Strategic communication: theory and experiment

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Chapter 4

Job market signaling and discrimination

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4.1 Introduction

World-wide, race and gender are ongoing factors determining whether a person gets a job or not, and whether a person receives a fair wage or not. In the U.S. labor market, unequal treatment of racial groups continues almost 50 years after the Civil Rights Act was introduced in 1964. For instance, compared to whites, African-Americans are twice as likely unemployed (Council of Economic Advisers, 1998). Racial inequality is a persistent phenomenon in other countries as well. Dutch workers from Moroccan descent are almost three times as likely to be unemployed compared to autochthonous Dutch (CBS, 2010). Similarly, even though gender differences declined in the 1980s and 1990s, sizable differences remain between male and female wages and in the relative presence of women in the highest paid jobs.[57]

In this paper, we contribute to the understanding of how labor market discrimination may arise even when groups are originally equally skilled. Such knowledge is essential to successfully fight discrimination, because different forms of discrimination may require different treatments. Broadly speaking, economists have offered two lines of explanation for discrimination in the labor market. One possibility is that the origin of discrimination

[57] Examples of empirical studies investigating unequal treatment in the labor marker include Blau and Kahn (1992, 2003), Goldin and Rouse (2000), Azmat, Güell and Manning (2006) and Arulampalam, Booth and Bryan (2007). For overviews, see Darity and Mason (1998) and Altonji and Blank (1999).

is taste-based (Becker, 1971). According to the standard interpretation, employers sacrifice profit by treating some group of workers worse, simply because they dislike them. The other possibility is that the differential treatment of groups is rooted in statistical discrimination (Phelps, 1972; Arrow, 1973; Coate and Loury, 1993; Fryer and Loury, 2005). Statistical discrimination occurs when employers' beliefs that the productivity of demographic groups differs induce these groups to behave differently, such that the employers' beliefs are supported by the data.

Statistical discrimination is a potentially more persistent problem than taste-based discrimination, because the former can persist in equilibrium while the latter may be eroded by competitive market forces.[58] Even though plausible stories of statistical discrimination have been proposed, it has not yet been possible to endogenously create statistical discrimination among equally skilled groups in the laboratory.[59] In an experiment that straightforwardly implements the model of Coate and Loury (1993), Fryer, Goeree and Holt (2005) hardly find any evidence of systematic statistical discrimination.

In the world of Coate and Loury, on a certain market day an employer receives a single application from a worker of either of two groups. The employer hires the worker if he is sufficiently sure that the worker has invested in her own quality.[60] The insight of Coate and Loury is that the game has multiple equilibria, so it may happen that the employer plays according to one equilibrium with one group and according to another equilibrium with the other group. In this case discrimination occurs. Yet it is also possible that the employer uses the same standard to judge workers from the two groups, preventing the occurrence of discrimination. The results of Fryer et al. suggest that the latter outcome is more likely.

We think that the model of Coate and Loury ignores an essential element that characterizes many labor markets. Usually there is competition between workers for the same job. Typically, the employer advertises a vacancy and receives multiple applications. At the end of the selection procedure, at most one of the applicants will be offered the job in question.

[58] Taste-based discrimination may survive in some niches of the labor market though. For instance, if customers have a taste for discrimination and are willing to pay to be served by workers from a certain group, employers may hire employees in accordance with the customers' tastes; see Akerlof and Kranton (2010) for a discussion of such examples.

[59] As we will explain in detail below, we add competition between workers to the setup of Coate and Loury (1993). In contrast, Phelps (1972) proposes a model where available productivity measures are noisier for minority workers. So ex-ante the groups are not equal. Arrow (1973) describes a model of statistical discrimination where employers offer lower wages to minorities. In contrast to Arrow, we focus on discrimination in job assignment, arguably the form of discrimination that is harder to detect and fight. Fryer and Loury (2005) study discrimination in a model where two groups compete in a tournament-like structure. Their approach differs for instance in their assumption about ex-ante differences between the groups.

[60] We will use the arbitrary convention that the employer is male and the worker is female.

Notice what happens if there are arbitrarily small differences in the historical rates according to which the two groups invest in their own quality. If there is no competition between workers, as in the original Coate-Loury model, the employer may hire the worker of either group because each group's investment rate is above the critical threshold. Or vice versa, he may not hire any worker because both investment levels are below the threshold. With competition for the same job, the situation differs dramatically. Now a small difference in the historical investment rates of the two groups will have a profound effect, because all other things equal the employer will hire a worker from the group with the slightly higher investment rate. With competition, small differences in historical investment rates thus have a strong impact on the employer's behavior, which discourages further investments of the disadvantaged group.

We use a combination of theory and laboratory experiments to investigate our conjecture that competition between workers drives statistical discrimination.[61] Theoretically, we illustrate the argument in a simple model. In an experiment, we find clear support for our intuition. That is, without competition between workers, we replicate the results of Fryer et al. and find no discrimination. With competition, we systematically find substantial discrimination.[62]

There is one striking difference between our experimental data and the predictions from the standard model. In our experiment, workers belonging to the discriminated group continue to invest in their quality at a fairly high rate even though theory predicts that they should completely be discouraged to invest once they are discriminated against. The key to explaining this puzzle lies in the fact that a substantial minority of the em-

[61] Laboratory experiments have the advantage that they allow to disentangle the different factors causing discrimination. Naturally occurring field data are difficult to interpret. Using the so-called Blinder-Oaxaca decomposition procedure, researchers have estimated the part of differential treatment due to differences in human capital and the part due to discrimination (Darity and Mason, 1998). Notice, however, that the human capital gap may actually be caused by statistical discrimination. With naturally occurring data, it is impossible to determine why the disadvantaged group refrains from investing in human capital. Likewise, existing field experiments have not been successful in distinguishing between taste-based theories and theories based on statistical discrimination (Riach and Rich, 2002).

[62] Our study contributes to a growing experimental literature on discrimination in the labor market. Two major differences with previous experimental papers are that we explicitly model the role of the employer and that we consider a situation where there are no ex-ante differences between the worker groups. Examples of experimental work on discrimination in the labor market include Schotter and Weigelt (1992), Corns and Schotter (1999), Feltovich and Papageorgiou (2004), Niederle, Segal and Vesterlund (2008) and Reuben, Sapienza and Zingales (2010). This literature is surveyed by Charness and Kuhn (2010). In other applications than the labor market, intergroup rivalry and discrimination between groups are rather easily triggered; early experiments in social psychology include Sherif, Harvey, White, Hood and Sherif (1954) and Tajfel, Billig, Bundy and Flament (1971). More recent contributions in economics include Fershtman and Gneezy (2001), Gneezy, Niederle and Rustichini (2003), List, (2004), Fershtman, Gneezy and Verboven (2005), Charness, Rigotti and Rustichini (2007), Andreoni and Petrie (2008), Fryer, Levitt and List (2008), Chen and Li (2009), Hargreaves Heap and Zizzo (2009), Abbink, Brandts, Hermann and Orzen (2010), Goette, Huffman, Meier and Sutter (2010) and Zizzo (2011). Anderson, Fryer and Holt (2007) provide an overview of this literature.

ployers refuses to discriminate between the two groups of workers even when it is in their interest to do so.

We extend the standard model by including a proportion of 'color blind' employers who do not condition their hiring decision on the group-identity of the worker; the remaining fraction of 'discriminating' employers may do so (as in the standard model). This model predicts that discrimination occurs either in hidden or in overt form. With hidden discrimination, the discriminating employer systematically favors one group when he cannot distinguish between the applicants of the different groups. In cases where he can rank the applicants, he does not discriminate. With overt discrimination, the discriminating employer never hires a worker from a particular group. This group is completely ignored by this type of employer, irrespective of the signal that any of its members may produce. The experimental data reveal that discriminating employers behave in line with the predictions of the hidden discrimination equilibrium. Workers from the disadvantaged group therefore have an ongoing (strong) incentive to invest in their own quality, because there is a good chance that they are hired – by the color blind or discriminating employer alike – when they produce a good test result.

The remainder of this paper is organized as follows. Section 4.2 describes the theory. It introduces a simple model and presents the main argument. Section 4.3 provides a description of the experimental design. Section 4.4 presents our experimental findings on the effect of competition. Section 4.5 discusses the extended model in which a proportion of the employers is color blind and provides a comparison with the data. In the concluding Section 4.6, we discuss how our findings relate to existing field data.

4.2 Theory

We consider a job market discrimination game with either no competition or with competition between workers from different groups. Our framework for the no-competition case closely follows the model of Coate and Loury (1993) and the experimental setup of Fryer et al. (2005). Although this setting allows for discrimination in equilibrium, there arguably is no compelling reason that this is indeed likely to be observed. If explicit competition between workers from different groups is added to this framework, however, the equilibria with systematic job market discrimination gain more drawing power relative to the other, non-discriminatory equilibria.

4.2.1 Setup without competition

Assume there are two groups of workers: green workers and purple ones. An employer has one vacancy, for which a randomly chosen worker applies. The employer observes the applicant's color. Payoffs are such that he prefers to hire the worker if and only if she is qualified. In particular, the employer gets 0 if he does not hire the worker, $x_q > 0$ if he hires a qualified worker and $-x_u < 0$ if he hires an unqualified worker. Workers always prefer to be employed independent of their qualifications (and color), receiving wage $w > 0$ instead of their outside option payoff of 0.

Workers can affect their qualifications by investing in skills development. If a worker invests she becomes qualified, otherwise she stays unqualified. Workers differ in their cost of investment. Let $G(c)$ be the fraction of workers with investment costs smaller than c. We assume that $G(c)$ is identical for both groups of workers. In terms of workers' characteristics, the two groups are thus ex ante identical. The employer does not know whether the worker is qualified when making his hiring decision. But he does receive a signal $\theta_i \in \{\theta^l, \theta^h\} \equiv \Phi$, with $\theta^l < \theta^h$, about the worker's qualification; here subscript $i \in \{g, p\}$ denotes the color of the worker. The probability of observing a particular signal depends on whether the worker invested or not. P_q^h gives the probability that $\theta_i = \theta^h$ for a qualified worker and P_u^h the corresponding probability if the worker is unqualified. Note that P_q^h and P_u^h are independent of color; workers are thus also in this respect ex ante equal. We assume that qualified workers are more likely to generate a high signal than unqualified ones are, i.e. that $P_q^h > P_u^h$. The exact order of play in the game can be summarized as follows:

1. Nature determines the color $i \in \{g, p\}$ of the worker with whom the employer is matched. Both the employer and the worker observe this color;

2. Nature draws the worker's costs of investment c_i from $G(c)$. Only the worker observes c_i;

3. The worker decides whether to invest in skills at cost c_i ($I_i = 1$) or not ($I_i = 0$). The employer does not observe this decision.

4. Nature generates a signal $\theta_i \in \{\theta^l, \theta^h\}$ about the worker's qualifications. If the worker invested in skills, the probability of a high signal θ^h equals P_q^h. In case she did not invest, this probability equals $P_u^h < P_q^h$;

5. The employer observes the signal θ_i (but not whether the worker invested, nor her investment costs), and decides whether to hire the worker;

6. Payoffs are obtained, with:

$$U_E = \begin{cases} 0 & \text{if no worker is hired} \\ x_q & \text{if a qualified worker is hired} \\ -x_u & \text{if an unqualified worker is hired} \end{cases} \tag{4.1}$$

$$U_{W_i} = \begin{cases} -c_i \cdot I_i & \text{if not hired} \\ w - c_i \cdot I_i & \text{if hired} \end{cases} \tag{4.2}$$

The above setup differs in one aspect from Coate and Loury (1993); they assume a continuous signaling technology with $\theta_i \in [\theta^l, \theta^h]$. An advantage of our discrete setup is that it is much easier to implement in the laboratory (cf. Fryer et al., 2005). From an empirical point of view it also makes sense to assume that employers are sometimes unable to rank the signals obtained from different candidates, i.e. are faced with applicants that are perceived to be of equal merit. In fact, policy measures based on 'positive action', like recently implemented in the UK,[63] allow and incite employers to favor candidates from minority groups, but only if they have the same skills and qualifications. In a continuous model the latter would be a probability zero event. At the end of this section we briefly discuss to what extent our qualitative predictions carry over to the situation with more than two signals, including the continuous case.

Turning to the equilibrium analysis, the employer is only willing to hire the color i worker if, upon observing signal θ_i, he is sufficiently confident that the worker is qualified. Let π_i denote his prior belief that a worker of color i is qualified. Using Bayes' rule, the employer's posterior belief after observing $\theta_i = \theta^{s_i}$ (for $s_i \in \{l, h\}$) then equals:

$$\xi\left(\pi_i, \theta^{s_i}\right) = \frac{\pi_i \cdot P_q^{s_i}}{\pi_i \cdot P_q^{s_i} + (1-\pi_i) \cdot P_u^{s_i}} = \frac{1}{1 + \left(\frac{1-\pi_i}{\pi_i}\right)\varphi^{s_i}} \tag{4.3}$$

with $\varphi^{s_i} \equiv \frac{P_u^{s_i}}{P_q^{s_i}}$ the likelihood ratio at θ^{s_i} (for $s_i \in \{l, h\}$). Note that from $P_u^h < P_q^h$ it follows that $\varphi^h < \varphi^l$ and thus $\xi\left(\pi_i, \theta^h\right) > \xi\left(\pi_i, \theta^l\right)$. The employer prefers to hire if $\xi\left(\pi_i, \theta^{s_i}\right) x_q - \left(1 - \xi\left(\pi_i, \theta^{s_i}\right)\right) x_u \geq 0$. His equilibrium hiring strategy thus equals:

$$\rho^*\left(\pi_i, \theta^{s_i}\right) = \begin{cases} 1 & \text{if } \left(\frac{1-\pi_i}{\pi_i}\right)\varphi^{s_i} < r \equiv \frac{x_q}{x_u} \\ \in [0,1] & \text{if } \left(\frac{1-\pi_i}{\pi_i}\right)\varphi^{s_i} = r \\ 0 & \text{if } \left(\frac{1-\pi_i}{\pi_i}\right)\varphi^{s_i} > r \end{cases} \tag{4.4}$$

where $\rho^*\left(\pi_i, \theta^{s_i}\right)$ denotes the probability that the color i worker is hired after observing signal $\theta_i = \theta^{s_i}$.

In equilibrium the employer's prior belief π_i that the color i worker is qualified should be correct. That is, given the employer's hiring strategy in (4.4) that results from beliefs π_i, the color i worker is induced to invest exactly in such a way that beliefs are confirmed. Throughout we assume that, in case the employer is indifferent between hiring and not

[63] See UK Equality Act 2010, Chapter 15, Part 11, Chapter 2, Section 159, available at: http://www.legislation.gov.uk/ukpga/2010/15/section/159.

hiring a worker, he always hires. Similarly so, we assume that the worker invests for sure in case of indifference.

An equilibrium that always exists is $\pi_g^* = \pi_p^* = 0$. If the employer believes that workers never invest in necessary skills he is never willing to hire. Workers in turn will indeed not invest, thereby confirming the employer's beliefs. The exact characterization of the equilibria that do contain equilibrium investment depends on the parameters of the model. In the main text we present the case for the parameters chosen in the experiment: $\{r, w, P_q^h, P_u^h, G(c)\} = \left\{\frac{2}{3}, 150, \frac{3}{4}, \frac{1}{4}, U[0,100]\right\}$.[64] In Appendix A we briefly elaborate on the characterization for the general case and with that illustrate that our parameterization is not a degenerate knife-edge one. Our experimental parameters have the advantage that, both without and with competition, only one symmetric and one asymmetric equilibrium with investment co-exists. With only a few equilibria that have a relatively simple structure and that are also well apart, it becomes easier for subjects to coordinate. This in turn makes it more likely that we are able to successfully distinguish discriminatory outcomes from non-discriminatory ones.

For ease of exposition, we always describe the equilibria in which discrimination takes place assuming that purple workers are discriminated against. Obviously, in these cases the exact mirror image equilibrium also exists in which green workers are discriminated against.

Proposition 1. *The job market discrimination game without competition allows the following equilibria:*

(a) *Equilibria without discrimination*

(a.1): The worker never invests and the employer never hires;

(a.2): Workers of each color invest whenever $c_i \leq 75$ (for $i \in \{g, p\}$) and for each color the employer hires only after observing a high signal;

(b) *Equilibria with discrimination*

(b.1): The purple worker never invests while the green worker invests when $c_g \leq 75$. Purple workers are never hired, the green worker is hired only after observing a high signal from this worker.

The intuition behind Proposition 1 is straightforward. Given that workers from the two color groups do not directly compete against each other, we can analyze the game as if the two groups are independently playing a game with the employer. For a given group i, two

[64] In the experiment we added a fixed payment of 20 to U_E in expression (4.1) and of 10 to U_{W_i} in expression (4.2). Obviously this does not affect the equilibrium predictions.

equilibrium outcomes exist: $\pi_i^* = 0$ and $\pi_i^* = \frac{3}{4}$. The latter follows from observing that when $\pi_i = \frac{3}{4}$, the color i worker is hired after a high signal (because $\frac{1}{3} \cdot \frac{1}{3} < \frac{2}{3}$ in (4.4)), but not after a low signal (as $\frac{1}{3} \cdot 3 > \frac{2}{3}$). Given that the employer only hires after observing a high signal, the worker's gross benefits of investing equal $w \cdot \left(P_q^h - P_u^h\right) = 75$. Hence for all $c_i \leq 75$ the worker invests, confirming $\pi_i = \frac{3}{4} = G(75)$ for $G \simeq U[0,100]$.

The equilibria for the entire game simply follow from combining the equilibrium outcomes per group, yielding $\left(\pi_g^*, \pi_p^*\right) \in \left\{(0,0), \left(\frac{3}{4}, \frac{3}{4}\right), \left(\frac{3}{4}, 0\right), \left(0, \frac{3}{4}\right)\right\}$. A first plausible equilibrium selection criterion is stability. Following Arrow (1971, 1973) and Coate and Loury (1993), Proposition 2 below considers local stability in reaction to small trembles ε_i in the employer's beliefs about the ex ante investment probability π_i of the color i worker.

Proposition 2. *All equilibria described in Proposition 1 are stable w.r.t. small perturbations in the prior beliefs π_i of the employer.*

The intuition behind Proposition 2 runs as follows. The employer's hiring strategy described in (4.4) comprises three 'regimes'. Only in the second indifference regime where $\left(\frac{1-\pi_i}{\pi_i}\right) \varphi^{s_i} = r$, small trembles in the employer's belief π_i will lead to a shift in regime and thus alter the employer's hiring strategy. For generic parameter values, however, either the first (hiring) or third (no-hiring) regime applies and small perturbations in π_i have no impact. As $\rho^* (\pi_i, \theta^{s_i})$ is unaffected, so is the worker's investment strategy.[65] A best response adjustment process thus leads to an immediate return to the original equilibrium. On top of stability, Pareto efficiency may provide an additional selection criterion. Both the employer and the worker alike are (weakly) better off the higher π_i^* is. The worker is better off because she is more likely to be hired, while the employer is better off because applicants are more qualified on average. From a welfare perspective coordination on the symmetric $\left(\pi_g^*, \pi_p^*\right) = \left(\frac{3}{4}, \frac{3}{4}\right)$ outcome would thus be best. Equilibrium discrimination, although possible, is less focal in this regard. Indeed, in their first experiment Fryer et al (2005) did not find evidence that subjects systematically discriminated. At the same time they also observed that workers' investment rates were always well above zero.

4.2.2 Setup with competition

The setup with competition shares many features with the one without competition. The main difference is that now the employer is matched with both a green and a purple applicant who compete for the same vacancy. The signaling technology is as before, with

[65] To illustrate this for the equilibrium described in (a.2) of Proposition 1, suppose the employer's prior belief is perturbed by ε_i such that she decides on the basis of belief $\pi_i^t = \frac{3}{4} + \varepsilon_i$ instead of the (equilibrium) prior $\pi_i = \frac{3}{4}$. Then from $\rho^* (\pi_i^t, \theta^{s_i}) = \rho^* \left(\frac{3}{4} + \varepsilon_i, \theta^{s_i}\right)$ in (4.4) it follows that the employer continues to hire the worker after a high signal as long as $\varepsilon_i > -\frac{5}{12}$, and to abstain from hiring after a low signal for any $\varepsilon_i > -\frac{3}{28}$. Hence for small trembles $|\varepsilon_i| < \frac{3}{28}$ the employer's strategy is unaffected and the worker's best response is $\pi_i^{t+1} = \frac{3}{4}$, in line with equilibrium (a.2). The intuition for equilibria (a.1) and (b.1) is similar.

the employer receiving two independent signals θ_g and θ_p, i.e. one from each applicant. After observing $\{\theta_g, \theta_p\}$, the employer decides whether to hire either the green worker, the purple worker, or none of them. Investment costs are drawn independently from $G(c)$ for each worker separately and are privately observed. Based on their draws workers simultaneously decide whether or not to invest.

As before, the employer is only willing to consider the color i worker as a serious candidate for the job if observing θ_i makes him sufficiently confident that she is qualified. This leads to the same requirement as in expression (4.4). Yet an additional requirement for actually hiring the color i worker is now that she is the best one available. That is, the employer prefers to hire the serious candidate for which he has the highest posterior belief $\xi\left(\pi_i, \theta^{s_i}\right)$ that she is qualified. In case both candidates are (serious and) equally qualified, the employer is indifferent and may choose one of them at random in equilibrium. The employer's hiring strategy thus now equals (for $i \neq j$):

$$\rho^*\left(\pi_i, \theta^{s_i}; \pi_j, \theta^{s_j}\right) = \begin{cases} 1 & \text{if } \left(\frac{1-\pi_i}{\pi_i}\right)\varphi^{s_i} < \min\left\{r, \left(\frac{1-\pi_j}{\pi_j}\right)\varphi^{s_j}\right\} \\ \in [0,1] & \text{if } \left(\frac{1-\pi_i}{\pi_i}\right)\varphi^{s_i} = \min\left\{r, \left(\frac{1-\pi_j}{\pi_j}\right)\varphi^{s_j}\right\} \\ 0 & \text{if } \left(\frac{1-\pi_i}{\pi_i}\right)\varphi^{s_i} > \min\left\{r, \left(\frac{1-\pi_j}{\pi_j}\right)\varphi^{s_j}\right\} \end{cases} \tag{4.5}$$

where $\rho^*\left(\pi_i, \theta^{s_i}; \pi_j, \theta^{s_j}\right)$ denotes the probability that the color i worker is hired.

Also with competition the equilibrium with $\pi_g^* = \pi_p^* = 0$ always exists. More interesting are the equilibria based on positive investment levels. From Proposition 1 it is immediate that $\left(\pi_g^*, \pi_p^*\right) = \left(\frac{3}{4}, 0\right)$ constitutes an equilibrium as well. If the employer never even considers to hire a purple worker, there is de facto no competition and the situation is as if the employer is matched with only a green worker. The symmetric equilibrium with investment ((a.2) in Proposition 1) is affected though. With competition the employer cannot hire both workers if both generate a high signal. One worker should be chosen and, in order to provide symmetric incentives, the employer should flip a fair coin in that case. Because a high signal is no longer sufficient for getting hired for sure, the worker is less willing to invest and $\pi_g^* = \pi_p^* < \frac{3}{4}$. Proposition 3 below contains a precise characterization of this equilibrium (see (a.2)).

Proposition 3. *The job market discrimination game with competition allows the following equilibria:*

(a) *Equilibria without discrimination*

(a.1): Workers never invest and the employer never hires;

(a.2): Workers of each color invest whenever $c_i \leq \frac{2100}{38} = 55\frac{5}{19}$ (for $i \in \{g, p\}$). The employer hires only after observing a high signal and flips a fair coin to decide who to hire after observing two high signals.

(b) *Equilibria with discrimination*

(b.1): The purple worker never invests while the green worker invests when $c_g \leq 75$. Purple workers are never hired, the green worker is hired only after observing a high signal from this worker.

Unlike the no-competition case, stability now makes the discriminatory equilibrium described in (b.1) much more focal than the non-discriminatory investment equilibrium described in (a.2).

Proposition 4. *The non-discriminatory investment equilibrium (a.2) described in Proposition 3 is unstable w.r.t. small perturbations in the beliefs π_i of the employer. The other two equilibria in Proposition 3 are stable in this respect.*

The stability of the discriminatory equilibrium (b.1) follows from the same intuition as in the previous subsection (cf. footnote 8). The instability of equilibrium (a.2) can be understood as follows. Suppose the employer's prior belief about the green worker's investment rate is trembled and becomes $\pi_g^t = \frac{21}{38} + \varepsilon_g$. If $\varepsilon_g > 0$, the employer will no longer toss a fair coin upon receiving two high signals but, given that now $\pi_g > \pi_p$, hire the green worker for sure.[66] Given this change in the employer's hiring strategy, the green worker would now like to invest whenever $c_g \leq 75$, i.e. $\pi_g^{t+1} = \frac{3}{4}$. Similarly so, the best response of the purple worker against the new hiring strategy, assuming $\pi_g = \frac{21}{38}$, equals $\pi_p^{t+1} = \frac{9}{32}$. Going one best response iteration further, for the lower investment level $\pi_p^{t+1} = \frac{9}{32}$ the employer never wants to hire a purple worker and, once realizing this, the purple worker does not want to invest: $\pi_p^{t+2} = 0$. This best response process thus converges to the discriminatory equilibrium (b.1).

With competition the discriminatory equilibrium is also no longer Pareto inefficient. This holds because the advantaged green worker now strictly prefers this equilibrium over equilibrium (a.2), as his probability of getting hired is higher. For the disadvantaged purple worker this is the other way around. Like the green worker, the employer also prefers the discriminatory equilibrium in expected payoff terms. The intuition here is that, although the probability that a worker is hired is lower in the discriminatory equilibrium, the expected quality of the hired worker is higher.

Summing up, both without and with competition a symmetric and an asymmetric equilibrium with equilibrium investment exists. Without competition both equilibria are stable and the symmetric equilibrium payoff dominates the asymmetric one. But with competition only the asymmetric equilibrium is stable and this equilibrium is also no

[66] For $\varepsilon_g < 0$ the reasoning is the same except that the two colors should be swapped.

longer payoff dominated. We therefore expect to observe systematic discrimination only in the treatment with competition between workers.

Qualitatively these predictions carry over to settings with more than two signals. With finitely many signals, this follows from the same intuition as above. In the symmetric equilibrium where $\pi_g^* = \pi_p^*$, there is a strictly positive probability that the two candidates have equal merit (i.e. $\theta_g = \theta_p$). Symmetric incentives require equal treatment in such cases and thus effectively a mixed strategy from the employer on the overall set $\Phi_{equal} = \{(\theta_g, \theta_p) \in \Phi \times \Phi \mid \theta_g = \theta_p\}$. Small perturbations in beliefs then induce the employer to immediately adapt his behavior by always favoring the candidate with $\pi_i > \pi_j$ in these contingencies. This discrete jump in the employer's hiring strategy leads to a breakdown of the symmetric equilibrium.

With continuous signals the probability of equal signals becomes negligible. Yet even then it is perfectly possible that the symmetric investment equilibrium is unstable, while the asymmetric equilibrium in which one group never invests is not. We illustrate this in Appendix B, using a continuous signaling technology that fits the exact setup of Coate and Loury (1993). The general intuition here is that in the symmetric equilibrium, small perturbations in the employer's beliefs induce him to slightly favor one type of worker over the other, boosting the investment incentives of the (now) advantaged worker and diminishing the incentives for the disadvantaged worker. Depending on the strength of these incentive changes, a subsequent best response path may lead players away from the symmetric equilibrium. In contrast, in the asymmetric equilibrium small perturbations in the beliefs about the disadvantaged group have no impact at all. Moreover, small perturbations regarding the advantaged group have a potentially smaller impact than in the symmetric investment equilibrium, because a feedback loop from changes in π_p^t (with purple the disadvantaged group) to subsequent changes in π_g^{t+1} is then absent. The instability of the symmetric investment equilibrium under competition is thus neither an artefact of the discrete nature of our sigaling technology, nor of the limitation to two signals only.

4.3 Experimental design and procedure

The computerized experiment was conducted at the CREED laboratory of the University of Amsterdam. Subjects were recruited from the student population in the standard way. At the start of the experiment, subjects were randomly assigned either the role of employer, green worker or purple worker. Subjects kept the same role throughout the experiment. Subjects read the role-specific instructions on the computer at their own pace and received a handout with a summary. The instructions provided context by using words like 'employer' and 'worker', but completely avoided loaded terms like 'discrimination'.

Appendix C provides the instructions for the experiment. All subjects had to answer some control questions testing their understanding of the instructions. The experiment would start only after each subject successfully answered each question.

Each subject received a starting capital of 900 points. In addition, subjects earned (or lost) money with their decisions in each period. At the end of the experiment, points were exchanged for euros at the rate of 1 eurocent for each point. The sessions lasted between one and two hours. A total of 144 subjects participated in the experiment. The average earnings per subject were 30.10 euros (in a range of 14.80 euros to 47.00 euros). In every session, 1 or 2 matching groups of 12 persons were formed, each containing 4 employers, 4 green workers and 4 purple workers. In each period, subjects were randomly rematched within their matching group.

Each subject participated only once in one of the two treatments: 'No Competition' and 'Competition'. The only difference between the treatments was that in Competition a purple and a green worker competed for the same job, while in No Competition either a green or a purple worker was available for the job. In No Competition, each employer was randomly matched to either a green or a purple worker and the unmatched worker was inactive and had to wait for one period. In Competition, each employer was randomly matched with one green and one purple worker and both workers were active. Subjects were aware that they would never be matched with the same person twice in a row.

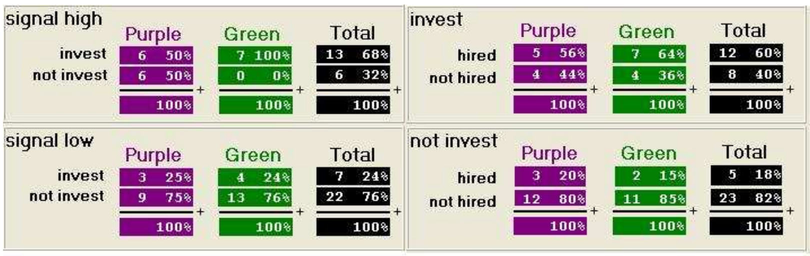
In the experiment, the exact order of play as described in Section 4.2 was used. At the start of each of the 50 periods, each active worker was informed of the personal cost of investment. Costs differed across workers and periods. Each cost was an independent draw from a uniform distribution, with every integer between 0 and 100 being equally likely. Then each active worker chose whether to 'invest' or 'not invest'. After the active workers made their investment decisions, independent signals were generated and sent to the employers. A signal could either be 'high' or 'low'. If a worker decided to invest, the employer would receive a high signal with probability $\frac{3}{4}$ and a low signal with probability $\frac{1}{4}$. If a worker decided not to invest, the employer would receive a high signal with probability $\frac{1}{4}$ and a low signal with probability $\frac{3}{4}$. The employer observed the signal but not the investment decision itself. After observing the signal, the employer decided whether or not to hire the given worker in No Competition, and whether to hire the green worker, the purple worker, or none of the workers in Competition. The procedure to generate the investment costs and the signaling technology were the same in both treatments.

At the end of the period, each subject received information about the investment decisions of the active workers, the signal(s) received by the employer and the hiring decision of the employer. A calculation of one's own earnings for this period was shown. Both treatments employed the payoffs listed in Figure 4.1. In No Competition, workers who

Figure 4.1: Payoffs used in the experiment; c denotes the worker's cost of investment

		Employer	
		Hire	Not Hire
Worker	Invest	160-c, 60	10-c, 20
	Not Invest	160, -40	10,20

Figure 4.2: Examples of social history screens of employers (left) and workers (right) based on hypothetical data



were inactive in a period received 10 points. At any moment, subjects could observe their current cumulative earnings.

In addition, subjects were continuously shown a social history screen that summarized the decisions in the previous periods of the own matching group. Workers and employers observed a different history screen. The employers' history screen showed for each category 'high signal' and 'low signal' how often workers had chosen to invest and not to invest. These numbers were given for each of the two colors separately as well as for the pooled data. The workers' history screen showed for each decision 'invest' and 'not invest' how often a worker was and was not hired, separately for each color and aggregated over the two colors. Examples of the history screens are shown in Figure 4.2.

We provided subjects with a history screen because we wanted to facilitate their strategic understanding of the game. Miller and Plott (1985) were the first to use a similar social history (on black board) in a signaling experiment. They introduced it in their later sessions to help subjects understand the relationship between types and choices. Other papers have used role reversion to accomplish this goal. In signaling games, after senders have become receivers, they do a better job in processing the meaning of a signal (e.g., Brandts and Holt, 1992). Notice that in our experiment especially the employers face a difficult task, because rational belief formation on their part requires the use of Bayes' rule. Gigerenzer and Hoffrage (1995) showed that subjects make much fewer errors against Bayes' rule if they are presented with natural frequencies like the ones they often encounter in real life. Given that our experiment is not about testing the validity of Bayes' rule in an abstract setting, it made sense to provide a history screen that summarized the relevant natural frequencies.[67]

4.4 Experimental results: Does competition trigger discrimination?

Statistical discrimination arises when employers believe that one group of workers invests more in their quality than another group. As a result, the disadvantaged group is discouraged to invest which confirms the employers' beliefs, even though the groups started from ex-ante equal positions. For each matching-group of subjects, we determined ex post which group was disadvantaged and which one was advantaged. The criterion that we used was the average hiring probability after a high signal. If over all 50 periods this probability was higher for the green group, then the green group was labeled advantaged and if it was higher for the purple group, then the purple group was labeled advantaged.

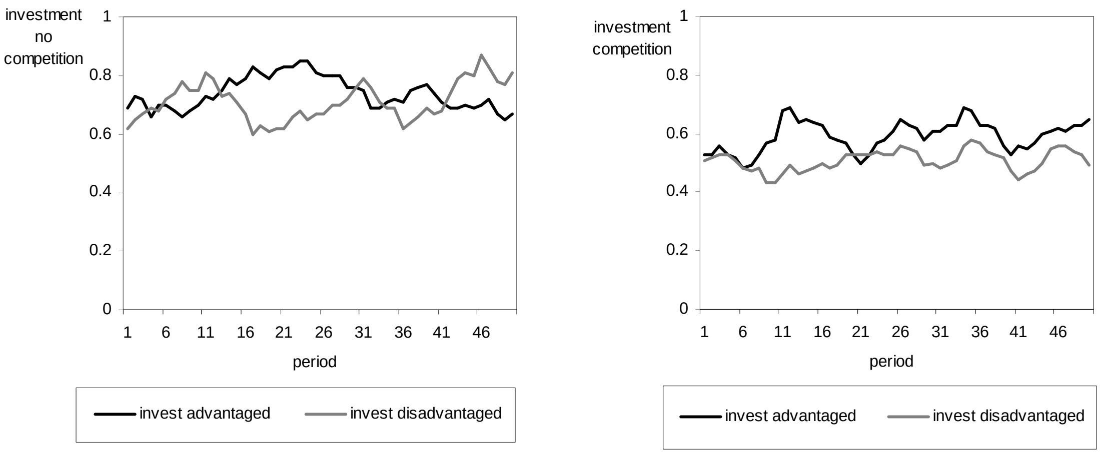
A consequence of this definition is that in each matching group we have one advantaged and one disadvantaged group, even in cases where the hiring probabilities differ only slightly.[68] Our main hypothesis is that the difference in hiring probabilities after a high signal between the advantaged and the disadvantaged group is higher in Competition than in No Competition. In agreement with our conjecture that we employed neutral colors, the green group turned out to be advantaged in 6 matching groups while the purple group was advantaged in the other 6 cases.

In Section 4.2 we argued that small differences in investment behavior may have profound implications for employers' hiring behavior when workers from different groups compete for the same job. Figure 4.3 displays the development of the average investment decisions in the two treatments. In No Competition, the investments for both the advantaged and disadvantaged group hover around 73%, not far away from the 75% investment level predicted by the non-discrimination investment equilibrium. Even though the advantaged group invests on average somewhat more than the disadvantaged group, there are some periods where the investment levels of the disadvantaged group surpass those of the advantaged group. In Competition, the difference in investment levels is more pronounced and less capricious. A noticeable difference in investment behavior arises approximately around period 10 after which disadvantaged workers consistently invest less

[67] Like the experiment of Fryer, Goeree and Holt (2005), our No Competition treatment is a straightforward implementation of the model of Coate and Loury (1993). There are some minor differences between our experiments. For instance, Fryer et al. use different payoff parameters, they consider a setting where the signal has three levels (low, medium and high) instead of two and in their experiment there are no inactive workers that we introduced to make No Competition comparable to Competition.

[68] In fact, in two matching groups of No Competition we could not distinguish between the groups on the basis of this criterion because all workers were always hired after a high signal. In these two cases we classified the groups on the basis of which group was more likely to be hired after a low signal.

Figure 4.3: Smoothed average investments across time



Remarks: For each period, the average investment level in the interval [period -2, period+2] is displayed.

Table 4.1: Investment decisions

Periods	treatment	disadvantaged invested	advantaged invested	Wilcoxon p
1-50	no competition	71.1%	74.1%	0.75
	competition	50.8%	59.3%	0.03
26-50	no competition	72.8%	72.2%	0.75
	competition	51.8%	61.0%	0.06

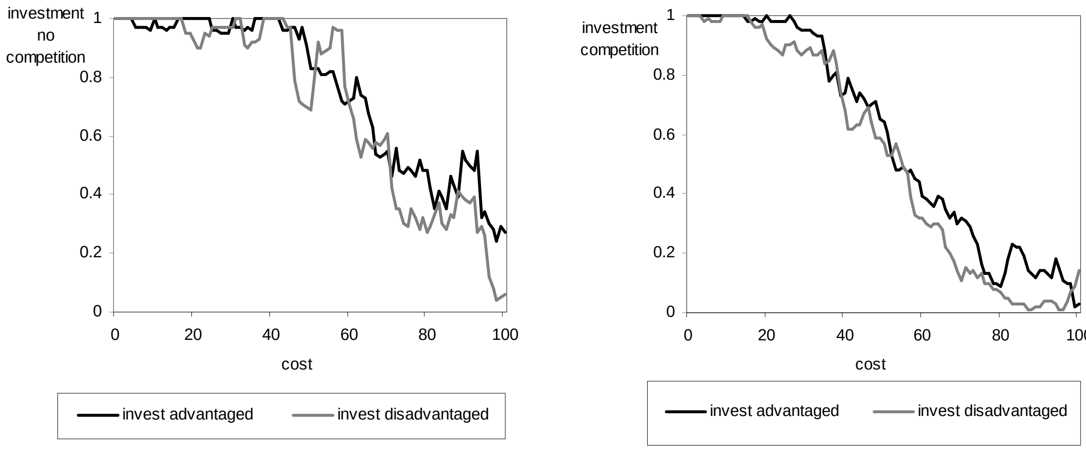
than advantaged workers.

These observations are confirmed in Table 4.1, where we see that in the Competition treatment the modest difference in investment rates of the disadvantaged and advantaged workers over all 50 periods is significant according to a Wilcoxon rank test. (Throughout this paper, we use a prudent testing procedure in which independent averages per matching group serve as data-points.) The corresponding difference in No Competition is not significant. The picture remains qualitatively the same when we limit our attention to the final 25 periods.

Figure 4.4 shows how the workers' investment decisions depend on their investment costs. The figure suggests that subjects use a cutoff rule and invest if and only if the cost level is sufficiently small. In agreement with the fact that in Competition it is less lucrative to invest because two workers compete for one job only, we find that subjects invest for a larger range of costs in No Competition.

Our main result is illustrated in Figure 4.5. The figure shows how often advantaged and disadvantaged workers were hired after sending a high signal over the different periods, separately for No Competition and Competition. The hiring percentages of advan-

Figure 4.4: Smoothed average investments as function of costs



Remarks:For each cost, the average investment levels for that cost in the interval [cost-2, cost+2] is displayed.

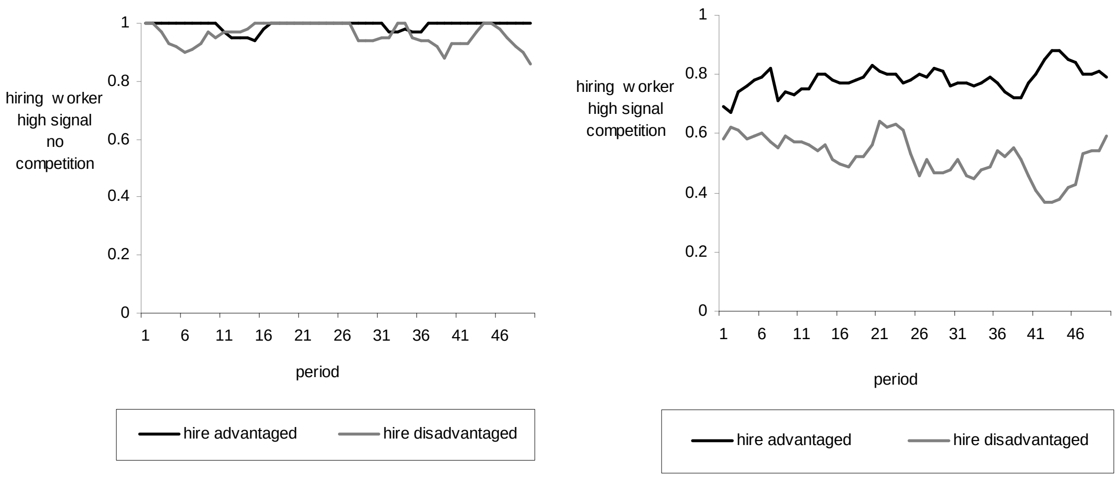
taged and disadvantaged workers are practically identical in No Competition, even though by construction the hiring percentages of the advantaged workers are higher on average. Almost all workers are hired after a high signal, irrespective of color. The picture is completely different for the competition treatment. Here, a clear gap in hiring percentages emerges from the start of the experiment. This gap is consistently sustained over the periods and seems to be growing.

Table 4.2 summarizes the hiring behavior of the employers and confirms the picture that emerges from Figure 4.5. Over all periods, the difference between the percentages of advantaged and disadvantaged workers hired after a high signal is substantially higher (25.8%) in Competition than in No Competition (3.1%). A Mann-Whitney test comparing the differences in hiring rates rejects that they are equal across treatments with $p < 0.01$. In Competition, discrimination of the disadvantaged workers is underlined in the cases where both colors generate high signals. In those cases the difference in hiring rates equals 40.6%.

If we look at the second half of the experiment only, the evidence for our conjecture that statistical discrimination emerges when workers of different groups compete for the same job is even more pronounced. Here, the difference in hiring rates after a high signal equals 31.6% in Competition and 4.7% in No Competition, and the difference in the differences is significant at $p < 0.01$. When both colors generate a high signal in the latter part of the experiment, the difference in hiring rates grows to 50.0%.[69]

[69]In agreement with theory, we do not find evidence of discrimination after a low signal. Workers are only occasionally hired after a low signal and the hiring rate does not depend on the color of the worker.

Figure 4.5: Smoothed average of hiring after high signal across time



Remarks:For each period, the average hiring levels for that period in the interval [period-2, period+2] is displayed.

Table 4.2: Hiring decisions

Periods	signal	treatment	disadvantaged hired (1)	advantaged hired (2)	difference (2-1)
1-50	high	no competition	96.1%	99.2%	3.1%
		competition	52.3%	78.1%	25.8%
				Mann-Whitney p	0.004
	low	no competition	19.4%	27.1%	7.7%
		competition	1.6%	4.8%	3.2%
				Mann-Whitney p	0.52
	2 high	competition	25.6%	66.2%	40.6%
	2 low	competition	2.5%	8.5%	6.0%
26-50	high	no competition	94.8%	99.5%	4.7%
		competition	47.8%	79.4%	31.6%
				Mann-Whitney p	0.006
	low	no competition	17.7%	31.1%	13.4%
		competition	0.7%	4.8%	4.1%
				Mann-Whitney p	1.00
	2 high	competition	19.4%	69.4%	50.0%
	2 low	competition	1.6%	9.4%	7.8%

Remarks: The cells list the average hiring behavior by the employer conditional on the treatment and whether the disadvantaged or advantaged worker emitted a low or a high signal (or in Competition, whether both workers emitted a low or a high signal). The Mann-Whitney tests compare the difference between the treatments of the differences in the employer's hiring behavior of the advantaged and disadvantaged worker.

The dynamics in the data are well in line with the intuition provided by the stability argument. In 4 of the 6 matching groups in Competition, the group that initially invested somewhat less than the other became already disadvantaged around period 10, and remained so throughout the entire experiment. In one matching group, the purple group of workers started investing a bit less in the first 5 periods and, conditionally on a high signal, was also hired at a lower rate initially. Then the purple group successfully boosted their investments and surpassed the green group by period 10, after which they were consistently favored by the employers until the end of the experiment. There was only one matching group where it took longer before the dust settled. In this group the green group started investing a bit more and was favored in the first 20 periods, after which the purple group successfully came back, invested more than green and was favored by the employers until the end of the experiment. In contrast, the picture is much more random for No Competition, where groups tended to be treated equally in the majority of cases. If differences were made in how colors were treated, the advantage changed back and forth throughout the experiment.[70]

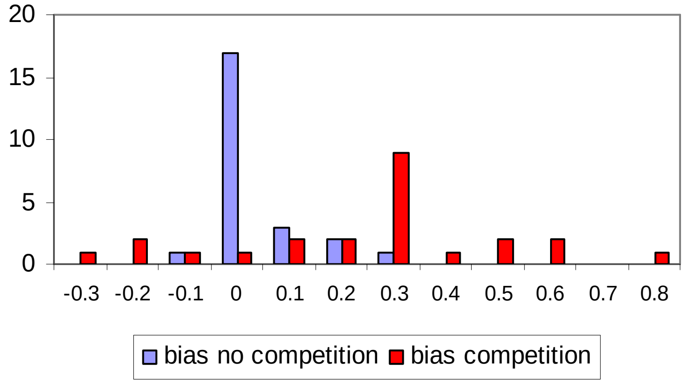
Another way of illustrating the difference between the two treatments is to calculate a 'bias' statistic for each individual employer and to plot the frequency distributions of biases. For each employer, we subtracted the relative frequency that a disadvantaged worker was hired given that the disadvantaged worker generated a high signal from the relative frequency that an advantaged worker was hired given that the advantaged worker produced a high signal. The resulting number is the employer's bias. Figure 4.6 provides the frequency distribution of bias types across treatments. Also from this perspective a clear difference between the treatments exists. The substantial mode of the bias distribution in No Competition is at 0. This reflects the fact that in this treatment most employers treat both groups of workers equally. In contrast, in Competition there is a clear shift to the right in the distribution and the mode of the bias parameter is at 0.3. Thus, whereas most employers refrain from discriminating in No Competition, they succumb to treating the groups differently in Competition.

Summarizing the results so far, the data clearly support our main conjecture. When there is no competition between workers of different groups, we confirm the finding of Fryer et al. (2005) that statistical discrimination is negligible or absent. Since there are some small differences between their design and ours, this suggests that this result is rather robust. When different groups of workers compete for the same job, however, we

[70] In two matching groups in No Competition there was no difference in hiring probability after a high signal at any moment. Group 1 of session 8 may serve as a rather typical example of how hiring probabilities changed if they did: in the first block of 10 periods, the purple workers were slightly favored, then the groups were treated exactly the same in the second and third blocks, after which the green workers were somewhat favored in the fourth block while the purple workers were a bit favored in the final block.

Figure 4.6: Frequency distributions of hiring biases. For each employer, the bias is calculates as

$$bias = \frac{\#\ advantaged\ workers\ hired\ given\ high\ signal}{\#\ advantaged\ workers\ with\ high\ signal} - \frac{\#\ disadvantaged\ workers\ hired\ given\ high\ signal}{\#\ disadvantaged\ workers\ with\ high\ signal}$$



find substantial statistical discrimination. In the latter case, small differences in initial investment behavior trigger long-lasting statistical discrimination.

4.5 Color blind and discriminating employers

Although the results confirm our main hypothesis, the data do not accord with all details of the theoretical analysis. The most striking difference is that disadvantaged workers continue to invest at a fairly high level, even though theory suggests that they should completely stop investing given that they are discriminated against. A key ingredient of an explanation for this puzzle is that some of the employers in Competition refrained from discriminating, despite being it in their best interest to do so. Like Figure 4.6 already shows, there are some employers in Competition that have biases close to 0. It thus appears that some of the employers completely ignore investment differences between the two groups and continue hiring both colors at an equal pace.

Based on our data we classify employers as being either 'color blind' or 'discriminating' in the following way. For each employer in Competition, we conditioned on the cases where the employer observed high signals from both workers and hired one of them. If in such situations the employer hired the advantaged worker in at least 75% of the cases, the employer is considered to be discriminating. Otherwise he is labelled color blind. Employing this definition, a substantial minority of 41.7% is found to be color blind.[71]

[71]One employer engaged in positive discrimination and hired disadvantaged workers significantly more often than advantaged workers when both had high signals. Given that this was only one subject, we decided

In the presence of color blind employers, theoretical predictions regarding the form statistical discrimination takes may change. To explore this, we analyze the setup of Subsection 4.2.2 assuming that a fraction β (with $0 < \beta < 1$) of the employers is color blind. These employers use the following hiring strategy (with $\rho^{CB}\left(\theta_i;\theta_j\right)$ the probability that the color i worker is hired):

$$\rho^{CB}\left(\theta_i;\theta_j\right)=\begin{cases} 1 & \text{if } \theta_i = \theta^h \text{ and } \theta_j = \theta^l \\ \frac{1}{2} & \text{if } \theta_i = \theta_j = \theta^h \\ 0 & \text{if } \theta_i = \theta^l \end{cases} \tag{4.6}$$

A color blind employer does not hire after observing two low signals, hires the worker with the higher signal if signals differ and hires either worker with equal probability in case of two high signals. Because a color blind employer ignores the workers' investment strategies π_i and π_j, he does not necessarily best respond. The remaining fraction $1-\beta$ of discriminating employers does so, however, as they optimize their expected payoffs (cf. expression (4.5)).

The characterization of equilibria for general values of β (and the other parameters in the model) is provided in Appendix A. Proposition 5 below does so for the particular parameters used in the experiment and the fraction of $\beta = 0.417$ observed. It focuses on the implications for the discriminatory equilibria.[72]

Proposition 5. *The job market discrimination game with competition and a fraction* $\beta = 0.417$ *of color blind employers allows the following discriminatory equilibria:*

(b.1): *Overt discrimination equilibrium*

The purple worker invests when $c_p \leq 21.94$, the green worker if $c_g \leq 69.38$. A color blind employer uses hiring strategy (4.6). A discriminating employer never hires the purple worker and hires the green worker only after observing a high signal from this worker.

(b.2): *Hidden discrimination equilibrium*

The purple worker invests when $c_p \leq 39.99$, the green worker if $c_g \leq 67.96$. A color blind employer uses hiring strategy (4.6). A discriminating employer hires the purple worker after a high signal from this worker and a low signal from the green worker and hires the green worker when observing a high signal from this worker.

to include this employer with the color blind employers.

[72]The presence of color blind employers does not affect the non-discriminatory equilibrium in which both workers invest (cf. equilibrium (a.2) in Proposition 3).

Table 4.3: actual hiring decisions and best responses in competition treatment

	color blind employers (41.7%)		discriminating employers (58.3%)	
combination signals	hire disadvantaged	hire advantaged	hire disadvantaged	hire advantaged
both low	2.6% [0.0%]	9.5% [0.0%]	2.5% [0.6%]	8.1% [0.0%]
advantaged low disadvantaged high	83.8% [97.1%]	1.0% [0.0%]	86.7% [88.5%]	0.6% [0.0%]
advantaged high disadvantaged low	0.0% [0.0%]	85.5% [100.0%]	1.2% [0.0%]	96.3% [100.0%]
both high	42.0% [26.8%]	46.4% [73.2%]	12.5% [6.8%]	81.3% [92.7%]

Remarks: The cells list the average actual hiring decisions. Between brackets best responses are displayed. Table is based on periods 1-50.

Equilibrium (b.1) in Proposition 5 corresponds to equilibrium (b.1) in Proposition 3. Here a discriminating employer openly discriminates, because he ignores purple workers altogether. Nevertheless, the presence of a fraction of color blind employers now induces the disadvantaged purple worker to invest with positive probability. Note that In the overt discrimination equilibrium, discriminating employers are easily identified, because they refrain from hiring disadvantaged workers even when these workers generate a higher signal.

Compared to Proposition 3, the presence of color blind employers opens up the possibility that discrimination takes place in a hidden form. In equilibrium (b.2) both types of employer hire the worker who generates the higher signal and different treatment only occurs after two high signals.[73] A discriminating employer then systematically hires the advantaged workers. Detecting this type of discrimination is much harder. Only after a series of hiring observations where both workers have equal merit, an outside observer will be able to distinguish a discriminating employer from a color blind one.

To assess which type of discrimination fits our experimental data best, Table 4.3 reports the hiring decisions of the color blind and discriminating employers conditional on the combination of signals observed.

It is not surprising that color blind employers hire the two types of workers with approximately equal probability when both produce a high signal, in contrast to the discriminating employers who favor the advantaged workers in such cases. This result is a direct consequence of the classification procedure. Most interesting is how discriminating employers behave when the disadvantaged worker generates a high signal and the advantaged worker a low signal. The table shows that in such cases discriminating employers

[73]To rationalize that the purple worker is hired by the discriminating employer if this worker has the higher signal, equilibrium (b.2) requires a sufficiently high fraction $\beta \geq 0.181$ of color blind employers in order to exist. Similarly so, equilibrium (b.1) requires $\beta \leq 0.624$ to rationalize that the discriminating employer ignores purpe workers. For a large range of β-values these two equilibria thus co-exist (obviously the π_i^* values in these equilibria vary with β, see Appendix A.3). Both equilibria are stable according to the stability criterion used in Section 4.2.

Table 4.4: Actual earnings and best response earnings employer in competition treatment (periods 1-50)

	color blind employers (41.7%)		discriminating employers (58.3%)	
combination signals	hire disadvantaged	hire advantaged	hire disadvantaged	hire advantaged
both low	17.1 (18.5)	20.0 (0.0)	18.0 (17.1)	19.6 (4.7)
advantaged low disadvantaged high	36.8 (37.8)	37.9 (40.8)	29.5 (42.7)	29.3 (43.1)
advantaged high disadvantaged low	43.7 (32.0)	43.9 (36.9)	40.7 (38.8)	41.1 (39.3)
both high	38.0 (38.1)	42.6 (38.0)	37.7 (39.9)	37.9 (41.4)

Remarks: The cells list the average actual hiring decisions. Standard deviations in parentheses. Table is based on periods 1-50.

overwhelmingly hire the disadvantaged worker. Thus, the statistical discrimination observed in our experiment is best described by the hidden discrimination equilibrium.

Table 4.3 also includes the best responses of the employers. When calculating these statistics, we assumed that the employers' beliefs coincided with what they observed in the social history screen and that their hiring decisions maximized expected payoffs given these beliefs. Qualitatively, the actual employer decisions match the best responses quite well, except for the case where color blind employers observed two high signals. In those cases, they should have hired the advantaged workers much more often than they did.

A natural question to ask is how costly it was for color blind employers to refrain from discriminating after observing two high signals. Given that their behavior stimulated disadvantaged workers to continue investing at a fairly high pace, it turns out not to have been that costly. Table 4.4 shows the actual earnings of the employers in comparison to the earnings that they would have received if they had adhered to the best response model. Like in Table 4.3, the main discrepancy between actual data and best responses occurs when color blind employers received two high signals.[74] In these cases employers earned roughly 10% less than they could have done with optimal choices.[75]

In agreement with the hidden discrimination equilibrium, disadvantaged workers continued investing at a high rate even while they were discriminated against. Theoretically, the possibility to be matched with a color blind employer prevents the unraveling of investments by disadvantaged workers. For the proportion of 41.7% color blind employers in the experiment, the equilibrium investment rate of disadvantaged workers equals 40.0%. In the second part of the experiment, disadvantaged workers invested at an even

[74] The signaling process has a stochastic nature which means that some employers can be unlucky by receiving relatively many high signals from workers who did not invest. To some extent, discriminating employers have been harmed by such randomness. Although their earnings are on average closer to their best response earnings, they do not earn more than color blind employers.

[75] The difference between actual and best response earnings when color blind employers face two high signals is weakly significant (Wilcoxon rank test, $p = 0.07$).

higher rate of 51.8%.[76] Possibly, some disadvantaged workers disliked being discriminated against, and fought back by investing somewhat more than predicted. Nevertheless, the hidden discrimination equilibrium organizes the main pattern observed in the data.

4.6 Conclusion

Theoretically and in an experiment, we showed that competition between workers causes statistical discrimination among originally equally skilled groups. When workers of different groups compete for the same job, accidental differences in workers' historical investment rates have profound effects on employers' hiring behavior. In our experiment, discrimination takes a hidden form. That is, a majority of the employers systematically favors workers of a particular group when they receive equal signals of the applicants. In the other cases, they tend to hire the worker with the higher ranked signal. This means that even the disadvantaged workers are relatively frequently hired, which makes it harder to detect discrimination. This aspect may limit the extent to which legal measures against discrimination can successfully be implemented.

The results of our paper are in line with empirical data on discrimination in the labor market. Azmat, Güell and Manning (2006) investigate the gender gap in unemployment rates among OECD countries. The countries with the highest overall unemployment rates, Spain, Greece and Italy, are also the countries where the gap between female and male unemployment rates is largest (11.91%, 10.36% and 7.04%, respectively). Between 1960 and 2000, the development of unemployment rates within each of these countries also reveals that unequal treatment of men and women becomes larger when the overall unemployment rate increases. The Mediterranean countries and other OECD countries differ in many respects, which makes it possible to attribute the differences in the gender gap to a multitude of factors.[77] The consistency between these empirical data and our experimental evidence suggests that the result is parsimoniously explained by the lack or presence of competition between workers.

What are the welfare implications of our results? The Pareto efficiency criterion is silent about which equilibrium (in the competition case) is better; the equilibria facilitating discrimination and those without discrimination can not be ranked on this criterion. From the perspective of overall surplus in society, one would rather perversely conclude that when there is a scarcity of jobs, society is well served by discrimination. This holds

[76] In Competition, the difference between actual and equilibrium investments of disadvantaged workers in the second part of the experiment is significant (Sign rank test, p=0.03).

[77] For instance, Azmat et al. (2006) suggest that differences in flow from employment into unemployment and from unemployment into employment, as well as differences in human capital, contribute to explaining the differences in the gender gap.

because discrimination may efficiently solve the coordination problem of who acquires costly education. When one group of workers is ignored, the other group has higher incentives to invest in quality, which makes it more attractive to hire workers from this group. The maximization of overall surplus goes together with substantial social injustice, though. In our view, governments should consider affirmative action programs in such situations. The game with competition between workers may serve as a fruitful testbed to compare the effectiveness of various affirmative action programs.

4.7 Appendix A

In this appendix we briefly elaborate on the characterization of equilibria for the general case $\{r, w, P_q^h, P_u^h, G(c)\}$ (with $r, w > 0$ and $P_q^h > P_u^h$).

4.7.1 A.1 Setup without competition

With $\rho^*(\pi_i, \theta^{s_i})$ the probability of being hired after signal s_i, the color i worker prefers to invest as long as $c_i \leq w \cdot \left(P_q^h - P_u^h\right) \cdot \left[\rho^*\left(\pi_i, \theta^h\right) - \rho^*\left(\pi_i, \theta^l\right)\right]$. The r.h.s. can be understood as follows. $\left(P_q^h - P_u^h\right)$ gives the increase – due to investment – in the probability that the color i worker generates a high signal. The term within square brackets gives the increase in probability that the worker is hired if her signal is high rather than low. Together, the product of these two terms gives the increase in the probability that the worker is hired that is caused by investment. Multiplied by the benefits w of getting the job this in turn gives the expected benefits from investment. In equilibrium the color i worker invests as long as the costs of investment do not exceed the expected benefits, hence:

$$\pi_i^* = G\left(w \cdot \left(P_q^h - P_u^h\right) \cdot \left[\rho^*\left(\pi_i, \theta^h\right) - \rho^*\left(\pi_i, \theta^l\right)\right]\right) \tag{4.A.1}$$

From (4.4) and $P_u^h < P_q^h$ it follows that: (i) $\rho^*\left(\pi_i, \theta^h\right) < 1 \Longrightarrow \rho^*\left(\pi_i, \theta^l\right) = 0$ and (ii) $\rho^*\left(\pi_i, \theta^l\right) > 0 \Longrightarrow \rho^*\left(\pi_i, \theta^h\right) = 1$. If the employer considers the worker marginally capable at most after a high signal, he certainly thinks she is incapable after a low signal. Similarly so, if the employer considers the worker already marginally suitable at least when $\theta_i = \theta^l$, then he certainly thinks she is suitable after $\theta_i = \theta^h$. Based on these two observations Proposition A.1 below characterizes the possible equilibria that may exist. Recall that we assume throughout that the employer hires for sure when indifferent, implying $\rho^*(\pi_i, \theta^{s_i}) \in \{0, 1\}$ in the no competition case.

Proposition A.1. *The job market discrimination game without competition allows the following equilibria* $\left(\pi_g^*, \pi_p^*\right)$, *with* π_i^* *for* $i = g, p$ *independently taken from:*

(a) $\pi_i^* = 0$. The employer never hires the color i worker. No further requirements are needed;

(b) $\pi_i^* = G\left(w \cdot \left(P_q^h - P_u^h\right)\right)$. The employer only hires the color i worker if $\theta_i = \theta^h$. To justify the employer's hiring strategy it should hold that:

$$\left(\frac{1-\pi_i^*}{\pi_i^*}\right) \cdot \left(\frac{P_u^h}{P_q^h}\right) \leq r \leq \left(\frac{1-\pi_i^*}{\pi_i^*}\right) \cdot \left(\frac{1-P_u^h}{1-P_q^h}\right) \tag{4.A.2}$$

The parameters used in the experiment are such that condition $(4.A.2)$ is satisfied for $\pi_i^* = G\left(w \cdot \left(P_q^h - P_u^h\right)\right)$ and thus equilibrium (b) exists. This is obviously not a knife-edge case. To illustrate, let $G(c) \simeq U[0,C]$ (for $C > 0$) and let $w < \frac{C}{(P_q^h - P_u^h)}$. The model then contains five parameters $\{r, w, P_q^h, P_u^h, C\}$. For $\pi_i^* = \frac{w}{C} \cdot \left(P_q^h - P_u^h\right)$ condition $(4.A.2)$ becomes:

$$\left[\frac{1-\frac{w}{C} \cdot \left(P_q^h - P_u^h\right)}{\frac{w}{C} \cdot \left(P_q^h - P_u^h\right)}\right] \cdot \left(\frac{P_u^h}{P_q^h}\right) \leq r \leq \left[\frac{1-\frac{w}{C} \cdot \left(P_q^h - P_u^h\right)}{\frac{w}{C} \cdot \left(P_q^h - P_u^h\right)}\right] \cdot \left(\frac{1-P_u^h}{1-P_q^h}\right)$$

From $P_q^h > P_u^h$ it follows that $\left(\frac{P_u^h}{P_q^h}\right) < \left(\frac{1-P_u^h}{1-P_q^h}\right)$. For any given $\{\overline{w}, \overline{P}_q^h, \overline{P}_u^h, \overline{C}\}$ thus a nonnegligible range of r-values exists for which condition $(4.A.2)$ is satisfied. Given the continuity of the l.h.s. and the r.h.s., this also holds for parameters that are near $\{\overline{w}, \overline{P}_q^h, \overline{P}_u^h, \overline{C}\}$.

4.7.2 A.2 Setup with competition

Assuming that the employer always hires one of the workers when indifferent between hiring and not-hiring, the following general characterization can be given.

Proposition A.2. *The job market discrimination game with competition allows the following equilibria:*

(a) *Equilibria without discrimination*

(a.1) $\pi_i^* = 0$ for $i = g, p$. The employer never hires. No further requirements are needed;

(a.2) $\pi_i^* = G(w \cdot \left(P_q^h - P_u^h\right) \cdot [\left(\pi_i^* \cdot P_q^h + (1-\pi_i^*) \cdot P_u^h\right) \cdot \frac{1}{2} + (\pi_i^* \cdot \left(1-P_q^h\right) + (1-\pi_i^*) \cdot \left(1-P_u^h\right))])$ for $i = g, p$. The employer only hires a worker with $\theta_i = \theta^h$ and flips a fair coin if $\theta_g = \theta_p = \theta^h$. To justify the employer's hiring strategy condition $(4.A.2)$ should hold for $i = g, p$;

(a.3) $\pi_i^* = G\left(w \cdot \left(P_q^h - P_u^h\right) \cdot \left[\frac{1}{2}\right]\right)$ for $i = g, p$. The employer always hires the worker with the highest signal and flips a fair coin in case $\theta_g = \theta_p$. It should hold that $\left(\frac{1-\pi_i^*}{\pi_i^*}\right) \cdot \left(\frac{1-P_u^h}{1-P_q^h}\right) \leq r$ for $i = g, p$;

(b) *Equilibria with discrimination*

(b.1) $\pi_g^* = G\left(w \cdot \left(P_q^h - P_u^h\right)\right)$ and $\pi_p^* = 0$. The employer never hires a purple worker, the green worker is hired iff $\theta_g = \theta^h$. For $\pi_i^* = \pi_g^*$ condition $(4.A.2)$ should hold;

(b.2) $\pi_g^* = G\left(w \cdot \left(P_q^h - P_u^h\right)\right)$ and $\pi_p^* = G(w \cdot \left(P_q^h - P_u^h\right) \cdot [(\pi_g^* \cdot \left(1 - P_q^h\right) + (1 - \pi_g^*) \cdot \left(1 - P_u^h\right))])$. The employer hires the purple worker iff $\theta_p = \theta^h$ and $\theta_g = \theta^l$, and hires the green worker iff $\theta_g = \theta^h$. For both $\pi_i^* = \pi_g^*$ and $\pi_i^* = \pi_p^*$ condition $(4.A.2)$ should hold;

(b.3) $\pi_g^* = G\left(w \cdot \left(P_q^h - P_u^h\right) \cdot \left[\pi_p^* \cdot P_q^h + (1 - \pi_p^*) \cdot P_u^h\right]\right)$ and $\pi_p^* = G(w \cdot (P_q^h - P_u^h) \cdot [\pi_g^* \cdot (1 - P_q^h) + (1 - \pi_g^*) \cdot \left(1 - P_u^h\right)])$. The employer hires the purple worker iff $\theta_p = \theta^h$ and $\theta_g = \theta^l$, and hires the green worker otherwise. For $\pi_i^* = \pi_g^*$ it should hold that $\left(\frac{1-\pi_i^*}{\pi_i^*}\right) \cdot \left(\frac{1-P_u^h}{1-P_q^h}\right) \leq r$ and for $\pi_i^* = \pi_p^*$ it should hold that $\left(\frac{1-\pi_i^*}{\pi_i^*}\right) \cdot \left(\frac{P_u^h}{P_q^h}\right) \leq r$. Moreover, $\pi_g^* \geq \pi_p^*$ should hold.

The characterization of π_i^* follows from a similar expression as in $(4.A.1)$, where the term within square brackets reflects the increase in the probability of getting hired if $\theta_i = \theta^h$ instead of $\theta_i = \theta^l$. Compared to Proposition 3 in the main text, the possible equilibria (a.3), (b.2) and (b.3) are new. In the symmetric equilibrium (a.3) the employer always hires a worker, even when two low signals are received. The same applies for asymmetric equilibrium (b.3), but there the green worker is favored in case of equal signals. These two equilibria cannot exist when condition $(4.A.2)$ is satisfied for $\pi_i^* = G\left(w \cdot \left(P_q^h - P_u^h\right)\right)$, i.e. when an equilibrium with positive investment levels exists in the no-competition case.[78]

In asymmetric equilibrium (b.2) the employer does not hire when two low signals are observed. The green worker invests more often than the purple one, so when two high signals are observed the green worker is chosen. The purple worker is hired only if $\theta_p = \theta^h$ and $\theta_g = \theta^l$. Because condition $(4.A.2)$ now has to be satisfied for both $\pi_g^* = G\left(w \cdot \left(P_q^h - P_u^h\right)\right)$ and $\pi_p^* < G\left(w \cdot \left(P_q^h - P_u^h\right)\right)$, this equilibrium only exists in a strict subset of the cases for which equilibrium (b.1) exists. We chose our parameters as to exclude this equilibrium. This has the advantage that only one symmetric and one asymmetric equilibrium with investment co-exists. Both these equilibria have a simple structure and are well apart. By excluding equilibrium (b.2) we also avoid that our design is potentially biased in favor of observing discrimination. The issue whether to coordinate on a non-discriminatory or discriminatory outcome is thus particularly salient in our case.

[78]Note that $\left(\frac{1-\pi_i^*}{\pi_i^*}\right) \cdot \left(\frac{1-P_u^h}{1-P_q^h}\right)$ is strictly decreasing in π_i^*. So, if $r \leq \left(\frac{1-\pi_i^*}{\pi_i^*}\right) \cdot \left(\frac{1-P_u^h}{1-P_q^h}\right)$ for $\pi_i^* = G\left(w \cdot \left(P_q^h - P_u^h\right)\right)$, we have $r < \left(\frac{1-\pi_i^*}{\pi_i^*}\right) \cdot \left(\frac{1-P_u^h}{1-P_q^h}\right)$ for all $\pi_i^* < G\left(w \cdot \left(P_q^h - P_u^h\right)\right)$. The conditions in (a.3) and (b.3) thus cannot be satisfied at the same time.

4.7.3 A.3 Setup with competition and color blind employers

Assume that a fraction β (with $0 < \beta < 1$) of the employers is color blind and employs hiring strategy (4.6). Proposition A.3 below provides a general characterization of the discriminatory equilibria in that case, by describing the investment behavior of the workers and the hiring strategy of the remaining fraction $1-\beta$ of discriminatory employers.

Proposition A.3. *The job market discrimination game with competition and a fraction β of color blind employers allows the following discriminatory equilibria:*

(b.1) $\pi_g^* = G(w \cdot \left(P_q^h - P_u^h\right) \cdot [(1-\beta) + \beta \cdot (1 - \frac{1}{2} \cdot \left(\pi_p^* \cdot P_q^h + \left(1-\pi_p^*\right) \cdot P_u^h\right))])$ and $\pi_p^* = G(w \cdot \left(P_q^h - P_u^h\right) \cdot [\beta \cdot (1 - \frac{1}{2} \cdot \left(\pi_g^* \cdot P_q^h + \left(1-\pi_g^*\right) \cdot P_u^h\right))])$. The discriminating employer never hires a purple worker and hires the green worker iff $\theta_g = \theta^h$. For $\pi_i^* = \pi_g^*$ condition $(4.A.2)$ should hold and for $\pi_i^* = \pi_p^*$ it should hold that $r \leq \left(\frac{1-\pi_i^*}{\pi_i^*}\right) \cdot \left(\frac{P_u^h}{P_q^h}\right)$;

(b.2) $\pi_g^* = G(w \cdot \left(P_q^h - P_u^h\right) \cdot [(1-\beta) + \beta \cdot (1 - \frac{1}{2} \cdot \left(\pi_p^* \cdot P_q^h + \left(1-\pi_p^*\right) \cdot P_u^h\right))])$ and $\pi_p^* = G(w \cdot \left(P_q^h - P_u^h\right) \cdot [(1-\beta) \cdot \left(\pi_g^* \cdot \left(1-P_q^h\right) + \left(1-\pi_g^*\right) \cdot \left(1-P_u^h\right)\right) + \beta \cdot (1 - \frac{1}{2} \cdot \left(\pi_g^* \cdot P_q^h + \left(1-\pi_g^*\right) \cdot P_u^h\right))]$ The discriminating employer hires the purple worker iff $\theta_p = \theta^h$ and $\theta_g = \theta^l$, and hires the green worker iff $\theta_g = \theta^h$. For both $\pi_i^* = \pi_g^*$ and $\pi_i^* = \pi_p^*$ condition $(4.A.2)$ should hold;

(b.3) $\pi_g^* = G(w \cdot \left(P_q^h - P_u^h\right) \cdot [(1-\beta) \cdot (\pi_p^* \cdot P_q^h + (1-\pi_p^*) \cdot P_u^h) + \beta \cdot (1 - \frac{1}{2} \cdot \left(\pi_p^* \cdot P_q^h + \left(1-\pi_p^*\right) \cdot P_u^h\right))])$ and $\pi_p^* = G(w \cdot \left(P_q^h - P_u^h\right) \cdot [(1-\beta) \cdot (\pi_g^* \cdot \left(1-P_q^h\right) + \left(1-\pi_g^*\right) \cdot (1-P_u^h)) + \beta \cdot (1 - \frac{1}{2} \cdot \left(\pi_g^* \cdot P_q^h + \left(1-\pi_g^*\right) \cdot P_u^h\right))])$. The discriminating employer hires the purple worker iff $\theta_p = \theta^h$ and $\theta_g = \theta^l$, and hires the green worker otherwise. For $\pi_i^* = \pi_g^*$ it should hold that $\left(\frac{1-\pi_i^*}{\pi_i^*}\right) \cdot \left(\frac{1-P_u^h}{1-P_q^h}\right) \leq r$ and for $\pi_i^* = \pi_p^*$ it should hold that $\left(\frac{1-\pi_i^*}{\pi_i^*}\right) \cdot \left(\frac{P_u^h}{P_q^h}\right) \leq r$. Moreover, $\pi_g^* \geq \pi_p^*$ should hold.

The characterization of workers' investment behavior again follows from a similar expression as in $(4.A.1)$, where the term within square brackets reflects the increase in the probability of getting hired if $\theta_i = \theta^h$ instead of $\theta_i = \theta^l$. This term now consists of two elements. With probability $1-\beta$ the worker faces a discriminating employer and the probability of getting hired after $\theta_i = \theta^h$ instead of $\theta_i = \theta^l$ equals the one as in Proposition A.2 for the corresponding case (this explains why we use the labels (b.1) through (b.3) in Proposition A.3 as well). With probability β, worker i faces a color blind employer and the increase in the probability of getting hired after $\theta_i = \theta^h$ instead of $\theta_i = \theta^l$ equals $(1 - \frac{1}{2} \cdot \left(\pi_j^* \cdot P_q^h + \left(1-\pi_j^*\right) \cdot P_u^h\right))$. The latter follows because with probability $\left(\pi_j^* \cdot P_q^h + \left(1-\pi_j^*\right) \cdot P_u^h\right)$ the competitor j generates a high signal as well and the employer then chooses each worker with equal probabilities. The overall term is simply the probability weighted average of the two elements.

Just as in the absence of color blind employers (cf. Appendix A.2), equilibrium (b.3) does not exist when condition $(4.A.2)$ is satisfied for $\pi_i^* = G(w \cdot (P_q^h - P_u^h))$. This is the case considered in the experiment. Equilibrium (b.1) only exists when the fraction of color blind employers β is not too large. This holds because π_p^* should be sufficiently low such that never hiring the purple worker is indeed a best response for the discriminating employer. For the parameters used in the experiment $\{r, w, P_q^h, P_u^h, G(c)\} = \{\frac{2}{3}, 150, \frac{3}{4}, \frac{1}{4}, U[0,100]\}$ it should hold that $\pi_p^* \leq \frac{1}{3}$, which is the case for $\beta \leq 0.624$.[79] In a similar vein, in equilibrium (b.2) the discriminating employer should be willing to hiring the purple worker after $\theta_p = \theta^h$, i.e. $\pi_p^* \geq \frac{1}{3}$ is needed. This requires a sufficiently high fraction of color blind employers $\beta \geq 0.181$.[80] Therefore, for $0.181 \leq \beta \leq 0.624$ the two types of equilibria co-exist.

4.8 Appendix B

In this appendix we consider the setup with competition assuming a continuous signaling technology. The single difference with Subsection 2.2 is that $\theta_i \in [\theta^l, \theta^h]$ instead of $\theta_i \in \{\theta^l, \theta^h\}$. As in Coate and Loury (1993) we assume w.l.o.g. that $[\theta^l, \theta^h] = [0,1]$. Let $F_q(\theta)$ $[F_u(\theta)]$ be the probability distribution of θ in case the worker is qualified [unqualified] and $f_q(\theta)$ $[f_u(\theta)]$ the corresponding density. We assume that the likelihood ratio at θ given by $\varphi(\theta) \equiv \frac{f_u(\theta)}{f_q(\theta)}$ is monotonically decreasing, implying $F_q(\theta) \leq F_u(\theta)$ for all $\theta \in [0,1]$ and that φ^{-1} exists. We also assume $\varphi(1) > 0$, i.e. there exists no signal that provides conclusive evidence that the worker is qualified for sure. The posterior belief $\xi(\pi_i, \theta_i)$ that a color i worker with prior π_i and signal θ_i is qualified is given by expression (3) in the main text when we replace φ^{s_i} by $\varphi(\theta_i)$ (and $P_q^{s_i}$ $[P_u^{s_i}]$ by $f_q(\theta_i)$ $[f_u(\theta_i)]$). Similarly so, with $\varphi(\theta_i)$ instead of φ^{s_i} and $\varphi(\theta_j)$ instead of φ^{s_j} the employer's hiring strategy is given by (5). From $\varphi(\theta_i)$ decreasing the employer considers the color i worker a serious candidate for the job if:

$$\theta_i \geq s^*(\pi_i) \equiv \min\left\{\theta \in [0,1] \,\middle|\, \left(\frac{1-\pi_i}{\pi_i}\right)\varphi(\theta) \leq r\right\}$$

[79] For the parameters used in the experiment the equilibrium level of π_p^* in equilibrium (b.1) equals:

$$\pi_p^* = \frac{\frac{11}{4}\beta + \frac{3}{32}\beta^2}{\frac{16}{3} - \frac{3}{16}\beta^2}$$

[80] For the parameters used in the experiment the equilibrium level of π_p^* in equilibrium (b.2) equals:

$$\pi_p^* = \frac{\left(\frac{3}{4} + \frac{1}{8}\beta\right) - \frac{3}{8}\left(1 - \frac{1}{2}\beta\right)\left(1 - \frac{1}{8}\beta\right)}{\frac{4}{3} - \frac{3}{32}\left(1 - \frac{1}{2}\beta\right)\beta}$$

$s^*(\pi_i)$ thus denotes the minimum signal needed for the color i worker to be seen as 'hirable'. With competition a high enough signal is not enough though to get the job, candidate i should also appear as being better than his competitor j; $\xi(\pi_i,\theta_i) \geq \xi(\pi_j,\theta_j)$. This is the case if:

$$\theta_i \geq b^*(\theta_j;\pi_i,\pi_j) \equiv \min\left\{\theta \in [0,1] \middle| \left(\frac{1-\pi_i}{\pi_i}\right)\varphi(\theta) \leq \left(\frac{1-\pi_j}{\pi_j}\right)\varphi(\theta_j)\right\}$$

The probability that a green worker is hired if he invests then equals:

$$\begin{aligned} H_{g,q} &\equiv \int_{s^*(\pi_g)}^{1} f_q(\theta_g)\cdot\left[\int_0^{b^*(\theta_g;\pi_p,\pi_g)} \left(\pi_p f_q(\theta_p)+(1-\pi_p)f_u(\theta_p)\right)d\theta_p\right]d\theta_g \\ &= \int_{s^*(\pi_g)}^{1} f_q(\theta_g)\cdot\sigma^*(\theta_g;\pi_g,\pi_p)d\theta_g \end{aligned}$$

The term within square brackets represents the probability that for a given signal θ_g the green worker is considered the best candidate available, i.e. the probability that the purple's signal θ_p is below the threshold $b^*(\theta_g;\pi_p,\pi_g)$. (We denote this probability as $\sigma^*(\theta_g;\pi_g,\pi_p)$.) The overall expression just integrates these over the relevant values of θ_g that surpass the employer's hiring threshold $s^*(\pi_g)$, weighted by their respective probability $f_q(\theta_g)$ of occurrence. The expression for $H_{g,u}$ in case the green worker does not invest is immediately obtained when the probability weights $f_q(\theta_g)$ are replaced by $f_u(\theta_g)$. The green worker will invest whenever $c \leq w\cdot\left(H_{g,q}-H_{g,u}\right)$.

In equilibrium, the employer's ex ante beliefs about the ex ante probabilities of investment (π_g,π_p) should be correct. This requires for the green worker:

$$\begin{aligned} \pi_g &= G\left(w\cdot\int_{s^*(\pi_g)}^{1}\left(f_q(\theta_g)-f_u(\theta_g)\right)\cdot\sigma^*(\theta_g;\pi_g,\pi_p)d\theta_g\right) && (4.7) \\ &\equiv \widehat{G}_g(\pi_g,\pi_p) && (4.8) \end{aligned}$$

The requirement for the purple worker follows from swapping subscripts g and p; denote this requirement as $\pi_p = \widehat{G}_p(\pi_p,\pi_g)$.

Together the two equilibrium conditions form a system that in general allows multiple solutions (π_g^*,π_p^*), possibly both symmetric and asymmetric ones. We are particularly interested in the stability of these equilibria. We thus postulate a dynamic adjustment process $\pi_g^{t+1} = \widehat{G}_g(\pi_g^t,\pi_p^t)$ and $\pi_p^{t+1} = \widehat{G}_p(\pi_p^t,\pi_g^t)$ and investigate how this process evolves when starting at values (π_g^0, π_p^0) "close to" the equilibrium (π_g^*, π_p^*) in question. This process converges to (π_g^*, π_p^*) if the two eigenvalues of the Jacobian J evaluated in (π_g^*, π_p^*) are smaller than one in absolute value, with:

$$J = \begin{pmatrix} \frac{\partial \widehat{G}_g(\pi_g,\pi_p)}{\partial \pi_g} & \frac{\partial \widehat{G}_g(\pi_g,\pi_p)}{\partial \pi_p} \\ \frac{\partial \widehat{G}_p(\pi_p,\pi_g)}{\partial \pi_g} & \frac{\partial \widehat{G}_p(\pi_p,\pi_g)}{\partial \pi_p} \end{pmatrix}_{(\pi_g,\pi_p)=(\pi_g^*,\pi_p^*)}$$

As in the main text, we focus on equilibria with $\pi_g \geq \pi_p$. A first observation is that $0 < \pi_i^* < \frac{\varphi(1)}{\varphi(1)+r}$ cannot occur in equilibrium. This holds because $s^*(\pi_i) = 1$ for all $\pi_i < \frac{\varphi(1)}{\varphi(1)+r}$ and thus the employer is unwilling to hire the color i worker even when $\theta_i = 1$. In a similar vein it follows that $\widehat{G}_i(\pi_i, \pi_j) = 0$ for all $\pi_i < \frac{\varphi(1)}{\varphi(1)+r}$. Thus, for $\pi_g^* = \pi_p^* = 0$ the Jacobian J equals the null matrix and the equilibrium in which neither color invests is stable.

Finding positive solutions to equation (4.7) and evaluating J for the general case is elusive. We therefore focus on a specific, yet flexible parameterization for which we can find (some) tractable solutions. Assume $F_u(\theta) = \theta$ and $F_q(\theta) = \theta^k$, with $k > 1$. In that case $f_u(\theta) = 1$, $f_q(\theta) = k \cdot \theta^{k-1}$ and $\varphi(\theta) \equiv \frac{f_u(\theta)}{f_q(\theta)} = \frac{1}{k} \cdot \theta^{1-k}$.[81] Here parameter k reflects the accuracy of the signaling technology; the higher k is, the more likely it becomes that a qualified worker generates a high signal. For convenience, let $G(c) \simeq U[0, \frac{1}{\gamma}w]$ for some $\gamma > 0$.

We consider two types of equilibria: asymmetric equilibria in which the purple worker does not invest and symmetric equilibria in which the two colors invest with equal probabilities.[82] First suppose $\pi_g^* \geq \frac{1}{1+rk} > \pi_p^* = 0$. In that case the green worker is always considered the best candidate, i.e. $\sigma^*(\theta_g; \pi_g, \pi_p) = 1$. From (4.7) we then obtain:

$$\widehat{G}_g(\pi_g, 0) = \gamma \cdot \left[F_u(s^*(\pi_g)) - F_q(s^*(\pi_g)) \right]$$

Hence $\widehat{G}_g(\pi_g, 0) \geq 0$, with $\widehat{G}_g(\frac{1}{1+rk}, 0) = 0 < \frac{1}{1+rk}$ and $\widehat{G}_g(1, 0) = 0$. Taking the derivative we get:

$$\begin{aligned} \frac{\partial \widehat{G}_g(\pi_g, 0)}{\partial \pi_g} &= \gamma \cdot \left(f_u(s^*(\pi_g)) - f_q(s^*(\pi_g)) \right) \cdot \frac{\partial s^*(\pi_g)}{\partial \pi_g} \\ &= \gamma \cdot \left(1 - \left(\frac{1-\pi_g}{\pi_g} \right) \cdot \frac{1}{r} \right) \cdot \frac{\partial s^*(\pi_g)}{\partial \pi_g} \end{aligned}$$

[81]From $k > 1$ we have $\frac{\partial \varphi}{\partial \theta} < 0$. The inverse likelihood ratio equals $\varphi^{-1}(\eta) = (k \cdot \eta)^{\frac{1}{1-k}}$. With φ^{-1} homogenous (of degree $\frac{1}{1-k}$), a convenient property is that $\varphi^{-1}(\alpha \cdot \varphi(\theta)) = a^{\frac{1}{1-k}} \cdot \theta$.

[82]Note that we only focus on asymmetric equilibria with $\pi_g^* = \pi^* > 0$ and $\pi_p^* = 0$, i.e. equilibria is which the purple worker does not invest at all. In general, asymmetric equilibria with $\pi_g^* > \pi_p^* > 0$ may potentially exist as well.

From $\frac{\partial s^*(\pi_g)}{\partial \pi_g} < 0$ on the relevant range $\left[\frac{1}{1+rk}, 1\right]$ we obtain that $\widehat{G}_g(\pi_g, 0)$ increases for $\pi_g < \frac{1}{1+r}$ and decreases for $\pi_g > \frac{1}{1+r}$.[83] Moreover, $\widehat{G}_g(\pi_g, 0)$ is concave on $\pi_g \in \left[\frac{1}{1+rk}, \frac{1}{1+r}\right]$, see Appendix 4.5 at the end. Therefore, either no or (generically) two solutions to $\pi_g = \widehat{G}_g(\pi_g, 0)$ exist. Because $\widehat{G}_g(\pi_g, 0)$ increases with k and equals zero for $k = 1$,[84] there exists a $k^E(r,\gamma) > 1$ such that for $k \geq k^E(r,\gamma)$ two asymmetric equilibria exist. The lower one is necessarily below $\frac{1}{1+r}$ and decreases with k. This equilibrium is necessarily unstable, because there $\widehat{G}_g(\pi_g, 0)$ approaches the π_g-line from below. The higher solution to $\pi_g = \widehat{G}_g(\pi_g, 0)$ increases with k and may be stable, especially when k is relatively low and the solution π_g^* is close to $\frac{1}{1+r}$. Below we verify the stability of this equilibrium by numerically calculating (the eigenvalues of) Jacobian J.

Second, consider symmetric equilibria with $\pi_g^* = \pi_p^* = \pi^* \geq \frac{1}{1+rk}$. Existence follows from looking at the solutions to $\pi_g = \widehat{G}_g(\pi_g, \pi_g)$. For $\pi_p = \pi_g$ we have from (4.7) that:

$$\begin{aligned}
\widehat{G}_g(\pi_g, \pi_g) &= \gamma \cdot \int_{s^*(\pi_g)}^{1} \left(f_q(\theta_g) - f_u(\theta_g)\right) \cdot \left[\int_0^{\theta_g} \pi_g f_q(\theta_p) + (1-\pi_g) f_u(\theta_p)\, d\theta_p\right] d\theta_g \\
&= \gamma \cdot \int_{s^*(\pi_g)}^{1} \left(f_q(\theta_g) - f_u(\theta_g)\right) \cdot \left[\pi_g \cdot F_q(\theta_g) + (1-\pi_g) \cdot F_u(\theta_g)\right] d\theta_g
\end{aligned}$$

It holds that $\widehat{G}_g(\frac{1}{1+rk}, \frac{1}{1+rk}) = 0$ and $\widehat{G}_g(1,1) = \gamma\left(\frac{1}{2} - \frac{1}{k+1}\right) > 0$. The function $\widehat{G}_g(\pi_g, \pi_g)$ has similar properties as $\widehat{G}_g(\pi_g, 0)$. In particular, it is increasing for $\pi_g \leq \overline{\pi}(r,\gamma) < \frac{1}{1+r}$ and decreasing for $\pi_g > \overline{\pi}(r,\gamma)$. Moreover, it is concave on $\pi_g \in \left[\frac{1}{1+rk}, \frac{1}{1+r}\right]$ (cf. Appendix B.1). Therefore, either no or (generically) two symmetric equilibria exist.[85] From (4.7) it follows that for $\pi_g \leq \frac{1}{1+r}$, necessarily $\widehat{G}_g(\pi_g, \pi_g) \leq \widehat{G}_g(\pi_g, 0)$.[86] This implies in turn that, whenever a symmetric equilibrium exists, necessarily two asymmetric ones (with $\pi_p^* = 0$) exist as well.

[83]For our parameterization $s^*(\pi_i) = \left(\frac{\pi_i}{1-\pi_i} \cdot rk\right)^{\frac{1}{1-k}}$ for $\pi_i \geq \frac{\varphi(1)}{\varphi(1)+r} = \frac{1}{1+rk}$ and $s^*(\pi_i) = 1$ for $0 \leq \pi_i < \frac{1}{1+rk}$. On the relevant range $\pi_i \geq \frac{1}{1+rk}$ it holds that $s^*(\pi_i)$ is strictly decreasing in π_i and strictly increasing in k. (For the latter, note that $\frac{\partial s^*(\pi_i)}{\partial k} = \frac{s^*(\pi_i)}{(1-k)^2} \cdot \left[\ln\left(\frac{\pi_i}{1-\pi_i} \cdot rk\right) + \frac{1}{k} - 1\right]$; the term within square brackets is non-negative and increasing in k for $\pi_i \geq \frac{1}{1+rk}$ and $k \geq 1$.)

[84]To see this, let $z(k;\alpha) = (\alpha k)^{\frac{1}{1-k}} - (\alpha k)^{\frac{k}{1-k}}$ (such that $\widehat{G}_g(\pi_g, 0) = \gamma \cdot z(k; \frac{\pi_g r}{1-\pi_g})$). Then $\frac{\partial z}{\partial k} = \frac{(\alpha k)^{\frac{k}{1-k}}}{(1-k)^2} \cdot [(\alpha k - 1) \cdot \ln \alpha k + (\alpha - 1) \cdot (1-k)]$. The term within square brackets is positive for all $\alpha \geq \frac{1}{k}$ (for $\alpha \leq 1$ this is immediate upon inspection, for $\alpha \geq 1$ this follows from observing that the term is increasing in α in that range).

[85]Note that if $\gamma\left(\frac{1}{2} - \frac{1}{k+1}\right) > 1$, the second (i.e. the higher) equilibrium is the corner solution $\pi_g^* = \pi_p^* = 1$.

[86]This follows because for for $\pi_g \leq \frac{1}{1+r}$ it holds that $f_q(\theta_g) - f_u(\theta_g) \geq 0$ for all $\theta_g \geq s^*(\pi_g)$, and in $\widehat{G}_g(\pi_g, \pi_g)$ these positive terms are weighted by factors smaller than one (while in $\widehat{G}_g(\pi_g, 0)$ they are weighted by one).

Table 4.5: Overview of asymmetric and symmetric equilibria

Table 4.B.1: Overview of asymmetric and symmetric equilibria

	$\pi_g^* = \pi^* > 0$ and $\pi_p^* = 0$		$\pi_g^* = \pi_p^* = \pi^* > 0$	
k	π^*_{Low}	π^*_{High}	π^*_{Low}	π^*_{High}
2	–	–	–	–
3	0.444	0.575^S	–	–
4	0.331	0.689^S	0.343	0.534
5	0.270	0.756^S	0.274	0.596
6	0.229	0.805^S	0.230	0.635
7	0.199	0.842^S	0.200	0.664
8	0.176	0.873^S	0.176	0.686
9	0.157	0.897	0.158	0.703
10	0.142	0.917	0.143	0.717
20	0.073	0.995	0.073	0.783

Remarks: Based on parameters used in experiment: $\gamma = \frac{3}{2}$ and $r = \frac{2}{3}$.

Only those equilibria with superscript S are stable.

For the symmetric equilibria the Jacobian J, evaluated in the equilibrium point, is symmetric. The eigenvalues λ_1 and λ_2 thus equal:

$$
\begin{aligned}
\lambda_1 &= \left(\frac{\partial \widehat{G}_g(\pi_g, \pi_p)}{\partial \pi_g} + \frac{\partial \widehat{G}_g(\pi_g, \pi_p)}{\partial \pi_p} \right)_{(\pi_g, \pi_p) = (\pi^*, \pi^*)} \\
\lambda_2 &= \left(\frac{\partial \widehat{G}_g(\pi_g, \pi_p)}{\partial \pi_g} - \frac{\partial \widehat{G}_g(\pi_g, \pi_p)}{\partial \pi_p} \right)_{(\pi_g, \pi_p) = (\pi^*, \pi^*)}
\end{aligned}
$$

Note that for $\pi_p = \pi_g$, the first eigen value λ_1 corresponds to $\frac{\partial \widehat{G}_g(\pi_g, \pi_g)}{\partial \pi_g}$. For the lower equilibrium solution it holds that $\frac{\partial \widehat{G}_g(\pi_g, \pi_g)}{\partial \pi_g}$ evaluated in π^* exceeds one (because there $\widehat{G}_g(\pi_g, \pi_g)$ approaches the π_g-line from below). Hence $\lambda_1 > 1$ and the equilibrium is unstable. The stability of the higher equilibrium solution can be determined by numerically calculating λ_1 and λ_2.

Table 4.5 provides an overview of the asymmetric and symmetric equilibria for the parameter values $\gamma = \frac{3}{2}$ and $r = \frac{2}{3}$ used in the experiment. It does so for various levels of k, i.e. for various precision levels of the signaling technology. By means of a superscript S the table also identifies the stable equilibria.

For low levels of k no equilibrium with positive investment levels exists. The intuition here is that if the signaling technology is very noisy, it is too difficult for a qualified worker to convince the employer that she is worth hiring. For higher values of k the signaling technology becomes more accurate and the employer is more easily convinced in case a high signal is observed. Asymmetic equilibria exist for a larger range of k-values than symmetric equilibria do. The asymmetric equilibrium based on $\pi^* = \pi^*_{High}$ is stable for intermediate k-values, while for the symmetric equilibrium this is not the case. Hence for a nonneglible range of k-values asymmetric and symmetric equilibria both exist, but only the asymmetric equilibrium (based on π^*_{High}) is stable. In terms of equilibrium investment levels, the case of $k = 5$ comes closest to the discrete setup considered in the experiment (with respectively $\pi^* = 0.750$ and $\pi^* = 0.553$); this case belongs to the relevant range.

Overall we conclude that the instability of the symmetric investment equilibrium under competition is not an artefact of the discrete signaling technology used in the experiment. Also with a continuous signaling technology it may very well happen that only some of the asymmetric investment equilibria are stable.

4.8.1 Appendix B.1: Concavity of $\widehat{G}_g(\pi_g, 0)$ and $\widehat{G}_g(\pi_g, \pi_g)$

We first show that $\widehat{G}_g(\pi_g, 0)$ is concave on $\pi_g \in \left[\frac{1}{1+rk}, \frac{1}{1+r}\right]$. From the expression for $\frac{\partial \widehat{G}_g(\pi_g,0)}{\partial \pi_g}$ we obtain:

$$\frac{\partial^2 \widehat{G}_g(\pi_g,0)}{\partial \pi_g^2} = \frac{\gamma}{r \cdot \pi_g^2} \cdot \frac{\partial s^*(\pi_g)}{\partial \pi_g} + \gamma\left(1 - \left(\frac{1-\pi_g}{\pi_g}\right) \cdot \frac{1}{r}\right) \cdot \frac{\partial^2 s^*(\pi_g)}{\partial \pi_g^2}$$

From $s^*(\pi_g) = \left(\frac{\pi_g}{1-\pi_g} \cdot rk\right)^{\frac{1}{1-k}}$ we have $\frac{\partial s^*(\pi_g)}{\partial \pi_g} = \frac{1}{1-k} \cdot s^*(\pi_g) \cdot \frac{1}{\pi_g \cdot (1-\pi_g)}$ and therefore:

$$\begin{aligned}
\frac{\partial^2 s^*(\pi_g)}{\partial \pi_g^2} &= \frac{1}{1-k} \cdot \frac{1}{\pi_g \cdot (1-\pi_g)} \cdot \frac{\partial s^*(\pi_g)}{\partial \pi_g} \\
&\quad + \frac{1}{1-k} \cdot s^*(\pi_g) \cdot \frac{(2\pi_g - 1)}{\pi_g^2 \cdot (1-\pi_g)^2} \\
&= \left[\frac{1}{1-k} \cdot \frac{1}{\pi_g \cdot (1-\pi_g)} + \frac{(2\pi_g - 1)}{\pi_g \cdot (1-\pi_g)}\right] \cdot \frac{\partial s^*(\pi_g)}{\partial \pi_g} \\
&= \left[2\pi_g - \frac{k}{k-1}\right] \cdot \frac{1}{\pi_g \cdot (1-\pi_g)} \cdot \frac{\partial s^*(\pi_g)}{\partial \pi_g}
\end{aligned}$$

Plugging this into the expression for $\frac{\partial^2 \widehat{G}_g(\pi_g,0)}{\partial \pi_g^2}$ we obtain after rearranging that:

$$\frac{\partial^2 \widehat{G}_g(\pi_g,0)}{\partial \pi_g^2} = \frac{\gamma \cdot \frac{\partial s^*(\pi_g)}{\partial \pi_g}}{r \cdot \pi_g^2 \cdot (1-\pi_g)} \left\{(1-\pi_g) + (\pi_g \cdot (1+r) - 1) \cdot \left[2\pi_g - \frac{k}{k-1}\right]\right\}$$

The term within curley brackets reaches its minimum for $\pi_g = \widehat{\pi}_g \equiv \frac{3}{4(1+r)} + \frac{1}{4} \cdot \frac{k}{k-1} > \frac{1}{1+r}$, and is decreasing for $\pi_g < \widehat{\pi}_g$ and increasing for $\pi_g > \widehat{\pi}_g$. At $\pi_g = \frac{1}{1+r}$ it equals $\frac{r}{1+r}$, hence for all $\pi_g \leq \frac{1}{1+r}$ it is strictly positive. This implies that $\widehat{G}_g(\pi_g, 0)$ is concave on $\left[\frac{1}{1+rk}, \frac{1}{1+r}\right]$.

We next show that $\widehat{G}_g(\pi_g,\pi_g)$ is increasing for $\pi_g \leq \overline{\pi}(r,\gamma) < \frac{1}{1+r}$ and decreasing for $\pi_g > \overline{\pi}(r,\gamma)$. From the expression for $\widehat{G}_g(\pi_g,\pi_g)$ we obtain:

$$\begin{aligned}
\frac{\partial \widehat{G}_g(\pi_g,\pi_g)}{\partial \pi_g} &= -\gamma \cdot \left(f_q(s^*(\pi_g)) - f_u(s^*(\pi_g))\right) \\
&\quad \cdot \left[\pi_g \cdot F_q(s^*(\pi_g)) + (1-\pi_g)\cdot F_u(s^*(\pi_g))\right] \cdot \frac{\partial s^*(\pi_g)}{\partial \pi_g} \\
&\quad + \gamma \cdot \left[\int_{s^*(\pi_g)}^{1} \left(\left(f_q(\theta_g) - f_u(\theta_g)\right) \cdot \left(F_q(\theta_g) - F_u(\theta_g)\right) \, d\theta_g \right] \\
&= \frac{\partial \widehat{G}_g(\pi_g,0)}{\partial \pi_g} \cdot \left[\pi_g \cdot F_q(s^*(\pi_g)) + (1-\pi_g)\cdot F_u(s^*(\pi_g))\right] \\
&\quad - \gamma \cdot \frac{1}{2}\left(F_q(s^*(\pi_g)) - F_u(s^*(\pi_g))\right)^2
\end{aligned}$$

Therefore, $\frac{\partial \widehat{G}_g(\pi_g,\pi_g)}{\partial \pi_g} < 0$ whenever $\frac{\partial \widehat{G}_g(\pi_g,0)}{\partial \pi_g} < 0$. In particular, $\widehat{G}_g(\pi_g,\pi_g)$ is certainly decreasing for $\pi_g \geq \frac{1}{1+r}$.Concavity on $\pi_g \in \left[\frac{1}{1+rk}, \frac{1}{1+r}\right]$ follows from observing that:

$$\begin{aligned}
\frac{\partial^2 \widehat{G}_g(\pi_g,\pi_g)}{\partial \pi_g^2} &= \frac{\partial^2 \widehat{G}_g(\pi_g,0)}{\partial \pi_g^2} \cdot \left[\pi_g \cdot F_q(s^*(\pi_g)) + (1-\pi_g)\cdot F_u(s^*(\pi_g))\right] \\
&\quad + \frac{\partial \widehat{G}_g(\pi_g,0)}{\partial \pi_g} \cdot \left(f_q(s^*(\pi_g)) + (1-\pi_g)\cdot f_u(s^*(\pi_g))\right) \cdot \frac{\partial s^*(\pi_g)}{\partial \pi_g} \\
&\quad + 2 \cdot \frac{\partial \widehat{G}_g(\pi_g,0)}{\partial \pi_g} \cdot \left(F_q(s^*(\pi_g)) - F_u(s^*(\pi_g))\right)
\end{aligned}$$

For $\pi_g < \frac{1}{1+r}$ all three terms on the r.h.s. are negative, so $\frac{\partial^2 \widehat{G}_g(\pi_g,\pi_g)}{\partial \pi_g^2} < 0$ on $\pi_g \in \left[\frac{1}{1+rk}, \frac{1}{1+r}\right]$.

4.9 Appendix C: Instructions

This appendix contains the instructions used in the Competition treatment of the experiment, both for employers are for workers. The instructions used in the No Competition treatment are similar.

4.9.1 Instructions for employers in Competition

Welcome to this experiment on decision-making. Please read the following instructions carefully. As soon as everyone has finished reading the instructions you will receive a handout with a summary. During the experiment you will be asked to make a number of decisions. Your decisions and those of other participants will determine your earnings. At the start of the experiment you will receive a starting capital of 900 points. In addition you will earn money with your decisions. The experiment consists of 50 rounds. During the experiment, your earnings will be denoted in points. Your earnings in the experiment equal the sum of the starting capital and your earnings in the 50 rounds. At the end of the experiment, your earnings in points will be transferred into money. For each point you earn, you will receive 1 euro cent. Hence, 100 points are equal to 1 euro. Your earnings will be privately paid to you in cash.

ROLES

Some participants have the role of EMPLOYER, some participants perform the role of PURPLE WORKER and some have the role of GREEN WORKER. In all 50 rounds you keep the same role and, if you are a worker, the same color.

Your role is: EMPLOYER

DECISIONS

In each round, each employer is matched with a GREEN and a PURPLE worker. The employer decides to hire either nobody, the green worker or the purple worker. The employer thus cannot hire both workers at the same time. The employer receives a positive payoff if s/he hires a worker who invested in her/his productivity, but receives a negative payoff if s/he hires a worker who did not invest in her/his productivity. If the employer hires nobody, s/he receives a small positive payoff. A worker earns a positive payoff if s/he is hired. If a worker is not hired, s/he earns a small positive payoff. S/He incurs a COST if s/he invests in her/his productivity, independently of whether or not s/he is hired. At the time the employer has to make the hiring decision, s/he is not informed about the investment decisions of the two workers. Instead, s/he receives a signal of the green worker and a signal of the purple worker that corresponds to the investment decisions of these workers in the following way.

If the worker invested, her/his signal is HIGH with probability 75% and it is LOW with probability 25%. If the worker did not invest, her/his signal is HIGH with probability 25% and it is LOW with probability 75%. So the signal is often but not always in agreement with the investment decision. The worker's probability that a signal is high or low does not depend on any other worker's probability that her/his signal was high or low. Also, the probability that a worker's signal is high or low is independent of decisions made by the worker in any previous round.

At the start of a round, each worker is informed of the own COST of investing. This cost will be a random number between 0 and 100 points. Each of these numbers is equally likely. In each round, every worker is assigned a new (and independent) cost level. Therefore, the different workers (most likely) have different costs in a round, and the same worker (most likely) has different costs across rounds.

PAYOFFS

The workers' investment decisions and the employer's hiring decision lead to the following payoffs:

(i) Payoff employer after hiring = 60 if hired worker invested.

(ii) Payoff employer after hiring = -40 if hired worker did not invest.

(iii) Payoff employer after not hiring = 20 (independent of workers' investment decisions).

(iv) Payoff worker after investing = 160 - cost if hired by employer.

(v) Payoff worker after investing = 10 - cost if not hired by employer.

(vi) Payoff worker after not investing = 160 if hired by employer.

(vii) Payoff worker after not investing = 10 if not hired by employer.

Notice that there are no differences in the rules for green and purple workers. In particular, there are no differences in the green worker's and purple worker's probabilities of good and bad signals. Also, the cost of investing is determined with the same procedure for the two groups of workers and the payoffs are also determined in exactly the same way.

SEQUENCE OF EVENTS

Summarizing, each round is characterized by the following sequence of events:

1. The workers are privately informed of the own cost of investment.
2. Each worker decides whether or not to invest.
3. The employer observes a high or low signal for each worker, but not the workers' investment decisions.
4. The employer decides to hire nobody, the green worker or the purple worker. Then employer and workers receive payoffs based on the choices made.

MATCHING PROCEDURE

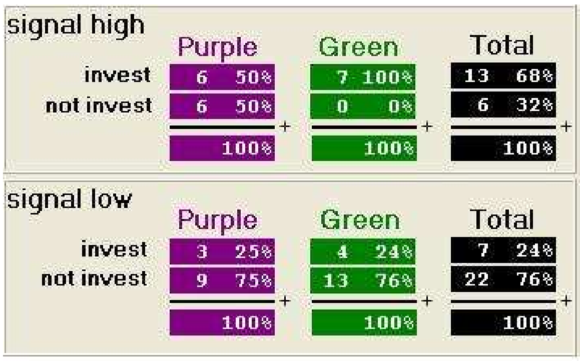
In each round, each employer will be randomly matched to another green worker and another purple worker. You will never learn with whom you are matched. The random matching scheme is chosen such that three participants will never be coupled again in two subsequent rounds.

INFORMATION END OF ROUND

At the end of a round, each participant will be informed of the choices of the participants with whom s/he is matched and the own payoff.

HISTORY OVERVIEW

The lower part of the screen provides an overview of the results of all rounds already completed. Apart from your own results in the previous rounds, the history overview also contains the results of 3 other employers. In total, you are thus informed about the past results of the same group of 4 employers (one of which is yourself) and 8 workers. Below you see an example of the history overview (with arbitrary numbers).



The upper part of the history overview shows what happened in the cases where employers received a HIGH signal. The row INVEST lists the number of cases in which the worker's signal was HIGH after investing. The row NOT INVEST lists the number of cases in which the worker's signal was HIGH after not investing. In the first purple column, the results for only the purple workers are listed and in the second green column the results for only the green workers are listed. In the final column the results of the two groups of workers are combined. In each cell, after the number the corresponding percentage is listed. The lower part of the history overview summarizes the previous choices of workers whose signal was LOW. (Workers observe a history overview that is organized in another way: they observe the number of times purple, green and combined workers are hired, separated for having made an investment or not.)

4.9.2 Instructions for workers in Competition

Welcome to this experiment on decision-making. Please read the following instructions carefully. As soon as everyone has finished reading the instructions you will receive a handout with a summary. During the experiment you will be asked to make a number of decisions. Your decisions and those of other participants will determine your earnings. At the start of the experiment you will receive a starting capital of 900 points. In addition you will earn money with your decisions. The experiment consists of 50 rounds. During the experiment, your earnings will be denoted in points. Your earnings in the experiment equal the sum of the starting capital and your earnings in the 50 rounds. At the end of the experiment, your earnings in points will be transferred into money. For each point you earn, you will receive 1 euro cent. Hence, 100 points are equal to 1 euro. Your earnings will be privately paid to you in cash.

ROLES

Some participants have the role of EMPLOYER, some participants perform the role of PURPLE WORKER and some have the role of GREEN WORKER. In all 50 rounds you keep the same role and, if you are a worker, the same color.

Your role is: WORKER

You will learn at the start of the experiment whether you are a green or purple worker.

DECISIONS

In each round, each employer is matched with a GREEN and a PURPLE worker. The employer decides to hire either nobody, the green worker or the purple worker. The employer thus cannot hire both workers at the same time. The employer receives a positive payoff if s/he hires a worker who invested in her/his productivity, but receives a negative payoff if s/he hires a worker who did not invest in her/his productivity. If the employer hires nobody, s/he receives a small positive payoff. A worker earns a positive payoff if s/he is hired. If a worker is not hired, s/he earns a small positive payoff. S/He incurs a COST if s/he invests in her/his productivity, independently of whether or not s/he is hired. At the time the employer has to make the hiring decision, s/he is not informed about the investment decisions of the two workers. Instead, s/he receives a signal of the green worker and a signal of the purple worker that corresponds to the investment decisions of these workers in the following way.

If the worker invested, her/his signal is HIGH with probability 75% and it is LOW with probability 25%. If the worker did not invest, her/his signal is HIGH with probability 25% and it is LOW with probability 75%. So the signal is often but not always in agreement with the investment decision. The worker's probability that a signal is high or low does not depend on any other worker's probability that her/his signal was high or low. Also, the probability that a worker's signal is high or low is independent of decisions made by the worker in any previous round.

At the start of a round, each worker is informed of the own COST of investing. This cost will be a random number between 0 and 100 points. Each of these numbers is equally likely. In each round, every worker is assigned a new (and independent) cost level. Therefore, the different workers (most likely) have different costs in a round, and the same worker (most likely) has different costs across rounds.

PAYOFFS

The workers' investment decisions and the employer's hiring decision lead to the following payoffs:

(i) Payoff employer after hiring = 60 if hired worker invested.

(ii) Payoff employer after hiring = -40 if hired worker did not invest.

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(v) Payoff worker after investing = 10 – cost if not hired by employer.

(vi) Payoff worker after not investing = 160 if hired by employer.

(vii) Payoff worker after not investing = 10 if not hired by employer.

Notice that there are no differences in the rules for green and purple workers. In particular, there are no differences in the green worker's and purple worker's probabilities of good and bad signals. Also, the cost of investing is determined with the same procedure for the two groups of workers and the payoffs are also determined in exactly the same way.

SEQUENCE OF EVENTS

Summarizing, each round is characterized by the following sequence of events:

1. The workers are privately informed of the own cost of investment.
2. Each worker decides whether or not to invest.
3. The employer observes a high or low signal for each worker, but not the workers' investment decisions.

4. The employer decides to hire nobody, the green worker or the purple worker. Then employer and workers receive payoffs based on the choices made.

MATCHING PROCEDURE

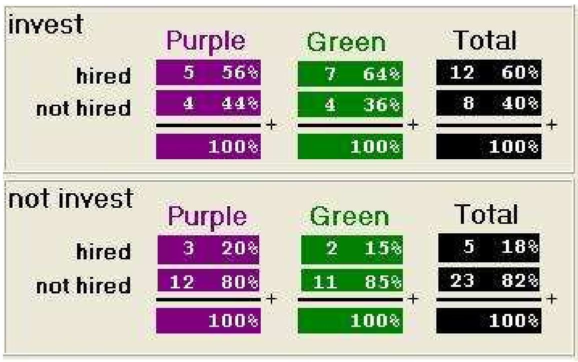
In each round, each employer will be randomly matched to another green worker and another purple worker. You will never learn with whom you are matched. The random matching scheme is chosen such that three participants will never be coupled again in two subsequent rounds.

INFORMATION END OF ROUND

At the end of a round, each participant will be informed of the choices of the participants with whom s/he is matched and the own payoff.

HISTORY OVERVIEW

The lower part of the screen provides an overview of the results of all rounds already completed. Apart from your own results in the previous rounds, the history overview also contains the results of 7 other workers. In total, you are thus informed about the past results of the same group of 8 workers (one of which is yourself) and 4 employers. Below you see an example of the history overview (with arbitrary numbers).



The upper part of the history overview shows what happened in the cases where workers chose to INVEST. The row HIRED lists the number of cases in which the employer decided to hire a worker after investing. The row NOT HIRED lists the number of cases in which the employer decided to not hire a worker after investing. In the first purple column, the results for only the purple workers are listed and in the second green column the results for only the green workers are listed. In the final column the results of the two groups of workers are combined. In each cell, after the number the corresponding percentage is listed. The lower part of the history overview summarizes the previous choices of employers after a worker did not invest in exactly the same way. (Employers observe a history overview that is organized in another way: they observe the number of investments and non investments of purple, green and combined workers, separated for the signal being high and the signal being low).