

# The Strategic Role of Pay Secrecy in Labor Markets with Matching Frictions

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## ABSTRACT:

This paper studies the strategic role of wage-secrecy arrangements, used by firms in labor contracts, to affect the dissemination of information regarding wages via professional social networks. We show that pay-secrecy policies arise in equilibrium and serve the firms to improve their bargaining position, in wage negotiations, by inducing search frictions that lower applicants' salary expectations.

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# 1 Introduction

“What are your salary expectations?” – just about anyone, who has ever been interviewed for a job, is familiar with the situation where the recruiter brings up the topic of pay to the table. The way an applicant answers this question may considerably affect the applicant’s employment prospects, both in terms of the likelihood of getting the job and the level of compensation offered by the employer. Job applicants typically prepare in advance for such salary-related questions by doing research on the average level of remuneration for the role sought adjusted for their experience. In modern labor markets, professional social networks, such as LinkedIn, serve as natural platforms through which job-related information (notably, the level of remuneration) is being transferred from existing employees to applicants. Acknowledging that informed applicants improve their bargaining stance relative to uninformed ones, employers attempt to make this information less accessible. One tool that serves this purpose is the use of wage secrecy arrangements.

Indeed, labor contracts often stipulate wage-secrecy clauses that require employees to maintain confidentiality regarding their pay-check. The use of such clauses is generally described as a strategic tool used by employers to: (i) mitigate the potentially demoralizing effect of pay gaps; and (ii) improve their bargaining position in wage negotiations. The first aspect is the main focus of Blumkin and Lagziel (2018) which explores the micro-foundations of wage secrecy at the firm level.<sup>1</sup> In the current paper we address the second aspect by exploring wage secrecy at the market level, focusing on the interaction amongst firms that compete over a pool of prospective employees.

We consider a market with two identical firms and a continuum of homogeneous job applicants seeking for job opportunities in both firms. Due to matching frictions only a fraction of applicants engages in wage bargaining with every firm. The outcome of the wage-bargaining process crucially depends on the wage-related information available to the applicants, which is acquired through interactions with current employees.

In the backdrop of matching frictions, which limit the scope of alternative job opportunities for the applicants, we show that in equilibrium firms strategically employ wage-secrecy policies to control the dissemination of wage-related information to job applicants. This, in turn, results in wage dispersion (amongst the ex-ante homogeneous workers) and allows both firms to derive positive rents. Notably, secrecy arrangements are shown to be more prevalent at high wage levels, and we further show that matching frictions arise endogenously in equilibrium. Although the presence of such frictions a-priori constraints the ability of the firms to recruit, it essentially serves as a coordination device that allows both firms to *tacitly collude* through the wage-secrecy mechanism, thereby ensuring that both derive positive rents.

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<sup>1</sup>See the literature review in Section 1.1 below.

## 1.1 Literature review

The effect of pay transparency on workers' satisfaction and incentives has been examined in several recent empirical studies (see Card et al. (2012), Perez-Truglia (2015) Rege and Solli (2015), and Cullen and Perez-Truglia (2018), *inter-alia*). The empirical evidence alludes to the role played by pay transparency in determining labor market outcomes both along the intensive margin (effort levels/performance) and the extensive margin (recruitment/retention). For instance, Rege and Solli (2015) use the 2001 policy change in the on-line availability of Norwegian tax records to show that the information shock increased job separation for low-earning workers relative to high-earning ones. More recently, Cullen and Perez-Truglia (2018) show, in a field experiment, that higher perceived peer salary decreases effort and output, as well as retention.

Somewhat surprisingly, there is a paucity of theoretical studies examining the desirability of incorporating wage-secrecy arrangements in the optimal design of labor contracts. A notable exception is the study by Danziger and Katz (1997), which demonstrates how a wage secrecy convention can serve to facilitate risk shifting between firms and workers in response to productivity shocks.

In Blumkin and Lagziel (2018) we take a first step to fill the void and explore the micro-foundations of wage secrecy at the firm level. We present a novel theoretical set-up where *ex-ante* homogeneous workers exhibit other-regarding preferences with respect to the remuneration of their co-workers (team-mates). Assuming that relative pay concerns induce over/under-paid workers to exert higher/lower effort levels, we characterize necessary and sufficient conditions for wage dispersion and wage secrecy to be part of the optimal labor contract. We demonstrate that wage secrecy serves to mitigate relative-pay concerns and allude to the role played by the extent of complementarity exhibited by the team's production function. These results hold in a general-equilibrium framework and are robust to the introduction of firms' free entry and workers' renegotiation power.

Our model also relates to a voluminous search literature in the context of the labor market (for an elaborate survey, see Rogerson et al. (2015)). One strand of this literature, that combines random matching with wage posting, focuses on pure wage dispersion, namely, exploring mechanisms via which workers with identical productivities are paid different wages in equilibrium. Typically in these models there is a continuum of homogeneous firms with no market power, each posting a single wage offer, so wage dispersion arises in equilibrium across firms, trade-offing higher wages with lower vacancy risks. In our set-up, instead, with both homogeneous firms and workers, wage dispersion arises in equilibrium at the firm level (and potentially also across firms). The latter is attained in a setting with only two identical firms that do possess some market power.<sup>2</sup> As shown in Blumkin and Lagziel (2018) and exemplified in the current study, wage dispersion at the firm level is crucial for wage-secrecy arrangements since firms have nothing to gain from limiting the dissemination of wage related information to current and/or prospective

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<sup>2</sup>Our qualitative results would hold under any finite number of firms.

employees, in case all workers are equally remunerated.

## 1.2 Structure of the paper

The paper is organized as follows. In Section 2 we present a reduced-form static set-up. In Section 3 we present the main results: (i) in Section 3.1 we characterize the equilibrium in the reduced-form set-up for different levels of matching frictions; (ii) in Section 3.2 we embed the one-stage problem into a dynamic set-up; (iii) in Section 3.3 we examine the optimality and robustness of the search procedure invoked in the reduced-form set-up; and (iv) in Section 3.4 we allow the matching frictions to be determined endogenously by the firms. Concluding remarks and general comments are given in Section 4.

## 2 The model

In this section we formulate a parsimonious analytical framework that demonstrates the role of wage-secrecy clauses in labor contracts. Wage secrecy is presented as a strategic tool used by firms to control the dissemination of wage-related information to prospective job applicants. Our model accentuates the central role played by professional social networks, serving as a key channel in modern labor markets via which job-related information is being transferred. To facilitate the exposition, we first present a (reduced form) single-stage problem and later extend it to a full-fledged dynamic set up.

Consider a market comprised of two identical firms and a continuum of risk-neutral homogeneous workers who search for available positions in both firms. The duration of the labor contract upon formation of a successful match between a worker and a firm is normalized to a single period. Firms employ a linear production function where the productivity of each worker is denoted by  $q > 0$ . Without loss of generality, we set the workers' outside option, associated with either alternative job opportunities outside the market or government support programs, to zero. We further normalize each firm's reservation to zero, with no loss in generality.

Evidently, the formation of a match between a firm and a typical worker is mutually beneficial given any wage level between 0 and  $q$ . However, match formation is restricted by some friction such that only a fraction  $p_i$  of applicants reaches a state of wage bargaining with firm  $i = 1, 2$ . The result of this wage bargaining process naturally depends on the applicants' wage expectations, formed based on information acquired during the search process, as explained below.

A major source of job-related information that ultimately shapes applicants' wage expectations follows from the interaction with existing employees through professional social networks. Using wage-secrecy arrangements, firms can partially control this process, thereby improving their bargaining position. The effect of various non-disclosure policies can be summarized in what we refer to as *the distribution of wage signals*, conveyed by the firm to its applicants. To simplify the exposition, we assume that each firm dictates a distribution of wage signals from which applicants randomly draw once (i.e., one signal from

each firm). These random draws reflect random encounters with employees in both firms. We later discuss how these distributions are formed, in equilibrium, through a proper choice of non-disclosure rules.

Specifically, each firm  $i$  dictates a wage-signalling function  $F_i \in \Delta\mathbb{R}_+$  which defines the distribution of wage signals that existing employees transmit. These signalling functions eventually lead to a realized wage distribution according to the following protocol. Each applicant is successfully assigned with firm  $i$  with probability  $p_i$ . A successfully assigned applicant conditions employment in the relevant firm on the signalled wage level (a take-it-or leave-it offer). In case an applicant is successfully assigned with both firms, he approaches only the high-signal firm with a symmetric tie-breaking rule. As, by presumption, each firm's reservation is normalized to zero, the applicant's offer is accepted. Unassigned applicants remain unemployed.

Several remarks are in order. First, notice that we assume that information acquisition precedes the assignment phase. This simplifies the analysis but does not affect the qualitative nature of the results. Further notice that our simplified bargaining set-up maintains a key feature of more general bargaining protocols: a monotonic relationship between the wage signal and the realized agreed wage. Given any mapping between the distribution of wage signals and the resulting wage distribution, an outcome of the bargaining process, the firm can properly choose the distribution of wage signals in a manner that implements its desired realized wage distribution. In this sense, the specification of the bargaining process is non-consequential for our qualitative results. For tractability, we resort to the simplified set-up in which wage signals coincide with the corresponding realized wage rates.<sup>3</sup> Finally notice that we impose an exogenous search procedure. In particular, applicants are assumed to sample twice and do it horizontally (one signal from each firm) rather than vertically (drawing twice from one of the firms). Moreover, the search procedure is assumed to be independent of the signaling functions. These restrictive assumptions will be discussed at length in Section 3.3, where we examine the optimality and robustness of the specified search procedure.

The expected profit of firm  $i$  from an accepted applicant, given a policy profile  $(F_1, F_2)$  and subject to a signal  $w$ , is

$$\pi_i(w|F_{-i}) = p_i \left[ 1 - p_{-i} \left[ 1 - F_{-i}(w) + \frac{1}{2} \Pr(w_{-i} = w) \right] \right] (q - w),$$

where  $p_j$  is the probability that the relevant applicant indeed reaches a state of bargaining with firm  $j$ , and  $w_j \sim F_j$ . To be clear, the term  $p_{-i} \left[ 1 - F_{-i}(w) + \frac{1}{2} \Pr(w_{-i} = w) \right]$  is the probability that the applicant is employed by firm  $-i$  rather than by firm  $i$ , due to a signal that exceeds  $w$ . Assuming that the mass of applicants is normalized to unity and with a slight abuse of notation, the expected

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<sup>3</sup>Typically, the applicant's bargaining power depends on the outside option, i.e., the wage signal drawn from the rival firm. Though this information is not observable to the negotiating firm, the firm can use the signaled wage level and its rival's signaling function to deduce the applicant's expected outside option. Thus, the outcome of the bargaining process becomes monotonic with respect to the wage signal, in line with our presumption.

payoff of firm  $i$  is denoted by  $\pi_i(F_i|F_{-i}) = \mathbf{E}_{F_i} [\pi_i(w|F_{-i})]$ . Thus, a profile  $(F_1, F_2)$  is an *equilibrium* if  $\pi_i(F_i|F_{-i}) \geq \pi_i(F'_i|F_{-i})$ , for every signaling function  $F'_i$  and for every firm  $i$ .

The implementation of a signalling system  $(F_1, F_2)$  hinges on the firms' secrecy policy which restricts employees from sharing their wage levels with others. In practice, firms exercise such policies by incorporating non-disclosure clauses in personal contracts. It is important to note that the signalling function need not coincide with realized wage distribution. Specifically, firm  $i$ 's realized wage distribution  $G_i$  is given by the CDF

$$G_i(w) = \frac{\mathbf{E}_{F_i} \left[ \frac{\pi_i(t|F_{-i})}{(q-t)} \mathbf{1}_{\{t \leq w\}} \right]}{\mathbf{E}_{F_i} \left[ \frac{\pi_i(t|F_{-i})}{(q-t)} \right]}, \quad (1)$$

which does not necessarily coincide with  $F_i$ . Such differences arise under secrecy policies in case some employees can disclose their wage levels while others cannot, or in case there exists some variation (either de jure, or de facto) in the enforcement of non-disclosure clauses. The one case that the signalling function and wage distribution must coincide is under an observable-wage policy, where the sharing of information is not restricted in any way, and all employees mitigate their wage level to others. In other words, a firm that facilitates an observable-wage policy has no control over its signaling function, since  $F_i$  represents the firm's actual wage distribution.

### 3 Main results

Our analysis consists of four parts. In the first part we analyse the previously defined single-stage game for any friction level. In the second part we embed the single-stage game into a repeated set-up, and substantiate the single-stage equilibria as stationary solutions of the dynamic problem. In the third part we study the applicants' search procedure and in particular the optimality of the applicants' choice to sample both firms, along with the ability of the firms to affectively manipulate this sampling rule. In the last part we revert from the exogenous-frictions set-up by allowing firms to strategically determine the extent of matching frictions in the labor market. Let us now review each of these parts separately.

First, in section 3.1, we maintain our assumption that frictions are exogenous and analyse the equilibria with respect to the level of matching friction in the market. An important insight from this part concerns the minimal level of friction which leads to wage dispersion and wage secrecy. As it turns out, *any* positive friction leads to wage dispersion and secrecy. That is, for every  $p_i \in (0, 1)$  there exists a unique equilibrium where the induced signals differ from the realized wages and both are fully supported on  $[0, q]$ . Notably, and in contrast to standard search theoretic models of the labor market, wage dispersion is shown to arise at the firm level (see our discussion in the literature review).

The second part of our analysis, given in Section 3.2, embeds the one-stage game into a repeated overlapping-generations set-up. We first show how our static analysis carries through to the dynamic

set-up. We then show how a proper choice of secrecy policy serves to reconcile the differences between the wage signals distributions and the realized wage distributions. In particular, we demonstrate that the realized wage distribution stochastically dominates the wage signals distribution, which implies that wage secrecy arrangements are, plausibly, more prevalent at high wage levels.

In the third part (Section 3.3) we examine the optimality and robustness of the hitherto exogenously invoked search procedure. In particular, we show that sampling horizontally (one draw from each firm) dominates sampling vertically (drawing twice from one of the firms) whenever the distributions of wage signals and the matching frictions are identical across firms. We further show that for sufficiently low levels of matching friction, there exist no signaling function that induces workers to search vertically. In other words, we prove that firms do not have a feasible way to manipulate the applicants' decision to sample across firms.

The fourth part of our analysis, presented in Section 3.4, extends the basic model by allowing every firm  $i$  to first choose its desired level of friction  $p_i$ , and later choose a signaling policy  $F_i$ . The main insight from this part concerns the firm's desire to introduce friction into the recruitment process, although the latter is a-priori counter-productive. A firm that introduces friction into its recruitment process de-facto limits its ability to attract new employees, while facilitating it for the other firm. We nevertheless prove that such losses, associated with induced matching frictions reflected in a lower assignment probability, are outweighed by the benefits associated with wage dispersion and wage secrecy, reflected in limited wage competition and consequently, lower expected wages. In a sense the combination of wage secrecy and the ability to set matching frictions serves the firms to coordinate on an equilibrium (i.e., an implicit collusion) in which they derive positive rents despite wage competition.

**Remark 1.** *To shorten the exposition and unless stated otherwise, the complete analysis and statements hold almost surely (a.s.), i.e., with probability 1. This remark holds throughout the paper since zero-measure deviations do not effect the expected payoff of either firm.*

### 3.1 The single-stage problem

We start with the one-stage game defined in Section 2. The first observation concerns the signaling functions in equilibrium. We show that, in equilibrium, both distributions have a convex support and that atoms are only possible at the end points, 0 and  $q$ . To be clear, we define an *atom* as a point  $w \in [0, q]$  such that  $\Pr(w_i = w) > 0$ , and  $F_i$  is not left-side continuous at  $w$ .

**Lemma 1.** *For fixed values  $p_1, p_2 \in (0, 1]$ , the wage signals in equilibrium are supported on a connected set with no atoms in  $(0, q)$ .*

All proofs are deferred to the Appendix.

Lemma 1 is motivated by the following reasoning. An interior atom of one firm provides a profitable deviation for the other firm, via an increase in the wage levels strictly above the atom. In response to

such deviation, the first firm would have an incentive to shift the atom downwards and decrease wage signals (and wage levels, accordingly), without affecting the probability to recruit applicants. This process cascades downwards, and stops at the lower end of the range of feasible wage signals. The only case where such profitable deviations do not exist is for atoms at one of the end points, either  $w = 0$  or  $w = q$ .

Note that an atom at the highest feasible level  $q$  guarantees a (point-wise) zero payoff. This outcome is maintained in equilibrium if and only if the firm cannot secure a positive payoff for any lower wage rate. We pursue this possibility in the following lemma, which considers a frictionless environment (i.e.,  $p_i = 1$  for both firms). Building on Lemma 1, it shows that the a frictionless environment leads to a *unique* equilibrium where both firms support *only* the maximal wage level.

**Lemma 2.** *If no frictions exist,  $p_1 = p_2 = 1$ , then there exists a unique equilibrium where both signaling functions induce only the highest signal  $q$  (i.e., both equal the Dirac measure  $\delta_q$ ).*

The competitive wage level  $q$  has specific characteristics that follow from Lemmas 1 and 2. If firm  $i$  can generate a strictly positive payoff, then it will not support wages sufficiently close to the competitive level  $q$ , since any atom at  $q$  generates a (point-wise) zero payoff. One thus concludes that the competitive wage level  $q$  is only supported by one firm if the other firm faces no friction and supports the unique wage level of  $q$ . The result in Lemma 2 is a replication of the familiar Bertrand paradoxical prediction that the outcome of a price (wage, in our case) competition between two firms coincides with the competitive equilibrium allocation. With no frictions in place, both firms engage in a “wage-war” which drives the equilibrium wage rate all the way up to its competitive level, where all rents are fully dissipated.

We now extend our analysis to account for the possibility of matching frictions. The next result establishes that in the presence of some friction, the Bertrand paradoxical result fails to hold. In particular, wage dispersion arises in equilibrium for any level of friction, which in turn implies that both firms derive positive rents. Theorem 1 also incorporates, as a special case, the frictionless scenario characterized in Lemma 2.

**Theorem 1.** *Given that  $0 < p_1 \leq p_2 \leq 1$ , the unique equilibrium is*

$$F_1(w) = \begin{cases} 0, & \text{for } w < 0, \\ \frac{w(1-p_1)}{p_1(q-w)}, & \text{for } 0 \leq w < qp_1, \\ 1, & \text{for } w \geq qp_1, \end{cases} \quad F_2(w) = \begin{cases} 0, & \text{for } w < 0, \\ \frac{q(p_2-p_1)+w(1-p_2)}{p_2(q-w)}, & \text{for } 0 \leq w < qp_1, \\ 1, & \text{for } w \geq qp_1. \end{cases}$$

*Under the given equilibrium, the expected payoff of firm  $i$  is  $p_i(1 - p_1)q$ .*

To fully grasp the economic intuition behind the expected payoff  $p_i(1 - p_1)q$ , consider the symmetric case with frictions, and denote  $p = p_1 = p_2 < 1$ . The value  $p(1 - p)$  denotes the probability that an applicant is matched only with firm  $i$ . As, by presumption, the outside option of an applicant is normalized to zero, firm  $i$  can hire the applicant by offering him the minimal wage level, extracting the

entire surplus and securing an expected payoff of  $p(1 - p)q$ . The presence of matching frictions, thus, limits the extent of competition over the pool of applicants and allows firms to derive strictly positive rents.

Notice that under any asymmetric scenario in which one firm (firm 2, with no loss in generality) has an advantage over its counterpart (firm 1), reflected in facing a higher probability of recruiting applicants conditional on both firms making the same wage offer ( $p_2 > p_1$ ), it sets an atom at the minimal wage level, that is  $\Pr(w_2 = 0) > 0$ . This atom sustains the equilibrium, by ensuring that firm 1 would find it optimal to offer the minimal wage level. For instance, when  $p_2 = 1$  and in the absence of an atom, the probability that firm 1 would recruit applicants by offering  $w_1 = 0$  would be zero, which clearly renders such a strategy suboptimal.

### 3.2 The dynamic set-up: an implementation issue

The previously studied single-stage problem should be viewed as a snapshot from a dynamic game with overlapping generations. Every individual is attached with the labor market for two consecutive periods (referred to as young and old generations, respectively): in the first period as a job applicant and in the second as an employee or unemployed, pending on match success. In any period the old generation of current employees and the young generation of job applicants overlap, and the former disseminate wage signals to the latter. In the period which follows the old generation quits the labor market, whereas the hired young generation (from the previous period) switches roles to become the current period's old generation overlapping with the newly born young generation of applicants. This game continues indefinitely. We turn now to demonstrate how our results carry through as a stationary solution for the dynamic model.

We assume that each firm is maximizing its discounted expected profits in the continuation game and let the friction levels be fixed at  $(p_1, p_2)$ . At the beginning of stage  $t \geq 1$ , every firm  $i$  employs a mass of employees under a wage distribution  $G_{i,t-1}$ , and chooses a distribution of wage signals, denoted by  $F_{i,t}$ . A new generation of applicants approaches both firms, and the single-stage game is played. After wages are realized and applicants are employed according to the relevant signals and probabilities, the “old” generation leaves the firms while the “new” generation of stage  $t$  becomes the “old” generation of stage  $t + 1$ . At the beginning of stage  $t + 1$ , each firm  $i$  employs a mass of employees with an associated wage distribution given by  $G_{i,t}$ , and chooses a corresponding distribution of wage signals given by  $F_{i,t+1}$ . This game continues indefinitely.

An immediate observation concerns the existence of a stationary equilibrium, which is attained by an infinite replication of the single-stage equilibrium characterized in Theorem 1. It is straightforward to verify that this indeed forms an equilibrium, since whenever one firm repeatedly plays its single-stage equilibrium strategy, replicating the optimal single-stage strategy constitutes a best response for the other

firm. Note that we do not claim these equilibria are unique (as is seldom the case in repeated games), so our focus in the remainder of this section would be on the issue of implementability.

To see how the stationary equilibrium is implemented, let the  $t$ -stage wage distribution  $G_{i,t-1}$  denote the state variable at stage  $t$ . As already observed, the distribution of wage signals  $F_{i,t}$  typically does not coincide with the realized wage distribution  $G_{i,t-1}$ . To support the stationary equilibrium, each firm thus relies on wage secrecy policy, implicitly defined by a mapping from the state variable  $G_{i,t-1}$  to the control variable  $F_{i,t}$ . In order to attain the desired distribution of wage signals each firm essentially “shuts down” a proper fraction of the wage signals. As shown in Lemma 3, the realized wage distribution  $G_i$  first-order stochastically dominates the distribution of wage signals,  $F_i$ .<sup>4</sup> The fact that wage secrecy arrangements turn out to be more prevalent at the higher end of the wage distribution appears to be empirically plausible, and essentially captures the role played by wage secrecy in restraining the competition between the two firms over the pool of job applicants.

To attain this “shut-down” property each firm can apply a simple binary rule such that some employees are allowed to disclose their level of remuneration, whereas others must refrain from sharing it. Alternatively, all employees could be subjected to identical non-disclosure clauses, but enforcement may vary and become stricter at the higher end of the distribution. To illustrate the role of wage secrecy to attain the desired mapping, consider the following example with a discrete support. Suppose that  $G$  supports two wage levels, 0 and  $q$ , with equal proportions. Further assume that the firm desires to induce the distribution  $(2/3, 1/3)$  over  $\{0, q\}$ . The latter can be implemented by allowing all 0-wage employees to disclose their level of remuneration, while restricting one half of the  $q$ -wage employees from doing so.

Notice that in a frictionless case both the distribution of wage signals and the distribution of realized wages collapse to an atom at the competitive wage rate,  $q$ . In this case, no wage secrecy is needed to support the stationary equilibrium, as the mass point at  $q$  constitutes an absorbing state. The following lemma characterizes the distributions of realized wage rates corresponding with the distributions of wage signals given in Theorem 1, and further establishes the first-order stochastic dominance of  $G$  over  $F$ .

**Lemma 3.** *Fix  $0 < p_1 \leq p_2 \leq 1$ , and consider the equilibrium distributions  $(F_1, F_2)$  from Theorem 1. The ex-post single-stage wage distributions of both firms is*

$$G_1(w) = \begin{cases} 0, & \text{for } w < 0, \\ \frac{w(2q-w)(1-p_1)^2}{(q-w)^2(2-p_1)p_1}, & \text{for } 0 \leq w < qp_1, \\ 1, & \text{for } w \geq qp_1, \end{cases} \quad G_2(w) = \begin{cases} 0, & \text{for } w < 0, \\ \frac{(p_2-p_1)(1-p_1) + \frac{w(1-p_1)^2(2q-w)}{2(q-w)^2}}{p_2(1-p_1) + \frac{p_1^2}{2}}, & \text{for } 0 \leq w < qp_1, \\ 1, & \text{for } w \geq qp_1. \end{cases}$$

*For every firm  $i$ , the wage distribution  $G_i$  (first-order) stochastically dominates the signaling function  $F_i$ .*

The proof is a straightforward computation according to Equation (1), hence omitted.

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<sup>4</sup>The time index is omitted to abbreviate notation, as we focus on a stationary equilibrium.

### 3.3 Vertical versus horizontal sampling

The extensive search literature emanating from the early seminal contributions by Stigler (1961, 1962), Diamond (1971), and Lippman and McCall (1976), emphasizes the costly nature of information acquisition by agents. The optimal search rule, typically characterized as repeated random draws from a given distribution following a cut-off (reservation) strategy, is known to depend on the properties of the distribution at stake. In two sided search models, the latter distribution is determined endogenously in equilibrium, both affecting, and being shaped by the optimal search rules.. For tractability reasons and to facilitate our exposition, we have thus far invoked an exogenous search procedure adopted by all job applicants. We have therefore not examined the optimal search rule from the perspective of the applicants, nor have we tested the extent to which the search rule is affected by the firms' signaling functions. In this section, we study the optimality and robustness of the invoked search procedures.

In the preceding analysis we assumed that job applicants draw one wage signal from each firm; we refer to this strategy as *horizontal* search. An alternative search strategy would be to draw twice from the same firm; we refer to this strategy as *vertical* search. The choice between horizontal and vertical sampling trades-off the likelihood of securing a job (enhanced by horizontal sampling), and the expected level of remuneration conditional on finding a job (enhanced by vertical sampling). Notice that the possibility to engage in vertical sampling hinges on a novel feature of our model, absent from standard search theoretic models of the labor market, which is the wage dispersion at the firm level. Such wage dispersion is essential for a wage-secrecy policy to be instrumental.

In this section we produce two key results. The first result establishes the dominance of horizontal sampling under the presumption of identical distributions of wage signals across firms. Indeed, by virtue of Theorem 1, the distributions of wage signals are identical in equilibrium under symmetric friction. However, the firms' optimal choice of signaling functions was based on the presumption that job applicants resort to horizontal sampling, independently of the choices made by the firms. Therefore, one must consider the possibility of a profitable deviation (by at least one firm) to an alternative signaling procedure which induces vertical sampling from applicants. This leads us to the second result of this section.

Our second result establishes that, for sufficiently low levels of friction, the horizontal sampling is indeed invariant to the choices made by the firms, in the sense that no firm can profitably deviate from the equilibrium path by inducing applicants to switch to vertical sampling. Notably, for sufficiently high levels of friction, such profitable deviations become feasible (see the example following Theorem 2).

Before proceeding to the formal analysis we make two simplifying assumption for tractability reasons. First, we capture the costly nature of search by letting job applicants sample only twice, rather than solving endogenously for the optimal intensity of search. Second, we assume a uniform level of friction  $p \in (0, 1)$ . Relaxing these assumptions will not change the qualitative nature of our results.

Formally, let  $w_i$  and  $\tilde{w}_i$  denote two i.i.d. wage samples from firm  $i$ . Given a uniform level of friction

$p \in (0, 1)$ , and an equilibrium profile  $(F_1, F_2)$ , an applicant's expected payoff from sampling both firms is

$$\Pi_{12}(F_1, F_2, p) = p^2 \mathbf{E}[\max\{w_1, w_2\}] + p(1-p) \mathbf{E}[w_1 + w_2] + 0 \cdot (1-p)^2,$$

while the expected payoff from double-sampling firm  $i$  is

$$\Pi_i(F_1, F_2, p) = p \mathbf{E}[\max\{w_i, \tilde{w}_i\}] + 0 \cdot (1-p).$$

The following Lemma 4 establishes the optimality of horizontal sampling under the presumption of identical distributions of wage signals. Note that the statement of Lemma 4 is not confined to the equilibrium profile, but holds for any two identical distributions, which is indeed the case under a uniform level of friction according to Theorem 1.

**Lemma 4.** *For every friction level  $p$  and signaling functions  $F_1 = F_2$ , it follows that horizontal sampling is a strictly dominant strategy (i.e.,  $\Pi_{12} > \Pi_i$ ).*

Next, we establish the invariance of horizontal sampling to the choices made by the two firms, assuming that the level of friction is sufficiently low.

**Theorem 2.** *Fix a friction level  $p \in (0.62, 1)$  and assume that firm 1 follows the equilibrium strategy  $F_1$ . Then, for every signaling function  $F$ , horizontal sampling is a strictly dominant strategy (that is,  $\Pi_{12}(F_1, F, p) > \Pi_2(F_1, F, p)$ ).*

Theorem 2 states that, for a low enough level of friction, no firm can profitably deviate from the equilibrium path characterized in Theorem 1, by inducing applicants to switch to vertical sampling. The rationale underlying the result derives from the fact that with low levels of friction, applicants extract much of the surplus, so that the deviating firm cannot offer much to its prospective employees. This situation changes markedly once friction levels are sufficiently high, as demonstrated in the following example.

**Example 1.** *Fix  $p = 0.5$  and consider the symmetric equilibrium defined in Theorem 1. If firm 1 diverts to a signaling function  $F$  such that*

$$F(w) = \begin{cases} 0, & \text{for } w < 0, \\ \frac{q}{4(q-w)}, & \text{for } 0 \leq w < \frac{q}{2}, \\ \frac{1}{2}, & \text{for } \frac{q}{2} \leq w < q, \\ 1, & \text{for } w \geq q, \end{cases}$$

*then the applicants' dominant strategy becomes  $\Pi_1$  and firm 1 secures a payoff strictly greater than  $\frac{q}{4}$ , its payoff under the symmetric equilibrium defined in Theorem 1.*

The underlying reasoning for the proposed deviation is as follows. The probability of a successful match under vertical sampling is given by  $p$ , whereas the corresponding probability under horizontal sampling is given by  $[1 - (1 - p)^2] > p$ . This generates a basic disadvantage for vertical sampling. To face this challenge the deviating firm needs to construct an elaborate strategy that simultaneously meets two requirements. First, it must maintain enough variation in its signaling function such that a double sample carries a significant advantage over a single sample. Second, the deviating firm must offer applicants a significantly higher expected remuneration relative to the other firm, such that the combination of the two criteria offsets the structural advantage of horizontal sampling. Both attributes are reflected in proposed signaling function given in Example 1, which is comprised of an atom at the maximal wage level  $q$  and a dispersed distribution over the support of the symmetric equilibrium defined in Theorem 1.

### 3.4 Strategic frictions

In the preceding sections we considered exogenous matching frictions that were shown to be essential for the emergence of wage dispersion and wage secrecy. In the current section we extend our analysis by allowing for an endogenous formation of frictions. These frictions may, for instance, be associated with the fact that applicants are partially informed about available job opportunities, say due to firms' limited advertising policies. It may also be associated with the firms' screening processes, where only a fraction of job candidates is eventually hired. Another possibility is the presence of a coordination friction in the random matching process, where several applicants may end up competing over a single open vacancy.

Regardless of the precise friction-inducing mechanism, the fact that job applicants are assumed to be homogenous raises a puzzling question: why should frictions emerge endogenously in equilibrium? That is, why should a firm introduce a friction that limits its ability to recruit workers and, allegedly, bounds its profits? As it turns out (and shown below), frictions emerge in equilibrium as a coordination device, which restrains the competition between firms over the pool of applicants. In the spirit of the seminal study by Kreps and Scheinkman (1983), introducing a 'capacity constraint', which could take the form of posting a limited number of job vacancies, serves a firm to credibly commit to recruiting a limited number of workers. This in turn induces its rival to offer lower wage signals knowing that it would still be able to hire enough workers, and ultimately enables both firms to derive positive rents. Without introducing these frictions, a firm would induce its rival to engage in an intense wage competition à la Bertrand, resulting in full dissipation of the rents. We turn next to the formal analysis.

Consider the following two-stage game. In the first stage both firms choose simultaneously their desired level of friction  $(p_1, p_2)$ , and in the second stage, firms choose their signaling functions  $(F_1, F_2)$ . Note that it is assumed that firms are committed to the friction levels chosen in the first stage. The solution concept we adopt is the Subgame Perfect Nash Equilibrium (SPNE). Relying on our previous analysis in Theorem 1, the following corollary characterizes the unique SPNE of the two-stage game.

**Corollary 1.** *In the unique SPNE one firm chooses a frictionless regime, while the other firm chooses a friction level of half,  $(p_i, p_{-i}) = (1, \frac{1}{2})$ , and in the second stage both follow the signaling functions given in Theorem 1. Under the given SPNE, the expected payoffs of firms  $i$  and  $-i$  are  $\frac{9}{2}$  and  $\frac{9}{4}$ , respectively.*

Two notable insights emerge from Corollary 1. The first, as alluded above, concerns the fact that frictions do arise endogenously in equilibrium. The introduction of such frictions serves as a commitment device to restrain the competition over the pool of workers and ultimately ensure that, in equilibrium, firms derive positive rents. The patterns of equilibrium where the introduction of frictions by one firm is reciprocated by reduced wage signals offered by its rival, is a form of tacit collusion between the two firms. In the likely presence of matching frictions in the labor market (associated with reasons other than the strategic motive we describe), detecting the collusive behavior would pose a daunting challenge to any regulator.

The second, which is somewhat striking, concerns the asymmetric nature of the equilibrium, although both firms and workers are assumed to be homogenous. The reason for this surprising result may be explained as follows. Provided that its rival is introducing some friction, a firm has a dominant strategy to refrain from introducing frictions so as to maximize its recruitment probability. Thus, a symmetric equilibrium with frictions is not feasible. An asymmetric equilibrium is however feasible, as switching to a frictionless regime would induce full dissipation of the rents for both firms (see our discussion following Theorem 1).<sup>5</sup>

## 4 In conclusion

Labor contracts often stipulate wage-secrecy clauses that require employees to maintain confidentiality regarding their pay-check. Such clauses are generally described as a strategic tool used by employers to improve their bargaining position in wage negotiations. In the current paper, we offer a positive explanation for this argument.

The thrust of our argument hinges on the presence of matching frictions in the labor market and the role of professional social networks in transmitting wage related information from current employees to imperfectly informed job applicants. In particular, we show that pay-secrecy policies arise in equilibrium and serve the firms to improve their bargaining position in wage negotiations, by inducing search frictions that lower applicants' salary expectations. The latter is mediated by differential secrecy policy which is more prevalent at high wage levels.

Although both firms and workers are assumed to be homogenous, we show that wage dispersion arises in equilibrium across firms and, notably, also within firms. The latter novel feature of our set-up is shown

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<sup>5</sup>Notice that the asymmetry obtained in our set-up is in contrast with Kreps and Scheinkman (1983) that derive a unique symmetric SPNE in a model with two identical firms engaging in a price competition á la Bertrand, after making capacity choices.

to be essential for the emergence of wage secrecy arrangements in equilibrium. It also raises some novel issues concerning the optimal search strategy employed by job applicants faced with the possibility of searching either across (horizontally) or within (vertically) firms. Another novel attribute of our results relates to the presence of matching frictions. In contrast with standard search theoretic models of the labor market, in which matching frictions are invoked exogenously, we show that frictions arise endogenously in equilibrium. Although the presence of frictions a-priori seems to limit the ability of firms to recruit workers, we demonstrate that the introduction of such frictions essentially serves as a coordination device that allows both firms to tacitly collude and derive positive rents.

In the current study we focused on the positive aspects of wage secrecy, so before concluding, a brief note on the normative implications is called for. Imposing a regulatory restriction that prevents firms from implementing wage-secrecy policies leads to a unique equilibrium in which all workers are remunerated according to their marginal productivity, and firms' rents are hence fully dissipated. With endogenously formed matching frictions, this would ensure that the aggregate social surplus is maximized. Thus, from an efficiency perspective, ruling out pay secrecy is socially desirable. Moreover, as wage secrecy entails wage dispersion amongst ex-ante homogeneous workers, ruling out pay secrecy may be warranted on equity grounds as well. However, as shown in Blumkin and Lagziel (2018), wage secrecy could be efficiency-enhancing at the firm level, serving to mitigate disincentives associated with relative pay/status concerns amongst workers. Thus, taking a broader perspective, one should be cautious in deriving direct policy conclusions from the current analysis.

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## Appendices

**Lemma 1.** *For fixed values  $p_1, p_2 \in (0, 1]$ , the wage signals in equilibrium are supported on a connected set with no atoms in  $(0, q)$ .*

**Proof.** Fix  $F_2$  and consider the point-wise payoff  $\pi_1(w|F_2)$  of firm 1. Assume that policy  $F_2$  produces an atom  $w_0 \in (0, q)$ , therefore  $\pi_1$  is not continuous at  $w_0$  such that  $\lim_{w \rightarrow w_0^-} \pi_1(w|F_2) < \pi_1(w_0|F_2)$ , and firm 1 would not support wage levels below and sufficiently close to  $w_0$ . Specifically, for a sufficiently small  $\varepsilon > 0$ , firm 1 can transfer any positive probability from  $(w_0 - \varepsilon, w_0]$  to  $w_0 + \varepsilon_0$  where  $0 < \varepsilon_0 < \varepsilon$ , and strictly increase its payoff due to the discontinuity. But if there exists an  $\epsilon > 0$  such that firm 1’s strategy does not support wages levels between  $w_0 - \varepsilon$  and  $w_0$ , then the atom at  $w_0$  is suboptimal. If either  $F_1(w_0) > 0$  or  $p_1 < 1$ , then firm 2 can strictly increase its positive payoff  $\pi_2(w_0|F_1) > 0$  by shifting the atom downwards, towards  $w_0 - \varepsilon$ ; this shift reduces costs without affecting the probability to recruit since  $F_1$  is fixed on  $(w_0 - \varepsilon, w_0]$ . Otherwise, if  $F_1(w_0) = 0$  and  $p_1 = 1$ , then firm 2 cannot hire applicants at wage level  $w_0$  and  $\pi_2(w_0|F_1) = 0$ . Thus, firm 2 can increase its expected payoff by shifting the atom upwards. The latter deviation provides a strict improvement unless firm 2’s expected payoff is necessarily zero at any wage level, which occurs if and only if  $F_1(w) = 0$  for every  $w < q$ . In other words, firm 2 can sustain an interior atom, in equilibrium, if and only if firm 1 follows an OP policy with a Dirac measure at  $q$  (a unique wage level of  $q$ ).

Yet, by the indifference principle, any atom at  $q$  implies a zero payoff from any wage level. Namely, assume that firm 1 sustains an atom at  $q$ , while firm 2 does not employ a Dirac measure at  $q$ . There

exists a wage level  $w^* \in [0, q)$  such that  $F_2(w^*) > 0$ , and  $\pi_1(w^*|F_2) > 0 = \pi_1(q|F_2)$ , so firm 1 has a strictly profitable deviation from  $q$  to  $w^*$ . Therefore, no firm would support the wage level  $q$  with positive probability unless the other firm does so as well, since it assures an expected payoff of zero independently of the other firm's strategy. We conclude that no interior atoms exist, and the payoff functions are continuous on  $(0, q]$ , where continuity at  $q$  follows from the  $(q - w)$  term of  $\pi_i$ .

We now prove that the distributions are supported on a connected set. Assume there exists an open interval  $I = (w_-, w_+) \subset [0, q]$  such that  $\Pr(w_2 \in I) = 0$ , while  $0 < F_2(w_-) < 1$ . By the elimination of interior atoms, we can take the maximal  $I$  that sustains the above conditions. In other words, we take the maximal interval  $I$  such that for any other interval  $I_0 \subset [0, q]$  where  $I \subsetneq I_0$ , it follows that  $\Pr(w_2 \in I_0) > 0$ . Since  $F_2$  is fixed on  $I$  while  $w$  increases, it follows that  $\pi_1$  is linearly decreasing on  $[w_-, w_+]$  and  $\pi_1(w_-|F_2) > \pi_1(w_+|F_2)$ . Note that  $w_+$  is generally not an atom of  $F_2$  unless  $w_+ = q$ , which ensures a linear decrease towards zero, in any case. So for some small  $\varepsilon > 0$ , firm 1 would not support wage levels in  $[w_+, w_+ + \varepsilon)$ , as these wage levels are strictly dominated by wage levels in  $I$ , sufficiently close to  $w_-$ . However, the maximal choice of  $I$  suggests that the interval  $[w_+, w_+ + \varepsilon)$  is supported by firm 2 with positive probability. This is clearly suboptimal since firm 2 has a strictly positive deviation of shifting these wage levels downwards. Therefore, we conclude that such  $I$  does not exist, and wage distributions are supported on a connected set, as needed. ■

**Lemma 2.** *If no frictions exist,  $p_1 = p_2 = 1$ , then there exists a unique equilibrium where both signaling functions induce only the highest signal  $q$  (i.e., both equal the Dirac measure  $\delta_q$ ).*

**Proof.** Assume that both firms choose an OP policy. The point-wise payoff of firm 1, given  $F_2$ , is  $\pi_1(w|F_2) = \left[ F_2(w) - \frac{\Pr(w_2=w)}{2} \right] (q - w)$ . If  $F_2$  supports a unique wage level of  $q$ , then firm 1's weakly dominant strategy is to follow the same Dirac measure, establishing an equilibrium where both get a zero expected payoff. Any other strategy of firm 1 would provide a profitable deviation to firm 2, so there exists no other equilibrium where  $\Pr(w_i = q) = 1$ . Moreover, the indifference principle suggests that, in equilibrium, an atom at  $q$  exists only if the maximal expected payoff is zero, thus no other equilibrium exists such that  $\Pr(w_i = q) > 0$ .

We move on to prove uniqueness under the assumption that  $\Pr(w_i = q) = 0$  for both firms. First, we eliminate the possibility of having an atom at 0. Assume that  $\Pr(w_2 = 0) > 0$ . If  $\Pr(w_1 = 0) > 0$ , then either firm can shift the atom upwards an profit by the increased probability of recruiting. Moreover, if only one firm supports an atom at 0, there is a zero probability to recruit applicants at this level, and the point-wise payoff is zero. Again, the indifference principle suggests that the maximal expected payoff at any wage level would also be zero, which leads to a unique atom at  $q$ , and the above-mentioned equilibrium.

Thus far we have established that any alternative equilibrium has no atoms, so the continuous payoff functions are given by  $\pi_i(w|F_{-i}) = F_{-i}(w)(q - w)$ . One can easily verify that  $F_1$  and  $F_2$  have the same

support a.s., similarly to the reasoning presented in the proof of Lemma 1. Denote the support by  $I_0$ , and assume there exists a wage level  $w \in I_0$  such that  $0 < F_2(w) < 1$ . This implies that the point-wise payoff at  $w$  and the expected payoff  $\mathbf{E}[\pi_1(w_1|F_2)]$  of firm 1 are strictly positive. However, the fact  $F_2(\inf I_0) = 0$  suggests that  $\pi_1(\inf I_0|F_2) = 0$ . By continuity, one can take a small  $\varepsilon > 0$  such that  $\pi_1(w|F_2) < \mathbf{E}[\pi_1(w_1|F_2)]$  for every  $w \in I_1 = [\inf I_0, \inf I_0 + \varepsilon)$ . This implies that the wage levels in  $I_1$  are suboptimal for firm 1, but  $\Pr(w_1 \in I_1) > 0$ . A contradiction. We conclude that no alternative equilibrium exists, as stated.  $\blacksquare$

**Theorem 1.** *Given that  $0 < p_1 \leq p_2 \leq 1$ , the unique equilibrium is*

$$F_1(w) = \begin{cases} 0, & \text{for } w < 0, \\ \frac{w(1-p_1)}{p_1(q-w)}, & \text{for } 0 \leq w < qp_1, \\ 1, & \text{for } w \geq qp_1, \end{cases} \quad F_2(w) = \begin{cases} 0, & \text{for } w < 0, \\ \frac{q(p_2-p_1)+w(1-p_2)}{p_2(q-w)}, & \text{for } 0 \leq w < qp_1, \\ 1, & \text{for } w \geq qp_1. \end{cases}$$

*Under the given equilibrium, the expected payoff of firm  $i$  is  $p_i(1-p_1)q$ .*

**Proof.** We first compute the point-wise and expected payoffs of both firms to establish an equilibrium, and later prove uniqueness. Note that the given strategies are well-defined as CDFs, both supported on  $[0, qp_1]$ , where  $F_1$  is non-atomic and  $F_2$  potentially has an atom of size  $1 - \frac{p_1}{p_2}$  at  $w = 0$ . Given  $(F_1, F_2)$ , the point-wise payoff functions are

$$\begin{aligned} \pi_1(w|F_2) &= p_1 \left[ 1 - p_2 \left[ 1 - F_2(w) + \frac{1}{2} \Pr(w_2 = w) \right] \right] (q - w), \\ \pi_2(w|F_1) &= p_2 \left[ 1 - p_1 \left[ 1 - F_1(w) \right] \right] (q - w). \end{aligned}$$

For  $w \in (0, qp_1]$ , the point-wise payoff of firm 1 is

$$\begin{aligned} \pi_1(w|F_2) &= p_1 \left[ 1 - p_2 \left[ 1 - F_2(w) \right] \right] (q - w) \\ &= p_1 \left[ 1 - p_2 \left[ 1 - \frac{q(p_2 - p_1) + w(1 - p_2)}{p_2(q - w)} \right] \right] (q - w) \\ &= p_1 \left[ (1 - p_2)(q - w) + q(p_2 - p_1) + w(1 - p_2) \right] \\ &= p_1 (1 - p_1) q, \end{aligned}$$

and the payoff is independent of  $w$ , establishing the indifference principle for any positive-measure set of valuations in  $[0, qp_1]$ . A similar computation for  $w = 0$  would show  $\pi_1(0|F_2) < qp_1(1 - p_1)$ . The latter inequality does not contradict the equilibrium statement since  $\Pr(w_1 = 0) = 0$  and zero-measure suboptimal outcomes do no effect the expected payoff. Also, any wage signal above  $qp_1$  is suboptimal, since it leads to higher wage levels without increasing the probability of recruiting an employee (by the fact that  $F_i(pq_1) = 1$ ).

Similarly, for every  $w \in [0, qp_1]$ , the point-wise payoff of firm 2 is

$$\begin{aligned}
\pi_2(w|F_1) &= p_2 [1 - p_1 [1 - F_1(w)]] (q - w) \\
&= p_2 \left[ 1 - p_1 \left[ 1 - \frac{w(1 - p_1)}{p_1(q - w)} \right] \right] (q - w) \\
&= p_2 [(1 - p_1)(q - w) + w(1 - p_1)] \\
&= p_2 (1 - p_1) q.
\end{aligned}$$

Again, the payoff is independent of  $w$ , and similar arguments (as noted for firm 1) hold for firm 2.

We move on to prove uniqueness. In case  $p_1 = 1$ , we revert back to Lemma 2. The statement of Lemma 2 is embedded in the current one, so we can assume that  $p_1 < 1$ . Assume, to the contrary, that a different equilibrium  $(F_1, F_2)$  exists. We know from Lemma 1 that the distributions have no atoms at  $(0, q)$  and the supports are connected sets.

We first focus on the least upper bound of the supports. Firm 2 can secure an expected payoff of at least  $p_2(1 - p_1)q$  by fixing a Dirac measure at  $w = 0$  (denote this measure  $\delta_0$ ). Therefore it will not support an atom at  $w = q$ , which produces a point-wise zero payoff. Using left-side continuity and the fact the support is connected, firm 2 will not support any wage levels close to  $q$ , thus firm 1 cannot support these wage levels as well. That is, wage levels close to  $q$  produce a point-wise payoff close to 0, while a strictly positive payoff for both firms can be secured by taking wage levels bounded away from  $q$ . We conclude that both firms have a strictly positive expected payoff, in equilibrium, while the least upper bound is strictly below  $q$ .

Let us now show that both distributions are supported on the same set of valuations.<sup>6</sup> Denote the support of  $F_i$  by  $I_i$  such that  $\inf I_i = \underline{w}_i$  and  $\sup I_i = \bar{w}_i$ . If either  $\underline{w}_1 \neq \underline{w}_2$  or  $\bar{w}_2 \neq \bar{w}_1$ , then one firm has a strictly decreasing payoff function at the high or low wage levels (the probability to recruit applicants remains fixed while wages increase). By Lemma 1 we know that both distributions are supported on a connected (positive-measure) set of valuations, so the latter conjecture yields a suboptimal expected payoff. We deduce that both distributions have the same support.

Denote  $\underline{w} = \inf I_i$  and  $\bar{w} = \sup I_i$ , and let us prove that  $\underline{w} = 0$ . Assume that  $\underline{w} > 0$ . In that case,  $\underline{w}$  is not an atom (by Lemma 1) and  $F_i(\underline{w}) = 0$ . Using left-side continuity, we get  $\lim_{w \rightarrow \underline{w}^+} \pi_2(w|F_1) = p_2(1 - p_1)(q - \underline{w})$ , which is strictly less than  $p_2(1 - p_1)q$  that firm 2 can secure with  $\delta_0$ . Hence, both distributions are necessarily supported on  $\underline{w} = 0 < \bar{w} < q$ . In addition, note that the profile of strategies where both firms support an atom at 0 cannot be an equilibrium, since each firm would revert to an infinitesimal increase, due to the discontinuity of the payoff function. So, we need to analyse the remaining possibilities of either no atoms, or a single atom for only one firm.

Consider the case where firm 1 does not have an atom at 0. We can employ the indifference principle for firm 2 over connected positive-measure sets, subject to  $F_1$ . The payoff function of firm 2 is continuous

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<sup>6</sup>We remind the reader that all statements hold almost surely, with probability 1.

and point-wise equals  $\pi_2(0|F_1) = p_2(1 - p_1)q$ . The fact there are no atoms above  $w = 0$  implies left-side continuity of the payoff function. Along with the indifference principle, it follows that the same point-wise payoff must hold throughout the support of  $F_2$ , specifically for  $w \rightarrow \bar{w}^+$ . Therefore,

$$\pi_2(\bar{w}|F_1) = p_2 \left[ 1 - p_1 \left[ 1 - F_1(\bar{w}) + \frac{1}{2}\Pr(w_1 = \bar{w}) \right] \right] (q - \bar{w}) = p_2(q - \bar{w}) = p_2(1 - p_1)q,$$

and  $\bar{w} = qp_1$ . Similarly, for every  $0 \leq w \leq qp_1$ , we get

$$\begin{aligned} p_2(1 - p_1)q &= \pi_2(w|F_1) \\ &= p_2 \left[ 1 - p_1 \left[ 1 - F_1(w) + \frac{1}{2}\Pr(w_1 = w) \right] \right] (q - w) \\ &= p_2 \left[ 1 - p_1 + p_1 F_1(w) \right] (q - w), \end{aligned}$$

which leads to  $F_1(w) = \frac{w(1-p_1)}{p_1(q-w)}$ , as already stated.

Now take  $F_2(w)$  and the maximal wage level  $\bar{w} = qp_1$ . Left-side continuity and the indifference principle yield

$$\pi_1(\bar{w}|F_2) = p_1 \left[ 1 - p_2 \left[ 1 - F_2(\bar{w}) + \frac{1}{2}\Pr(w_2 = \bar{w}) \right] \right] (q - \bar{w}) = p_1(q - qp_1) = p_1(1 - p_1)q.$$

Applying the same reasoning as before, the point-wise payoff  $p_1(1 - p_1)q$  must hold throughout the support of  $F_1$ . The latter statement holds up to a zero-measure set w.r.t.  $F_1$  (which does not have an atom at  $w = 0$  by assumption), so there is no problem with the evident discontinuity at  $w = 0$ , generated by the symmetric tie-breaking rule. Specifically, for every  $0 < w \leq pq$ , we get

$$\begin{aligned} p_1(1 - p_1)q &= \pi_1(w|F_2) \\ &= p_1 \left[ 1 - p_2 \left[ 1 - F_1(w) + \frac{1}{2}\Pr(w_2 = w) \right] \right] (q - w) \\ &= p_1 \left[ 1 - p_2 + p_2 F_2(w) \right] (q - w), \end{aligned}$$

which leads to  $F_2(w) = \frac{q(p_2-p_1)+w(1-p_2)}{p_2(q-w)}$ . Note that  $\Pr(w_2 = 0) = 1 - \frac{p_1}{p_2} \geq 0$ , so  $p_1 < p_2$  leads to an atom of  $F_2$  at  $w = 0$ .

We should now consider the other possibility where firm 1 supports an atom at  $w = 0$ . Denote  $a = \Pr(w_1 = 0) > 0$ . Since both firms cannot simultaneously have an atom at  $w = 0$ , we can use the continuity of  $\pi_1$  and the indifference principle on connected positive-measure sets to compare  $\pi_1(0|F_2)$  and  $\pi_1(\bar{w}|F_2)$ . Namely,

$$\begin{aligned} p_1(q - \bar{w}) &= \pi_1(\bar{w}|F_2) \\ &= \pi_1(0|F_2) \\ &= p_1 \left[ 1 - p_2 \left[ 1 - F_2(0) + \frac{1}{2}\Pr(w_2 = 0) \right] \right] (q - 0) \\ &= p_1 \left[ 1 - p_2 \left[ 1 - 0 \right] \right] q, \end{aligned}$$

which yields  $\bar{w} = qp_2$ . A similar comparison of  $\lim_{w \rightarrow 0^+} \pi_2(w|F_1)$  and  $\pi_2(\bar{w}|F_1)$ , which follows from right-side continuity at  $w = 0$ , and left-side continuity at  $w = \bar{w}$ , yields

$$\begin{aligned}
p_2(q - \bar{w}) &= \pi_2(\bar{w}|F_1) \\
&= \lim_{w \rightarrow 0^+} \pi_2(w|F_1) \\
&= \lim_{w \rightarrow 0^+} p_2 \left[ 1 - p_1 \left[ 1 - F_1(w) + \frac{1}{2} \Pr(w_1 = w) \right] \right] (q - w) \\
&= p_2 \left[ 1 - p_1 \left[ 1 - F_1(0) \right] \right] (q - 0) \\
&= p_2 \left[ 1 - p_1 \left[ 1 - a \right] \right] q.
\end{aligned}$$

Thus,  $\bar{w} = qp_1(1 - a)$ . Since both distributions have the same support, we get  $qp_1(1 - a) = \bar{w} = qp_2$ , and  $p_2 = p_1(1 - a) < p_1$ . A contradiction to the initial condition of  $p_1 \leq p_2$ . In conclusion,  $F_1$  is non-atomic whenever  $p_1 \leq p_2$ , and uniqueness follows.  $\blacksquare$

**Lemma 4.** *For every friction level  $p$  and signaling functions  $F_1 = F_2$ , it follows that horizontal sampling is a strictly dominant strategy (i.e.,  $\Pi_{12} > \Pi_i$ ).*

**Proof.** Fix  $p \in (0, 1)$  and  $F_1 = F_2 = F$  supported on some set  $I$  of positive signals. We need to show that  $\Pi_{12}(F, F, p) - \Pi_1(F, F, p) > 0$ . That is,

$$\begin{aligned}
\Pi_{12} - \Pi_i &= p^2 \mathbf{E}[\max\{w_1, w_2\}] + p(1 - p) \mathbf{E}[w_1 + w_2] - p \mathbf{E}[\max\{w_1, \tilde{w}_1\}] \\
&= p^2 \mathbf{E}[\max\{w_1, \tilde{w}_1\}] + 2p(1 - p) \mathbf{E}[w_1] - p \mathbf{E}[\max\{w_1, \tilde{w}_1\}] \\
&= (p^2 - p) \mathbf{E}[\max\{w_1, \tilde{w}_1\}] + 2p(1 - p) \mathbf{E}[w_1] \\
&= p(1 - p) [2\mathbf{E}[w_1] - \mathbf{E}[\max\{w_1, \tilde{w}_1\}]]
\end{aligned}$$

where the second equality follows from the fact that all distribution are identical. To compute the expected value, note that  $\mathbf{E}[X] = \int_{\mathbb{R}_+} [1 - F_X(t)] dt$ . Hence,

$$\begin{aligned}
\frac{\Pi_{12} - \Pi_i}{p(1 - p)} &= 2\mathbf{E}[w_1] - \mathbf{E}[\max\{w_1, \tilde{w}_1\}] \\
&= 2 \int_{\mathbb{R}_+} [1 - F(t)] dt - \int_{\mathbb{R}_+} [1 - F^2(t)] dt \\
&= \int_{\mathbb{R}_+} \{2[1 - F(t)] - [1 - F(t)][1 + F^2(t)]\} dt \\
&= \int_{\mathbb{R}_+} [1 - F(t)] \{2 - [1 + F(t)]\} dt \\
&= \int_{\mathbb{R}_+} (1 - F(t))^2 dt > 0,
\end{aligned}$$

as needed.  $\blacksquare$

**Theorem 2.** Fix a friction level  $p \in (0.62, 1)$  and assume that firm 1 follows the equilibrium strategy  $F_1$ . Then, for every signaling function  $F$ , horizontal sampling is a strictly dominant strategy (that is,  $\Pi_{12}(F_1, F, p) > \Pi_2(F_1, F, p)$ ).

**Proof.** Fix  $p > 0.62$ , the equilibrium strategy  $F_1$ , and a signaling function  $F$  supported on  $[0, q]$ . Let  $w_f$  and  $\tilde{w}_f$  denote the two i.i.d. wage samples from  $F$ . We need to show that  $\Pi_{12}(F_1, F, p) > \Pi_2(F_1, F, p)$ . That is,

$$\begin{aligned}
\frac{\Pi_{12} - \Pi_2}{p} &= p\mathbf{E}[\max\{w_1, w_f\}] + (1-p)\mathbf{E}[w_1 + w_f] - \mathbf{E}[\max\{w_f, \tilde{w}_f\}] \\
&= \mathbf{E}[p \max\{w_1, w_f\} + (1-p)[w_1 + w_f] - \max\{w_f, \tilde{w}_f\}] \\
&= \int_{[0, q]} \{p[1 - F_1(t)F(t)] + (1-p)[1 - F_1(t) + 1 - F(t)] - [1 - F^2(t)]\} dt \\
&= \int_{[0, q]} \{F^2(t) + F(t)[-pF_1(t) - 1 + p] + (1-p)[1 - F_1(t)]\} dt \\
&= \int_{[0, qp]} \{F^2(t) + F(t)[-pF_1(t) - 1 + p] + (1-p)[1 - F_1(t)]\} dt + \int_{[qp, q]} \{F^2(t) - F(t)\} dt \\
&\geq \int_{[0, qp]} \{F^2(t) - F(t)[1 - p(1 - F_1(t))] + (1-p)[1 - F_1(t)]\} dt - \frac{q(1-p)}{4},
\end{aligned}$$

where the last inequality follows from a point-wise minimization of  $F^2(t) - F(t)$ . We can follow a similar point-wise minimization for the function in first integral w.r.t.  $F(t)$ , and get

$$\frac{\Pi_{12} - \Pi_2}{p} \geq \int_{[0, qp]} \{(1-p)[1 - F_1(t)] - \frac{1}{4}[1 - p(1 - F_1(t))]^2\} dt - \frac{q(1-p)}{4}.$$

Using  $F_1$  explicitly, one gets  $1 - F_1(t) = \frac{pq-t}{p(q-t)}$  and  $1 - p(1 - F_1(t)) = \frac{q(1-p)}{q-t}$ . Hence, the previous inequality translates to

$$\begin{aligned}
\frac{\Pi_{12} - \Pi_2}{p} &\geq \left[ \frac{1-p}{p} \right] \int_{[0, qp]} \frac{pq-t}{q-t} dt - \left[ \frac{q^2(1-p)^2}{4} \right] \int_{[0, qp]} \frac{1}{(q-t)^2} dt - \frac{q(1-p)}{4} \\
&= \frac{1-p}{p} \int_{[0, qp]} \frac{pq-t}{q-t} dt - \frac{q(1-p)p}{4} - \frac{q(1-p)}{4}.
\end{aligned}$$

A straightforward computation of the first integral yields  $\int_{[0, qp]} \frac{pq-t}{q-t} dt = pq + q(1-p) \ln(1-p)$ . Therefore,

$$\begin{aligned}
\frac{\Pi_{12} - \Pi_2}{p(1-p)q} &\geq \frac{p + (1-p) \ln(1-p)}{p} - \frac{1+p}{4} \\
&= \frac{3-p}{4} + \frac{(1-p) \ln(1-p)}{p},
\end{aligned}$$

and one can verify that the last function is strictly positive for  $p \in (0.62, 1)$ . ■

**Corollary 1.** *In the unique SPNE one firm chooses a frictionless regime, while the other firm chooses a friction level of half,  $(p_i, p_{-i}) = (1, \frac{1}{2})$ , and in the second stage both follow the signaling functions given in Theorem 1. Under the given SPNE, the expected payoffs of firms  $i$  and  $-i$  are  $\frac{q}{2}$  and  $\frac{q}{4}$ , respectively.*

**Proof.** For every friction profile  $(p_1, p_2)$ , Theorem 1 states that firm  $i$ 's unique equilibrium expected payoff is  $p_i(1 - \min\{p_1, p_2\})q$ . By this uniqueness outcome and the use of a SGPE, we can restrict the analysis to the preliminary stage of choosing the friction levels. Hence, we consider an axillary one-stage game where firms simultaneously choose friction levels  $(p_1, p_2)$  and firm  $i$ 's payoff is  $p_i(1 - \min\{p_1, p_2\})$ . Given  $p_{-i} \leq 1$ , the best response of firm  $i$  is either to play  $p_i = 1 \geq p_{-i}$ , which generates a payoff of  $1 - p_{-i}$ , or to choose some value  $p_i < p_{-i}$ , which yields a payoff of  $p_i(1 - p_i)$ . So, for  $p_2 = 1$  the best response of firm 1 is  $p_1 = 0.5$ , and symmetry suggests that the best response of firm 2 is  $p_2 = 1$ , which establishes an equilibrium. Now fix a profile  $(p_1, p_2) \neq (0.5, 1)$ . Clearly  $p_1 = p_2 = 1$  is not an equilibrium so we can ignore this possibility. Assume, w.l.o.g., that  $p_1 \leq p_2$ . Again, the best response of firm 2 is  $p_2 = 1$ , and then firm 1 would deviate to  $p_1 = 0.5$ . We revert back to the only possibility where one firm chooses a friction of half and the other chooses a frictionless regime, thus concluding the proof. ■