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Search Costs and Efficiency: Do Unemployed Workers Search Enough?*

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Abstract

Many labor market policies affect the marginal benefits and costs of job search. The impact and desirability of such policies depend on the distribution of search costs. In this paper, we provide an equilibrium framework for identifying the distribution of search costs and we apply it to the Dutch labor market. In our model, the wage distribution, job search intensities, and firm entry are simultaneously determined in market equilibrium. Given the distribution of search intensities (which we directly observe), we calibrate the search cost distribution and the flow value of non-market time; these values are then used to derive the socially optimal firm entry rates and distribution of job search intensities. From a social point of view, some unemployed workers search too little due to a hold-up problem, while other unemployed search too much due to coordination frictions and rent-seeking behavior. Our results indicate that jointly increasing unemployment benefits and the sanctions for unemployed workers who do not search at all can be welfare-improving.

Keywords: job search, search cost heterogeneity, labor market frictions, wage dispersion, welfare

JEL codes: J64, J31, J21, E24, C14

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1 Introduction

1.1 Motivation and Summary

There exists a significant amount of heterogeneity in terms of the intensity with which workers search for jobs.[1] Understanding the sources and implications of this heterogeneity is important because many of the active labor market policies that we observe aim at increasing job search intensity. Examples include (i) unemployment sanctions, like cuts in the benefits paid to the unemployed who do not engage in active job search (see Abbring et al., 2005), (ii) counseling and monitoring, like advising long term unemployed workers on how to draft application letters (see van den Berg and van der Klaauw, 2006), (iii) financial aids, like subsidizing child care in order to increase the number of actively searching workers (see Heckman, 1974; Graham and Beller, 1989), or (iv) re-employment bonus schemes (see Meyer, 1996). The evaluation of policy programs of this kind is not easy because, on the one hand, it is difficult to measure job search intensity directly and, on the other hand, a change in the search effort of the treatment group affects the wage distribution and matching rates for the non-treated workers as well so the general equilibrium effects can be substantial. In this paper, we calibrate the primitive parameters of an equilibrium search model with endogenous search intensity and free entry of vacancies. Those primitives are the search cost distribution, the value of home production and the capital cost of vacancy creation. The calibrated values can then be used to calculate the socially optimal search intensities and level of labor market tightness.

Specifically, we consider a discrete-time dynamic labor market with a continuum of identical, infinitely-lived workers and free entry of vacancies. Firms enter the market and post wages to maximize profits. At each point in time, workers are either employed at one of the firms or unemployed. Employed workers stay in their job until their match with the firm is destroyed by some exogenous shock and they become unemployed again. Unemployed workers search for jobs. Since search intensity is the policy parameter of interest, we explicitly model it as the number of jobs workers choose to apply for. For each application submitted, a worker incurs a search cost. This cost captures the necessary effort a worker has to exert in order to successfully apply to a vacancy and possibly generate an offer, such as finding the vacancy, learning about the firm, writing an application letter, and preparing for a potential interview. Since workers differ in their ability to find job opportunities and to generate offers, we assume that search costs differ amongst workers and are drawn from a common non-degenerate cumulative distribution function (cdf). As in Gautier and Moraga-González (2005) (who consider a one-period version of this model with identical workers), wages, the number of applications, and firm entry are jointly determined in a simultaneous-moves game. For the usual reasons, as explained in Burdett and Judd (1983) and Burdett and Mortensen (1998), firms play mixed

[1] See Bloemen (2005), Lammers (2008) and van der Klaauw et al. (2003).

strategies and offer wages from a continuous wage offer distribution. In our model, equally productive workers earn different wages because of three reasons: (i) some workers have low search costs so, everything else equal, they are better at generating wage offers than high search cost workers, (ii) for a given search cost, some workers receive more job offers than others, and (iii) for a given number of job offers, some receive a better best-offer than others.

Rather than assuming an exogenous specification for a matching function (see the summary of empirical studies in Petrongolo and Pissarides, 2001), the matching process is not only endogenously determined by the firms' and workers' participation decisions, but also by the search efforts of heterogeneous workers. Therefore, in our model, the primitive parameters are not the elasticities of an exogenously specified matching function but the quantiles of the search cost distribution. As in Albrecht et al. (2006), our aggregate matching function is based on micro-foundations and determined by the interplay between two coordination frictions: (i) workers do not know where other workers send their job applications and (ii) firms do not know which workers other firms make employment offers to. These two frictions operate in different ways for different distributions of worker search intensities and have implications on wage determination and firm entry. The empirical distribution of search intensities in combination with our theoretical model gives the distribution of marginal benefits of search. Since a worker continues to send applications till the marginal benefits of search equal the marginal cost, we can use this optimality condition to retrieve the magnitude of search costs for a given search intensity.

To illustrate the difference between our model and models where either the wage distribution or search intensity is exogenous, consider the effects of a policy intervention such as an increase in the minimum wage. A priori, this policy makes search more attractive so one would expect all workers to search harder after the shock. In our model, however, very intensive search will be discouraged because the wage distribution becomes more compressed. Consequently, the matching rate, the job offer arrival rate and the wage distribution are not policy invariant. Moreover, the way these endogenous variables respond to policy changes depends on the primitive search cost distribution.

The various policies mentioned above can be interpreted in this framework as aiming at either changing the marginal benefits of search and or the distribution of search costs. For example, one goal of subsidizing child care is to reduce the fraction of the labor force that does not search at all, while counseling unemployed workers is likely to lower the cost of writing effective application letters and increase the mean number of job applications. Besides policies that aim to directly affect search intensity, redistribution policies like UI insurance, sanctions and minimum wages also affect search intensity indirectly. Without a suitable framework there is no way we can tell whether we should stimulate search intensity for all workers, only for particular groups or not at all.

We calibrate our model to the Dutch labor market. We find that, in the decentralized market equilibrium, too few workers search, while the workers who search on average send too many job applications. The first result can be explained by a standard hold-up problem. Workers typically receive only part of the social benefits of their investments in search and therefore workers with high search cost invest too little in search. The second result on excessive search of the low-search cost workers is due to congestion externalities and rent seeking behavior. Submitting more applications increases the expected maximum wage offer, but workers do not internalize the fact that sending more applications increases the probability that multiple firms consider the same candidate. A final source of inefficiency lies in the entry decisions of vacancies. Given the search and participation strategies of the workers, too few firms enter the market. Quantitatively, our results indicate that the three sources of inefficiency together lead to a market surplus which is approximately 10% lower than in the social optimum. We show that this number is approximately two thirds of the total welfare loss compared to the Walrasian equilibrium and that it is robust to various alternative specifications of our model.

Interestingly, these results suggest that the introduction of a moderate binding minimum wage can be desirable for two reasons: (i) it increases participation in search because the expected wage increases; and (ii) it weakens the rent-seeking motive to send multiple applications because it compresses the wage distribution. Those effects can also be reached by increasing both UI benefits and the sanctions for workers who do not search.

The paper is organized as follows. After discussing the related literature below, we introduce the model in section 2. Section 4 shows how the distribution of search costs can be calibrated using the empirical distribution of searches. In section 5, we analyze efficiency by comparing the socially optimal allocation with the market equilibrium. Section 6 provides a discussion and 7 concludes.

1.2 Related Literature

Our paper contributes to multiple strands of literature. From a theoretical point of view, our model is similar to the non-sequential search model of Burdett and Judd (1983), in which—using labor market terminology—wage dispersion arises because some workers get multiple job offers while others do not. As in Gautier and Moraga-González (2005), we model job offers as the outcome of a micro-founded process in which workers initiate contact by sending applications and some applications do not result in offers. We extend the model of Gautier and Moraga-González (2005) to an infinite horizon and by introducing heterogeneity in search costs. While various papers have analyzed models in which workers send multiple applications simultaneously, e.g. Albrecht et al. (2006), Gautier and Wolthoff (2009), Galenianos and Kircher (2009), Kircher (2009), Wolthoff (2014), these papers all maintain the assumption that workers are homogeneous with respect to their search cost, making them unsuitable for studying distributions of search intensities.[2]

From an empirical point of view, we contribute to the literature that confronts search models with the data. Most of this literature is based on (variations of) the models by Burdett and Mortensen (1998) and Postel-Vinay and Robin (2002, 2004), which treat the process by which workers and firms meet as a black box. Instead, we consider a fully micro-founded model which makes it possible to analyze how this meeting process is affected by changes in the environment or policy. To our knowledge, there does not exist previous work using a labor market version of the Burdett and Judd (1983) model with rationing as in Gautier and Moraga-González (2005), which is what we do here and which allows us to analyze the importance of congestion externalities.

2 Model

Environment. We consider the steady state of a discrete-time labor market. The labor market is populated by a measure 1 of workers and a positive measure of firms, determined by a free entry condition. Both firms and workers are risk-neutral and discount the future at a factor $\frac{1}{1+r}$. Each worker supplies one indivisible unit of labor and each firm requires one such unit of labor to produce output. At any given point in time, a worker is therefore either employed by one of the firms or unemployed, while a firm is either matched with one of the workers or has a vacancy.

Timing. Each period starts with a measure $1-u$ of existing matches, formed in one of the previous periods, and a measure u of unemployed workers. The interaction between workers and firms within a period takes place in a number of phases. First, there is vacancy creation during the entry phase. Unemployed workers apply to one or more of these vacancies during the search phase. Simultaneously, agents produce output in the production phase. In the last phase, some of the existing matches are destroyed and new matches are formed.

Entry. At the beginning of each period, new firms can enter the market by creating a vacancy. The vacancy creation cost equals $k>0$ and entry will take place until the expected payoff from vacancy creation equals zero. We denote the equilibrium number of vacancies by $v>0$.

Search. In the search phase, each of the u unemployed workers learns his search cost c, which is a random draw from a common distribution $S(c)$ with support on $[0,\infty)$. By paying the

[2] To highlight the novel element in our model, we keep the model stylized and abstract from other sources of wage dispersion, such as heterogeneity in workers' reservation wages (as in Albrecht and Axell, 1984) or on-the-job search, potentially combined with firm heterogeneity (see e.g. Burdett and Mortensen, 1998; Bontemps et al., 2000; Mortensen, 2003).

search cost, a worker can send an application to a random vacancy.[3] Since a worker does not learn the result of an application until the matching phase, he may have an incentive to send multiple applications as long as his search cost c is sufficiently low (see Morgan and Manning, 1985). Sending several applications at a time reduces the risk of remaining unmatched and increases the chance of getting a juicy offer.

We denote by $a(c)$ the number of applications a worker with search cost c sends out, incurring a total cost equal to $C(a) = ca(c)$, and assume throughout that at least some workers send more than 1 application.[4] For computational reasons, we will impose a maximum, A, on the number of applications that a worker can send in any given period, but as A can be an arbitrarily large but finite integer, this restriction is rather weak.

Production. Agents produce output during the production phase. Existing matches between workers and firms create output with value $y > 0$. From this output, the firm pays the worker his wage w and keeps the remainder, $y - w$.

Home Production and Unemployment Benefits. Unemployed workers receive a payoff that consists of two components: the economic value h of their home production (or leisure) and unemployment benefits $B(a)$. The level of unemployment benefits may depend on the worker's search behavior, to capture the fact that—in most OECD countries—workers may face a partial loss of benefits if they do not actively search for a job. We assume that $B(a)$ takes the following form

$$B(a) = \begin{cases} (1-\pi)\,b & \text{for } a = 0, \\ b & \text{for } a \in \{1, \ldots, A\}, \end{cases}$$

where b is the default level of benefits and $\pi \in [0,1]$ is the expected penalty for lack of search effort.

Separation. After production is completed, a fraction $\delta \in [0,1]$ of the existing matches experience a job destruction shock. The workers affected by the shock flow back to unemployment. We assume that these workers must experience at least one period of unemployment. That is, they can only search for a job again in the next period.[5]

[3] In our model, we regard the cost of search as the necessary effort a worker has to exert in order to successfully apply to a vacancy and possibly generate an offer. This effort is nontrivial and includes the time spent on locating suitable vacancies, gathering all necessary documents to apply, drafting attractive application letters, filling in forms, preparing for the interview, etc.

[4] We relax the linearity of $C(a)$ in section 5.

[5] This assumption is standard in discrete-time models and not crucial for our results. It merely simplifies expressions somewhat by ruling out multiple transitions between employment states within the same time period.

Matching. Once job applications have been received by the vacancies, each vacancy receiving at least one application randomly selects a candidate and rejects all other applicants.[6] The firm makes a wage offer w to the selected candidate. Workers that receive one or more wage offers accept the highest one as long as it is higher than their endogenously determined reservation wage w_R. Other wage offers are rejected, after which a new period starts.

We denote a worker's matching probability by m_W and a firm's matching probability by m_F. Aggregate consistency requires that $m_F = \frac{u}{v} m_W$, while the steady state condition implies that

$$u = \frac{\delta}{\delta + m_W}. \tag{1}$$

3 Market Equilibrium

In this section, we characterize the equilibrium of the model outlined above. We start by deriving expressions for the equilibrium queue length and distribution of the number of job offers. Subsequently, we describe workers' application and job offer acceptance decisions. We conclude the equilibrium analysis by characterizing firms' entry and wage offer decisions.

3.1 Queue Lengths and Job Offers

Application Distribution. Because of the heterogeneity in the search cost c, workers will differ in the number of applications $a(c)$ that they send. To keep notation succinct, it will be convenient to define the probability mass function p_a, for $a \in \{0, 1, 2, \ldots, A\}$, representing the fraction of unemployed workers sending a applications in equilibrium. Our assumption that some workers send more than one application then corresponds to $1 - p_0 - p_1 > 0$.

Queue Length. Since search is random, all firms are equally likely to receive applications from the unemployed workers. This implies that the queue length, i.e. the expected number of applications per vacancy, is equal to the total number of applications divided by the number of vacancies:

$$\lambda = \frac{u}{v} \sum_{a=1}^{A} a p_a. \tag{2}$$

Job Offer Probability. Due to the infinite size of the labor market, the number of applications a specific vacancy receives follows a Poisson distribution with mean equal to the queue length λ.[7] Likewise, the number of competitors that a worker faces at a given firm

[6] By allowing firms to approach one candidate, we follow Albrecht et al. (2006) and Galenianos and Kircher (2009). Other papers—e.g. Kircher (2009), Gautier and Holzner (2014), and Wolthoff (2014)—consider alternative meeting technologies in which firms can approach multiple workers if necessary. Which meeting technology is a more accurate description of real-life labor markets is still an open empirical question.

[7] Albrecht et al. (2004) and Albrecht et al. (2006) discuss the urn-ball matching technology with multiple applications in detail.

also follows a Poisson distribution with mean λ.[8] In case an individual worker competes with i other applicants for a job, the probability that the individual in question will get the job equals $1/(1+i)$. Therefore, the probability ψ that an application results in a job offer equals

$$\psi = \sum_{i=0}^{\infty} \frac{1}{i+1} \frac{e^{-\lambda}\lambda^{i}}{i!} = \frac{1}{\lambda}\left(1 - e^{-\lambda}\right). \tag{3}$$

Job Offer Distribution. Given a certain number of applications, the number of wage offers that a worker receives then follows a binomial distribution. More precisely, for a worker who sends a applications the probability $\chi(j|a)$ to get $j \in \{0, 1, \dots, a\}$ job offers equals

$$\chi(j|a) = \binom{a}{j} \psi^{j} (1-\psi)^{a-j}.$$

We denote the fraction of unemployed workers that receive j job offers by q_j. This fraction is equal to the product of p_a and the probability that these a applications result in exactly j job offers, summed over all possible a:

$$q_j = \sum_{a=j}^{A} \chi(j|a)\, p_a. \tag{4}$$

Note that if a positive mass of workers sends a applications (i.e. $p_a > 0$), then—by the properties of the binomial distribution—the mass of workers receiving exactly $j \in \{0, \dots, a\}$ job offers (i.e. $q_j > 0$) is also positive.

3.2 Workers' Problem

Strategy. An unemployed worker's strategy consists of two components: i) how many applications $a(c)$ to send out, and ii) whether to accept the highest wage offer or reject it in order to search again in the next period. As common in labor search models, workers will use a threshold rule for the second component. That is, they will accept the highest wage offer if and only if it exceeds their reservation wage, which we denote by w_R.

Value of Employment. In order to derive a worker's optimal strategy, we specify two discrete-time Bellman equations. The first defines the expected discounted lifetime income $V_E(w)$ of a worker who is employed at a wage w in the production phase of the current period, i.e.

$$V_E(w) = w + \frac{1}{1+r}\left((1-\delta) V_E(w) + \delta V_U\right), \tag{5}$$

[8] See e.g. Lester et al. (2015), who call this property of the Poisson distribution "independence".

where V_U denotes the value of unemployment. In words, the value of employment equals the sum of the wage w and the discounted value of employment if the worker stays in the job in the next period (with probability $1-\delta$) or the discounted value of unemployment if the match with the firm gets destroyed (with probability δ).

Value of Unemployment. Unemployed workers face a trade-off when deciding how many applications to send out. Applying to one more job is costly but it brings two sorts of benefits: one, it reduces the probability of remaining unmatched and two, it increases the likelihood to get a better paid job. Therefore, an unemployed worker with search cost c chooses the number of applications a in such a way that she maximizes her expected discounted lifetime payoff $V_U(a|c)$, which equals

$$V_U(a|c) = h+B\left(a\right)-C\left(a\right)+\frac{1}{1+r}\left(\sum_{j=1}^{a}\chi\left(j|a\right)\int_0^\infty \max\left\{V_U, V_E(w)\right\}dF^j\left(w\right)+\chi\left(0|a\right)V_U\right).$$

In words, the value of unemployment for a worker with search cost c who applies for a jobs equals the sum of home production h, unemployment benefits $B\left(a\right)$ and the expected discounted payoff of his search strategy, net of search costs $C\left(a\right)=ca$. The applications result in j wage offers with probability $\chi\left(j|a\right)$, each of which is a random draw w from the wage offer distribution F, which we will derive below. In case of multiple offers, the worker accepts the best one as long as that offer gives a higher payoff than remaining unemployed. If the worker fails to find a job, he remains unemployed.

Given a search cost c, the optimal number of applications to send is $a(c)=\arg\max V_U\left(a|c\right)$. If we define $V_U\left(c\right)=\max_a V_U\left(a|c\right)=V_U\left(a\left(c\right)|c\right)$, the (unconditional) value of unemployment equals

$$V_U=\int_0^\infty V_U(c)dS\left(c\right). \tag{6}$$

Reservation Wage. It is straightforward to show that the value of employment is strictly increasing in w. Hence, workers will indeed use a threshold rule when deciding whether to accept the highest wage offer or not. To derive the optimal threshold, i.e. the reservation wage w_R, it will be useful to define ζ_a as the expected wage in excess of w_R for a worker who sends a applications. That is,

$$\zeta_a=\sum_{j=1}^{a}\chi\left(j|a\right)\int_{w_R}^\infty\left(w-w_R\right)dF^j\left(w\right)=\int_{w_R}^\infty\left(w-w_R\right)d\left(1-\psi+\psi F\left(w\right)\right)^a, \tag{7}$$

where the second equality follows from the binomial theorem.

Note that w_R must satisfy $V_E(w_R) = V_U$. This implies

$$V_U = \frac{1+r}{r} w_R$$

and

$$V_E(w) = \frac{1+r}{r+\delta}\left(w + \frac{\delta}{r} w_R\right).$$

Using these equations and (7), the reservation wage w_R then equals the fixed point of the following equation,

$$w_R = h + \int_0^\infty \max_a \left(B(a) + \frac{1}{r+\delta}\zeta_a - C(a)\right) dS(c). \tag{8}$$

This equation (8) satisfies the sufficient conditions for a contraction mapping as given by Blackwell (1965). Therefore, a unique solution for the reservation wage w_R exists.

Number of Applications. Using integration by parts, it is straightforward to establish that the function ζ_a is monotonically increasing in a. Therefore, the workers' maximization problems induce a partition of the support of the search cost distribution as follows. In equilibrium, a worker sends another application as long as the marginal benefits are greater than or equal to the marginal search cost c. There exists a cutoff value Γ_a which makes a worker indifferent between sending out a and $a-1$ job applications, i.e. $V_U(a|\Gamma_a) = V_U(a-1|\Gamma_a)$, for all a. From the expressions above, it follows that Γ_a is equal to

$$\Gamma_a = \begin{cases} \frac{1}{r+\delta}\zeta_1 + \pi b & \text{for } a = 1, \\ \dfrac{1}{r+\delta}(\zeta_a - \zeta_{a-1}) & \text{for } a \in \{2, \ldots, A\}. \end{cases} \tag{9}$$

It is straightforward to show that Γ_a is a decreasing function of a. This implies that workers continue searching as long as Γ_a is larger than their search cost c. That is,

$$a(c) = \begin{cases} 0 & \text{for } \Gamma_1 < c, \\ i & \text{for } \Gamma_{i+1} < c \leq \Gamma_i \text{ and } i \in \{1, \ldots, A-1\}, \\ A & \text{for } c \leq \Gamma_A. \end{cases}$$

Hence, the fractions p_a of workers sending a job applications satisfy the following conditions:

$$p_a = \begin{cases} 1 - S(\Gamma_1) & \text{for } a = 0, \\ S(\Gamma_a) - S(\Gamma_{a+1}) & \text{for } a \in \{1, \ldots, A-1\}, \\ S(\Gamma_A) & \text{for } a = A. \end{cases}$$

3.3 Firms' Problem

Strategy. An unmatched firm makes two decisions, i.e. i) whether to enter the market by creating a vacancy, and ii) which wage offer to make. The assumption of free entry implies that the first decision is fairly trivial: firms will continue to enter the market until the value of a vacancy equals zero. In order to derive the optimal wage offers, we again rely on Bellman equations, after first establishing that the equilibrium must exhibit wage dispersion.

Wage Dispersion. A firm with a vacancy offers a randomly selected applicant a wage w. In order to be attractive to both the firm and the applicant, this wage should be higher than the applicant's reservation wage w_R, but lower than the value of the output y that will be produced in case of a match. Within the interval $[w_R, y]$, the firm faces a trade-off: posting a lower wage increases the firm's payoff $y - w$ conditional on matching, but it also increases the probability that an applicant who receives multiple offers rejects the offer and chooses to work for a different firm.

As in Burdett and Judd (1983) and Burdett and Mortensen (1998), wage dispersion must arise in equilibrium because some applicants will compare multiple job offers while others will not. Denote the equilibrium wage offer distribution by $F(w)$ and its support by $[\underline{w}, \overline{w}]$. Because a worker has no other offers with strictly positive probability, the lower bound of the support must be equal to the workers' reservation wage, $\underline{w} = w_R$.

Value of a Match. A firm employing a worker has a periodical match payoff equal to $y - w$. In the next period, the firm is still active with probability $1-\delta$; otherwise it has a vacancy again. In equilibrium, free entry implies that the lifetime expected payoff of a vacancy V_V equals zero. Hence, the firms' value $V_F(w)$ of being matched with a worker earning a wage w is given by

$$V_F(w) = y - w + \frac{1-\delta}{1+r} V_F(w). \tag{10}$$

Value of a Vacancy. A firm with a vacancy offering a wage w hires a worker with an endogenously determined probability $m_F(w)$. In this case, the firm obtains a value $V_F(w)$ in the next period. If the firm fails to match (with probability $1 - m_F(w)$), it receives $V_V = 0$ in the next period. Hence, the value of a vacancy, conditional on offering a wage w, equals

$$V_V(w) = -k + \frac{1}{1+r} m_F(w) V_F(w). \tag{11}$$

Matching Probability. A firm planning to make a wage offer w successfully hires a worker if and only if i) the firm has at least one applicant and ii) the applicant that the firm selects receives either no other job offers or only offers paying less than w. In appendix A.1, we derive the following expression for the probability $m_F(w)$ of this event,

$$m_F(w) = \frac{u}{v}\sum_{j=1}^{S} jq_j F^{j-1}(w). \tag{12}$$

Wage Offer Distribution. The equilibrium wage offer distribution $F(w)$ is determined by an indifference condition: in equilibrium, each wage in the support of F must yield the same expected payoffs to a firm. That is, $F(w)$ is implicitly defined by the equation $V_V(w) = V_V(\underline{w})$, which after substitution of equation (10) and (12) reduces to

$$\sum_{j=1}^{S} jq_j F^{j-1}(w) = q_1 \frac{y-\underline{w}}{y-w}. \tag{13}$$

Evaluating (13) at the upper bound $\overline{w}$, where $F(\overline{w}) = 1$, gives :

$$\overline{w} = y - \frac{q_1}{\sum_{j=1}^{S} jq_j}(y-\underline{w}), \tag{14}$$

which is strictly smaller than y, since $q_1 > 0$. Hence, firms always post wages below the productivity level. This is because a wage equal to y would give the firm a payoff of zero with probability one, while posting a lower wage gives a strictly positive expected payoff, since there is a positive probability that some applicants do not receive other offers.

Entry. Using (10) and (11) to rewrite the free entry condition $V_V(w) = 0$, one obtains

$$0 = -k + \frac{1}{r+\delta}\frac{u}{v}q_1(y-\underline{w}). \tag{15}$$

This expression implicitly determines the free-entry equilibrium number of vacancies v in the market.[9]

4 Calibration

We apply the model to the Dutch labor market. Calibration or estimation of the model can be performed in a variety of ways, depending on the data available. As shown in Hong and Shum (2006), (partial) identification of the search cost distribution is possible using only the cross-sectional wage distribution (in addition to aggregate labor market statistics), as workers with lower search costs will in expectation earn higher wages. We followed that approach in the working paper version (see Gautier et al., 2011); however, an obvious challenge to this approach is that wage variation may stem from various other sources, like unobserved

[9]Recall that q_1 depends on v.

Table 1: Distributions of the Number of Applications (p_a) and Job Offers (q_j).

Data source: Bloemen (2005).

a, j	p_a		q_j
	Data	Calibration	
0	0.359	0.359	0.833
1	0.163	0.162	0.134
2	0.115	0.121	0.026
3	0.093	0.090	0.005
4	0.071	0.068	0.001
$\geq$5	0.199	0.200	0.000

productivity differences. In this version, we therefore follow a different, more direct approach, using data regarding the number of applications that workers send.

Application Distribution. Information on the distribution of the number of applications is provided by Bloemen (2005) on the basis of the Dutch Socio-Economic Panel 1987/1988, a household survey collected by Statistics Netherlands. In the survey, individuals who described themselves as unemployed were asked to indicate the number of times they had applied for a job in the previous two months. The distribution of responses, which is displayed in the second column of Table 1, is censored at 5 applications. As we require information on the entire application distribution, we identify p_a for $a \geq 5$ parametrically. It turns out that—conditional on applying at least once—the (censored) empirical distribution can be approximated very well by a (censored) geometric distribution, i.e. $\frac{p_a}{1-p_0} = (1-\alpha)^{a-1}\,\alpha$. We jointly calibrate p_0 and α, which yields $p_0 = 0.359$ and $\alpha = 0.253$ (see Table 1, third column).[10]

Time Period. By using data on the number of applications from Bloemen (2005), we implicitly set the period length equal to two months. While this is longer than the one-month period length used in many papers that calibrate to the US labor market (e.g. Shimer, 2005), it appears to be a reasonable choice for the Dutch labor market in the late eighties. In fact, van Ours and Ridder (1992) suggest an even longer period length by documenting on the basis of Dutch recruitment data from early 1987 that "almost all applicants arrive during the first 2 weeks after the announcement of the vacancy, and most vacancies are filled within the next 2.5 months, a period during which few new applicants arrive." We fix the periodical interest rate at $r = 0.008$, corresponding to an annual interest rate of 5% and set the maximum number of

[10] Recall that the model assumes that workers who send zero applications cannot match. While it is not uncommon for labor force surveys to indicate that these workers may still find a job, this assumption is standard in the search literature (see e.g. Pissarides, 1984; Mortensen and Pissarides, 1994; Moen, 1997; Kircher, 2009; Menzio and Shi, 2011).

applications equal to one a day, i.e. $A = 60$.[11]

Labor Market Stocks and Flows. Statistics Netherlands reports that in 1988 of the 5.868 million individuals in the Dutch labor force, on average 5.378 million were employed and 0.490 million were unemployed (Statistics Netherlands, 2014). This implies $u = 0.084$.

Data from the OECD indicates that the median unemployment duration in the Netherlands in 1988 was approximately one year (OECD, 2014). This corresponds to a matching rate of $m_W = 0.167$ per 2 months. In the equilibrium of our model, workers match as long as they get at least one job offer, i.e. with probability

$$m_W = 1 - q_0 = 1 - \sum_{a=0}^{A} (1-\psi)^a \, p_a. \tag{16}$$

Hence, $m_W = 0.167$ requires that each application results in a job offer with probability $\psi = 0.082$. The corresponding distribution q_j of the number of job offers can be calculated from (4) and is presented in the last column of Table 1. Most workers obtain either zero or one job offer per period, but a small fraction receives multiple offers.

Equation (2) and (3) then jointly determine the measure of vacancies, yielding $v = 0.017$. Aggregate consistency implies that a firm's matching probability is equal to $m_F = \frac{u}{v} m_W = 0.806$ per period. Finally, the steady state condition (1) requires the job destruction probability to equal $\delta = 0.015$.

Wage Distribution. The wage offer distribution $F(w)$ is implicitly determined by equation (13), which depends on q_j , y and $\underline{w}$. Given the distribution of job offers q_j in Table (1) and the normalization $y = 1$, only a value for $\underline{w}$ is still required. We obtain such a value by using information on the labor share, which the OECD reports to be 0.709 for the Netherlands for 1988 (OECD, 2014).

The equivalent to the labor share in our model is the average accepted wage. Note that the distribution of accepted wages, which we denote by $G(w)$, differs from the distribution $F(w)$ of offered wages, because some workers can compare wage offers, making high wage offers more likely to be accepted. In order to derive an expression for $G(w)$, consider a worker who receives $j > 0$ job offers. He will only accept a wage that is lower than some value w if all his j job offers are lower than this value. As a result, the following relationship between $G(w)$ and $F(w)$ holds:

$$G(w) = \frac{\sum_{j=1}^{S} q_j F^j(w)}{1 - q_0}. \tag{17}$$

The average accepted wage then equals $w_{avg} = \int_{\underline{w}}^{\overline{w}} w dG(w)$, which after substitution of (14)

[11] Note that $p_{60} < 10^{-8}$, so this choice has no impact on our results.

and (17) simplifies to a function of $\underline{w}$ alone, as we show in appendix A.2. This function can be inverted to get the surprisingly simple expression

$$\underline{w} = y - \frac{1 - q_0}{q_1}\left(y - w_{avg}\right).$$

Equating w_{avg} to 0.709 therefore yields $\underline{w} = 0.639$ and, by equation (14), $\overline{w} = 0.766$.[12]

Entry Cost. Using equation (15), we can write the entry cost k as a function of variables for which we have obtained a value, i.e.

$$k = \frac{1}{r+\delta}\frac{u}{v}q_1\left(y - \underline{w}\right).$$

This yields $k = 9.998$. While this value may appear high, it is important to keep in mind that firms—on average—incur the entry cost for only 2.5 months before enjoying the payoffs of a match for more than 11 years.[13]

Unemployment Benefits. The maximum replacement rate for unemployment benefits was 70% in 1988. Various eligibility criteria, the finite duration of benefits and a maximum on the insured wage suggest that the average replacement rate should be lower.[14] At the same time, data from Statistics Netherlands indicates that the Dutch government spent about 13,350 euros per unemployed worker in 2005, which corresponds to approximately 40% of the average wage in that year (Statistics Netherlands, 2014). Similar data is unfortunately hard to obtain for 1988, but as unemployment benefits became less generous between 1988 and 2005, 40% seems a lower bound for the replacement rate. In line with these considerations, we set b equal to 50% of w_{avg}, which amounts to $b = 0.355$.[15]

Unemployment Sanctions. Abbring et al. (2005) document—on the basis of a number of sources—that the most common sanction for lack of search effort is a 20 percentage point decrease in the replacement rate for 13 weeks. Given a replacement rate of 50% and ignoring discounting, this number is equivalent to a penalty of 60% during our two-month period.[16] However, Abbring et al. (2005) argue that the number of sanctions is relatively small, which suggests that monitoring is not perfect. In line with this, we set the expected penalty π equal to 10%.[17]

[12] Hence, our calibration implies a mean-min value of 0.709/0.639 = 1.110. See Hornstein et al. (2011) for a detailed discussion of this statistic.

[13] We discuss some ways to obtain lower values of k in section 6.

[14] See Abbring et al. (2005) for a description of the Dutch unemployment benefit system.

[15] Other values of b do not lead to qualitatively different results.

[16] $20\%/50\% \times 13/(52/6) = 60\%$.

[17] Our qualitative results do not depend on this specific choice.

Search Cost Distribution. Knowledge of the wage offer distribution and the application distribution is sufficient to partially identify the search cost distribution. To see this, realize that information on the wage offer distribution allows us to calculate ζ_a and Γ_a as defined in (7) and (9), respectively. Since Γ_{a+1} represents the marginal gains from sending $a+1$ rather than a applications, the application distribution p_a is informative of the mass of agents with a search cost between Γ_{a+1} and Γ_a. This procedure gives us A cutoff points $(\Gamma_1, ..., \Gamma_A)$ of the search cost distribution $S(c)$. Figure 1 illustrates this idea.

For some purposes, e.g. for assessing the efficiency of the market equilibrium, we need the full distribution (i.e. for every possible value of c). On the interval $[0, \Gamma_1]$, i.e. for all workers who apply at least once, we obtain this by using linear interpolation between the cutoff points:

$$S(c) = \sum_{j=i+1}^{A} p_j + \tfrac{p_i}{\Gamma_i - \Gamma_{i+1}} (c - \Gamma_{i+1}) \quad \forall c \in [\Gamma_{i+1}, \Gamma_i) \text{ and } i = \{1, ..., A\} \ ,$$

where we define $\Gamma_{A+1} = 0$. This assumption is relatively weak as long as the cutoff points are not too sparse.

Our calibration procedure provides no information on the search cost of workers who do not apply, other than the fact that their search cost must exceed the marginal gain of a first application, $c > \Gamma_1$. Our baseline assumption will be that the search cost distribution keeps increasing linearly for these values of c, with the same slope as just before Γ_1, until it reaches 1. Hence, on this interval $S(c)$ is given by

$$S(c) = \begin{cases} 1 - p_0 + \tfrac{p_1}{\Gamma_1 - \Gamma_2} (c - \Gamma_1) & \forall c \in [\Gamma_1, \Gamma_0) \\ 1 & \forall c \geq \Gamma_0 \end{cases} \ , \text{ where } \Gamma_0 = \Gamma_1 + \frac{p_0}{p_1} (\Gamma_1 - \Gamma_2) \, .$$

Admittedly, this assumption is rather strong, so we will consider two alternatives: i) all workers who do not apply have infinite search costs, i.e. $S(c) = 1 - p_0$ for all $c \in [\Gamma_1, \infty)$; and ii) all workers who do not apply have search costs (marginally higher than) Γ_1, i.e. $S(c) = 1$ for all $c \in [\Gamma_1, \infty)$. These alternatives form an upper and a lower bound, respectively.

Figure 2 displays our search cost distribution. Weighted by the number of applications, the average search cost of an unemployed worker is 0.167, i.e. approximately 17% of periodical output or 24% of the average periodical wage.[18]

Home Production. Identification of the value of home production is possible from (8). As we show in appendix A.3, this equation combined with the assumption of piecewise linearity

[18] This number is of course independent of any assumption about the search costs of workers who do not search.

Figure 1: Identification of the Search Cost Distribution.

For illustrative purposes, the figure shows a special case in which $w_R = 0$ and $A = 5$. The wage offer distribution $F(w)$ determines the marginal benefits of search, Γ_a (panel 1). Workers choose their search intensity such that the marginal gain of an additional application does not exceed the marginal cost (panel 2). Hence, the probability that search costs are between Γ_{a+1} and Γ_a equals p_a (panel 3).

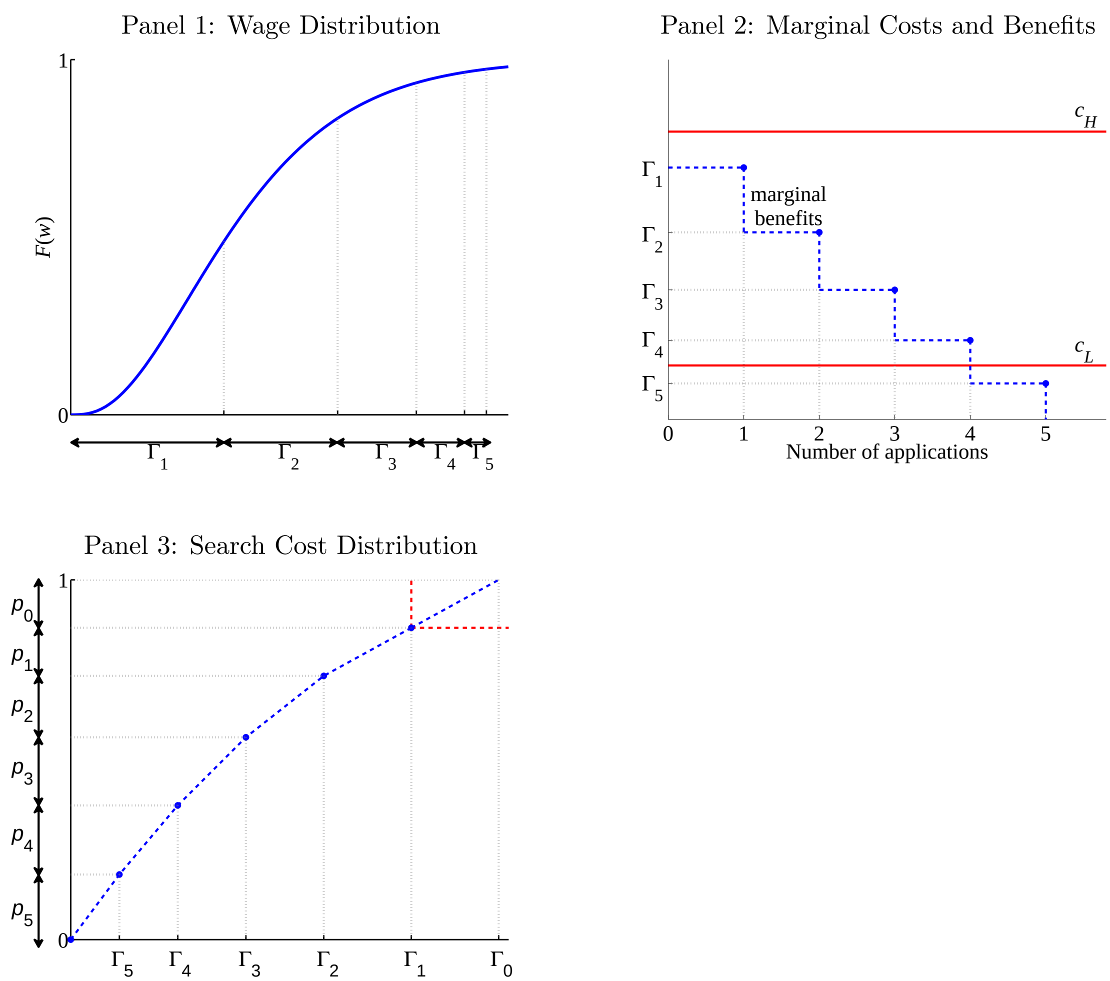
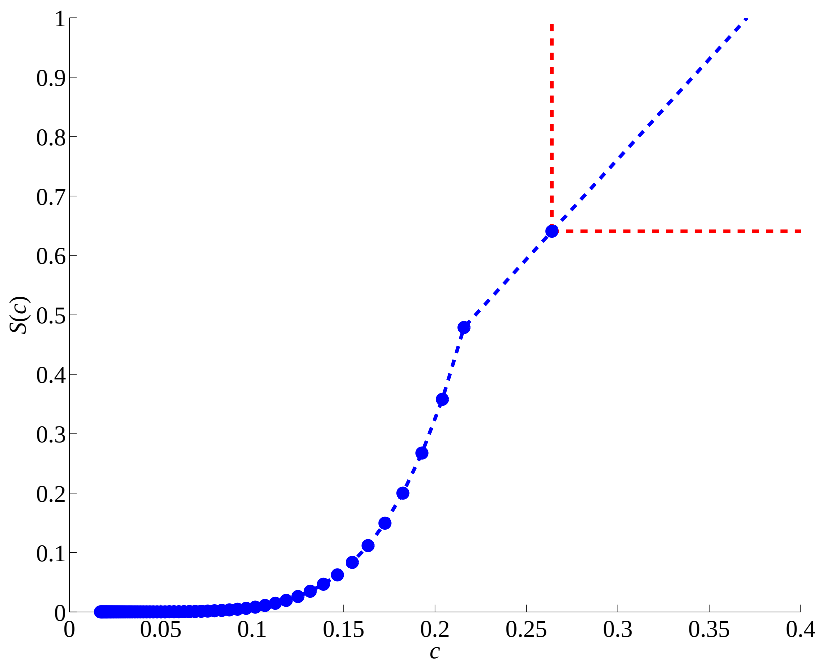


Figure 2: Calibrated Search Cost Distribution

Blue markers: calibrated cut-off points $\left(\Gamma_i, \sum_{a=i}^{S} p_a\right)$. Blue lines: linear interpolation / extrapolation. Red lines: lower bound and upper bound on search costs for non-searchers.



of $S(c)$ gives

$$h = w_R - \frac{1}{r+\delta} \sum_{a=1}^{A} p_a \left(\zeta_a - \frac{1}{2} a \left(\zeta_{a+1} - \zeta_{a-1} \right) \right) - b \left(1 - \pi p_0 - \frac{1}{2} \pi p_1 \right),$$

where we define $\zeta_{A+1} = \zeta_A$ to simplify notation. This equation implies a value $h = 0.220$, which is approximately 34% of the reservation wage.[19]

5 Planner's Solution

Efficiency. An interesting policy issue is whether the decentralized market equilibrium is efficient, i.e. are the search decisions by workers and the entry decisions by firms socially optimal? A priori, there is no obvious answer to the question whether the number of applications sent by workers in the market equilibrium is too high or too low from a social planner's point of view. On the one hand, workers might underinvest in search since they face a standard hold-up problem: They only receive a part of the social benefits of their investments in search. On the other hand, workers might also send too many applications, since they only take into account their own expected payoff and ignore the congestion effects their applications cause in the market.

The entry decisions of firms might form a last source of inefficiency. Albrecht et al. (2006) show that when all workers search two or more times, efficient entry requires full ex ante and full ex post (i.e. Bertrand) competition for workers. This is not the case in our model. There is no full ex ante competition, since the firm that offers the lowest wage in the market receives as many applications as the other firms, and there is no full ex post competition, because a firm that offers the job to a worker with (an) other offer(s) still has a positive expected payoff.

Planner's Objective and Constraints. To quantify these effects and analyze efficiency of the market equilibrium, we consider the problem of a (constrained) social planner who—starting from the above steady state—aims at maximizing the present discounted value of future surplus (i.e., output, net of search and vacancy creation costs). We give the planner access to two tools: he decides in each period i) how many vacancies are opened, and ii) how many applications each worker sends.

With respect to the matching frictions, we distinguish two different cases. First, we consider a social planner who is constrained in the sense that he cannot solve the coordination frictions in the market. This type of planner faces the same matching function as the market, which was given in equation (16). Second, we consider an unconstrained planner who can match

[19] The sum of home production and (expected) unemployment benefits then equals $h + (1 - \pi p_0) b = 0.562$, which is approximately halfway between the values of Shimer (2005) and Hall and Milgrom (2008).

workers and firms in a Walrasian way. This type of planner generates a number of matches that equals the minimum of the number of searchers and the number of vacancies:

$$m_W^* = \frac{1}{u}\min\left\{u\left(1-p_0\right), v\right\}.$$

Comparing outcomes under these two types of planner allows us to decompose the efficiency loss in the market into a part that is directly due to frictions and a part that is due to distorted incentives.

Recursive Formulation. As common in the literature, we express the problem in a recursive way and in terms of the labor market tightness $\theta = \frac{v}{u}$ instead of v (see e.g. Shimer, 2004; Rogerson et al., 2005). Let $V(u)$ be the expected present value of future surplus when the current unemployment rate is u. Then, the following Bellman equation holds:

$$V(u) = \max_{a(c),\theta} y(1-u) + \left(h - \int_0^\infty a(c)\, c dS(c) - k\theta\right)u + \frac{1}{1+r}V\left(u'\right), \tag{18}$$

where $u' = \delta(1-u) + (1-m_W)u$ denotes unemployment in the next period. Note that the unemployment benefits $B(a)$ do not appear in (18) as they are assumed to be financed by lump-sum taxation and are simply a form of redistribution. Using the values obtained above, we can numerically solve this maximization problem and confront the market outcome with the social optimum.

Constrained Planner's Results. The third column of Table 2 presents the key parameters of the constrained planner's solution. We observe important differences relative to the market equilibrium. First, the planner increases the number of searchers: unemployed workers who were not applying should send one application instead. At the same time, the planner ends the practice of sending multiple applications. Although almost half of all unemployed workers have search costs low enough to make it privately optimal to apply multiple times, these workers fail to take into account that this increases the probability that multiple firms consider the same candidate, which is socially wasteful. Given the calibrated values of the entry and application cost, the negative effect dominates and it is socially desirable that these workers only apply once each period. Finally, the planner finds it optimal to increase labor market tightness θ.

As a result of these changes, unemployment decreases by approximately 4 percentage points, relative to the market equilibrium. The increase in θ and the reduction in u almost exactly offset each other, as revealed by the relatively small change in the number of vacancies v. All together, the planner increases expected present value of future surplus (18) by approximately 10% relative to the market.

Table 2: Market Equilibrium and Planner's Solution

	Market	Planner	
		constr.	unconstr.
p_0	0.359	0.000	0.000
p_1	0.162	1.000	1.000
p_2	0.121	0.000	0.000
p_3	0.090	0.000	0.000
p_4	0.068	0.000	0.000
$p_{\geq 5}$	0.200	0.000	0.000
θ	0.140	0.347	1.000
u	0.084	0.045	0.015
v	0.017	0.015	0.015
m_W	0.167	0.328	1.000
m_F	0.806	0.944	1.000
Surplus	89.56	98.26	102.25
Gain		9.7%	14.2%

Unconstrained Planner's Results. The last column of Table 2 presents the results for the unconstrained planner. The optimal strategy resembles that of the constrained planner, except that the unconstrained planner wants to increase the labor market tightness even more, as the coordination frictions can be fully eliminated. Under this scenario, unemployment drops to 1.5%, while the number of vacancies again does not change very much.[20] In total, surplus is now 14% higher than in the market equilibrium. Hence, roughly two thirds of the total efficiency loss is caused by wrong incentives while the coordination frictions account for the remaining one third. As the former inefficiency is easier to address with policy than the latter, this result suggests that the welfare effects from well-designed labor market programs can be substantial.

Bounds. To analyze to what extent our efficiency results depend on the linear extrapolation of the search cost distribution for non-searchers, we solve the planner's problem also for the two alternative scenarios, in which all non-searchers are assumed to have the lowest possible ($c = \Gamma_1$) or the highest possible ($c \to \infty$) search cost, respectively. This provides us with an upper and a lower bound on the planner's efficiency gain. Table 3 presents the results, together with the baseline solution from table (2) to facilitate comparison.

The solution for $c = \Gamma_1$ looks very similar to the baseline solution along all dimensions. The solution for $c \to \infty$ differs a bit more. Most importantly, but not surprisingly, the planner

[20]Note that despite the absence of matching frictions, unemployment is not eliminated as workers who lose their job have to wait until the next period before they can match again.

Table 3: Bounds on Planner's Solution

	Constrained Planner			Unconstrained Planner		
	$c \to \infty$	Baseline	$c = \Gamma_1$	$c \to \infty$	Baseline	$c = \Gamma_1$
p_0	0.359	0.000	0.000	0.359	0.000	0.000
p_1	0.641	1.000	1.000	0.641	1.000	1.000
p_2	0.000	0.000	0.000	0.000	0.000	0.000
p_3	0.000	0.000	0.000	0.000	0.000	0.000
p_4	0.000	0.000	0.000	0.000	0.000	0.000
$p_{\geq 5}$	0.000	0.000	0.000	0.000	0.000	0.000
θ	0.240	0.347	0.332	0.641	1.000	1.000
u	0.064	0.045	0.046	0.023	0.015	0.015
v	0.015	0.015	0.015	0.015	0.015	0.015
m_W	0.223	0.328	0.316	0.641	1.000	1.000
m_F	0.931	0.944	0.951	1.000	1.000	1.000
Surplus	97.08	98.26	98.91	101.77	102.25	102.47
Gain	8.4%	9.7%	10.4%	13.6%	14.2%	14.4%

does not want the non-searchers to apply even once in this case. Nevertheless, total surplus again does not change much, implying that the overall bounds on the welfare gains from our baseline case are relatively narrow.

6 Discussion

In this section, we discuss some of our key assumptions and results, along with a few potentially interesting extensions of our basic framework.

General Search Cost Functions. A first important assumption is that a worker's total search cost $C(a)$ is linear in the number of applications that he sends. In real life, $C(a)$ might be concave if workers invest a lot of time in drafting the first application letter but spend less time on the subsequent ones. Alternatively, $C(a)$ might be convex if workers have easy access to a small number of vacancies (e.g. via their network of friends and colleagues), but have to search really hard to find other job openings. In general, various different shapes may coexist.

We therefore generalize our analysis in appendix B by assuming that, in each period, each worker—instead of drawing a search cost c—independently draws a search cost *function* $C(a)$ from a given set $\mathcal{C}$. We only impose two very weak restrictions on the search cost functions in $\mathcal{C}$: each feasible $C(a)$ is (i) equal to zero for $a = 0$ and (ii) weakly increasing in a. Despite this level of generality, we find that our baseline results are robust. First, the welfare gains change only slightly. As we discuss in more detail in the appendix, this is because the changes in the calibrated values for the search costs and home production mostly offset each other. Second, the main message remains that—given our endogenous matching process—more workers should send a small number of applications.

Match-Specific Productivity. A second assumption is that all matches are equally productive. Alternatively, one could allow productivity to be match-specific, e.g. by assuming that only a fraction $\phi < 1$ of the applicants (iid across all firm-worker pairs) has productivity y, while the remaining applicants have productivity 0. Due to the way in which we calibrate the model, using direct evidence on workers' number of applications and matching probability, this extension has no effect on the estimated search cost distribution. However, it increases the number of vacancies v, lowers the entry cost k, and may increase the number of applications that the planner wants workers to send. For example, $\phi = 0.5$ roughly doubles the number of vacancies ($v = 0.032$) and halves the entry cost ($k = 4.99$). Although the planner instructs some workers to search twice in this case, our main message remains unchanged.[21]

Entry Cost. The baseline calibration resulted in a relatively high value for the entry cost k. The reason for this is that relatively few firms enter the market, even though they match quickly, capture a sizable fraction of the surplus, and remain matched for a long time. Although the high value of k has limited impact on our results—only affecting the planner's choice of entry—it might be useful to consider what extensions of the model would yield a lower estimate. Since we obtain a value for k from the free entry condition, anything that decreases the benefits of opening a vacancy will reduce our estimate. Match-specific productivity, as described above, is one example. Alternatively, introducing a cost of maintaining capital during the match or firing costs, reduces firms' match payoff. Allowing for on-the-job search would reduce the expected match duration. We leave these extensions for future research.

Inefficiency. Our result that some workers search too little while other workers search too much is—to the best of our knowledge—new in the literature. It is the result of two countervailing forces. On the one hand, workers capture only part of the match surplus, creating a hold-up problem which causes them to search too little. On the other hand, they have an incentive to send multiple applications in order to get a higher wage offer. From the planner's point of view, this rent-seeking behavior merely creates congestion externalities, which means that workers might search too much.[22] Which force dominates depends on a worker's realization of the search cost. This contrasts models like Pissarides (1984, 2000) in which all meetings between workers and firms are bilateral and wages are determined by Nash bargaining. In that

[21] As data limitations prevent reliable identification of ϕ, we do not report these results in detail, but they are available upon request.

[22] See Gautier and Moraga-González (2005) and Albrecht et al. (2006) for a detailed discussion.

case, a worker's choice of search intensity only affects how quickly he meets a firm and has no effect on his wage. Hence, the incentive to engage in rent-seeking behavior disappears and the natural result is that search intensity is always too low.

Gautier and Holzner (2014) argue that in a simultaneous search setting, as we use here, wage determination and matching efficiency are not independent. They model the labor market as a bipartite network, in which unemployed workers and vacancies are the nodes and applications form the links. The wage mechanism then affects both the distribution of networks that can arise and the number of trades on a realized network. One important factor is whether firms that fail to hire a candidate can move on to ('recall') the next candidate in the same period. If this is the case, the congestion externalities are smaller and it is more desirable that workers send out multiple applications. In Kircher (2009), firms can contact all their applicants (full recall), while Wolthoff (2014) endogenizes this decision by introducing a cost for each contact. Gautier and Holzner (2014) also have full recall and show that allowing firms to change their wage offer after the network has been formed improves efficiency.

7 Conclusion

We present a discrete-time dynamic labor market model. Unlike most of the literature, we explicitly define the search intensity as the number of applications that workers choose to send out per period, taking into account the fact that each application is costly. As such, the model provides a micro-founded framework for the evaluation of public policies intended to increase job search intensity. We characterize the equilibrium and show how a relatively small amount of aggregate data is sufficient to identify the model's parameters, including the cross-sectional distribution of search costs.

Taking the coordination frictions, the calibrated value of home production, and the calibrated search cost distribution as given, we then solve the problem of a (constrained) social planner and find that, by choosing workers' search decisions and firms' entry decisions optimally, the planner could achieve welfare gains up to 10%. We show how this value is robust to various different specifications of the search costs. The planner's solution indicates that in the market equilibrium too many unemployed workers do not search at all. At the same time, some unemployed workers send too many applications, in an attempt to get a very high wage offer, but ignoring the negative externalities this imposes on others.

Our results suggest that labor market policies should aim at increasing search effort along the extensive margin rather than the intensive margin. Interestingly, the introduction of higher UI benefits or a moderate binding minimum wage could improve efficiency along both margins. It would increase the gains from searching a small number of times by increasing the expected wage offer, while lowering the gains from sending many applications by compressing the wage distribution. We leave a quantitative analysis of the welfare gains of this kind of policies for future research.[23]

[23]Compared to other empirical equilibrium search models in the literature, we have modeled the matching process and search intensity with a lot more detail, but in other respects our model is stylized. For example, we abstract from risk-aversion, productivity differences across workers, persistent components in search costs, or firms' ability to make multiple offers in the same period, all of which may affect the optimal level of UI benefits of the minimum wage.

A Derivations

A.1 Firm's Matching Probability

A firm matches if it offers its candidate a higher wage than all other firms competing for the same worker. The probability for a firm to have at least one applicant with productivity y is equal to $1-e^{-\lambda}$. The conditional probability that the candidate has sent a applications is given by $\frac{ap_a}{\sum_{i=1}^{A} ip_i}$ and the $a-1$ other applications of the candidate result in $j \in \{0, 1, ..., a-1\}$ other job offers with probability $\chi(j|a-1)$, which are all lower than w with probability $F^j(w)$. Hence, the matching probability of a firm offering w is given by

$$m_F(w) = \left(1 - e^{-\lambda}\right) \sum_{a=1}^{A} \frac{ap_a}{\sum_{i=1}^{A} ip_i} \sum_{j=0}^{a-1} \chi(j|a-1) F^j(w).$$

By using $1 - e^{-\lambda} = \lambda\psi = \frac{u}{v} \sum_{i=1}^{A} ip_i\psi$ and the definition of $\chi(j|a-1)$, we can simplify this expression as follows

$$\begin{aligned} m_F(w) &= \frac{u}{v} \sum_{a=1}^{A} ap_a \sum_{j=0}^{a-1} \binom{a-1}{j} \psi^{j+1} (1-\psi)^{a-1-j} F^j(w) \\ &= \frac{u}{v} \sum_{a=1}^{A} \sum_{j=1}^{a} ap_a \binom{a-1}{j-1} \psi^j (1-\psi)^{a-j} F^{j-1}(w) \\ &= \frac{u}{v} \sum_{j=1}^{A} jq_j F^{j-1}(w). \end{aligned}$$

A.2 Lower Bound Wage Distribution

Substitution of (17) in the expression for w_{avg} and applying a change of variables yields

$$w_{avg} = \frac{1}{1-q_0} \int_0^1 w(z)\, d \sum_{j=1}^{A} q_j z^j,$$

where, by inversion of (13),

$$w(z) = y - \frac{(y - \underline{w})\, q_1}{\sum_{j=1}^{S} jq_j z^{j-1}}.$$

Hence,

$$w_{avg} = y - \frac{q_1}{1-q_0} (y - \underline{w})$$

or

$$\underline{w} = y - \frac{1-q_0}{q_1} (y - w_{avg}).$$

A.3 Home Production

Equation (8) implies

$$h = w_R - \int_0^\infty \max_a \left(B(a) + \frac{1}{r+\delta}\zeta_a - ca \right) dS(c) \tag{19}$$

To calculate the integral, partition the support of $S(c)$ into the intervals $[\Gamma_{A+1}, \Gamma_A)$, $[\Gamma_A, \Gamma_{A-1})$, ..., $[\Gamma_2, \Gamma_1)$, $[\Gamma_1, \Gamma_0]$, where Γ_{A+1} and Γ_0 are the lower bound and the upper bound of the support of $S(c)$. Due to the linear interpolation, the density $s(c)$ is constant on each of these intervals. Let s_a denote the value of $s_c(c)$ on the interval $[\Gamma_{a+1}, \Gamma_a)$. Then,

$$s_a = \frac{S(\Gamma_a) - S(\Gamma_{a+1})}{\Gamma_a - \Gamma_{a+1}} = \frac{p_a}{\Gamma_a - \Gamma_{a+1}}.$$

Substituting this in (19), we can write

$$h = w_R - b(1 - \pi p_0) - \sum_{a=1}^{A} \int_{\Gamma_{a+1}}^{\Gamma_a} \left(\frac{1}{r+\delta}\zeta_a - ca \right) \frac{p_a}{\Gamma_a - \Gamma_{a+1}} dc,$$

which after calculation of the integral and substitution of (9) reduces to

$$h = w_R - \frac{1}{r+\delta} \sum_{a=1}^{A} p_a \left(\zeta_a - \frac{1}{2} a \left(\zeta_{a+1} - \zeta_{a-1} \right) \right) - b \left(1 - \pi p_0 - \frac{1}{2} \pi p_1 \right),$$

where we define $\zeta_{A+1} = \zeta_A$ to simplify notation.

B General Search Cost Functions

Individual Rationality. It may seem that little can be said about a worker's search cost function as we only have one observation of the number of applications that he sends. However, individual rationality imposes considerable structure. To see this, denote by $C(a|a^*)$ the search cost function of a worker, conditional on this worker sending a^* applications in equilibrium. As an example, let the worker send $a^* = 2$ applications in equilibrium at a cost $C_2 \equiv C(2|2)$. A number of observations can then be made. First, $C_2 \leq \Gamma_1 + \Gamma_2$ or otherwise the worker would have been better off not applying. Second, $C(1|2) \geq C_2 - \Gamma_2$ or otherwise the worker would have been better off applying once. Likewise, $C(a|2) \geq C_2 + \sum_{j=3}^{a} \Gamma_a$ for all $a \in \{3, \ldots, A\}$ or otherwise the worker would have been better off applying a times. Finally, the assumption that $C(\cdot)$ is weakly increasing implies that $C(1|2) \leq C_2$. Figure 3 illustrates these restrictions.

Bounds. As we do not observe the worker's exact value of C_2, we again construct bounds. The lowest search costs are obtained if $C_2 = 0$ and $C(a|2)$ follows the lower boundary of the

Figure 3: Feasible Search Cost Functions

Red area: set of feasible search cost functions $C(a|2)$ for a worker who sends two applications in equilibrium at cost C_2.

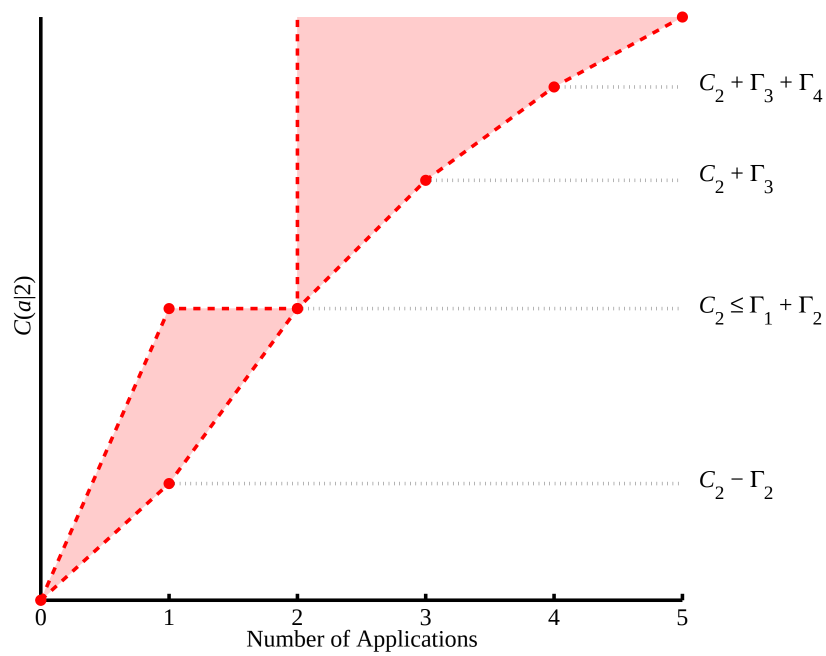
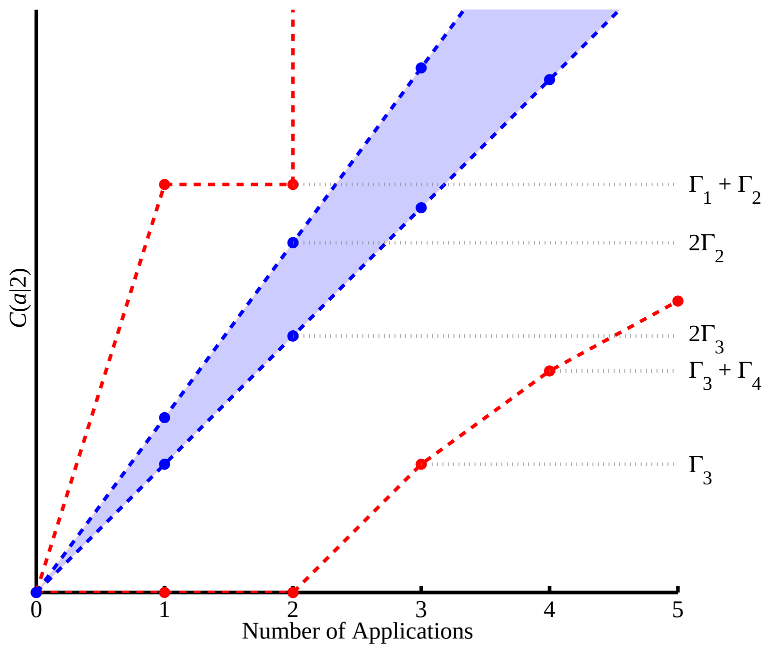


Figure 4: Bounds on Search Cost Functions

Red lines: upper bound and lower bound of feasible search cost functions for a worker who sends two applications in equilibrium. Blue area: linear search cost functions used in baseline model.



set indicated in figure 3. The highest search costs are obtained if $C_2 = \Gamma_1 + \Gamma_2$ and $C(a|2)$ follows the upper boundary of this set. Figure 4 plots these bounds, together with the linear search cost functions used in the baseline model. Similar bounds can be obtained for workers who send $a^* \neq 2$ applications in equilibrium.[24]

Home Production. By imposing either the upper bound or the lower bound of the search costs functions instead of the linear ones, we change the option value of continued search, which results in a different value for the value of home production h.[25] To see this, note that a worker's reservation wage equation now equals

$$w_R = h + \sum_{a^*=0}^{A} p_{a^*} \left(B(a^*) + \frac{1}{r+\delta} \zeta_{a^*} - C(a^*|a^*) \right). \qquad (8')$$

[24]Note that, unlike in the linear case, we cannot rule out that a worker who sends 10 applications in equilibrium would pay more for sending 5 applications than a worker who actually sent 5 applications.

[25]This was not the case above, when we changed the search costs of workers sending zero applications. As they did not actually incur these costs, the option value remained unchanged.

The lower bound implies $C(a^*|a^*) = 0$ for all a^*. Hence,

$$h = w_R - b(1 - \pi p_0) - \frac{1}{r+\delta} \sum_{a^*=0}^{A} p_{a^*} \zeta_{a^*},$$

which yields $h = -0.202$. When workers incur the maximum possible search costs $\sum_{i=1}^{a^*} \Gamma_i$ in equilibrium, we get $h = w_R - (1 - \pi) b$, which implies $h = 0.320$.

Planner's Results. We let the planner take the new values for h into account when determining his solution for either of the bounds.[26] Table 4 presents the results. For the lower bound on the search costs, the planner wants all workers to search exactly once. This resembles the solution in table 3, when we only relaxed the search costs of the workers who did not apply. The welfare gain is 8.0% for the constrained planner and 13.6% for the unconstrained planner, which—perhaps somewhat surprisingly—is a bit lower than in the baseline case. The explanation for this lies in the fact that h is considerably lower now, which is a countervailing force against the reduction in the search costs in the calculation of surplus.

The results for the upper bound on the search costs differ a bit more from table 3. In particular, the planner wants more workers to abstain from searching. The reason is simple. As we are considering the upper bound, workers who sent many (say, a^*) applications in equilibrium have a high search cost, $\sum_{i=1}^{a^*} \Gamma_i$, even for applying once. This cost exceeds the social benefit of applying, so it is better to let these workers not search at all. We find that the cutoff is around $a^* = 6$. That is, the workers who sent $a^* \in \{1, 2, \ldots, 6\}$ applications in equilibrium—roughly half of all workers—should apply once, while the workers who sent $a^* \in \{0, 7, 8, \ldots, A\}$ applications in equilibrium should not search. The welfare gain is 6.4% for the constrained planner and 12.8% for the unconstrained planner—the higher search costs are now mitigated by the corresponding increase in h.

[26] Note that the change in h does not affect market surplus, since—by construction—it is exactly offset by the change in expected search costs in equilibrium.

Table 4: Planner's Solution for Non-Linear Search Cost Functions

	Constrained Planner			Unconstrained Planner		
	Max Costs	Baseline	Min Costs	Max Costs	Baseline	Min Costs
p_0	0.471	0.000	0.000	0.471	0.000	0.000
p_1	0.529	1.000	1.000	0.529	1.000	1.000
p_2	0.000	0.000	0.000	0.000	0.000	0.000
p_3	0.000	0.000	0.000	0.000	0.000	0.000
p_4	0.000	0.000	0.000	0.000	0.000	0.000
$p_{\geq 5}$	0.000	0.000	0.000	0.000	0.000	0.000
θ	0.218	0.347	0.381	0.529	1.000	1.000
u	0.071	0.045	0.041	0.028	0.015	0.015
v	0.016	0.015	0.016	0.015	0.015	0.015
m_W	0.199	0.328	0.353	0.529	1.000	1.000
m_F	0.912	0.944	0.928	1.000	1.000	1.000
h	0.320	0.220	-0.202	0.320	0.220	-0.202
Output	95.24	98.26	96.76	101.02	102.25	101.72
Gain	6.4%	9.7%	8.0%	12.8%	14.2%	13.6%

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