Agent-Based Simulation Model for Social and Workplace Segregation

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Abstract. The relationship between social segregation and workplace segregation had been traditionally studied as a one-way causal relationship mediated by referral hiring. In this paper we introduce an alternative framework which describes the dynamic relationships between social segregation, workplace segregation, individuals' homophily levels, and referral hiring. An agent-based simulation model was developed based on this framework. The model describes the process of continuous change in composition of workplaces and social networks of agents, and how this process affects levels of workplace segregation and segregation of social networks of the agents (people). The results of the simulation model include: (1) social segregation and workplace segregation may co-evolve even when hiring of workers occurs mainly through formal channels and population is initially integrated (2) majority groups tend to be more homophilous than minority groups, and (3) referral hiring may be beneficial for minority groups when the population is highly segregated.

Keywords: social networks, segregation, referral hiring, agent-based simulation.

1 Introduction

According to the contact hypothesis [1], more contact between different social (ethnic, racial and/or religious) groups would promote tolerance and social integration. When social networks of people become segregated and homophilous the chance of their contacts to cross their groups' boundaries is reduced. Similarly, workplace segregation may also reduce the chance of inter-group contact. In addition to these negative social effects, workplace segregation may have negative economic consequences. For example it may introduce high levels of income and employment inequality between different groups in the society ([4], [8], [10], [18]). Besides, workplace segregation may affect the whole economic system through its effects on the efficiency allocating workers to jobs [2].

Referral hiring (hiring through the use of social or familial contacts), has been considered the main source of workplace segregation. Granovetter ([9], [10]) found that more than half of workers in the U.S. knew about their jobs through informal methods (friends, relatives, and other social contacts). In a recent study conducted by

the authors about workplace and social segregation in Egypt[1], 65 percent of workers and 54 percent of employers depend on these informal methods of employment. Besides, the homophily hypothesis implies that people are more likely to create social ties with similar others, or "birds of a feather flock together" [14]. This similarity among network actors may be evaluated, among other factors, on the basis of race, religion and ethnicity. Thus when using social networks to search for jobs, it is more probably that people will have job information from others of the same ethnicity, race and/or religion as their own, and this may promote workplace segregation.

According to the pervious analysis, researchers have studied the relationship between social segregation (segregation in the social networks of different ethnic, racial and/or religious groups) and workplace segregation as a one-way causal relationship. In this relationship, the independent variable, traditionally, was the level of social segregation and the dependent variable was the level of workplace segregation, with the level of referral hiring as moderating variable (see for example [5], [17] and [18]).

However, empirical literature (for example [11]) confirms that high percentage of our social relations comes from organizations (like workplaces). So, these organizations contribute to the construction of the pool of candidates whom people might create social relations with. Thus, when this pool becomes segregated this would promote social segregation and vice versa. This argument implies that workplace segregation can affect (as well as be affected by) social segregation.

In this paper we introduce a general framework to study the dynamic relationships between social segregation, workplace segregation, homophily levels, and referral hiring where each variable may affect the others. To test the validity of this framework, an agent-based simulation model for the labour market was developed. The model creates an artificial society where agents (people) use their social networks to search for jobs. As simulation time passes, agents change their social networks by creating new social links (ties) with each other while some other links dissolve. Also, the composition of workplaces (the proportion of workers from different societal groups) may change through the processes of firing and hiring of workers. The presented model describes this process of continuous changes in composition of workplaces and social networks of agents, and how this process affects levels of workplace segregation and segregation of the social networks of agents.

After this introduction, we introduce the proposed framework for the relationship between social segregation and workplace segregation in section 2. Then in section 3 the agent-based simulation model is presented. The results of the simulation model are discussed in section 4, and finally section 5 presents the conclusion.

2 General Framework for the Relationship between Social Segregation and Workplace Segregation

As summarized in Fig. 1, social segregation may affect workplace segregation (each arrow in Fig. 1 indicates positive causal relationships between the variables at its two

[1] Egypt can be divided, according to religion, to a majority Muslim population and a minority Coptic Christians (about 10 percent of total population).

sides). When firms tend to hire new workers through referrals, especially referrals from other existing worker (insider referrals), and when social networks of people tend to be segregated, this would promote workplaces segregation. On the other hand when workplaces become segregated this would reduce the chance for people from different social groups to meet and create social relations at work, and this would increase social segregation.

Individual's homophily[2] level works as biasness towards creating social ties with similar others. So, higher levels of homophily would coincide with higher level of social segregation. On the other hand, when social networks of people become less segregated this means that they have higher chance to have contacts with others of different groups, and this would hinder their homophilous attitudes.

The relationship between homophily levels and workplace segregation can be described as follows. Individuals' homophily level may affect workplace segregation through its effects on exit patterns of workers and hiring discrimination. As empirical studies show (for example [16]), workers with high levels of homophily tend to stay longer in segregated workplaces where their groups are over-represented than other workplaces. Also, higher homophily levels among employers would promote hiring discrimination (employers' preferences to hire workers of the same social group as their own [2]), and this would increase workplace segregation. In return, workplace segregation may affect homophily levels of individuals. Segregated workplaces reduce the chance for inter-group contact to happen, which promotes homophilous attitudes and vice versa.

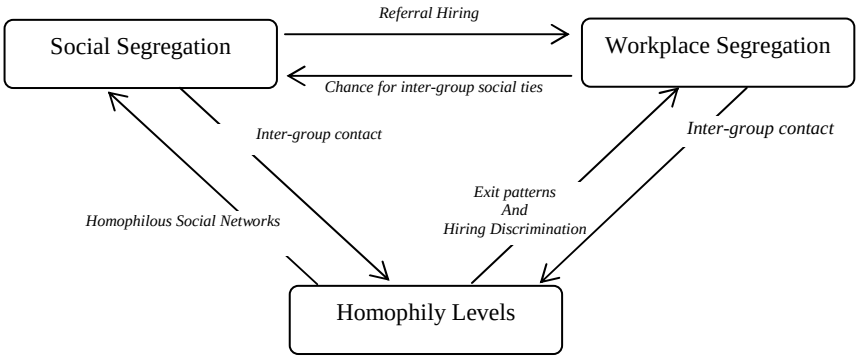

Fig. 1. The proposed framework to study the relationship between social segregation and workplace segregation.

3 Agent-Based Simulation Model

Based on the proposed framework presented in the previous section, we present an agent-based model which describes the dynamic relationship between the main variables: social segregation, workplace segregation, homophily levels, and referral

[2] "Homophily is the principle that a contact between similar people occurs at a higher rate than among dissimilar people" ([14], p. 416).

hiring. First, we describe the model's specification then we discuss some of the simulation results.

3.1 Agents

The model creates an artificial society of N equally-qualified agents (persons). Each agent can belong to one of two different social groups: A or B (simply we call them Red and Green). Assume that A (Red) is the minority group, and its proportion in the society is P (where $0<P<0.5$).

3.2 Social Networks

Social Network is a "...set of people who are most likely to be sources of a variety of rewarding interactions, such as discussing a personal problem, borrowing money, or social recreation" ([13], p. 78). Each agent has it own ego-centric social network. For each agent, the maximum possible size of its social network (maximum number of alters at one time) is S_i, $i=1, 2,\ldots, N$.

Homophily Levels. Agents create social links with each other based on their *homophily levels*, $h_i \in [0,1]$. Agent's homophily level indicates its biasness to create social links with other agents of the same colour (group) as its own. For example, a Red agent would create a social link to another Red agent with the following probability[3]:

$$\text{Prob (Red to Red)} = \begin{cases} p + h(1-p) & \text{if } p > 0 \\ 0 & \text{Otherwise} \end{cases} \quad (1)$$

, and it creates a link to a Green agent with the complement probability. In formula (1), (small) p refers to the proportion of Red agents available *within the context of link creation*. For example, when a Red agent joins a workplace, and it is about to create a social link to one of the existing co-workers, p would refer to the proportion of other Red workers (who are not already in link with the agent) in that workplace.

Based on formula (1), with $h=0$, all links are created at random, and all agents will have the same probability p to create links with Red agents and the probability $1-p$ to create links with Green agents. With $h=1$, each agent would create links only with other similar agents (if such agents are available otherwise with other agents of different colour).

Agents are initialized with a zero homophily level. However, agent's homophily level changes over time, and it is assumed to depend – in addition to its current level - on five factors: (1) composition of its social network, (2) average homophily level of alters in its social network, (3) composition of its workplace, (4) average homophily

[3] Analogously, $\text{Prob (Green to Green)} = \begin{cases} (1-p) + hp & \text{if } p < 1 \\ 0 & \text{otherwise} \end{cases}$

level of its workmates, and (5) overall average homophily of all agents in society. Thus, for a Red agent, its homophily level at time $t+1$, h_{t+1}, can be written as a weighted average of its homophily level h_t and the effects of these five factors as:

$$h_{t+1} = [h_t + \alpha_1(p_n - P)/(1-P) + \alpha_2(\textit{mean homophily of alters}) + \alpha_3(p_w - P)/(1-P) + \alpha_4(\textit{mean homophily of workmates}) + \alpha_5(\textit{overall mean homophily of all agents})] / (1 + \alpha_1 + \alpha_2 + \alpha_3 + \alpha_4 + \alpha_5) \quad (2)$$

Where h_t is agent's homophily level at time t, p_n is the proportion of alters of Red colour in agent's social network, p_w proportion of Red workmates, and α_1, α_2, α_3, α_4 and α_5 are constants.

Directed vs. Undirected Links. In forming their social networks agents create directed (asymmetric), rather than undirected (symmetric), social links with each other. The reason behind this assumption is the potential asymmetry in the evaluation of social links, and the asymmetry in job knowledge and access [17].

Origins of Social Relations. In line with Fischer [6], agents create social links through three sources: workplaces, other friends/relatives (other links) and random acquaintances. At each time step of a simulation run, each "working" agent has a probability L_W to create a social link to one of his co-workers. Also, at each time step, each agent has a probability L_N to create a new link with another agent through its existing social network (in other words, with another agent who is already linked with one of agent's social network). Finally, at each time step, each agent has a probability L_R to create a new link with another random agent. Finally, to keep the initial distribution of links constant among agents, all extra links (more than S_i) will be removed at random.

3.3 Workplaces and Jobs

Our artificial labour market includes a number of firms, F, each has a number of jobs (θ_f). We assume that all the jobs are identical (so, any agent can do any job with the same efficiency). Each firm has a "colour" which indicates the group identity of its owner/manager (employer). Suppose that proportion of Red firms is P. Hiring discrimination for a firm f, D_f, is defined as the mean homophily level of its workers multiplied by a regulating scalar *discrimination-const*. Besides, each firm, f, has a total of t_f agents (workers), which can be divided into r_f Red agents and g_f Green agents, such that $t_f = r_f + g_f$, and let $p_f = r_f / t_f$ be the proportion of the minority (Red) group inside this firm. Finally, let $T = \sum_f t_f$ denote total number of currently working agents.

Hiring Process. At each time step each firm hires a number of agents (workers) to fill its vacant jobs. Firms can hire new agents either through referrals from current

workers (with probability *R*) or through formal channels (with probability 1-*R*). If a firm decided to hire a worker through formal methods it would simply pick one of the unemployed workers at random. In case of hiring through referrals from current workers, firms may practice hiring discrimination against the candidate workers. Let *G* represents the group of candidate workers, i.e., unemployed workers who have social links with at least one of the current workers in the firm (If no such workers exist, firms hire through formal channels). For example, a Red firm would hire a Red agent through referral with the probability:

$$\text{Prob (Red firm to hire Red worker through referral)} = \begin{cases} p + D_f(1-p) & \text{if } p > 0 \\ 0 & \text{Otherwise} \end{cases} \quad (3)$$

, and it hires a Green agent with the complement probability, where *p* refers to the proportion of Red agents in the group *G*.

Firing Process. At each time step of the simulation run, each working agent will be fired from (or will exit) its workplace with some probability. This probability depends on agent's homophily level, *h*, and how far the proportion of its group inside the workplace, *p*, is from the overall group proportion in the society, *P*. The probability of a Red agent to be fired from its workplace at any time step is given by:

$$E_R = \beta(1 + h\,(P - p)) \quad (4)$$

Where β is a constant regulating the speed of workers' turnover. For an agent with zero-homophily, its probability to be fired would be constant and equals β regardless of the proportion, *p*, of its group in the workplace (which is intuitive). On the other hand, an agent with a non-zero homophily, *h*, would have an increasing probability to be fired as its group's proportion *p* decreases, and vice versa.

3.4 Statistics and Indexes

We are particularly interested in measuring levels of social segregation and workplace segregation in addition to employment levels for minority and majority groups.

Index of Social Segregation. The segregation index, *S*, developed by Freeman [7][4] is used to measure level of social segregation. *S* measures the deviation of the distribution of links between two agents from different groups from the distribution expected when links are created at random, and it is given by ([7], p. 416):

$$S = \begin{cases} \dfrac{E(e^*) - e^*}{E(e^*)} & \textit{If and only if } E(e^*) \geq e^* \\ 0 & \textit{Otherwise} \end{cases} \quad (5)$$

[4] Although Freeman developed this index to measure segregation in social networks with undirected links, it can be shown that it is still valid for our case of directed links as well.

Where *E(e*)* is the expected number of links between two agents from different groups under the assumption that links are created at random, and *e** is the actual number of such links.

E(e)* is given by (adapted from Freeman [7], p. 416):

$$E(e^*) = \frac{2NLP(1-P)}{N-1} \qquad (6)$$

Where *L* is the total number of links in the global social network, and *N* (number of agents) and *P* (proportion of Red agents) are as defined before.

Indexes of Workplace Segregation. A modified version of the Gini index, $\hat{G}$, developed by Carrington and Troske [3] will be used to measure workplace segregation. $\hat{G}$ measures the deviation of the segregation curve from the case of randomness (which represents the case in which workers are randomly allocated to firms) and is given by Carrington and Troske ([3], p. 406):

$$\hat{G} = \begin{cases} \dfrac{G-G^*}{1-G^*} & if \quad G \geq G^* \\ \dfrac{G-G^*}{G^*} & if \quad G < G^* \end{cases} \qquad (7)$$

$$\text{Where } G = \sum_{i=1}^{F}\sum_{j=1}^{F} t_i t_j \left| p_i - p_j \right| / 2T^2 P(1-P) \qquad (8)$$

Where *G* is the calculated standard Gini index ([12], p. 5) and *G** is the calculated Gini index if the workers (with minority proportion *P*) were randomly distributed to the firms (with given sizes)[5].

The modified Gini index is more suitable, than the standard Gini index or other indexes which measure the deviation of the segregation curve from the evenness, for our model for two reasons. Firstly, we are interested in simulating a labour market with small-to-medium firms (which increases the possibility to get a high Gini index with a complete random allocation of workers). Secondly, we are particularly interested in measuring the *systematic* rather than *random* changes in workplace segregation.

3.5 Model Dynamics

The simulation starts with creating an artificial society of a number of agents from two different groups with a random social network for each agent. A number of firms

[5] G* can be calculated by simulating a random allocation of workers, with given *N* and *P*, to a number of firms *F*, with specified size distribution. The value of *G** used in subsequent sections is the average of value obtained through simulating the random allocation of workers to firms in 200 simulation runs.

F are created, each with a specified number of jobs θ_f, and then agents are assigned randomly to firms. The final step of the initialization process is to calculate and plot statistics for this initial stage, which include mainly indexes of segregation for workplaces and social network. Then at each time step:

1. Each agent will be fired with the proper probability (as described earlier)
2. Each firm will hire a number of agents, either randomly (through formal channels) or through referrals from current workers, depending on the probability R.
3. Agents update their homophily levels (according to equation (2)) and their social networks. Each agent creates a link through workplace (if agent is employed), through other links and/or randomly with the proper probabilities (L_W, L_N and/or L_R respectively).
4. Statistics are calculated and plotted.

4 Simulation Results

In the following we summarize the results of the simulation model[6] regarding workplace segregation, social segregation and unemployment levels of minority and majority groups. The results are based on the values of parameters shown in Table 1.

Table 1. Parameters values and description for the simulation model.

Parameter	Description	Value
General		
Sim-run	Number of simulation runs	30
Sim-time	Number of time steps for each simulation run	500
α_1, α_2, α_3, α_4 and α_5	constants regulating the change in homophily levels.	0.4
β	A constant regulating the probability of an agent to be fired.	0.1
Agents		
N	Total number of agents	1000
P	Proportion of the minority (Red) group	0.2
Social Networks		
S_i	Size of social networks of agents	10
L_w [7]	Probability of creating a new link with other co-workers	0.3
L_N	Probability of creating a new link through current links	0.4
L_R	Probability of creating a new link randomly	0.01
Workplaces		
F	Number of firms	40
θ_f	Number of jobs in each firm	20
discrimination-const	A regulating scalar for hiring discrimination	1

4.1 Referral Hiring, Workplace Segregation and Social Segregation

The results summarized in Fig. 2 show the co-evolution of workplace segregation and social segregation with different levels of referral hiring. Both workplace segregation

[6] The model is written in Netlogo 4.0 [19]

[7] The probabilities L_w, L_N, and L_R may not add to one because they are not mutually exclusive.

and social segregation increase with increasing level of referral hiring. An interesting result is that *significant levels of workplace segregation and social segregation may evolve even when hiring of workers occurs mainly through formal channels and the society is initially integrated*. The random allocation of workers to firms may introduce some level of workplace segregation which triggers an increasing (but still low) level of homophily and social segregation which, in turn, promotes workplace segregation (through the exit patterns of workers), and so on.

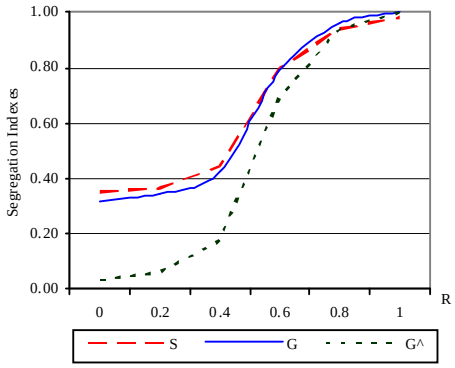

Fig. 2. Co-evolution of workplace segregation (G and $\hat{G}$) and social segregation (S) for different levels of referral hiring (R).

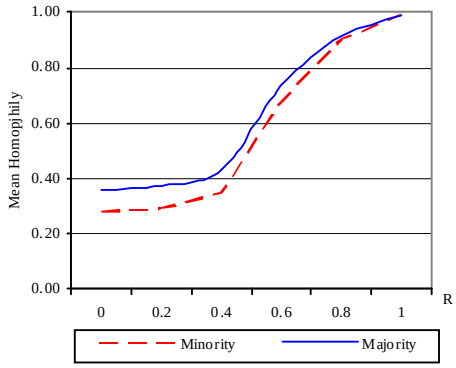

Fig. 3. Final mean homophily levels for minority and majority groups for different levels of referral hiring (R).

4.3 Homophily Levels

The results of the simulation show that even when we start with a zero-level of homophily, *agents of majority groups, generally, end with higher homophily levels than those of minority groups* (as shown in Fig. 3). The main reason behind that is minority people have higher chance to have outgroup links (through social networks or workplaces) than majority group members.

4.4 Employment Inequality

An interesting result of the simulation model is that It seems that, *increasing levels of referral hiring would be beneficial for minority groups when population is highly segregated and harmful otherwise*. Fig. 4 shows, minority unemployment generally decreases with increasing level of referral hiring until it reaches its minimum level (with R=0.8 in our experiment), then increases after that. When referral hiring is low (hence, lower levels of workplace and social segregation), all unemployed agents will have the same chance to join any workplace with vacant jobs, and will have the same probability to exit their workplaces, hence all social groups will have similar

unemployment levels (around 20% in our experiment). This is clearly illustrated in Fig. 5 with the case of *R=0*. But with higher levels of referral hiring (the cases *R=0.8* and *R=1*), minority unemployment tends to be higher than majority unemployment at the early stage of simulation run, which is characterized by (still) lower levels of workplace and social segregation. However, as time passes and segregation increases referral hiring benefits minority's employment. For example, when *R=0.8*, minority unemployment attains a stationary level of 0.16. When level of referral hiring is close to one, a complete segregation of workplaces (and social networks) is reached and the firms are distributed proportionally between minority and majority groups, hence all groups will have the same unemployment level (0.2).

This result regarding the relationship between referral hiring and minority employment is consistent with the result of Tassier and Menczer' model [18] where they show that:

"more random social networks [majority groups] *yield higher employment rates than less random social networks* [minority groups] *if the population is integrated* [in early stage of our simulation] *or information flows about job vacancies are random* [low level of referral hiring]. *However if the population is highly segregated and information flows about job vacancies are non-random* [with high level of referral hiring in later stages of simulation run] *then less random social networks have higher employment rates than more random social networks. This second finding holds because non-random social networks allow a group to better contain job information inside the group when a population is segregated."* ([18], p. 1)

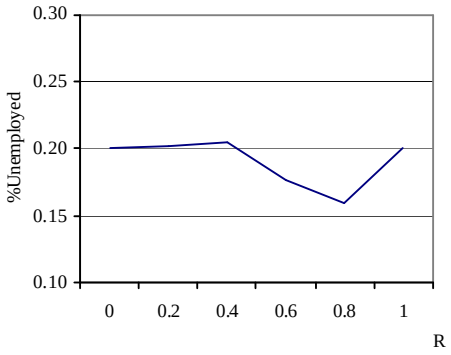

Fig. 4. Unemployment levels of minority group for different levels of referral hiring, *R*.

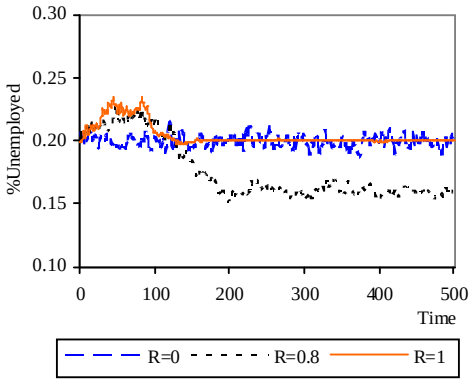

Fig. 5. Unemployment levels of minority group across time with *R=0, 0.8 and 1*.

5 Model Validation

The model's behaviour was checked against empirical data driven from the Egyptian labour market and social networks. Three sources of data was used to estimate model's parameters: Workers' Status in Industrial Enterprises Survey (WSIES),

Table 2. Estimated values for model's parameters based on data about social networks and workplaces in Egypt.

Parameter Name	Parameter Value	Source
Minority proportion (P):	0.06	SCS
Overall unemployment rate	0.13	SCS
Number of workers (N)	4800	WSIES
Number of firms (F)	165	WSIES
Total number of jobs	4176	WSIES
Number of jobs in each firm (θ_f)	Same distribution as WSIES	WSIES
Number of Coptic employers	14	WSIES
Number of Muslim employers	151	WSIES
discrimination-const	0.7	WSIES
Level of referral hiring	0.65	ED
L_W, L_N and L_R	0.3, 0.5, 0.01 (respectively)	ED
Maximum network size of agents (S_i)	Normal (8,3)	ED

Social Contract Survey (SCS), and Empirical Data (ED) gathered by the researchers. Table 2 presents the estimated values for model's parameters.

The results presented in Table 3 show that there a great level of similarities between the observed values of the variables and the simulated values. Most of the confidence intervals (CI's) of the difference between of the observed and simulated values contain the zero point, indicating that they are not statistically different.

Table 3. Comparing observed and simulated values of variables in the simulation model.

Variable Name	Observed Value	Simulation Value	Std. Error	95% CI of Difference
Social Segregation	0.802	0.796	0.004	(-0.013, 0.001)
Workplace Segregation - Gini	0.932	0.925	0.003	(-0.0136, 0.0002)
Muslims unemployment	0.133	0.1334	0.0002	(-0.0008, 0.0009)
Copts unemployment	0.079	0.074	0.003	(-0.011, 0.002)

6 Conclusion

In this paper we introduce a general framework which describes the dynamic relationships between social segregation, workplace segregation, homophily levels, and referral hiring. An agent-based simulation model was developed and the results of the model support the proposed framework. The results of the simulation model

indicated that labour market may experience significant levels of workplace segregation and social segregation even when hiring of workers occurs mainly through formal channels. The results also show that majority groups tend to be more homophilous than majority groups, and referral hiring may be beneficial for minority groups especially when the population is highly segregated, and the relationship between referral hiring and minority unemployment is not linear. Finally, the model is validated against empirical data from the Egyptian labour market and social networks, and there was a great similarity between the observed and simulated results.

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