{P_1/2} \sqrt{\frac{c_1(x)}{w - t|x|}} dx \quad (25)$$

and

$$\Gamma_2(P_1, P_2) \equiv \sqrt{\frac{\beta}{\alpha(P_2)}} \frac{2}{P_2} \int_{P_1/2}^{(P_1+P_2)/2} \sqrt{\frac{c_2(x)}{w - t|x|}} dx$$

Since $\Gamma_1(P_1, P_2)$ is independent of P_2 we can denote it as $\Gamma_1(P_1)$.

We also suppose in the sequel that network-size benefits are smaller than search and commuting costs so that Γ_1 increases in P_1 and Γ_2 in P_2 . We have the following result:¹⁸

Proposition 1. Consider the equilibrium defined in Definition 1. If the wage w is large enough, then the following labor-market condition

$$\max\{\Gamma_1(P_1), \Gamma_2(P_1, P_2)\} < 0.384 \quad (26)$$

holds, and there exists a unique equilibrium for which $1/3 < E_1^*/P < 1$ and $1/3 < E_2^*/P < 1$.

Fig. 2 illustrates this proposition. The first constraint, $\Gamma_1(P_1) < 0.384$, puts an upper bound on the central population, $\bar{P}_1 \equiv \Gamma_1^{-1}(0.384)$. This bound expresses that the central population should not be too large and therefore too much dispersed for its workers to have incentives to search and take jobs. The second constraint, $\Gamma_2(P_1, P_2) < 0.384$, puts an upper bound on the peripheral population, $\bar{P}_2(P_1) \equiv \Gamma_2^{-1}(P_1, 0.384)$.¹⁹ The bound is needed for the peripheral population be able to outbid the other population at the periphery of the city. For the sake of simplicity, it is further assumed that w is large enough so that there is no corner solution for which $e_i^*(x) = n_i(x) = 0$.

¹⁸ Other kinds of equilibria (such as incompletely mixed equilibria) than the segregated equilibria may exist either for the same parameter values studied in Proposition 1 or other parameter values.

¹⁹ Here, Γ_2^{-1} is the inverse of $\Gamma_2(P_1, P_2)$ with respect to the second argument.

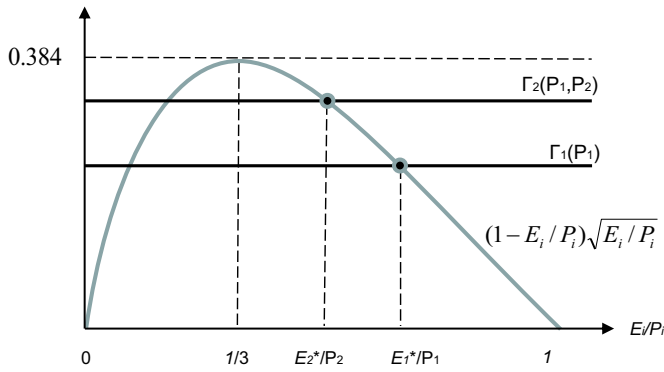


Fig. 2. Urban equilibrium with two populations.

In sum, these conditions hold when both populations are not too large.

4.1. No network size effects

To determine the employment rate for each population, let us first consider the case when there are no network-size effects.

Proposition 2. Consider the equilibrium defined in Definition 1 and suppose that there are no network-size effects ($\alpha_1 = \alpha_2 = \alpha$). Then, the employment rate of the central population 1, E_1/P_1 , is always higher than that of the peripheral population 2, E_2/P_2 , whatever population sizes. Moreover, E_2/P_2 decreases with higher P_1 and P_2 . The worker's employment probability $e_i(x)$ decreases with larger distance to the job center $|x|$, and abruptly falls at the border between the two populations, $x = b_1$. The number of social interactions $n_i(x)$ also decreases with distance from the center but abruptly rises or falls at the border b_1 depending on whether their employment probability $e_i(x)$ is high or low.

Fig. 3 (upper panel) depicts the equilibrium employment levels in this equilibrium. We see that the central population always experiences a higher employment rate because it has a better average access to its social network. As a result, workers have more incentives of finding a job. The employment level falls dramatically at the border between the two populations. This is because the peripheral population has a social network that is more dispersed spatially and has a lower quality in term

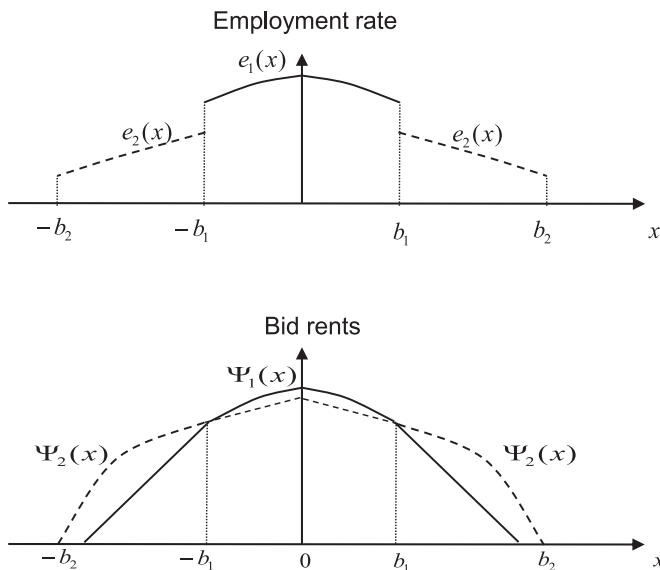


Fig. 3. Urban equilibrium with two populations and no network-size effects Population 1 at the center (solid lines), population 2 at city edges (dashed lines).

of its members' job experiences.

Fig. 3 (lower panel) also displays the equilibrium land rent for the two populations. Workers from the central population pay a higher land price to occupy the central locations and have no incentives to move away from there. Indeed, by relocating at a peripheral location, such a worker would raise her commuting cost and her expected costs of social interactions so that she would lose her incentives to search and take a job. She would then be employed less often, lose income and be unable to overbid the peripheral population. In a similar way, the peripheral population outbids the other population in the periphery and does not want to relocate from there. Indeed, would a worker of this population relocate close to the job center, he would benefit from lower commuting costs but lose access to his own social network, which would also reduce her employability, income and ability to match the land bids offered around the city center.

4.2. Network size effects

Assume now that there are network-size effects so that $\alpha_1 \equiv \alpha(P_1) \neq \alpha_2 \equiv \alpha(P_2)$. Then, the employment rate of the central population is higher than that of peripheral population if and only if $\Gamma_1(P_1) \leq \Gamma_2(P_1, P_2)$, or equivalently,

$$\sqrt{\frac{\alpha(P_1)}{\alpha(P_2)}} > \frac{\frac{1}{P_1} \int_0^{P_1/2} \sqrt{\frac{c_1(x)}{w-tx}} dx}{\frac{1}{P_2} \int_{P_1/2}^{(P_1+P_2)/2} \sqrt{\frac{c_2(x)}{w-tx}} dx} \quad (27)$$

where the right-hand side (RHS) of this inequality is smaller than one and independent of the social interaction travel cost τ . If (27) holds, the central population always has a higher employment rate than the other population. Because $c_1(x) < c_2(x)$ and $\alpha'(P) > 0$, this inequality holds for $P_1 \geq P_2$. Intuitively, the central population has a locational advantage that can only be increased by the stronger network size effects. By continuity, this property holds true when the central population is slightly lower than the peripheral one. However, when it is small enough, the central population can face too weak network effects that lead to a lower employment rate. This happens if the LHS of (27) has a lower slope than the RHS at $P_1 = 0$. This means that the slope of $\alpha(P_1)$ at $P_1 = 0$ should be small enough. The following proposition gives a sufficient conditions under which this is true.

Proposition 3. Suppose the presence of network-size effects so that $\alpha_1 \equiv \alpha(P_1) \neq \alpha_2 \equiv \alpha(P_2)$, $\alpha(0) = 0$ and $\alpha'(0) < 0.2177 \times \alpha(P)/P$. Then, there exists a population size threshold $\hat{P}_1$ below which the central population experiences a lower average employment rate than the peripheral population, i.e.

$$E_1/P_1 < E_2/P_2, \forall P_1 \in (0, \hat{P}_1)$$

This is one of our key results, which shows that, if the central population is small enough, it can experience a lower average employment rate than the other population. Hence, (ethnic) minority groups may face worse labor market outcomes even if they live at the vicinity of job centers, which is what we observe in cities such as New York or Chicago, for example. Reciprocally, the (white) majority group may have better job prospects and earnings even though they reside farther away from the employment district. In this case, its members compensate their locational disadvantages by a social network that is larger and of higher quality in terms of job information. This is because there is a trade-off between residing far away from job providers and peers, which implies higher commuting costs, higher costs of interacting with peers and thus lower search activities, and belonging to a large population, which increases the network-size effects and thus increases search activities. In this urban equilibrium (Equilibrium 2), the ethnic

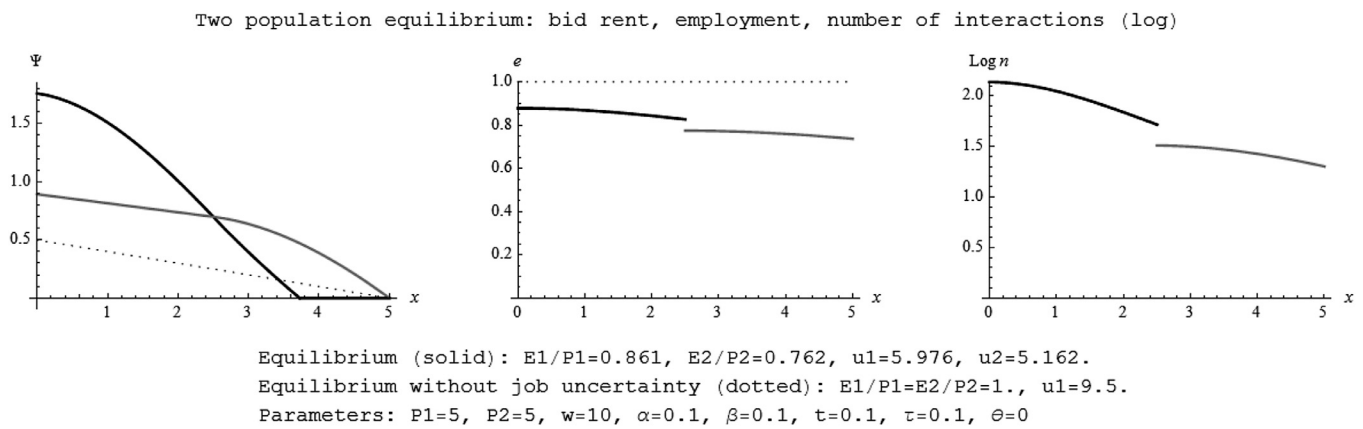


Fig. 4. Urban equilibrium with two populations without network size effect ($\theta = 0$).

minorities face ethnic segregation but no spatial mismatch since they reside close to jobs.²⁰

This result is quite unique as it can explain the *low employment rates of ethnic minorities both when they reside close and far away from jobs*. If we interpret these equilibria as illustrating European and American cities, then it is true that in both cases, minority workers tend to experience a much higher unemployment rate than their native counterparts (Gobillon et al., 2014; Rathelot, 2014). Zenou (2013, Table 1, p. 123) provides further empirical evidence of this result in selected American cities. Accordingly, the size of the black population in those cities is much smaller than that of the white population while the black population also experiences a higher unemployment rate. Whites tend to experience (slightly) higher unemployment rates in cities where they reside further away from jobs. For example, in a city such as Los Angeles (a “new” city), white families tend to live further away from the business district than in a city such as New York or Chicago (an “old” city).

To further illustrate the above results, we present two examples with and without network-size effects. In Fig. 4, we depict the land rent, employment and intensity of social interaction in the absence of network-size effects ($\alpha(P) = 0.1$), as discussed in Proposition 2. We can see that the workers of the central population experience a higher employment rate at each location than those of peripheral population. Moreover, the former socially interact more with their peers than the latter because of a higher quality social network in terms of employment information. This is an illustration of the European city (or a new American city) where ethnic minorities tend to live at the outskirts of the city and experience higher unemployment rate than the white majority population that resides closer to the city center.

We now introduce network-size effects by assuming that $\alpha(P) = \alpha_0 P^\theta$ with $\alpha_0 > 0$ and $\theta > 1$. Since $\alpha'(P) = \alpha_0 \theta P^{\theta-1}$, we obtain $\alpha'(0) = 0$ and $\alpha(P)/P = \alpha_0 P^{\theta-1} > 0$. As a result, Proposition 3 applies for all $\theta > 1$ since the condition $\alpha'(0) < 0.2177 \times \alpha(P)/P$ always holds. Fig. 5 depicts the land rent, employment and intensity of social interaction for the parameter values $\alpha_0 = 0.1$ and $\theta = 1.5$. In addition, it depicts the case of a large enough peripheral population compared to the central population, so that the former is nine times higher than the latter (i.e. $P_2/P_1 = 9$). In that case, we obtain the results of Proposition 3: the minority group has lower employment rates although it has residence close to the job center. This can explain the American situation of old cities such as New York or Chicago where city-centers host ethnic minorities (mainly blacks and Hispanics) and urban peripheries host

whites majority groups that have lower unemployment rates. We also see that the minority individuals tend to choose to interact *more intensively* with their peers but on a much smaller area than the whites. This is because there are few minority workers and they all reside close to each other at the vicinity of the job center. As a result, since the costs of interacting are low, they tend to socially interact a lot with each other but, because the size of their network is quite small, they have less chance to find a job and, as a result, their social network will be of worse quality than that of the white workers. The fact that ethnic minorities tend to use more their social networks than whites but have a lower successful rate in finding a job is well-documented (see e.g. Battu et al., 2011).

Proposition 3 is novel because it highlights the feedback effect of space and segregation on labor-market outcomes. If we take two identical populations in all possible characteristics, then employment discrepancies result from the existence of spatial segregation and the resulting spatial organization of workers' social networks. Workers obtain job information through social contacts with their own communities. It is clear that this mechanism contrasts with those presented by the existing literature that assumes exogenous discrimination by landlords or by employers (see e.g. Brueckner and Zenou, 2003; Zenou, 2013; Verdier and Zenou, 2004). However, the force that creates employment discrepancies is here the strong *homophily* in social networking since populations do not interact with each other. On the one hand, such homophily may stem from common culture, language or religion that enhance trust, communication and reciprocally within each group. On the other hand, one may argue that homophily arises from discrimination or other sorts of racially target beliefs or behaviors. In the latter case, our result stems in an indirect way from racial attitudes. In the next section we attenuate the importance of strong homophily by allowing workers to interact with individuals from the other population. We show that the majority population does not interact with the minority population if it benefits from high quality and large size of social network. Strong homophily then arises endogenously.

5. Inter-group social interactions

So far, we have imposed that workers only socially interact with workers from their own population. This was justified by the existing barriers between social networks such as ethnic or language barriers. In this section, we discuss the possibility of inter-group social interactions and show under which conditions workers choose to socially interact exclusively within their own population. In other words, we want to show how and why *ethnic segregation arises in both the social and spatial dimension*.

Assume now that workers from population i choose their numbers of interactions both with their own population i (denoted by $n_{ii}(x)$) and

²⁰ In this model, we do not include different transportation modes, which could reduce the “real” distance to jobs. Indeed, in the United States, even if black workers reside close to jobs, they use public transportation to commute, which is often of poor quality (for example, in Los Angeles). In Europe, public transportation is of much better quality and may reduce the time distance between residential location and jobs.

Two population equilibrium: bid rent, employment, number of interactions (log)

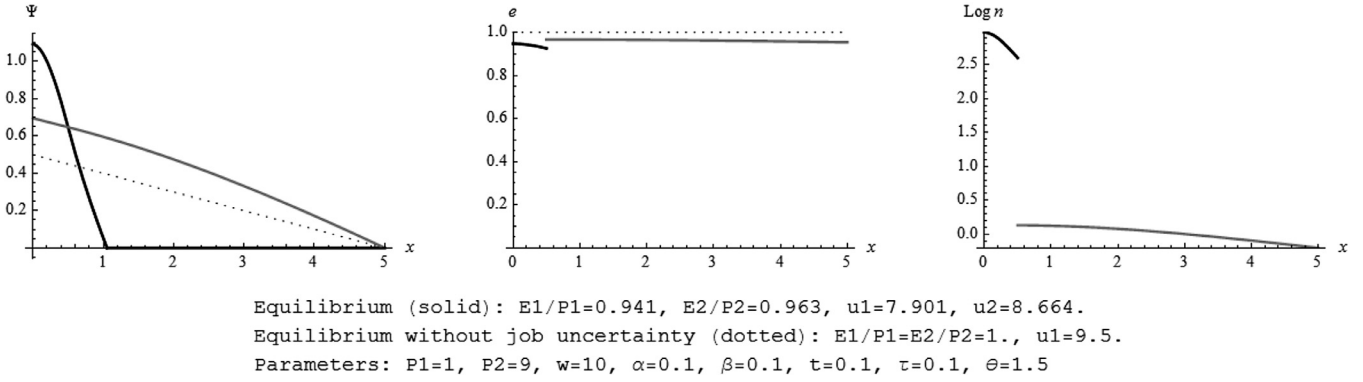


Fig. 5. Urban equilibrium with two populations and network-size effects.

with the other population j (denoted by $n_{ij}(x)$). As before, the individual's probability of finding a job depends on the number of social interactions and the aggregate employment rate of the visited population. In addition, language and/or ethnic differences create communication and/or trust issues that may yield possible negative biases in the effectiveness of transmitting information on job opportunities. For that, we assume that the probability of finding a job for a worker of type i is now given by:

$$\pi_i(x) \equiv \left[\alpha_i n_{ii}(x) \frac{E_i}{P_i} + \gamma \alpha_j n_{ij}(x) \frac{E_j}{P_j} \right]$$

where $\gamma \in (0,1)$ is a negative bias in inter-group communication. This plays a role similar to the *preference bias* discussed in Currarini et al. (2009). The parameter γ could also be interpreted as *ameeting bias* parameter where individuals from a given group tend to meet less people from the other group. This extended model obviously collapses to our benchmark model when $\gamma \rightarrow 0$. The worker's employment probability is still given by (2), i.e. $e_i(x) = f[\pi_i(x)] \equiv \pi_i(x)/[\pi_i(x) + \beta]$. The bid rent function is given by the maximal land rent that the worker can afford and can now be written as:

$$\Psi_i(x) = \max_{n_{ii}(x), n_{ij}(x)} [e_i(x)(w - t|x|) - n_{ii}(x)c_i(x) - n_{ij}(x)c_j(x)] - u_i$$

subject to $n_{ii}(x) \geq 0$ and $n_{ij}(x) \geq 0$, where $c_i(x)$ and $c_j(x)$ are given by (16) and (17). The optimal number of social interactions is determined as follows. First, if $c_i(x)/(\alpha_i E_i/P_i) < c_j(x)/(\gamma \alpha_j E_j/P_j)$, the worker only chooses to interact with her own population so that

$$(\alpha_i E_i/P_i) f'[\alpha_i n_{ii}^*(x) E_i/P_i] = \frac{c_i(x)}{w - t|x|} \quad (28)$$

and $n_{ij}^*(x) = 0$. Obviously, this is equal to the optimal number of interactions $n_i^*(x)$ that is chosen when there are no inter-group interactions and given by (19). Second, if $c_i(x)/(\alpha_i E_i/P_i) > c_j(x)/(\gamma \alpha_j E_j/P_j)$, the worker chooses to interact only with the other population j so that

$$(\gamma \alpha_j E_j/P_j) f'[\alpha_j n_{ij}^*(x) E_j/P_j] = \frac{c_j(x)}{w - t|x|} \quad (29)$$

and $n_{ii}^*(x) = 0$. Finally, if $c_i(x)/(\alpha_i E_i/P_i) = c_j(x)/(\gamma \alpha_j E_j/P_j)$, the worker chooses to interact with any mix of the two populations.

To solve this social-interaction choice, we consider the spatially-segregated city equilibria described in the previous section, where the subscripts $i = 1$ and 2 refer respectively to the central and peripheral populations.²¹

²¹ The case of the spatially-integrated city where workers can interact with people from both populations can be found in the Online Appendix B.2.

Proposition 4. Consider the spatially-segregated city described in Definition 1. If

$$\frac{1}{\gamma} \left(\frac{2P_1 + P_2}{2P_1} \right) > \frac{\alpha_2 E_2/P_2}{\alpha_1 E_1/P_1} > \gamma \left(\frac{2P_1 + P_2}{2P_1} \right) \quad (30)$$

hold, then no workers want to interact with workers from the other population.

In the spatially-segregated city, the central population will not interact with the peripheral population if it has a strong employment advantage and/or if the peripheral population has a strong employment disadvantage, and/or if it benefits from a stronger network-size effects, and/or if the inter-group communication is ineffective (strong preference bias). The first inequality in (30) gives the condition for which this is true. In the absence of network size effects, the condition always holds because the LHS of first inequality in (30) is larger than one while, by Proposition 2, the RHS is lower than one as the equilibrium aggregate employment rate of the central population is always larger than that of peripheral population ($E_1/P_1 > E_2/P_2$). This is not that surprising given that the benefit of reaching an individual from the peripheral population is less effective in terms of acquisition of job information and more costly in terms of travel cost because they are more spread at the periphery of the city. This property still holds in the presence of network size effects provided that the latter are not too strong (flat $\alpha(P)$).

Similarly, the peripheral population will not interact with central population if the former has no strong employment disadvantage and/or if the latter has no strong employment advantage, and/or if the former benefits from strong enough network-size effects, and/or if the inter-group communication is ineffective (strong preference bias). This is expressed by the second inequality in (30). The peripheral population has no incentive to seek interactions with the other population if the effectiveness of inter-group communication is low enough. The peripheral population has a clear benefit of “chasing” the members of the central population, which spreads over a more compact area and conveys more job information. The negative bias in inter-group communication is therefore necessary to reduce the incentives to interact with the central population. However, in the absence of network-size effects, this bias needs not to be very strong. As an illustration, a 10%-minority population will not interact with a 90%-majority population for any bias γ lower than 0.93 when the aggregate employment rates are 94% and 92% for the central and peripheral populations.²² Finally, *ceteris paribus*, the absence of inter-group social interactions holds provided that the population occupying the center is relatively large compared to the one at the periphery. This indeed keeps the RHS low enough in the second condition of (30). In this sense, the combination of spatial

²² See Table C1 in the Online Appendix C at the entry $(P_1, P_2) = (1, 0.1)$.

segregation and absence of inter-group interactions – as we have studied above – is more likely to be consistent with the urban configuration where a minority group locates far away from the job center.²³

To sum up, Proposition 4 gives the conditions for an equilibrium where ethnic segregation endogenously arises in both the social and spatial dimensions. It is important to note that the key of this result lies in the role of space. Indeed, in the absence of travel cost for social interactions ($\tau = 0$), workers would choose to interact only with the population with the highest quality and network size (see conditions (28) and (29) with $c_i(x) = 0$). The land market induces each population to remain located on different compact area(s) of the city, leading to the physical separation of the populations. In turn, this creates distances between the members of both populations and leads to the disconnection of their social networks.

6. Directed search interactions

Social network members generally prefer interactions with geographically nearer peers. For that reason, workers should have a preference to interact with others living in their vicinity. To match this fact, we now consider that search interactions are *directed* in the sense that workers choose the frequency of interactions according to the location of their interaction partners. This contrasts with the previous sections, in which workers chose the frequency of search interactions without knowing the location of the interaction partners (*random search*). For the simplicity, we go back to the model where workers only interact with other workers from the same group.

As in Section 4, we consider a central and peripheral population of size P_1 and P_2 that respectively spread over the supports $D_1 = [-b_1, b_1]$ and $D_2 = [-b_2, -b_1] \cup (b_1, b_2]$.²⁴ Under directed search, each worker located at x and belonging to group i chooses the number of interactions $n_i(x, y)$ with each other group member located at y . Such interactions gives her a probability of finding a job equal to

$$\pi_i(x, y) = \alpha_i v[n_i(x, y)] e_i(y)$$

which rises with the repetition of interaction, $n_i(x, y)$, and the employment likelihood of the person she meets, $e_i(y)$. As before, α_i denotes the network size effect, $\alpha(P_i) > 0$. For analytical convenience we now define $v(z) \equiv 1 - \exp(-z)$, which is increasing and concave, with $v(0) = 0$.²⁵ Quite naturally, there are decreasing returns to the number of social interactions. In contrast to the previous sections, each individual has now incentives to interact more frequently with those specific workers with higher employment probability $e_i(y)$ and therefore stronger probability to convey work information. The probability of finding a job depends on the total set of interactions and is given by:

$$\begin{aligned} \pi_i(x) &= \int_{D_i} \pi_i(x, y) dy = \int_{D_i} \alpha_i v[n_i(x, y)] e_i(y) dy \\ &= \int_{D_i} \alpha_i (1 - \exp[-n_i(x, y)]) e_i(y) dy \end{aligned} \quad (31)$$

As before, the probability of being employed is equal to $e_i(x) = \pi_i(x) / [\pi_i(x) + \beta]$.

The bid rent is given by the maximal land rent that the worker can afford given her chosen frequency of directed searches:

$$\Psi_i(x, u_i) = \max_{n_i(x, \cdot)} e_i(x)(w - t|x|) - \int_{D_i} \tau|x - y| n_i(x, y) dy - u_i \quad (32)$$

where $\tau|x - y|$ is the travel cost for a single search interaction. The

highest bid is offered for the number of interactions solving by the following first order condition:

$$v'[n_i^*(x, y)] = \frac{1}{\alpha_i e_i(y) f'[\pi_i(x)]} \frac{\tau|x - y|}{(w - t|x|)} \quad (33)$$

which has a unique solution for n_i^* because $v(\cdot)$ is a decreasing function. Under directed search, the frequency of search interactions rises the employment likelihood of the visited individual, $e_i(y)$, and falls with the distance to him, $|x - y|$. Ceteris paribus, workers interact more often with spatially closer workers. From a job search perspective, workers prefer to live closer to other employed workers.

Plugging the solution of (33) in (31) gives the probability of finding a job as

$$\pi_i(x) = \alpha_i E_i - \frac{\alpha_i P_i}{f'[\pi_i(x)]} \frac{c_i(x)}{(w - t|x|)}$$

where $c_i(x) = \int_{D_i} \tau|x - y| dy / P_i$, $i = 1, 2$, are the average travel costs given by (16) and (17). This probability rises with higher employment E_i and higher network effects α_i in population i because this increases the quality of the social network in term of conveying job information. It also falls with larger average travel cost $c_i(x)$ and commuting cost $t|x|$. Solving the last equality for $\pi_i(x)$ and plugging this in $e_i(x) = \pi_i(x) / [\pi_i(x) + \beta]$, we get the following employment probability:

$$e_i^*(x) = 1 - \frac{\beta + \sqrt{\beta^2 + 4\alpha_i\beta(\beta + \alpha_i E_i^*)P_i\vartheta_i(x)}}{2(\beta + \alpha_i E_i^*)} \quad (34)$$

where

$$\vartheta_i(x) = \frac{c_i(x)}{w - t|x|}$$

It can be seen that $e_i^*(x)$ increases when $c_i(x)$ decreases with x . Therefore, within the same population, the employment rate rises when workers are located closer to the job center. The difference in a worker's employment probability between two populations not only depends on her location but also on the aggregate employment E_i and the size of her population P_i . Aggregating the employment probabilities across workers of each group gives the labor market condition for each population $i = 1, 2$:

$$2(\beta + \alpha_i E_i^*) E_i^* - (\beta + 2\alpha_i E_i^*) P_i = F_i(E_i^*, P_1, P_2) \quad (35)$$

where

$$\begin{aligned} F_1(E_1^*, P_1, P_2) &= 2 \int_0^{P_1/2} \sqrt{\beta^2 + 4\alpha_1\beta(\beta + \alpha_1 E_1^*)P_1\vartheta_1(x)} dx \\ F_2(E_2^*, P_1, P_2) &= 2 \int_{P_1/2}^{(P_1+P_2)/2} \sqrt{\beta^2 + 4\alpha_2\beta(\beta + \alpha_2 E_2^*)P_2\vartheta_2(x)} dx \end{aligned}$$

Condition (35) reflects the same tradeoff between employment, network size and social interaction cost as condition (24) under random search. Condition (35) is however more involved because workers' interaction frequencies depend on the location of every visited interaction partner. Many properties are nevertheless similar to those of random searches. For instance, it can readily be seen that $F_i(E_i^*, P_1, P_2)$ is a function of E_i and P_i only. As a result, the central population's aggregate employment depends only on its own size P_1 . It can also be shown that the labor market condition is satisfied only for a population size of P_1 , which is smaller than some upper bound $\bar{P}_1$. Similarly, there also exist two equilibria with high and low employment rates. For the sake of realism, we again focus on the high-level employment rates. Fig. 6 depicts the population-employment locus of population 1 with a solid leaf-like curve. The population size $\bar{P}_1$ indicates the largest feasible city size. The point (E_1, P_1) show an equilibrium with (highest) equilibrium employment level E_1 when the population central size is $P_1 = 30$. It can be seen that larger central population have higher aggregate employment level E_1 but lower its employment rate E_1/P_1 (i.e. lower slope of the ray from origin $(0, 0)$ to (E_1, P_1)). The reasons are the same as in the random search model.

²³ For instance, using the population entries of Table C1 in the Online Appendix C, we find that, for any $\gamma \geq 0.3$, population 2 has no incentives to interact with population 1 if it is a minority group ($P_2 < P_1$), but do want to interact with population 1 if it is a majority group ($P_2 > P_1$).

²⁴ The reader may refer to the Online Appendix D.1. for an introductory analysis of urban equilibrium with directed search and a single population.

²⁵ The choice of this utility function is motivated by the analytical tractability in the aggregation of endogenous employment probability (31).

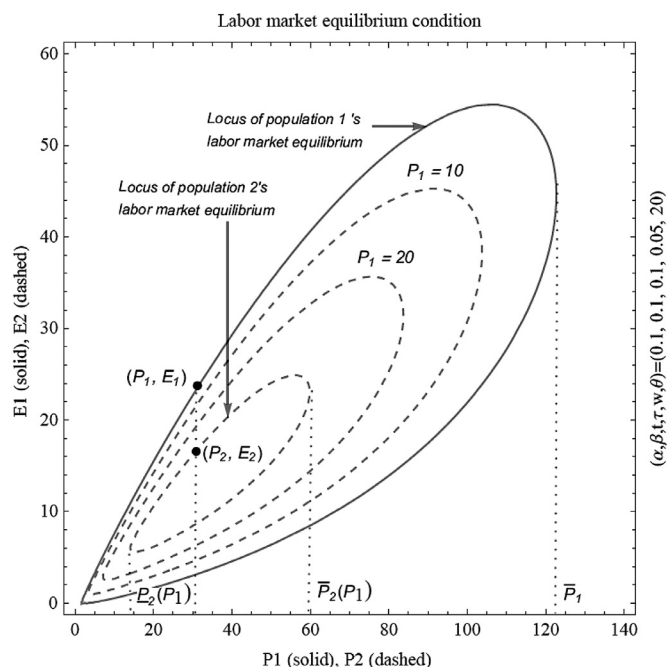


Fig. 6. Labor market conditions with directed search. *Note:* Each curve displays the locus of aggregate employment and population size. The locus E1-P1 for the central population 1 is shown by the same solid curve while the locus E2-P2 for the peripheral population 2 is displayed by the dashed curve. Dashed curve correspond to population 1's sizes P1 = 10, 20 and 30. The equilibrium allocation $\{(E1, P1), (E2, P2)\}$ is displayed for population sizes P1 = P2 = 30.

The equilibrium employment in the peripheral population is determined by condition (35) for $i = 2$ using the term $F_2(E_2^*, P_1, P_2)$. The dashed curves in Fig. 6 represent the loci of those equilibria in (P_2, E_2) for values of $P_1 = 10, 20$ and 30 . We obtain the same properties as in the case of random search. For a given P_1 , there exists an upper envelope $\bar{P}_2(P_1)$ such that the labor market condition has a solution. There also exist two employment equilibria, and we focus on the one with the highest employment. Fig. 6 displays equilibrium allocations (E_1, P_1) and (E_2, P_2) for identical population sizes $P_1 = P_2 = 30$. Both the aggregate employment level E_2 and rate E_2/P_2 are smaller for the peripheral community than for the central one. Labor market conditions jointly hold if $P_1 < \bar{P}_1$ and $P_2 < \bar{P}_2(P_1)$. It also apparent from Fig. 6 that the labor markets can support equilibria with peripheral populations larger or smaller than central ones (to see this, the reader may increase or decrease P_2 along the dashed curve). To sum up, labor market properties are qualitatively the same under directed and random search. The only new property is the existence of a minimum size for the peripheral population $\underline{P}_2(P_1)$ (see Fig. 6). This is because the latter population must benefit from sufficient social interactions to overcome its disadvantage in terms of job search and commuting to the employment center.

We can now close the land market equilibrium. At such an equilibrium, a location x hosts the population with the highest land bid rent $\Psi_i(x, u_i)$, defined in expression (9) with equilibrium interaction frequencies $n_i^*(x, y)$ given by (33). It can easily be shown that $\Psi(x, u_i)$ is a decreasing function of x but it is difficult to show analytically that the central population outbids the peripheral one in the interval $[-b_1, b_1]$ and that the reverse is true in the intervals $[-b_2, b_1]$ and $[b_1, b_2]$.²⁶ Therefore, each land market equilibrium must be found in a numerical exercise for each configuration of populations.

To better understand the way the equilibrium is calculated, we have run some numerical simulations. Table 1 displays the results for a set of population configurations for which both the labor and land market clear in the absence of network size effects.

It can be seen from [Table 1](#) that equilibrium solutions exist only when the population sizes are neither too small nor too large. Populations should not be too larger to avoid too high distance to the job center and between their members. They should be not too small to allow enough social interactions and find jobs. Also, the equilibrium employment rate for each population decreases with the size of each population or equivalently with the size of the city.

Finally, we study the impact of network-size effects. Figs. 7 and 8 are computed for no network effects: $\alpha(P) = 0.5$. In Fig. 7, the size of the central population is higher than that of peripheral one (i.e. $P_1/P_2 = 1.8$) and, quite naturally, workers from the central population experience a higher employment rate than those from the other population and outbid the latter for land around the job center. Interestingly, the social interaction decisions, $n_i(x, y)$, are not anymore as before, i.e. smoothly decreasing with distance from the job center (as in Fig. 5), but strongly vary with location with a spike at own residential location. Indeed, one can see that individuals meet more often and thus search more intensively around their own location and tend to little interact with individuals residing further away. In other words, when search is directed, *social interactions are very localized*. This is a well documented empirical fact (see e.g. Rosenthal and Strange, 2003; Rosenthal and Strange, 2008; Marmaros and Sacerdote, 2006; Argazi and Henderson, 2008; Bayer et al., 2008; Kim et al., 2017). Fig. 8 shows the equilibrium when the peripheral population is larger, $P_2/P_1 = 1.8$. It displays similar properties except that the peripheral population now experiences a higher employment rate: $E_2/P_2 = 0.878 > 0.798 = E_1/P_1$. Indeed, since the size of peripheral population is larger, individuals from this population mostly meet people residing in nearby locations but have a higher area of search than that of central population. As a result, they socially interact more with their peers, which leads to more search activity and compensates for their disadvantage in terms of location far away from jobs and from peers.

Fig. 9 includes network-size effects so that $\alpha(P) = 0.5P$. Most results are similar to that of Fig. 8 except that social interactions are very localized so that people mainly interact with workers residing at the same location. Interestingly, for the same parameter values, the employment ratio $(E_2/P_2)/(E_1/P_1)$ is much higher in Fig. 9 than in Fig. 8 (1.16 versus 1.10) due to the network-size effects, which gives a double advantage of having a larger population size (more social interactions $n(x, y)$ and higher network effects $\alpha(P)$).

7. Discussion and policy implications

7.1. Discussion

We have developed a model where the social and geographical spaces are key determinants of workers' labor-market outcomes. Indeed, a person's employability is a function of his or her referral network, and this network is both a function of the person's community and residence.

It is well documented that there are many potential determinants of the ethnic employment gap. In particular, *discrimination* (in the labor and housing markets) of minorities and *educational differences* have been put forward as the main reasons for explaining the ethnic employment gap between minorities and natives (Neal, 2006). The aim of our model is to shut down these two well-known explanations and to focus instead on a network and spatial segregation story. In the first equilibrium, the ethnic employment gap is due to the *spatial segregation* of minorities and their *low-quality social network*. In the second equilibrium, the main explanation of the ethnic employment gap is the *low size and poor quality* of the *social network* of ethnic minorities.

The first explanation based on the segregation of ethnic minorities is well-documented by the spatial mismatch and segregation literatures (Ihlanfeldt and Sjoquist, 1998; Gobillon et al., 2007; Fryer, 2010). Similarly, it is well-established that ethnic minorities tend to use extensively their social networks for finding jobs (Fernandez and

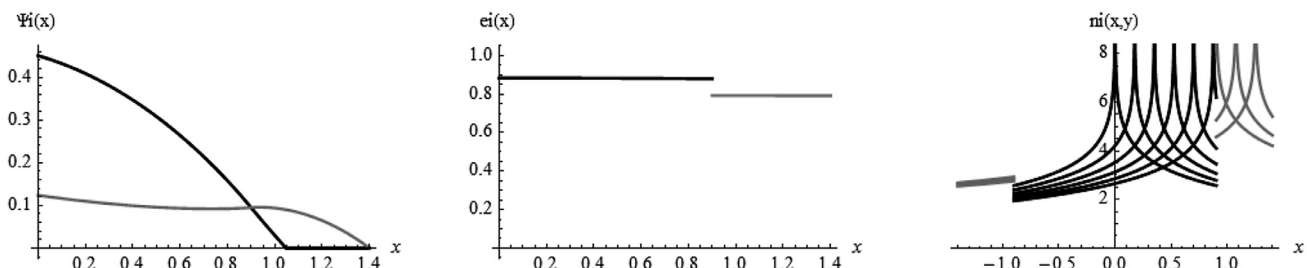
²⁶ See Online Appendix D.2 where we show some of these results.

Table 1
Aggregate employment rates (percent) E_1/P_1 and E_2/P_2 .

		P_2							
		6	8	12	16	20	24	28	32
P_1	6	(76, 58)	(76, 71)	--	--	--	--	--	--
	12	(80, 38)	(80, 63)	(80, 67)	(80, 69)	(80, 70)	--	--	--
	18	--	(80, 54)	(80, 61)	(80, 64)	(80, 65)	(80, 65)	(80, 64)	--
	24	--	--	(78, 53)	(78, 57)	(78, 59)	(78, 60)	(78, 59)	(78, 59)
	30	--	--	--	(76, 48)	(76, 51)	(76, 53)	(76, 53)	(76, 53)
	36	--	--	--	--	--	--	--	(74, 42)

A “--” indicates that there is no solution for the labor market conditions. A “--” indicates no land market equilibrium. Parameters: $(\alpha, \beta, t, \tau, w, \alpha(P)) = (0.1, 0.1, 0.1, 0.05, 20, 0.1)$.

Directed Search Equilibrium with Two Populations : bid rent, employment, number of interactions

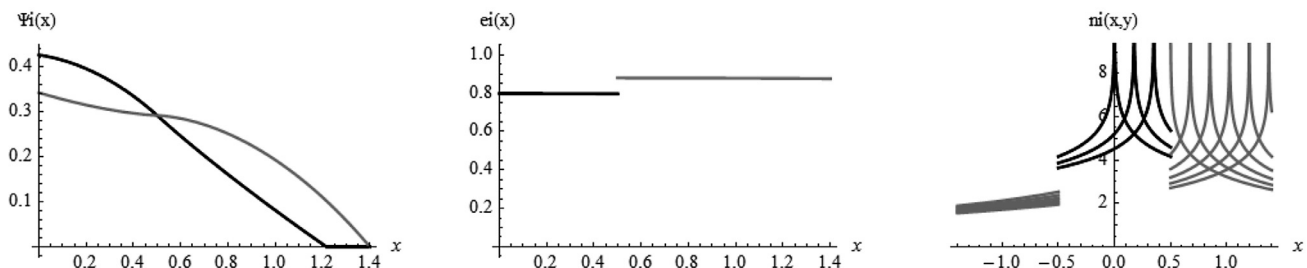


$E1/P1=0.883$, $E2/P2=0.792$, $u1=15.218$, $u2=7.416$.

Parameters: $P1=1.8$, $P2=1.$, $w=10$, $\beta=0.1$, $t=0.1$, $\tau=0.1$, $\alpha(P)=0.5 \cdot P^0$

Fig. 7. Directed search with no network-size effects and employment higher close to the CBD.

Directed Search Equilibrium with Two Populations : bid rent, employment, number of interactions



$E1/P1=0.798$, $E2/P2=0.878$, $u1=7.439$, $u2=15.055$.

Parameters: $P1=1$, $P2=1.8$, $w=10$, $\beta=0.1$, $t=0.1$, $\tau=0.1$, $\alpha(P)=0.5 \cdot P^0$

Fig. 8. Directed search with no network-size effects and employment higher in the periphery.

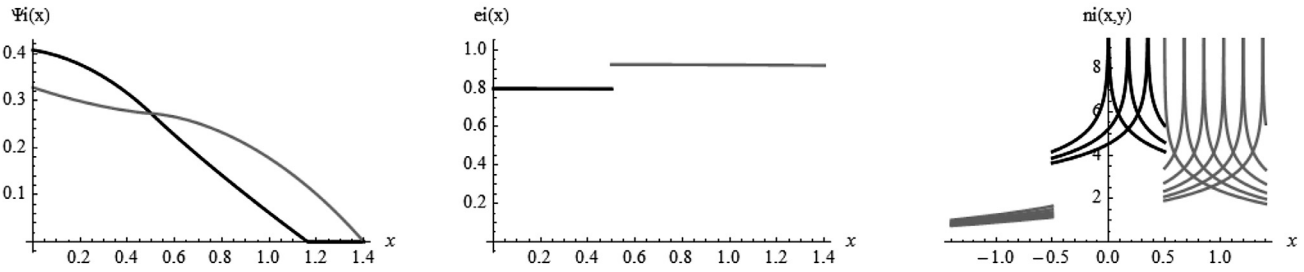
Fernandez-Mateo, 2006; Battu et al., 2011; Hellerstein et al., 2014; Dustmann et al., 2016) and that minorities are more likely to obtain their job through networks than non-minorities (Green et al., 1995; Elliott, 2000).

What about the size and quality of ethnic minorities' social networks. For the size, our model just states that the population of minorities in the city has to be smaller than that of the majority group. Apart from very few American cities, most cities in the United States and in Europe have a smaller population size of ethnic minorities. If the population is smaller, then this implies that the size of the social network is lower. This is because we are mainly considering weak-tie relationships and assume that ethnic minorities mostly socially interact with people from the same ethnic group, which is a well-documented fact

(see e.g. Elliott, 2001; Fernandez and Fernandez-Mateo, 2006; Dustmann et al., 2016).

The key question is thus about the quality of the social networks of ethnic minorities. Is it true that their social network has a lower quality than that of the majority group? A simple way of measuring quality is to examine how effective are minorities in finding a job through their social networks. Research has shown that informal job networks are less effective in finding jobs for ethnic minorities than other methods (e.g. Battu et al., 2011), are detrimental for the earnings of minorities (e.g. Falcon, 1995; Korenman and Turner, 1996; Green et al., 1999) and ethnic minorities (especially in the US) are excluded from white networks (e.g., Royster, 2003). Thus, the imagery that emerges from these studies is that minorities are stuck in the “wrong networks,” that is,

Directed Search Equilibrium with Two Populations : bid rent, employment, number of interactions



$$E1/P1=0.798, E2/P2=0.923, u1=7.459, u2=16.027.$$

$$\text{Parameters: } P1=1, P2=1.8, w=10, \beta=0.1, \tau=0.1, \tau=0.1, \alpha(P)=0.5 \cdot P^1$$

Fig. 9. Directed search with network-size effects.

those that are less likely to lead to a job or to low-wage jobs. Clearly, this is not causal evidence but this just illustrates the difference in network quality between different groups.

We would now like to discuss the policy implications of our results.

7.2. Policy implications

It should be clear that our equilibria are not socially optimal because of the different externalities generated by search, spatial and social frictions. As a result, there is room for a policy discussion. Using the results of our model, we can thus draw some policy implications that may improve the integration of minority workers in the city and help them find a job.

We have shown in our model that distance to jobs is crucial in understanding labor-market outcomes of ethnic minorities. If *geographical segregation and spatial mismatch* are the main culprit for the adverse labor-market outcomes of minority workers, then, following Boustant (2012), we can divide policy solutions to segregation into three categories: *place-based policies*, *people-based policies*, and *indirect approaches* to the problems of segregation.

Place-based policies either improve minority (poor) neighborhoods, rendering them more attractive to white and firm entrants, or require white (rich) suburbs to add housing options affordable to lower-income homeowners or renters.²⁷ Examples of such policies are the *neighborhood regeneration policies*. These policies have been implemented in the US and in Europe through the *enterprise zone programs* (see e.g. Bondonio and Greenbaum, 2007; Givord et al., 2013; Briant et al., 2015) and the *empowerment zone programs* (Busso et al., 2013). In the

context of our model, by bringing firms closer to workers, these programs will help workers have better job information and, thus, will be more likely to find a job. These policies will thus eventually raise the community's employment rate and the quality of its social network.

People-based policies assist homeowners or renters directly, through stronger enforcement of fair housing laws, offers of housing vouchers, or improved access to mortgage finance (such as the Community Reinvestment Act of 1977). Examples of such policies are the Moving to Opportunity (MTO) programs (Katz et al., 2001; Rosenbaum and Harris, 2001; Kling et al., 2005), which give housing assistance to low-income families to help them relocate to better and richer neighborhoods. In the context of our model, the MTO programs may help minority workers move closer to the workplaces, which will reduce their commuting time and will give the workers more incentives to apply and find a job. Such new hires raise the community employment rate and generate more job information within the community (higher quality social network).

Finally, *indirect approaches* target the symptoms of residential segregation, rather than the root causes—for example, by improving public transportation to reduce the isolation of black neighborhoods (see e.g. Sanchez, 1999; Blumemberg and Manville, 2004). In the context of our model, better access to jobs via an improved public transportation system raises incentives to work and find a job. If more minority community members get to work, the quality of their social network improves and helps those unemployed workers to find a job. Such programs, however, are not likely to change the spatial equilibrium and will keep minority far away from jobs.

Appendix. Proofs

Proof of Proposition 1. We can proceed as in the proof of Proposition A2 in the Online Appendix A. Since $\Phi(E_i)$ is still defined by (A.11), with subscript i on the E s and the P s, then there is a unique equilibrium for which $1/3 < E_1^*/P_1 < 1$ and $1/3 < E_2^*/P_2 < 1$ if

$$\max\{\Gamma_1(P_1), \Gamma_2(P_1, P_2)\} < 0.384$$

holds, which is (26). The first constraint, $\Gamma_1(P_1) < 0.384$, puts the same bound as for the homogenous-population case. If network effects are not too important, $\Gamma_1(P_1)$ is an increasing function and the above condition sets an upper bound on population 1, $\bar{P}_1 \equiv \Gamma_1^{-1}(0.384)$ where Γ_1^{-1} is the inverse of the function $\Gamma_1(P_1)$. Otherwise, it defines an interval, of the form $[\bar{P}_a, \bar{P}_b]$ with $\bar{P}_a < \bar{P}_b \leq w/t$.

The second constraint, $\Gamma_2(P_1, P_2) < 0.384$, puts another bound for population 2. If network effects are not too important, $\Gamma_2(P_1, P_2)$ is an increasing function of P_2 so that the above condition sets an upper bound $\bar{P}_2(P_1) \equiv \Gamma_2^{-1}(P_1, 0.384)$ where Γ_2^{-1} is the inverse of the function $\Gamma_2(P_1, P_2)$ w.r.t the second argument. The upper bound $\bar{P}_2(P_1)$ falls with P_1 , from $\bar{P}_1$ at $P_1 = 0$ to zero at some threshold population $\underline{P}_1$. One can check that $\bar{P}_2(0) = \bar{P}_1$ where $\underline{P}_1$ is such that $\Gamma_2(\underline{P}_1, 0) = 0.384$. It can be checked that $\underline{P}_1 < \bar{P}_1$. Therefore, condition (26) holds if $P_1 < \bar{P}_1$ and $P_2 < \bar{P}_2(P_1)$. Otherwise, if $\Gamma_2(P_1, P_2)$ is a decreasing function of P_2 , the condition sets lower bound.

²⁷ For recent overviews on place-based policies, see Kline and Moretti (2014) and Neumark and Simpson (2015).

We also need to check that there are no corner solutions. The conditions are given by (23), which are:

$$\frac{c_1(P_1/2)}{w - tP_1/2} < \frac{\alpha_1 E_1}{\beta P_1}$$

and

$$\frac{c_2((P_1 + P_2)/2)}{w - t(P_1 + P_2)/2} < \frac{\alpha_2 E_2}{\beta P_2}$$

Since the equilibrium employment level rises with higher wage w , the RHS of each condition rises with w while the LHS falls with it. The conditions are then satisfied for sufficiently high w . $\square$

Proof of Proposition 3. Suppose the existence of network size effects: $\alpha_i = \alpha(P_i)$ with $\alpha'(P_i) > 0$. We prove that there exists a population size P_1 such that $E_1/P_1 > E_2/P_2$ under the conditions that $\alpha(0) = 0$ and $P\alpha'(0)/\alpha(P) < 0.2177$.

We first characterize the RHS of (27). Let us first define the function

$$\Phi(a, b) = \int_0^1 \sqrt{\frac{1 + az^2}{1 - bz}} dz$$

This integral has no explicit expression. It can nevertheless numerically be shown for all arguments that $\Phi(a, b) > 0$ while $\Phi(a, b)$ is concave increasing in a and convex increasing in b . Also, we have $\Phi(0, 0) = 1$, $\Phi(0, 1) = 2$, $\Phi(1, 1) = 2.459$ and $\Phi(1, 0) = 1.14779$, while $\Phi(a, 0) > 1$.

Lemma 1. We have:

$$\frac{1}{P_1} \int_0^{P_1/2} \sqrt{\frac{c_1(x)}{w - t|x|}} dx = \sqrt{\frac{\tau P_1}{16w}} \Phi\left(1, \frac{tP_1}{2w}\right)$$

and

$$\frac{1}{P_2} \int_{P_1/2}^{(P_1+P_2)/2} \sqrt{\frac{c_2(x)}{w - t|x|}} dx = \frac{1}{2} \sqrt{\frac{\tau(2P_1 + P_2)}{4(w - tP_1/2)}} \Phi\left(\frac{P_2}{2P_1 + P_2}, \frac{tP_2}{2w - tP_1}\right)$$

Proof. We compute

$$\begin{aligned} \frac{1}{P_1} \int_0^{P_1/2} \sqrt{\frac{c_1(x)}{w - t|x|}} dx &= \frac{1}{2b_1} \sqrt{\frac{\tau}{2b_1}} \int_0^{b_1} \sqrt{\frac{b_1^2 + x^2}{w - tx}} dx \\ &= \sqrt{\frac{\tau b_1}{8w}} \int_0^1 \sqrt{\frac{1 + z^2}{1 - \frac{tb_1}{w}z}} dz \\ &= \sqrt{\frac{\tau b_1}{8w}} \Phi\left(1, \frac{tb_1}{w}\right) \\ &= \sqrt{\frac{\tau P_1}{16w}} \Phi\left(1, \frac{tP_1}{2w}\right) \end{aligned}$$

and

$$\begin{aligned} \frac{1}{P_2} \int_{P_1/2}^{(P_1+P_2)/2} \sqrt{\frac{c_2(x)}{w - t|x|}} dx &= \frac{1}{P_2} \sqrt{\frac{\tau}{2(b_2 - b_1)}} \int_{b_1}^{b_2} \sqrt{\frac{(b_2^2 - 2b_1x + x^2)}{w - tx}} dx \\ &= \frac{1}{P_2} \sqrt{\frac{\tau}{2(b_2 - b_1)}} \int_0^{b_2-b_1} \sqrt{\frac{(b_2^2 - 2b_1(z + b_1) + (z + b_1)^2)}{w - t(z + b_1)}} dz \\ &= \frac{1}{P_2} \sqrt{\frac{\tau}{2}} (b_2 - b_1) \int_0^1 \sqrt{\frac{b_2^2 - 2b_1((b_2 - b_1)y + b_1) + ((b_2 - b_1)y + b_1)^2}{w - t((b_2 - b_1)y + b_1)}} dy \\ &= \frac{1}{P_2} \sqrt{\frac{\tau}{2}} (b_2 - b_1) \int_0^1 \sqrt{\frac{(b_1 + b_2 + y^2(b_2 - b_1))}{w - tb_1 - t(b_2 - b_1)y}} dy \\ &= \frac{1}{P_2} \sqrt{\frac{\tau(b_1 + b_2)}{2(w - tb_1)}} (b_2 - b_1) \int_0^1 \sqrt{\frac{1 + \frac{b_2 - b_1}{b_1 + b_2}z^2}{1 - t\frac{b_2 - b_1}{w - tb_1}z}} dz \\ &= \frac{1}{P_2} \sqrt{\frac{\tau(b_1 + b_2)}{2(w - tb_1)}} (b_2 - b_1) \Phi\left(\frac{b_2 - b_1}{b_1 + b_2}, t\frac{b_2 - b_1}{w - tb_1}\right) \\ &= \frac{1}{2} \sqrt{\frac{\tau(2P_1 + P_2)}{4(w - tP_1/2)}} \Phi\left(\frac{P_2}{2P_1 + P_2}, \frac{tP_2}{2w - tP_1}\right) \end{aligned}$$

This proves Lemma 1. $\square$

With this lemma, we can write the RHS of (27) as

$$G(P_1, P_2) = \frac{\frac{1}{P_1} \int_0^{P_1/2} \sqrt{\frac{c_1(x)}{w-t|x|}} dx}{\frac{1}{P_2} \int_0^{(P_1+P_2)/2} \sqrt{\frac{c_2(x)}{w-t|x|}} dx} = \sqrt{\frac{(2w-tP_1)P_1}{32w(2P_1+P_2)}} \frac{\Phi\left(1, \frac{tP_1}{2w}\right)}{\Phi\left(\frac{P_2}{2P_1+P_2}, \frac{tP_2}{2w-tP_1}\right)}$$

Denoting $P = P_1 + P_2$, we readily get

$$G(P, 0) = 0$$

$$G(P, 0) = \frac{1}{4} \sqrt{\frac{w-tP/2}{2w}} \frac{\Phi\left(1, \frac{tP}{2w}\right)}{\Phi(0, 0)} \in (0, 0.4331)$$

The graph of $G(P, 0)$ lies in the interval $(0, 0.4331)$ because $\Phi(0, 0) = 1$, $\Phi(1, 1) = 2.459$, $tP/2 < w$ and $\Phi(a, b)$ is an increasing function of b . So, $G(P, 0)$ is bounded by 0.4331. Also, denoting $P_1 = \lambda P$ and $P_2 = (1 - \lambda)P$, we write

$$G(\lambda P, (1 - \lambda)P) = \sqrt{\lambda} \sqrt{\frac{(2w - t\lambda P)}{32w(\lambda + 1)}} \frac{\Phi\left(1, \lambda \frac{tP}{2w}\right)}{\Phi\left(\frac{1-\lambda}{\lambda+1}, \frac{(1-\lambda)tP}{2w-t\lambda P}\right)}$$

For small enough λ , this function tends to

$$G(\lambda P, (1 - \lambda)P) \simeq \sqrt{\lambda} A\left(\frac{tP}{2w}\right)$$

where

$$A(b) \equiv \sqrt{\frac{1}{32} \frac{\Phi(1, 0)}{\Phi\left(1, \frac{tP}{2w}\right)}}$$

is a decreasing concave function of b taking values in the interval $(0.4666, 1)$.

We then characterize the LHS of (27). Let us set

$$H(\lambda) = \sqrt{\frac{\alpha(P_1)}{\alpha(P_2)}} = \sqrt{\frac{\alpha(\lambda P)}{\alpha((1 - \lambda)P)}}$$

and let assume that $\alpha(0) = 0$. So, $H(0) = 0$ and $H(1) = +\infty$.

Finally, the population $P_1 = \lambda P$ has higher aggregate employment if and only if

$$H(\lambda) \leq G(\lambda P, (1 - \lambda)P)$$

Observe that $H(0) = G(0, P) = 0$ and $H(1) > G(P, 0)$. So, a sufficient condition for this inequality to hold is that, for sufficiently small λ ,

$$\frac{\alpha(\lambda P)}{\alpha((1 - \lambda)P)} < \lambda \left(A\left(\frac{tP}{2w}\right) \right)^2 \quad (36)$$

which holds if

$$\frac{d}{d\lambda} \left(\frac{\alpha(\lambda P)}{\alpha((1 - \lambda)P)} \right) < \left(A\left(\frac{tP}{2w}\right) \right)^2$$

Applied at $\lambda = 0$, this yields

$$\frac{P\alpha'(0)}{\alpha(P)} < \left(A\left(\frac{tP}{2w}\right) \right)^2$$

Since $A\left(\frac{tP}{2w}\right) > 0.4666$, a sufficient condition is that

$$\frac{P\alpha'(0)}{\alpha(P)} < 0.2177 \quad (37)$$

This proves Proposition 3. $\square$

Example. Suppose assume $\alpha(P) = \alpha_0 P^\theta$ so that $\alpha'(P) = \alpha_0 \theta P^{\theta-1}$. Then condition (37) is true for all $\theta > 1$. If $\theta \leq 1$, we can use condition (36) so that

$$\frac{\lambda^{\theta-1}}{(1 - \lambda)^\theta} < \left(A\left(\frac{tP}{2w}\right) \right)^2 \quad (38)$$

However, this is never satisfied for $A\left(\frac{tP}{2w}\right) \in [0.4666, 1]$. The following table gives the minimal and maximal ranges for which the central population has a larger aggregate employment rate for various network effect parameters θ . In this table, the range is the open intervals $(0, \lambda) = (0, P_1/P)$ where λ solves the binding condition (38) evaluated at $A\left(\frac{tP}{2w}\right) = 0.4666$ and $A\left(\frac{tP}{2w}\right) = 1$.

θ	$(0, \min P_1/P)$	$(0, \max P_1/P)$
1.	(0.00, 0.00)	(0.00,0.00)
1.4	(0.00, 0.10)	(0.00,0.29)
1.8	(0.00, 0.22)	(0.00,0.36)
2.2	(0.00, 0.29)	(0.00,0.40)
2.6	(0.00, 0.33)	(0.00,0.42)
3.	(0.00, 0.35)	(0.00,0.43)
...	...	...
∞	(0.00, 0.50)	(0.00, 0.50)

Minimal and maximal ranges for which the central population has larger aggregate employment rate.
Network size effect: $\alpha(P) = \alpha_0 P^\theta$.

Proof of Proposition 4. Consider the *segregated city* equilibrium where population 1 resides in the centered interval $[-b_1, b_1]$ and population 2 in the periphery intervals $[-b_2, -b_1) \cup (b_1, b_2]$ as defined in Definition 1. Let us show under which condition the two populations do not interact with each other.

Because of the symmetry, we can restrict our attention to $x > 0$. Population 1 does not interact with population 2 if

$$\frac{c_1(x)}{\alpha_1 E_1/P_1} < \frac{c_2(x)}{\gamma \alpha_2 E_2/P_2} \Leftrightarrow \frac{c_2(x)}{c_1(x)} > \frac{\gamma \alpha_2 E_2/P_2}{\alpha_1 E_1/P_1}, \forall x \in [0, b_1]$$

Population 2 does not interact with population 1 if

$$\frac{c_2(x)}{\alpha_2 E_2/P_2} < \frac{c_1(x)}{\gamma \alpha_1 E_1/P_1} \Leftrightarrow \frac{c_2(x)}{c_1(x)} < \frac{\alpha_2 E_2/P_2}{\gamma \alpha_1 E_1/P_1}, \forall x \in (b_1, b_2]$$

These conditions imply

$$\min_{x \in [0, b_1]} \frac{c_2(x)}{c_1(x)} > \frac{\gamma \alpha_2 E_2/P_2}{\alpha_1 E_1/P_1} \quad \text{and} \quad \max_{x \in (b_1, b_2]} \frac{c_2(x)}{c_1(x)} < \frac{\alpha_2 E_2/P_2}{\gamma \alpha_1 E_1/P_1}$$

Given that $c_2(x)/c_1(x)$ is monotonically decreasing in x , for all $x > 0$, we compute

$$\min_{x \in [0, b_1]} \frac{c_2(x)}{c_1(x)} = \max_{x \in (b_1, b_2]} \frac{c_2(x)}{c_1(x)} = \frac{c_2(b_1)}{c_1(b_1)} = \frac{2P_1 + P_2}{2P_1}$$

This yields the conditions

$$\frac{2P_1 + P_2}{2\gamma P_1} > \frac{\alpha_2 E_2/P_2}{\alpha_1 E_1/P_1} > \gamma \frac{2P_1 + P_2}{2P_1}$$

which are reported in (30). $\square$

Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jue.2018.01.004.

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