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Abstract

Team production is a frequent feature of modern organizations. Combined with team incentives, team production can create externalities among workers, since their utility upon accepting a contract depends on their team's performance and therefore on their colleagues' productivity. We study the effects of such externalities in a competitive labor market if workers have private information on their productivity. We find that in any competitive equilibrium there must be Pareto-efficient separation of workers according to their productivity. We further find that externalities facilitate equilibrium existence, where under a particular condition on workers' indifference curves even arbitrarily small externalities guarantee equilibrium existence.

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1 Introduction

Many modern firms employ innovative human resource management practices that include team production, team incentives, and profit sharing (Ichniowski and Shaw 2003). Team production often comprises many tasks, all of which must be well executed for a team to be successful. A worker's productivity then depends on the productivity of his team colleagues. In particular, a worker will be less productive if matched with less productive co-workers.[1] Combined with team incentives, team production implies that the utility a worker gets upon accepting a job depends on the characteristics of his colleagues. This stands in contrast to standard job market signaling and screening models that assume that the utility a worker gets upon accepting an employment contract depends exclusively on the terms of the contract and the worker's own productivity.[2]

Despite the practical and theoretical relevance of the subject, no paper has yet analyzed how team production – and the thereby arising externalities among workers – affect competitive labor markets if workers have private information on their productivity.[3] To fill this gap we investigate a screening version of Spence's (1973) job market signaling model while introducing a simple externality between workers. In our model, firms compete for workers. Employment contracts specify wages and some task requirements, where a worker's costs of complying with the task requirements depends on his productivity. By combining wages and task requirements, firms can thus screen workers according to their productivity. Contrary to the standard framework, a worker's utility upon accepting a contract does not only depend on his productivity and the contract, but also on the average productivity of the co-workers in his chosen firm.

We show that whenever there exists a competitive equilibrium, then firms make zero profit, workers are separated according to their productivity, and the inefficient task requirement

[1]Kremer (1993) illustrates this complementarity in production by an extreme but illuminating example: the explosion of the space shuttle Challenger in 1986, which happened because one single component, the O-ring, malfunctioned. Further examples of "O-ring production functions" are discussed in Dalmazzo (2002), Fabel (2004), and Jones (2011).

[2]The discussed externalities among workers also arise naturally in partnerships that employ profit sharing. Partnerships with profit sharing are very common in many industries, including law, accounting, investment banking, management consulting, or medicine. See for example Hansmann (1996), Farrell and Scotchmer (1988), and Encinosa, Gaynor, and Rebitzer (2007). In these industries, the quality of potential partners is likely to play an important role in employment choices.

[3]We provide a detailed overview of the related literature in Section 2.

needed for separation is minimized. More intriguingly, we prove that externalities among workers facilitate equilibrium existence, where under a particular condition on workers' indifference curves in contract space, arbitrarily small externalities guarantee existence. Since Rothschild and Stiglitz (1976) it is known that in the standard framework there does not exist a competitive equilibrium in pure strategies if the fraction of low-productivity workers is sufficiently small.[4] The reason is that any competitive equilibrium must be a separating equilibrium in which high-productivity workers face the minimum task requirement needed to ensure separation from low-productivity workers. This minimum task requirement – and thus the inefficiency arising from private information – does not depend on the fraction of low-productivity workers. If the fraction of low-productivity workers is sufficiently small, the separating equilibrium can therefore be destroyed by a Pareto-dominating pooling contract that specifies a zero task requirement and sets wages so as to make a small positive profit when accepted by all workers. Because pooling is ruled out in equilibrium, there exists no competitive equilibrium.

These arguments no longer hold in the case of externalities among workers. The reason is that externalities entail that market entrants offering a pooling contract might not be able to attract high-productivity workers: given that none of the other high-productivity workers accepts the new contract, each high-productivity worker finds it optimal not to accept the contract, as he would otherwise work with low-productivity colleagues, which he dislikes. Since the pooling contract makes losses when attracting only low-productivity workers, market entry is unprofitable. Hence, a competitive equilibrium exists. The externality creates a coordination problem among workers, and selecting the right equilibrium response to market entry ensures equilibrium existence.

The above result suggests that the externality has to be sufficiently large to ensure equilibrium existence. We show that this is not true if some firms offer "latent contracts." Such latent contracts are not accepted by any workers in equilibrium, but they turn out to be very useful to deter market entry. Because these latent contracts are offered by firms that only employ low-productivity workers, high-productivity workers do not accept them in equilibrium, since they would otherwise suffer from being matched with only low-productivity colleagues. Low-productivity workers never find these latent contracts attractive, because wages are too

[4]We also focus on pure strategies in this model and prove equilibrium existence for this case. For an analysis of mixed strategy equilibria in models of adverse selection see Dasgupta and Maskin (1986a, 1986b) and Rosenthal and Weiss (1984).

low to compensate them for the high task requirement. Given this situation, consider market entry of a firm that wants to attract both low-productivity and high-productivity workers. If this new firm indeed manages to attract all low-productivity workers, then this unintentionally renders previously latent contracts appealing to high-productivity workers, because accepting such a contract no longer has the drawback of being matched with low-productivity colleagues. Since latent contracts thus make it more difficult for market entrants to attract high-productivity workers, they can render profitable market entry impossible. In fact, we can show that under a particular condition on workers' indifference curves in contract space – more productive colleagues make changes in wages relatively more influential on workers' utility than changes in the task requirement – the supremum utility that high-productivity workers can get from accepting a previously latent contract after market entry is infinitely large, even if the externality is arbitrarily small. Equilibrium existence is in this case guaranteed, since latent contracts ensure that market entrants can never attract high-productivity workers without making losses. In contrast to the argument in the previous paragraph, coordination problems are no longer part of the story: for all equilibrium contract choices, the new firm always attracts all low-productivity workers, and all high-productivity workers accept a previously latent contract.

2 Related Literature

Our paper complements the large existing literature on adverse selection. We distinguish between papers that focus on team production, equilibrium existence, externalities and coordination, and latent contracts.

2.1 Team Production and Adverse Selection

The present paper primarily contributes to the literature on team production in markets with adverse selection. Landers, Rebitzer, and Taylor (1996) study lawyers with privately known productivity, who either work independently, or join law firms with the option to later become partners. Lawyers and partners in law firms benefit from productive colleagues. This creates externalities among workers, since young lawyers prefer to join firms with more productive employees. In related studies, Demski and Sappington (1984) and McAfee and McMillan (1991) analyze team incentive contracts if workers have private information on their productivity. They show that workers' wages might optimally depend on their colleagues' production, even if production is independent across team members. Firms thus deliberately create externalities among workers.

Landers, Rebitzer, and Taylor (1996) study monopsonistic firms in which current partners extract all rents from future partners. Both Demski and Sappington (1984) and McAfee and McMillan (1991) consider situations in which firms do not compete for workers, but try to extract workers' rents. Therefore, the most important difference to this literature on adverse selection in teams is that only our paper considers competitive labor markets. Over the past decades, technological progress, globalization, and organizational changes have intensified competition for the kind of business professionals required for effective team production.[5] Our analysis thus complements the existing literature on team production in the practically relevant aspect of labor market competition.

The present paper builds on Kosfeld and von Siemens (2009, 2011), who study heterogeneous corporate cultures in competitive labor markets. Externalities arise in that context since some workers are conditionally cooperative and want to be matched with other conditionally cooperative workers. The present analysis extends Kosfeld and von Siemens (2009, 2011) by looking at arbitrarily small externalities and the use of latent contracts.

2.2 Equilibrium Existence and Adverse Selection

The present paper also contributes to the literature on equilibrium existence in competitive markets with adverse selection. Wilson (1977) and Riley (1979) demonstrate that equilibrium existence is ensured if firms can react to market entry by withdrawing or adding contracts. Hellwig (1987), Bester (1985), and Cho and Kreps (1987) provide an additional foundation for these arguments by modeling the firms' strategic interaction as a non-cooperative game.[6] Our paper shows that – in particular with the use of latent contracts – externalities ensure equilibrium existence, even when firms cannot react to market entry.

Our analysis also illustrates a more subtle difference between latent contracts and contracts offered in response to market entry. Latent contracts must not attract low-productivity workers given that these workers receive their equilibrium utility. In contrast, contracts that are posted after market entry must satisfy only a weaker incentive compatibility constraint: they must not attract low-productivity workers given that these workers receive their higher deviation utility after market entry. However, contracts that are posted after market entry

[5] The so-called "war for talent" appears to be a key issue for practitioners and is therefore widely discussed in the popular management literature. Cf. Chambers, Foulon, Handfield-Jones, Hankin, and Michaels (1998) and Wooldridge (2006).

[6] See also the recent contributions by Mimra and Wambach (2011) and Netzer and Scheuer (forthcoming).

must make positive profit if accepted only by high-productivity workers. Otherwise, firms do not have incentives to offer these contracts. Latent contracts need not make positive profits since their pure existence deters market entry. They might thus ensure equilibrium existence, although they satisfy a relatively strong incentive compatibility constraint.

Pushing a different equilibrium concept, Gale (1992) and Dubey and Geanakoplos (2002) argue that in competitive markets, market participants do not act strategically, but consider aggregate market outcomes as unaffected by their own actions. Adverse selection arises in this context if the utility levels generated by trade do not only depend on the terms of trade, but also on privately observed characteristics of the involved trade partners. This creates externalities similar to our paper. However, in a Walrasian market these externalities are inextricably connected to the existence of adverse selection, and cannot be changed without changing the adverse selection problem. We instead can vary the strength of the externality, and at the same time keep the original adverse selection problem fixed. In contrast to Gale (1992) and Dubey and Geanakoplos (2002), we can therefore study the impact of arbitrarily small externalities among traders in competitive markets with substantial problems of adverse selection.

2.3 Externalities and Coordination

The present analysis further complements recent papers on externalities and coordination in competitive markets with adverse selection. Inderst and Wambach (2001) study the role of exogenous capacity constraints in insurance markets. If demand exceeds capacity, insurance companies must turn some customers away. An insuree's expected utility when applying for an insurance contract thus depends on the contract choices of other insurees. The resulting externalities create coordination issues during the contract acceptance stage. This ensures equilibrium existence if capacity constraints are sufficiently severe. In Picard (2012) firms can offer participating insurance contracts, and in Mimra and Wambach (2010) firms choose upfront capital. Both papers show that insurance firms endogenously create large externalities among insurees, which guarantees equilibrium existence. Guerrieri, Shimer, and Wright (2010) provide similar arguments in the context of a competitive labor market. Search frictions there imply that market tightness determines the probability with which workers are matched with a firm offering the desired employment contract. Market tightness is endogenously determined in equilibrium, and by construction sufficiently large to ensure equilibrium existence.

The present paper provides similar arguments that are based on externalities among workers created by team production and team incentives. But in contrast to the above papers, it shows that under a particular condition on workers' indifference curves in contract space, even arbitrarily small externalities in combination with latent contracts ensure equilibrium existence. This result is based on the strategic use of latent contracts, while latent contracts are not considered in the above papers. Moreover, coordination issues are not necessary to stabilize separating equilibria: with latent contracts there exists a unique equilibrium response to market entry, in which the entrant attracts only low-productivity workers.

2.4 Latent Contracts

The importance of latent contracts connects the present paper to Attar, Mariotti, and Salanié (forthcoming) and Attar, Mariotti, and Salanié (2011). They show that latent contracts are important for equilibrium existence in markets with adverse selection and non-exclusive competition. Applying their general analysis to a labor market context, Attar, Mariotti, and Salanié (forthcoming) consider workers who have private information on their ability. Workers can sell one divisible unit of time to several firms. The opportunity costs of selling time to firms are higher for workers with high ability. Latent contracts then discourage market entry by cream-skimming firms, since workers can circumvent quantity restrictions by trading unused time capacity with incumbent firms. This stabilizes pooling equilibria.

The present paper demonstrates that in the presence of externalities, latent contracts can also facilitate equilibrium existence in markets with adverse selection and exclusive competition. But in contrast to Attar, Mariotti, and Salanié (forthcoming) latent contracts do not stabilize pooling but separating equilibria. This shows that in the presence of adverse selection, the use of latent contracts in markets with negative externalities and exclusive competition results in rather different equilibrium outcomes than the use of latent contracts in markets without externalities but non-exclusive competition.

3 Model

We consider a continuum of workers with total mass normalized to one. Workers have either high or low productivity. Let $\Theta = \{\ell, h\} \subset \mathbb{R}$ be the workers' type space with $h > \ell$. It is common knowledge that $\mu_0 \in]0, 1[$ is the mass of high-productivity workers, but individual types are private information. A countably infinite number of homogeneous firms compete for workers. Firms can enter the market at zero costs to offer workers finite sets of contracts.

Let $n \in \mathbb{N}$ be the identity of a firm. A contract $c = (t, w, n)$ describes a task requirement $t \in \mathbb{R}_+$ and wage benefits $w \in \mathbb{R}$ that yields the worker some benefits upon acceptance. Additionally, it includes the firm's identity $n \in \mathbb{N}$. The task requirement could represent, e.g., a minimum number of working hours or some quality requirements. Firms can determine task requirements and wages but are endowed with a fixed identity. Let $\mathcal{C} = \mathbb{R}_+ \times \mathbb{R} \times \mathbb{N}$ denote the contract space. Let C_n denote some set of contracts offered by firm n and let $C = \bigcup_{n \in \mathbb{N}} C_n$ describe the total set of offered contracts.

In our model we consider a simple screening version of Spence's (1973) job market signaling model.[7] As commonly assumed in the literature the task is not productive and thus serves as a pure and inefficient screening device. The strategic interaction between firms and workers is described by the following sequence of actions. First, firms simultaneously offer workers finite menus of contracts. Second, workers simultaneously choose among the set of offered contracts. Third, workers satisfy the task requirements and receive the wage benefits as specified by their contract choices. Fourth, payoffs and profits are realized. In the following we provide further details and specify our equilibrium concept.

3.1 Workers' Utility Functions and Externalities

Our paper extends the literature on competitive labor markets with adverse selection by assuming that a worker's utility upon accepting a contract can directly depend on the contract choices of other workers. Let function $u : \Theta \times [\ell, h] \times \mathcal{C}$ describe agents' preferences where $u(\theta, y, c)$ characterizes the utility of a worker of type θ who accepts contract c offered by firm n that employs workers with average productivity y. Firms are homogeneous, thus we assume that workers have no preferences over firms' identities as such, i.e., $u(\theta, y, (t, w, n)) = u(\theta, y, (t, w, \tilde{n}))$ for all $n, \tilde{n} \in \mathbb{N}$. Firm identities are only required since workers need not be indifferent between two contracts specifying the same task requirements and wages if firms attract workers with different average productivity. We assume that u is at least twice partially differentiable in y, t, and w with $u_t < 0$, $u_w > 0$, $u_{tw} = 0$, $u_{tt} \geq 0$, and $u_{ww} \leq 0$. Further, function u is unbounded above with respect to wage benefits w, and unbounded below with respect to task requirement t. Externalities among workers are formalized as follows.

[7] We essentially follow the exposition in Chapter 13 of Mas-Colell, Whinston, and Green (1995) with two productivity levels. In Section 5 we discuss the case with a continuum of productivity levels.

Assumption 1 (Externality Workers). *For all* (y, c) *we have*

$$u_y(\theta, y, c) > 0 \text{ for all } y < \theta \text{ and } u_y(\theta, y, c) = 0 \text{ for all } y \geq \theta. \tag{1}$$

A worker's utility upon accepting a contract offered by some firm is increasing in the average productivity of workers attracted by the same firm, as long as the average productivity is lower than the worker's own productivity. In case a worker's productivity is weakly lower than the average productivity, he no longer experiences a negative externality. A low-productivity worker's utility upon accepting a contract thus does not depend on the average productivity of workers attracted by the same firm. Our specification implies that the average productivity of workers attracted by the same firm affects workers' utility, even if different types accept different contracts. We therefore assume that firms either cannot fully prevent, cannot credibly commit to fully prevent, or simply do not want to fully prevent externalities among their workers.

Externalities of this kind arise naturally in many labor market contexts. For example, high-productivity workers might suffer from the pure presence of low-productivity workers. Low-productivity colleagues can reduce the reputation of the firm. See Landers, Rebitzer, and Taylor (1996) or more recently Bar-Isaac (2007). Alternatively, workers might derive intrinsic satisfaction from smooth and cooperative team production, where teams work smoothly if and only if all team members are highly productive. Hamilton, Nickerson, and Owan (2003) provide empirical evidence for non-monetary utility gains from working in teams.

While high-productivity workers might suffer directly from low-productivity colleagues, in many situations externalities among workers emerge only if firms implement particular team performance payment schemes.[8] Holmström (1982) and Mookherjee (1984) indeed show that optimal wages for one worker often condition on the performance of other workers. Joint performance evaluation is optimal if workers can increase their colleagues' performance. Che and Yoo (2001) argue that firms reward team performance to increase the cooperation among workers and thereby reduces agency costs. McAfee and McMillan (1991) show that individual performance evaluation need not outperform team performance evaluation, although individual production is technologically independent. In these cases externalities among workers arise, because firms optimally implement particular team performance evaluation schemes.

[8] For example, less productive workers slow down production lines, they contribute less to team production, or they cause quality problems that impede efficient production. Even if team output depends on the average productivity of team members, workers with fixed wages might not care for the productivity of their colleagues. Externalities immediately arise if wages condition on team performance.

We assume that high-productivity workers suffer from low-productivity colleagues, whereas low-productivity workers do not benefit from high-productivity colleagues. One justification for this asymmetry is that sometimes, high-productivity workers either cannot or do not want to help low-productivity workers, whereas low-productivity workers drag down high-productivity colleagues. An alternative justification is that the team production technology is characterized by the "weakest-link principle," see for example Kremer (1993), Dalmazzo (2002), Fabel (2004), and Jones (2011). A low-productivity worker then does not benefit from more productive colleagues, since he with his own low productivity already precludes successful team production. While it may be that the assumption is not necessarily true in every situation, it allows us to spell out the implications of team externalities in markets with adverse selection precisely.[9] In Section 5 we discuss how our results might change if low-productivity workers also benefit from the presence of high-productivity colleagues.

Summarizing, externalities among workers can arise for various reasons, including optimal contract choices of firms. Since we focus on adverse selection, we do not model explicitly any underlying moral hazard problems and corresponding optimal team performance contracts. Instead, we consider our utility functions as a reduced form representation of the contractual environment in combination with the technological production process. For illustration, we introduce the following example, to which we return repeatedly throughout the paper.

Example: *Suppose that after joining firms, workers are matched into a team of two with another employee of the same firm. The two workers are promised a bonus if the team meets a performance target. Like in Kremer (1993) production consists of many tasks, all of which must be well executed for the team to be successful. High-productivity workers can do the job, whereas the presence of at least one low-productivity worker causes the team to fail. High-productivity workers then dislike being matched with a low-productivity colleague. Low-productivity workers, on the other hand, do not care about their colleague's productivity, since their own presence is already sufficient to ensure that they never get the team bonus. High-productivity workers' utility upon accepting the offered employment contract thus depends on the fraction of low-productivity workers employed by the same firm. For low-productivity workers this is not the case.*

[9] If low-productivity workers do not benefit from high-productivity colleagues, their optimal contract choices do not depend on the contract choices of high-productivity workers. This reduces coordination problems due to multiple equilibria at the acceptance stage.

Firms offer contracts that specify a task requirement t and a base wage w. Part of the compensation package is a team bonus γw with $\gamma > 0$. The bonus is exogenously tied to the base salary; it is paid if and only if the team is successful, which happens if and only if both team members are highly productive. Let $b(y)$ be the probability of being matched with a high-productivity worker if y is the average productivity of workers employed by firm n. We must have $b(\ell) = 0$ and $b(h) = 1$. The firm might use some internal mechanisms to affect worker matching, but our results hold as long as complete separation is impossible and b is increasing in y. Then a worker's expected utility upon accepting contract $c = (t, w, n)$ is

$$u(\theta, y, c) = \begin{cases} w - t/\ell & \text{if} \quad \theta = \ell \\ w - t/h + b(y)\gamma w & \text{if} \quad \theta = h \end{cases} \tag{2}$$

where t/θ are the usual productivity-dependent costs of completing tasks.

We often refer to workers' preferences over different task requirements and wages, given that they are pooled with workers with some fixed average productivity. Define a worker's indifference curve $\bar{U}_\theta(y)$ in (t, w)-space as the set of all combinations of task requirements and wages which – if offered by a firm attracting workers with average productivity y – yield workers with productivity θ constant utility. Formally, this indifference curve is defined as

$$\bar{U}_\theta(y) = \{(t, w) \in \mathbb{R}_+ \times \mathbb{R} : u(\theta, y, (t, w, n)) \equiv \bar{u}, \bar{u} \in \mathbb{R}\}. \tag{3}$$

Indifference curves have slope $-u_t(\theta, y, c)/u_w(\theta, y, c)$, where by definition the slope does not depend on the average attracted productivity of colleagues for low-productivity workers, but can depend on the average productivity of colleagues for high-productivity workers. As usual we assume that the slope of workers' indifference curves is decreasing in θ for all y. We formalize this as follows.

Assumption 2 (Single-Crossing Property)**.** *For all (y, c) we have*

$$-u_t(h, y, c)/u_w(h, y, c) < -u_t(\ell, y, c)/u_w(\ell, y, c). \tag{4}$$

This is our version of the Spence-Mirrlees or single-crossing property. Requiring it to hold for all y imposes a restriction: changing the average attracted productivity must not affect the slope of the indifference curves of high-productivity workers so as to upset the single-crossing property. Moreover, we assume that the difference in the slope of the indifference curves of workers with high and low productivity is bounded away from zero.

Assumption 3 (Intersection Indifference Curves). *For all* (y, c) *we have*

$$-u_t(\ell, y, c)/u_w(\ell, y, c) + u_t(h, y, c)/u_w(h, y, c) > q \tag{5}$$

for some $q \in I\!R_+$.

This ensures that any two indifference curves of the two types of workers intersect. Finally, we assume that the average attracted productivity y has a monotone influence on the slope of high-productivity workers' indifference curves.

Assumption 4 (Monotonicity). *For all* (y, c) *we have*

$$\frac{\partial}{\partial y}\big(- u_t(h, y, c)/u_w(h, y, c)\big) \tag{6}$$

is either weakly positive or weakly negative.

We normalize a worker's utility to zero in case he accepts no contract. We also assume that $u(\theta, \theta, (0, 0, n)) = 0$ for all (θ, n). If a worker is pooled with workers of his productivity and accepts a contract that specifies zero task requirement and zero wage benefits, he thus gets a utility equal to his outside option.

3.2 Firms' Profits and Externalities

Our results are driven by externalities among workers, so that firms' profit functions could be defined as usual. For the purpose of generality we show that including analogous externalities in the firms' profit function is unproblematic. Let function $v : \Theta \times [\ell, h] \times \mathcal{C} \to I\!R$ describe firms' profits, where $v(\theta, y, c)$ is firm n's profit per worker with productivity θ accepting contract $c = (t, w, n)$ if the firm attracts workers of average productivity y. We assume that v is at least once partially differentiable in t and w with $v_w < 0$ and $v_t = 0$. We focus on adverse selection and the associated costs of separation and thus take the task requirement to be non-productive. In this we follow Spence (1973), who also assumes that education has no impact on worker productivity. The function v is unbounded below with respect to wage benefits w. Firms prefer high-productivity workers so that $v(h, y, c) > v(\ell, y, c)$ for all (y, c).

Assumption 5 (Externality Firms). *For all* (y, c) *we have*

$$v_y(\theta, y, c) \geq 0 \textit{ if } y < \theta \textit{ and } v_y(\theta, y, c) = 0 \textit{ if } y \geq \theta. \tag{7}$$

The presence of low-productivity workers might reduce the firm's profit per high-productivity employee, but as the definition shows this externality can also be set to zero without affecting our results. Let $\eta(\theta, c, C)$ be the mass of workers with productivity θ accepting contract c if set C of contracts is offered. Firm n that offers contracts $C_n \subseteq C$ then makes total profits

$$\sum_{\theta \in \Theta} \sum_{c \in C_n} \eta(\theta, c, C)\, v(\theta, y, c). \tag{8}$$

Firms get an outside option profit of zero if they do not attract any workers. We assume that $v(\theta, \ell, (0, 0, n)) > 0$ for all $\theta \in \Theta$ and $n \in \mathbb{N}$. A firm thus gets more than its outside option if it can attract workers with a contract that specifies a zero wage. Together with the assumption on workers' outside option, this ensures that mutually beneficial contracting between firms and workers is possible.

Example (cont'd): *The profit of a firm that employs a worker with productivity θ and promises base wage w is $\theta - w$ if the worker's team is not successful, and $(1+\gamma)\theta - (1+\gamma)\, w$ if the team is successful. We can vary the importance of our externality by varying γ, and we can do so without simultaneously affecting the problem of adverse selection in the labor market. If γ is zero we get a simple screening version of Spence's job signaling model.*

3.3 Equilibrium Concept

In the presences of externalities, workers' utility upon accepting a contract depends on the acceptance decisions of other workers. In this section we describe how we account for this in our equilibrium concept. Intuitively speaking, we extend the notion of Rothschild and Stiglitz (1976) by defining a competitive equilibrium as a finite set of offered contracts together with workers' general contract acceptance rule. Concerning the workers we require that their acceptance decisions form a Bayesian equilibrium for all finite sets of offered contracts.[10] Workers therefore maximize expected utility given the contractual options and given the equilibrium contract choices of the other workers. Conditional on workers' equilibrium behavior, an equilibrium set of offered contracts satisfies two conditions. First, each firm makes at least zero profit. Otherwise, a firm could increase its profits by leaving the market. Second, profitable market entry is impossible. Perfect competition is thus formalized via a no-market-entry condition. In the following we make our equilibrium concept formally precise.

Consider first workers' strategy space and thus their contract acceptance rules. Let $\mathcal{P}(\mathcal{C})$ be the power set of contract space $\mathcal{C}$. We only consider equilibria in which all workers share the

[10] A Bayesian equilibrium need not exist if an infinite number of contracts is offered. However, since the equilibrium set of contracts is finite by assumption, and we only consider market entry by single firms that offer finite menus of contracts, it is sufficient to specify workers' acceptance decisions for finite sets of offered contracts.

same productivity-dependent contract acceptance rule, therefore we can suppress indexation for workers' identity. We define the strategy space $\mathcal{A}$ for workers as the set of all contract acceptance functions $a : \Theta \times \mathcal{C} \times \mathcal{P}(\mathcal{C}) \to [0, 1]$ that define for all possible sets of offered contracts C the probabilities $a(\theta, c, C)$ with which the worker accepts contract c if he has productivity θ. These acceptance probabilities are weakly positive, and they cannot add up to more than one given any set of offered contracts. They might add up to less than one since workers need not accept any offered contract. The acceptance probabilities must further satisfy $a(\theta, c, C) = 0$ for all $c \notin C$ since workers cannot accept contracts that are not being offered.

Consider next the average productivity of workers accepting particular contracts. Together with the commonly known distribution of high-productivity and low-productivity workers, the equilibrium acceptance rule a^* determines the mass $\eta^*(\theta, c, C)$ of workers with productivity θ accepting contract c for all possible sets of offered contracts C. Let $A^*(n, C)$ be the corresponding total mass of workers attracted by firm n given some set of offered contracts C. If the total mass of attracted workers $A^*(n, C)$ is strictly positive, the average productivity of employees of firm n is given by

$$y^*(\theta, n, C) = \frac{1}{A^*(n, C)} \sum_{\tilde{c} \in C_n} \sum_{\tilde{\theta} \in \Theta} \eta^*(\tilde{\theta}, \tilde{c}, C)\, \tilde{\theta}. \tag{9}$$

Generically, because a single worker has mass zero, he does not influence the average productivity of workers attracted by firm n. Only in case a single worker with productivity θ is the only worker employed by that firm, the worker's productivity equals average productivity and thus $y^*(\theta, n, C) = \theta$.

We can now formally define the optimality condition for workers' equilibrium acceptance rule. We require that their equilibrium acceptance rule forms a Bayesian equilibrium for all possible finite sets of offered contracts. Formally, this implies the following.

Property 1 (Optimality Contract Acceptance Choices)**.** *For all finite C we have*

$$a^* \in \arg\max_{a \in \mathcal{A}} \Big\{ \mu_0 \sum_{c \in C} a(h, c, C)\, u(h, y^*(h, n, C), c) + (1 - \mu_0) \sum_{c \in C} a(\ell, c, C)\, u(\ell, y^*(\ell, n, C), c) \Big\}. \tag{10}$$

Given the equilibrium behavior of workers, consider next firms. Following Rothschild and Stiglitz (1976) we do not model the strategic interaction between firms explicitly. Instead, a competitive equilibrium is an equilibrium set of offered contracts C^* which satisfies two properties given the equilibrium acceptance rule of workers a^*. First, no firm makes losses in equilibrium. Let N^* denote the set of firms that offer contracts in equilibrium. Then we can formalize the first condition on the equilibrium set of offered contracts as follows.

Property 2 (No Losses)**.** *For all $n \in N^*$ we have*

$$\sum_{c \in C_n} \sum_{\theta \in \Theta} \eta^*(\theta, c, C^*)\, v(\theta, y^*(\theta, n, C^*), c) \geq 0. \tag{11}$$

Moreover, profitable market entry must be impossible. We formalize this as follows.

Property 3 (No Market Entry)**.** *There exists no $n \notin N^*$ and finite C_n such that*

$$\sum_{c \in C_n} \sum_{\theta \in \Theta} \eta^*(\theta, c, C^* \cup C_n)\, v(\theta, y^*(\theta, n, C^* \cup C_n), c) > 0. \tag{12}$$

Finally, we impose an equilibrium refinement on acceptance rules to sharpen predictions. Due to externalities there can be multiple equilibria at the acceptance stage. The following refinement rules out competitive equilibria that exist only because workers re-coordinate on better acceptance decisions once otherwise irrelevant new contracts are offered. This ensures market entry if workers coordinate on bad contract acceptance decisions in equilibrium. We formalize this as follows. For a more extensive discussion of a similar refinement in a similar context, see pp.790-791 in von Siemens (2012).

Property 4 (No Switch)**.** *Take any $n \notin N^*$ and finite C_n. Suppose that $a^*(\theta, c, C^* \cup C_n) = 0$ for all $\theta \in \Theta$, $c \in C_n$. Then $a^*(\theta, c, C^* \cup C_n) = a^*(\theta, c, C^*)$ for all $c \in C^*$.*

We define a competitive equilibrium as a contract acceptance rule a^* in combination with a finite set of contracts C^* that satisfies Properties 1 to 4.

One of our main results is that in any competitive equilibrium, workers with high and low productivity work in separate firms under separate contracts. Since firms' identities as such are irrelevant, the model is silent on which firm offers which contract in equilibrium. However, workers' utility functions and firms' profit functions uniquely pin down the task requirements and wages of contracts that are accepted by workers with high and low productivity. These contracts include wages (w_ℓ, w_h) and task requirement t_h that are defined implicitly by

$$v(\ell, y, (0, w_\ell, n)) = 0 \tag{13}$$

$$v(h, h, (t_h, w_h, n)) = 0 \tag{14}$$

$$u(\ell, y, (t_h, w_h, n)) = u(\ell, y, (0, w_\ell, n)). \tag{15}$$

Since a low-productivity worker's utility does not depend on the average productivity of his colleagues, the choice of y in (13) and (15) is irrelevant. Since no worker cares for the identity of firms as such, the choice of n in (13) to (15) is also irrelevant. We show in the appendix that our assumptions on v and u guarantee the existence of a unique solution to (13) to (15) with $w_h > w_\ell$ and $t_h > 0$. We define the sets of contracts

$$C_\ell \quad = \{\, (t, w, n) \in \mathcal{C} : t = 0 \text{ and } w = w_\ell \,\} \tag{16}$$

$$C_h \quad = \{(t, w, n) \in \mathcal{C} : t = t_h \text{ and } w = w_h\} \tag{17}$$

with generic elements $c_\ell \in C_\ell$ and $c_h \in C_h$. A *best separating equilibrium* is then a competitive equilibrium that satisfies the following property.

Property 5 (Best Separating Equilibrium)**.**

1. *$C^* \cap C_\ell$ and $C^* \cap C_h$ are both non-empty.*
2. *For each $\theta \in \{l, h\}$, there exists at least one contract $c \in C^* \cap C_\theta$ with $a^*(\theta, c, C^*) > 0$, and there exists no contract $\tilde{c} \in C^* \cap C_{\neg\theta}$ with $a^*(\theta, \tilde{c}, C^*) > 0$.*
3. *There exists no firm $n \in N^*$ that offers contracts $\{c, \tilde{c}\} \subset C^*$ such that $a^*(h, c, C^*) > 0$ and $a^*(\ell, \tilde{c}, C^*) > 0$.*

Thus, in a best separating equilibrium: first, some firms offer contracts from the sets C_ℓ and C_h, since otherwise Pareto-efficient separation is not possible; second, high-productivity workers accept at least one contract from the set of contracts C_h designed for high-productivity workers, and they accept no contract from the set of contracts C_ℓ specified for low-productivity workers. The analogous condition holds for low-productivity workers; finally, workers separate across firms according to their productivity.

4 Results

We first derive necessary and sufficient conditions for the existence of a best separating equilibrium if firms do not offer latent contracts, that is, contracts that are not accepted in equilibrium. We then characterize the supremum utility of high-productivity workers who accept latent contracts that in a best separating equilibrium are offered by firms that only attract low-productivity workers. This allows us to derive necessary and sufficient conditions for the existence of a best separating equilibrium if firms can offer latent contracts. We complete our results by demonstrating that any competitive equilibrium must be a best separating equilibrium. This allows us to characterize the necessary and sufficient conditions for the existence of a competitive equilibrium.

4.1 Existence of Best Separating Equilibria without Latent Contracts

In the following we characterize the necessary and sufficient conditions for the existence of a best separating equilibrium if firms do not offer latent contracts. These best separating equilibria have the following property.

Property 6 (No Latent Contracts). *$\forall c \in C^*$ there exists $\theta \in \{\ell, h\}$ such that $a^*(\theta, c, C^*) > 0$.*

The following lemma implies that if all contracts offered in equilibrium are accepted by some workers in equilibrium, the utility loss of high-productivity workers from being pooled with only low-productivity workers must exceed the minimum screening costs to ensure separation. All proofs can be found in the appendix.

Lemma 1 (Best Separating Equilibrium, No Latent Contracts). *A best separating equilibrium satisfying Property 6 exists for all $\mu_0 \in (0,1)$ if and only if $u(h, h, (t_h, w_h, n)) \geq u(h, \ell, (0, w_h, n))$.*

Contrary to a situation without externalities, market entry with a pooling contract need not be profitable even if the fraction of low-productivity workers $1 - \mu_0$ is arbitrarily small. The reason is that with externalities, there exists an equilibrium at the acceptance stage in which high-productivity workers do not accept the new contract, because (they expect and this is confirmed in equilibrium that) only low-productivity workers are attracted by the new firm. Since the new firm then makes losses, it does not enter.

Figure 1 illustrates the main economic insight behind this argument. The best separating contracts can be found in the lower left corner and in the upper right corner where the two types' indifference curves $\bar{U}_h(h)$ and $\bar{U}_\ell(y)$ intersect. Low-productivity workers face zero task requirement $t_\ell = 0$ while high-type workers face a strictly positive task requirement $t_h > 0$. Wages w_ℓ and w_h are such that low-productivity workers are indifferent between mimicking and not mimicking high-productivity workers, while firms make zero profit. Denote by w_p the zero-profit wage for pooling contracts that attract all workers. Wage w_p increases in the fraction of high-productivity workers μ_0, and it converges to the wage w_h as μ_0 converges to one. In the standard case without externalities, profitable market entry therefore becomes possible as μ_0 exceeds some cutoff strictly smaller than one. This holds because both low- and high-productivity workers can be made better off with a pooling contract P than with their old separating contract – contract P lies strictly above both types' indifference curves, and at the same time pays slightly less than the break-even pooling wage w_p. See our example in Figure 1. In this case there exists no competitive equilibrium.

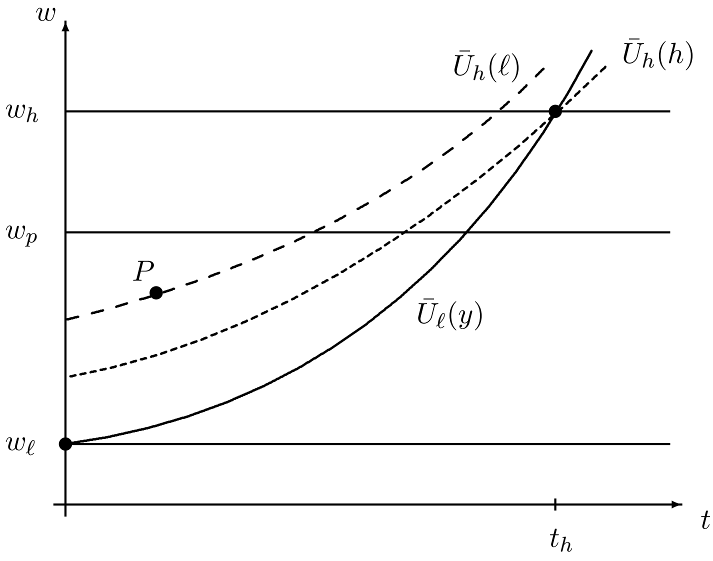

Figure 1: Illustration best separating contracts.

With externalities the situation looks different, since the utility levels corresponding to the indifference curves of high-productivity workers now depend on the average productivity y of these workers' colleagues. It is no longer clear that the high-productivity workers' indifference curve running through pooling contract P corresponds to a higher utility level than the utility level that corresponds to the original indifference curve $\bar{U}_h(h)$ under separation. In Figure 1 this is illustrated by the new dashed indifference curve $\bar{U}_h(l)$ that specifies the high-productivity workers' utility in P in case only low-productivity workers are attracted by the contract. Contract P now need not draw both low-productivity and high-productivity workers: even though low-productivity workers prefer the pooling contract P over their old contract with task requirement 0 and wage w_ℓ, high-productivity workers prefer their old contract with task requirement t_h and wage w_h if only low-productivity workers accept contract P. Market entry is no longer profitable. Intuitively, the externality between workers helps sustain separating equilibria by reducing high-productivity workers' payoffs associated with pooling. The region of the parameter space $\mu_0 \in (0, 1)$ for which separating equilibria exist expands.

Example (cont'd): *In our example the best separating contracts specify $w_\ell = \ell$ for low-productivity workers, and $w_h = h$ and $t_h = \ell(h - \ell)$ for high-productivity workers. These contracts can form a competitive equilibrium for all μ_0 if and only if*

$$\gamma h \geq \frac{\ell(h - \ell)}{h}. \tag{18}$$

Choosing their contract, high-productivity workers can secure themselves the bonus $\gamma\, h$, but *they incur screening costs $t_h/h = \ell(h-\ell)/h$. By accepting the pooling contract, they save the screening costs, but as they are matched with low-productivity workers they loose the bonus. If the relation γ of bonus to base salary – which in our example corresponds to a measure of the externality among workers – is sufficiently large, there always exists a best separating equilibrium. This condition cannot be fulfilled if the externality γ disappears.*

4.2 Latent Contracts and the Preemption of Market Entry

Lemma 1 describes conditions for the existence of a best separating equilibrium in which all offered contracts are accepted. Firms thus do not offer any contracts that are not in C_ℓ or C_h. We next consider the more general case in which the equilibrium set of offered contracts may contain contracts that are not accepted by any worker in equilibrium. We show that such latent contracts can be used to prevent market entry. We further show that if more productive colleagues make changes in wages for high-productivity workers relatively more important than changes in work task requirements – which means that more productive colleagues make high-productivity workers' indifference curves in contract space flatter – then arbitrarily small externalities in combination with latent contracts guarantee equilibrium existence.

The argument runs as follows. Consider a firm that attracts only low-productivity workers in a best separating equilibrium. Suppose this firm also offers some contract that would be very attractive for high-productivity workers if it attracted only high-productivity workers, but in equilibrium this contract is not accepted as the firm only attracts low-productivity workers. If another firm enters the market and draws all low-productivity workers, the old firm offering the previously latent contract employs no workers any more. It thus suddenly becomes very attractive for high-productivity workers. If the new firm cannot draw any high-productivity workers, it makes negative profits and there is no market entry.[11]

To analyze latent contracts in our setup, let Γ be the set of all combinations of wages and task requirements that in a best separating equilibrium do not attract any high-productivity workers if offered by a firm who currently attracts only low-productivity workers. Γ contains

[11]The argument resembles the line of reasoning in Riley (1979) who allows firms to offer new contracts and thereby to skim off the good types after market entry. The main difference is that in our model such contracts are already offered in equilibrium.

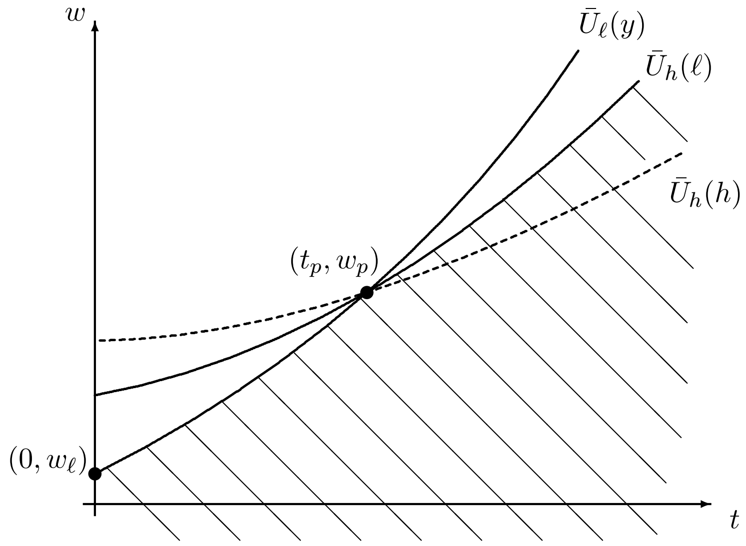

Figure 2: Set Γ is the shaded area.

all task requirements t and wages w that satisfy

$$u(\ell, y, (t_\ell, w_\ell, n)) \geq u(\ell, y, (t, w, n)) \tag{19}$$

$$u(h, h, (t_h, w_h, n)) \geq u(h, \ell, (t, w, n)). \tag{20}$$

Since a low-productivity worker's utility does not depend on the average productivity of his colleagues, the choice of y in (19) is irrelevant. Since workers do not care for the identity of their employers as such, the choice of n is irrelevant in both (19) and (20). Because latent contracts do not attract any workers in equilibrium, they cannot cause losses. No constraint concerning the profits of the offering firm is needed. Define

$$U_p = \sup_{(t,w)\in\Gamma} \big\{u(h, h, (t, w, n))\big\} \tag{21}$$

as the supremum utility of high-productivity workers who accept a latent contract which is offered by a firm that – after market entry – attracts no workers. We obtain the following result.

Lemma 2 (Supremum Utility)**.** *Consider the supremum utility U_p as defined in (21).*

1. *If $\frac{\partial}{\partial y}\big(-u_t(h, y, c)/u_w(h, y, c)\big) \geq 0$ then $U_p = u(h, h, (t_p, w_p, n))$ where (t_p, w_p) is implicitly defined by $u(\ell, y, (0, w_\ell, n)) = u(\ell, y, (t_p, w_p, n))$ and $u(h, h, (t_h, w_h, n)) = u(h, \ell, (t_p, w_p, n))$.*
2. *If $\frac{\partial}{\partial y}\big(-u_t(h, y, c)/u_w(h, y, c)\big) < 0$ then $U_p = +\infty$.*

Figure 2 illustrates Lemma 2. Set Γ is the shaded area under the indifference curves $\bar{U}_\ell(y)$ and $\bar{U}_h(\ell)$. If, as is assumed in case 1 of Lemma 2, increasing the average productivity of colleagues does not flatten the indifference curves of high-productivity workers, the supremum utility U_p is finite and attainable by accepting a latent contract with task requirement and wage (t_p, w_p). But increasing y can also flatten the indifference curves of high types. This is case 2 in Lemma 2, which is illustrated in the Figure by the indifference curve $\bar{U}_h(h)$ being flatter than the indifference curve $\bar{U}_h(\ell)$ at the point of intersection (t_p, w_p). Starting from this point of intersection, it is possible to reach ever higher utility levels for high-productivity workers by moving up along $\bar{U}_h(\ell)$ without violating any constraints. The supremum utility U_p it then equal to infinity.

4.3 Existence of Best Separating Equilibria

We can now characterize the necessary and sufficient conditions for the existence of a best separating equilibrium when firms can use latent contracts to discourage market entry.

Lemma 3 (Best Separating Equilibrium, Latent Contracts)**.** *A best separating equilibrium exists for all $\mu_0 \in (0,1)$ if and only if $U_p \geq u(h, \ell, (0, w_h, n))$.*

Case 2 in Lemma 2 implies that if the presence of more productive colleagues flattens high-productivity workers' indifference curves, the utility that high-productivity workers get by accepting a previously latent contract after market entry can be made arbitrarily large, even if externalities are arbitrarily small. By Lemma 3 arbitrarily small externalities then ensure existence of a best separating equilibrium, because a market entrant cannot profitably attract all workers. Lemma 2 and Lemma 3 imply our first main result which we summarize in the following Proposition.

Proposition 1 (Equilibrium Existence, Arbitrarily Small Externalities)**.** *Suppose that $\frac{\partial}{\partial y}\big(- u_t(h,y,c)/u_w(h,y,c)\big) < 0$. Then, arbitrarily small externalities ensure existence of a best separating equilibrium for all $\mu_0 \in (0,1)$.*

Note that this result is not due to multiple equilibria at the acceptance stage and workers' failure to coordinate: there are no multiple equilibria at the acceptance stage if U_p is infinitely large. In this case low-productivity workers strictly prefer the new pooling contract no matter what high-productivity workers do. Once all low-productivity workers are attracted by the market entrant, each high-productivity worker can be given an arbitrarily large utility via a latent contract. They thus prefer the latter to the new pooling contract even if all other high-productivity workers join the new firm. In any equilibrium at the acceptance stage, the market entrant thus makes losses. Profitable market entry is not possible.

Our analysis shows that the impact of more productive colleagues on the slope of high-productivity workers' indifference curves plays an important role in our analysis. If a higher fraction of high-type colleagues flattens the indifference curves of high-productivity workers, arbitrarily small externalities guarantee equilibrium existence. The condition on workers' indifference curves is, in fact, quite natural and likely to be satisfied in many situations of interest. For example, if firms use team performance contracts, more high-productivity colleagues imply that high-productivity workers should benefit more from an increase in bonus payments. The reason is that more high-productivity colleagues make it easier for high-productivity workers to ensure high team performance. Put the other way round, more low-productivity colleagues will *decrease* the probability of attaining good team performance and therefore also *decrease* the marginal utility from wages for high-productivity workers. In consequence, indifference curves of high-productivity workers become flatter if the fraction of high-type colleagues increases, ensuring equilibrium existence for arbitrarily small externalities. Case 2 in Lemma 2 is thus not only theoretically interesting, but also satisfied in many typical team production environments. This can also be seen in our example.

Example (cont'd): *In a best separating equilibrium, a high-productivity worker is indifferent between his equilibrium contract and any latent contract that specifies for task requirement $\tilde{t}$ a base salary*

$$\tilde{w} = \tilde{t}/h + h(1+\gamma) - \frac{1}{h}\ell(h-\ell). \tag{22}$$

Among these contracts we look for a latent contract that satisfies two conditions. First, the latent contract is not accepted by low-productivity workers. Using these workers' equilibrium utility yields the following condition

$$\tilde{t} \geq \frac{\ell h}{h-\ell}\left(h(1+\gamma) - \ell - \frac{1}{h}(h-\ell)\right). \tag{23}$$

Second, the latent contract must attract all high-productivity workers after market entry. If the pooling contract only attracts low-productivity workers, a high-productivity worker who joins the new firm never gets the bonus and thus does not earn more than utility h. He prefers the latent contract in case

$$\tilde{t} \geq \frac{h}{\gamma}\left(h(1+\gamma) - \frac{1}{h}\ell(h-\ell)\right). \tag{24}$$

Market entry can therefore be prevented by a latent contract that specifies a task requirement *sufficiently large so as to satisfy both (23) and (24). Such a contract can be easily found for any strictly positive level of externality γ.*

In the example, it is important that team bonus and base wage are tied together. If team bonuses were fixed and firms could vary only the base wage, high-productivity workers would still prefer to have high-productivity colleagues. But the presence of low-productivity workers would have no impact on the slope of the indifference curves of high-productivity workers. Even with latent contracts, small externalities would then not guarantee equilibrium existence.

The key role of latent contracts in our model is to prevent market entry. This connects our analysis to the literature on competitive equilibria in markets with moral hazard and non-exclusive contracting. With non-exclusive contracting, principals are limited in their ability to prevent workers from contracting with other principals. Arnott and Stiglitz (1991) show that there exist competitive equilibria in insurance markets in which agents buy insurance from only one firm that makes strictly positive profits. Market entry is prevented by latent insurance policies. The argument is the following: if a new firm offers a more attractive insurance policy, agents accept the new contract. But they subsequently find it attractive to use previously latent contracts to buy additional insurance. This destroys agents' incentives to avoid accidents, so that the new insurance policy makes expected losses. Anticipating this, no firm enters the market. Our results show that if there are externalities among workers, similar arguments hold in markets with adverse selection and exclusive contracting.[12]

4.4 No Pooling and Existence of Competitive Equilibria

So far we have focused on the necessary and sufficient conditions under which externalities ensure the existence of a best separating equilibrium. We now proceed to show that whenever there exists a competitive equilibrium in pure strategies, it is a best separating equilibrium. We thus obtain segregation in the labor market, also in the presence of externalities between workers. The main step is to show that there cannot be pooling in equilibrium. The proof essentially follows the standard procedure absent externalities.

[12] In a related article, Hellwig (1983) gives firms the option to communicate to other firms any contractual relationship with an agent. Firms might condition the terms of their contracts on this information. Results remain similar. For a more recent contribution to this literature, see Bisin and Guaitoli (2004).

Lemma 4 (No Pooling)**.** *In any competitive equilibrium there are no contracts* $c \in C_n^*$ *and* $\hat{c} \in C_n^*$ *offered by some firm* n *with* $a^*(\ell; c, C^*) > 0$ *and* $a^*(h; \hat{c}, C^*) > 0$*.*

Adapting the arguments by Rothschild and Stiglitz (1976), it is now easy to show that any competitive equilibrium must be a best separating equilibrium. Since only low-productivity workers exert an externality on high-productivity workers, low-productivity workers behave as if there were no externalities at all. In any competitive equilibrium they must thus be offered at least one contract from set C_ℓ. If high-productivity workers are not offered at least one contract from C_h, then a new firm can enter the market and offer a contract that brings these workers closer to their utility in the best separating equilibrium. This contract is designed so as to never attract low-productivity workers. High-productivity workers can then be certain that they will be either alone or among themselves whenever they accept the new contract. High-productivity workers are thus attracted, while low-productivity workers stick to their old contract choices. The new contract then yields the firm strictly positive profits, and there is market entry.

Lemma 5 (Only Best Separating Equilibria)**.** *Any competitive equilibrium is a best separating equilibrium.*

We omit the formal proof. Lemma 5 extends Lemma 4 by argueing that there must be Pareto-efficient separation in any competitive equilibrium. This result echoes Rothschild and Stiglitz (1976). Although externalities facilitate equilibrium existence, they thus do not affect equilibrium predictions. Moreover, necessary and sufficient conditions for the existence of a best separating equilibrium are necessary and sufficient conditions for the existence of any competitive equilibrium. We summarize this result in our final proposition.

Proposition 2 (Existence Competitive Equilibrium)**.** *There exists a competitive equilibrium for all* $\mu_0 \in (0, 1)$ *if and only if* $U_p \geq u(h, \ell, c)$*.*

5 Discussion

This paper shows that negative externalities between workers can mitigate the equilibrium existence problem in competitive markets with adverse selection. While most assumptions in our model are common and – at least in our view – also quite natural, there remains the question, how different modifications might affect our results.

5.1 Positive Externalities

One important question relates to the effect of positive externalities such that low-productivity workers profit from the presence of high-productivity colleagues. Since a full exploration is beyond the scope of this paper, it is left for future research and we focus instead on our intuitions. Suppose in the following that as before high-productivity workers suffer from low-productivity colleagues, but now low-productivity workers also benefit from high-productivity colleagues. Assume further that the profits per low-productivity worker weakly increase in the fraction of high-productivity colleagues.

In general, positive externalities complicate the analysis because they facilitate profitable market entry. In contrast to our previous analysis, cross-subsidizing contracts now play a major role. To see this, note that with positive externalities, low-productivity workers have additional incentives to accept relatively low wages, if they are in return matched with high-productivity colleagues. This increases the scope for redistribution within firms. In addition, the presence of high-productivity workers can increase the profitability of low-productivity workers. In both cases, market entrants that want to attract both low- and high-productivity workers can use cross-subsidization to attract high-productivity workers.

Positive externalities further facilitate market entry, because they restrict the construction of equilibria at the contract acceptance stage that discourage market entry. If there are only negative externalities, a new firm offering pooling contracts always attracts low-productivity workers. With positive externalities, however, low-productivity workers might only come if they expect to have high-productivity colleagues. There then exists no equilibrium at the acceptance stage in which the market entrant attracts only low-productivity workers. To deter market entry it must thus be possible to construct an equilibrium in which the new firm attracts no workers at all. This is difficult since then high-productivity workers who deviate determine the average productivity of workers attracted by the new firm.

Overall, positive externalities thus seem to facilitate profitable market entry. This destabilizes both pooling and separation. However, positive externalities generate a tendency towards less separation and more pooling. The reason is that because low-productivity workers want to pool with high-productivity workers, the minimum task requirement for high-productivity workers that ensures separation must increase. This can push the utility of high-productivity workers below their outside option. In that case there exists no separating equilibrium.

Furthermore, positive externalities might also affect the slope of the indifference curves of low-productivity workers. The minimum task requirement of high-productivity workers to sustain separation might thus be smaller within a single firm than across two separate firms. This can make separation within firms more attractive for high-productivity workers than separation across firms. Last but not least, positive externalities can stabilize pooling, since firms might no longer want to lure away low-productivity workers, even if these currently generate positive profits. This holds because these workers generate losses without their high-productivity colleagues.

The above arguments suggest that positive externalities might rule out separation and thus overpower the effects of negative externalities in our present model. This is not the case. First, high-productivity workers still prefer to be separated from low-productivity workers. Negative externalities continue to destabilize pooling. Second, workers must still be separated according to their productivity within firms, if firms want to use cross-subsidizing contracts. This imposes screening costs that limit the scope for cross-subsidization. Via both channels negative externalities make it more difficult for pooling contracts to attract all workers. Positive externalities thus create a tendency towards more pooling, but do not necessarily rule out the existence of separating equilibria.

Finally, the existence of positive externalities has no substantial impact on the consequences of latent contracts. The only difference is that incentive compatibility for low-productivity workers must account for the fact that being matched with high-productivity workers becomes more attractive. Our result that arbitrarily small negative externalities might substantially facilitate equilibrium existence continues to hold. Overall, the above arguments suggest that positive externalities create a tendency towards pooling, and negative externalities create a tendency towards separation. Whether pooling or separation prevails depends on the relative strength of the effects.

5.2 Continuum of Types

A second question is how a continuum of productivity types would affect our results. So far, our analysis only considers the case in which workers have either high or low productivity. We conjecture that our main result – the impact of latent contracts on equilibrium existence – will carry over to the more general case. Suppose there exists a continuum of productivity types for workers while all other assumptions of our model continue to hold. Firms can still offer contracts that are potentially attractive to very productive workers, but are not accepted in equilibrium since these firms attract only workers with lower productivity. After market entry these contracts suddenly become attractive to very productive workers. Given the right continuity assumptions concerning the utility functions of workers, it should be possible to find an interior cut-off productivity level such that in equilibrium, all workers with lower productivity are attracted by the market entrant, while all workers with higher productivity pool on the previously latent contract. The reason is that continuously shifting workers with higher productivity from the market entrant to the latent pooling contract continuously changes the relative attractiveness of the alternative contracts. Latent contracts continue to stabilize separating competitive equilibria.

While the mechanics of the model seem to work in the same direction, it may be that equilibrium existence requires that a continuum of firms offers a continuum of latent contracts. Since it is difficult to spell out the exact details of such an analysis, we focus in this paper on a more tractable setup with only two types.

6 Conclusion

This paper analyzes the effect of negative externalities on competitive labor markets that are characterized by adverse selection. The economic source of the externality in our model lies in the team production process employed by firms. In a sense, a particular form of externality already exists in standard adverse selection models: the presence of low-productivity workers prevents firms from offering high wages to high-productivity workers without requiring them to produce some minimum task requirement that ensures separation. The externalities we have in mind are more direct as they arise only once workers contract with the same firm. It is crucial that these externalities lie beyond the control of firms, are voluntarily left in place, or are even created by firms. To see this suppose firms credibly guarantee to protect high-productivity workers from low-productivity colleagues – for example by structural means that separate types within the organization, or by committing to precisely specified contractual terms. Since this makes pooling contracts attractive again, there is market entry, and the equilibrium existence problem persists. But it is not clear whether firms can indeed credibly commit to eliminate externalities among their workers. For example, having separate plants for workers of different productivity might be prohibitively expensive or impossible given the production technology. Moreover, the externalities might arise because firm adopt certain production technologies or organizational practices like team production. Externalities then cannot be avoided without fundamentally changing the production process. Finally, we show that under a particular condition there exists a competitive equilibrium even if the effective externality – what remains after firms do their best to separate workers according to their productivity – is arbitrarily small. Unless firms fully eliminate all externalities, equilibrium existence is then guaranteed.

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Appendix (Proofs)

Definition of a Best Separating Equilibrium

We first show that (13) and (14) pin down the wage levels. Since $v(\ell, y, (0, 0, n)) > 0$ and v is unbounded below with regard to w, continuity of v, $v_w < 0$, and the intermediate value theorem imply that there exists a unique, finite, and strictly positive w_ℓ satisfying (13). By the same argument there exists a unique, finite, and strictly positive w_h satisfying (14). Since $v_t = 0$, wage w_h does not depend on t_h.

We next show that w_h exceeds w_ℓ. Note that inequality $v(h, y, c) > v(\ell, y, c)$ holds for all (y, c). Then $v(h, h, (t_h, w_\ell, n)) > v(\ell, h, (t_h, w_\ell, n))$. Further, $v_t = 0$ implies that $v(\ell, h, (t_h, w_\ell, n)) = v(\ell, h, (0, w_\ell, n))$, and $v_y(\ell, y, c) = 0$ yields $v(\ell, h, (0, w_\ell, n)) = v(\ell, \ell, (0, w_\ell, n))$. The last equality with (13) imply $v(h, h, (t_h, w_\ell, n)) > 0$. Equation (14) then yields $w_h > w_\ell$ and thus $u(\ell, y, (0, w_h, n)) > u(\ell, y, (0, w_\ell, n))$ since $u_w > 0$. Since u is unbounded below with regard to t, continuity of u, $u_t < 0$, and the intermediate value theorem complete the proof by implying the existence of a unique, finite, and strictly positive t_h satisfying (15).

Proof of Lemma 1

We first show that workers get more than their outside option in a best separating equilibrium. This holds directly for low-productivity workers since $w_\ell > 0$, $u_w > 0$, and $u(\ell, y, (0, 0, n)) = 0$ for all y. By definition, $u(\ell, h, (t_h, w_h, n)) = u(\ell, h, (0, w_\ell, n))$. This yields $u(h, h, (t_h, w_h, n)) > u(h, h, (0, w_\ell, n))$ as $t_h > 0$ and the single crossing property holds for all

y. However, $u(h, h, (0, w_\ell, n)) > 0$ follows from $w_\ell > 0$, $u_w > 0$, and $u(h, h, (0, 0, n)) = 0$. In equilibrium high-productivity workers thus get more than their outside option.

We next show that the condition in the lemma is necessary and sufficient for the existence of a best separating equilibrium in which firms offer no latent contracts.

Part 1: Sufficiency

Consider a best separating equilibrium in which all offered contracts are accepted. Firms thus only offer contracts in $C_\ell \cup C_h$. By definition this equilibrium cannot be upset by a firm that enters the market and then attracts only one type of workers.

We next show that if a firm can enter the market and necessarily attract all workers in at least one equilibrium at the acceptance stage, then it must attract all workers with low productivity in all equilibria at the acceptance stage. Suppose firm $\tilde{n}$ enters the market with contracts $\tilde{c}_\ell = (\tilde{t}_\ell, \tilde{w}_\ell, \tilde{n})$ and $\tilde{c}_h = (\tilde{t}_h, \tilde{w}_h, \tilde{n})$ for workers ℓ and h. Because otherwise low-productivity workers ℓ optimally rejects, $u_y(\ell, y, c) = 0$ and $u_t < 0$ imply that $\tilde{w}_\ell > w_\ell$. Because they do not care for the average productivity of their colleagues, low-productivity workers' acceptance decisions do not depend on the behavior of high-productivity workers. If $a^*(\ell, \tilde{c}_\ell, C^* \cup C_{\tilde{n}}) = 1$ in one equilibrium at the acceptance stage, $\tilde{n}$ must also attract all low-productivity workers in any equilibrium at the acceptance stage. Note that $v_y(\ell, y, c) = 0$, $v_t = 0$, and $\tilde{w}_\ell > w_\ell$ imply that $v(\ell, y, \tilde{c}_\ell) < 0$. Offering pooling contracts, firm $\tilde{n}$ thus makes losses unless it can attract high-productivity workers.

We proceed to show that for every equilibrium at the acceptance stage in which the entrant attracts workers with high productivity and breaks even, there exists another equilibrium with $a^*(h, \tilde{c}_h, C^* \cup C_{\tilde{n}}) = 0$. Given these acceptance decisions firm $\tilde{n}$ makes losses and thus does not enter the market.

Suppose $a^*(h, \tilde{c}_h, C^* \cup C_{\tilde{n}}) > 0$ and firm $\tilde{n}$ makes no losses. If $y_{\tilde{n}}$ is the average productivity of workers attracted by the market entrant, then $v(h, y_{\tilde{n}}, \tilde{c}_h) > 0$ holds. With $v_w < 0$, $u_w > 0$, $u_t < 0$, and $v_t = 0$, this implies that high-productivity workers who accept $\tilde{c}_h$ cannot get more utility than $u(h, y_{\tilde{n}}, (0, \tilde{w}_h, n))$ where $\tilde{w}_h$ solves $v(h, y_{\tilde{n}}, (0, \tilde{w}_h, n)) = 0$. Take w_h as defined in (13) to (15). The task is not productive $v_y(h, y, c) \leq 0$, therefore $y_{\tilde{n}} \leq h$ implies $w_h \geq \tilde{w}_h$. Then acceptance decisions $a^*(\ell, \tilde{c}_\ell, C^* \cup C_{\tilde{n}}) = 1$ and $a^*(h, \tilde{c}_h, C^* \cup C_{\tilde{n}}) = 0$ with $y_{\tilde{n}} = \ell$ form an equilibrium at the acceptance stage. Low-productivity workers act optimally by the above arguments. High-productivity workers who accept $\tilde{c}_h$ get at most $u(h, \ell, (0, \tilde{w}_h, \tilde{n}))$ and thus less than $u(h, \ell, (0, w_h, n))$. They get $u(h, h, (t_h, w_h, n))$ by accepting $c \in C_h$. As $u(h, h, (t_h, w_h, n)) \geq u(h, \ell, (0, w_h, n))$ by the condition in the lemma, they prefer c_h.

We have thus shown that whenever there exists an equilibrium at the acceptance stage in which an entering firm might make positive profit, it is possible to construct an equilibrium at the acceptance stage in which the entering firm makes losses. Consequently, there is no market entry.

Part 2: Necessity

To prove necessity of the condition in the lemma, we show that when the condition is violated, profitable market entry is possible, if the fraction of workers with high productivity exceeds a certain threshold. For that we show that at any equilibrium at the acceptance stage, the entering firm makes strictly positive profit. For that result it is important to remember that high-productivity workers get utility $u(h, h, (t_h, w_h, n))$ in a best separating equilibrium, where this utility is independent from the fraction of high-productivity workers.

We first show that as the fraction of high-productivity workers becomes sufficiently large, there exist contracts that (i) make strictly positive profit if accepted by all workers, and (ii) give high-productivity workers more than their equilibrium utility $u(h, h, (t_h, w_h, n))$ even if workers believe that the new firm only attracts workers with low productivity. Consider any sequence $\{\mu_k\}_{k \in \mathbb{N}}$ of prior probabilities with $\mu_k < 1$ for all $k \in \mathbb{N}$ and $\lim_{k \to \infty} \mu_k = 1$. Define $y_k = \ell + \mu_k (h - \ell)$ and $\epsilon_k = 1/k$. Given μ_k suppose firm $\tilde{n}$ enters the market with a pooling contract $c_k = (0, w_k - \epsilon_k, \tilde{n})$ where w_k is implicitly defined by $\mu_k \, v(h, y_k, (0, w_k, \tilde{n})) + (1 - \mu_k) v(\ell, y_k, (0, w_k, \tilde{n})) = 0$. The firm makes strictly positive profits if it can attract all workers. Then $v_t = 0$ and continuity of v imply that $\lim_{k \to \infty} w_k = w_h$. If $u(h, h, (t_h, w_h, n)) < u(h, \ell, (0, w_h, n))$, continuity of u implies that there exists a $k_0 \in \mathbb{N}$ such that for all $k \geq k_0$ we have $u(h, \ell, (0, w_k, \tilde{n})) > u(h, h, (t_h, w_h, n))$. The last inequality follows from the violation of the condition in the lemma.

We complete the proof by showing that there exists no best separating equilibrium, because a firm could then enter the market with a contract as defined above, attract all workers, and thus make strictly positive profit in all equilibria at the acceptance stage. Given the above characterization take any μ_k with $k \geq k_0$. Given prior probability μ_k and market entry by firm $\tilde{n}$, low types accept c_k since $w_k > w_\ell$. Since $u(h, \ell, c_k) > u(h, h, (t_h, w_h, n))$, high types prefer c_k to any $c_h \in C_h$ even if they believe that the market entrant only attracts low-productivity workers. The single-crossing property and $t_h > 0$ imply that high types prefer contract $c_h \in C_h$ to any contract $c_\ell \in C_\ell$ even if the firm that offers c_ℓ does not attract any low types. Only contracts in $C_\ell \cup C_h$ are offered. Transitivity implies that $a^*(h, c_k, C^* \cup c_k) = 1$ and $a^*(\ell, c_k, C^* \cup c_k) = 1$ in any equilibrium at the acceptance stage. Finally, note that the above argument ensures that there exists an equilibrium at the acceptance stage in which the market entrant attracts all workers. As it thereby makes strictly positive profits, firm $\tilde{n}$ enters the market. *Q.E.D.*

Proof of Lemma 2

We look for the supremum U_p as defined in (21). We have to distinguish two cases. In the first case, maximizing $u(h, h, (t, w, n))$ subject to the constraints (19) and (20) has a finite solution. The supremum defined in (21) can then be attained by a contract $c \in \Gamma$. In the second case, (19) and (20) do not constrain the utility of workers with high productivity $u(h, h, (t, w, n))$. In this case the supremum as defined in (21) is equal to infinity.

Part 1: Solution Exists

Consider first the case in which the maximization problem has a finite solution (t, w, n). This solution can be characterized as follows. First, at least one of the constraints (19) and (20) must be binding. Otherwise, one can increase the wage benefits w without violating any constraint so that $U_p > u(h, h, (t, w, n))$ for such (t, w). Second, suppose that (19) is binding while (20) is slack. Take marginal changes $dw, dt > 0$ with $dw/dt = -u_t(\ell, y, c)/u_w(\ell, y, c)$. This keeps (19) and (20) satisfied by the single-crossing property, but $u(h, h, (t + dt, w + dw, n)) > u(h, h, (t, w, n))$ so that $U_p > u(h, h, (t, w, n))$ for any (t, w, n). Third, consider (t_p, w_p, n) so that by definition both (19) and (20) are binding. By the boundedness condition (5) such a point of intersection exists.

We can now derive the condition under which further contract changes cannot increase $u(h, h, c)$ so that the maximization problem has a finite solution. Consider marginal changes $dw, dt > 0$ with $dw/dt = -u_t(h, \ell, (t_p, w_p, n))/(u_w(h, \ell, (t_p, w_p, n))$. This keeps (20) satisfied while slackening (19) by the single-crossing property. Then $\frac{\partial}{\partial y}\{-u_t/u_w\} \geq 0$ implies that $u(h, h, (t_p, w_p, n)) \geq u(h, h, (t_p + dt, w_p + dw, n))$ so that contract (t_p, w_p, n) provides high-productivity workers with the maximum utility $U_p = u(h, h, (t_p, w_p, n))$. Since at least one of the constraints (19) and (20) must be binding if there exists a solution to the maximization problem, there exist no other contract changes that increase $u(h,h,c)$. Together with the condition on the slope $\frac{\partial}{\partial y}\{-u_t/u_w\} \geq 0$, this proofs the first part of the lemma.

Part 2: No Solution Exists

If $\frac{\partial}{\partial y}\{-u_t/u_w\} < 0$, then the maximization problem has no finite solution. The reason is that the above marginal changes $dw, dt > 0$ starting from (t_p, w_p, n) keep all constraints satisfied, but imply $u(h,h,(t_p,w_p,n)) < u(h,h,(t_p+dt, w_p+dw, n))$. This increase in utility is bounded away from zero by (5). Because one can find similar cumulative contract adjustments, there exists a sequence $\{(t_k, w_k)\}_{k\in\mathbb{N}}$ of task requirements and wages with $(t_k, w_k) \in \Gamma \, \forall \, k \in \mathbb{N}$ so that $\lim_{k\to\infty} u(h,h,(t_k,w_k,n)) = +\infty$. Then $U_p = +\infty$, which proves the second part of the lemma. *Q.E.D.*

Proof of Lemma 3

The proof closely follows the proof of Lemma 1. The only difference is that firms now offer latent contracts. To prevent market entry, it must be possible to construct an equilibrium at the acceptance stage where the entrant firm attracts no high-productivity workers. Given that the entrant always attracts all low-productivity workers, the relevant condition is that the utility of high-productivity workers by accepting employment at the new firm in case the new firm attracts only low-productivity workers must not exceed the supremum utility that high-productivity workers can get by accepting a latent contract.

Consider a best separating equilibrium in which firm n offers a contract $c_\ell \in C_\ell$ that attracts all low-productivity workers. Suppose n also offers a contract $c_n \notin C_\ell \cup C_h$ while $c_n \in \Gamma$. Contract $c_n = (t_n, w_n, n)$ is not accepted in equilibrium, but it changes the conditions under which a newly offered contract $\tilde{c}_h$ can attract type h. Contract $\tilde{c}_h$ need not attract high-productivity workers if and only if they have a better option in C^*. High-productivity workers who accept c_n can now get $u(h,h,(t_n,w_n,n))$ once n no longer attracts any low-productivity workers. There consequently exists $c_n \in \Gamma$ so that they reject $\tilde{c}_h$ for all $\mu_0 \in (0,1)$ if and only if $U_p \geq u(h,\ell,(w_h,0,\tilde{n}))$. *Q.E.D.*

Proof of Lemma 4

We now show that there cannot exist pooling in any competitive equilibrium. Consider an equilibrium in which firm n offers one or several contracts and attracts all types of workers. Let $y^*(\theta,n,C^*) \in (\ell,h)$ be the average type of worker it attracts in equilibrium. Since in equilibrium the firm attracts strictly positive mass of workers, $y^*(\theta, n, C^*)$ does not depend on the productivity $\theta \in \Theta$. The proof proceeds in two steps.

Part 1: Strictly Positive Profits with Low Types

In the first step suppose that the firm that attracts both types in equilibrium makes strictly positive profits with its low-productivity employees. We continue to show that there can then be market entry by a firm that skims off these low-productivity workers.

Let $c = (t, w, n)$ be a contract offered by n that attracts low-productivity workers while $v(\ell, y, c) > 0$. Suppose firm $\tilde{n}$ enters the market with contract $\tilde{c} = (t, w + \epsilon, \tilde{n})$ with $\epsilon > 0$. Then $u_w > 0$ and $u_y = 0$ for low-productivity workers imply that $u(\ell, \tilde{y}, \tilde{c}) > u(\ell, y, c)$ for any $(\tilde{y}, y)$. Consequently, $a^*(\ell, \tilde{c}, C^* \cup \tilde{c}) = 1$ and contract $\tilde{c}$ can attract at least all low-productivity workers in any equilibrium at the acceptance stage. Further, $v_y(\ell, y, c) = 0$ and $v(\ell, y, c) > 0$ imply that $v(\ell, \ell, \tilde{c}) > 0$ for small ϵ. Finally, $v(h, y, \tilde{c}) > v(\ell, y, \tilde{c})$ for all y so that $\tilde{c}$ always yields firm $\tilde{n}$ strictly positive profits, no matter what type of workers are attracted. As $\tilde{c}$ attracts at least all low-productivity workers, the original situation cannot form an equilibrium after market entry. Note that because firms offer finite menus of contracts, there exists at least one equilibrium at the acceptance stage, where the profits of the market entrant would increase further, if it would manage to attract also high-productivity workers.

Part 2: Weakly Negative Profits with Low Types

To complete the proof suppose that the firm n that attracts both types in equilibrium makes losses with its low-productivity employees. This implies that its high-productivity workers cross-subsidize their low-productivity colleagues. We show that there can then be market entry by a firm that skims off these high-productivity workers.

Suppose there exists no $c \in C_n^*$ that attracts low-productivity workers and makes positive profit $v(\ell, y^*(\ell, n, C^*), c) > 0$. As firm n otherwise makes losses, there must exist a contract $\hat{c} = (\hat{t}, \hat{w}, n) \in C_n^*$ that attracts high-productivity workers and $v(h, y^*(h, n, C^*), \hat{c}) \geq 0$. Next suppose firm $\tilde{n}$ enters the market with contract $\tilde{c} = (\hat{t}, \hat{w} - \epsilon, \tilde{n})$ with $\epsilon > 0$. Optimality of the original contract choice, $u_w > 0$ and $u_y(\ell, y, c) = 0$ imply that for contract c accepted by low-productivity workers in equilibrium we have $u(\ell, y, c) \geq u(\ell, y, \hat{c}) > u(\ell, \tilde{y}, \tilde{c})$ for any y and $\tilde{y}$. Then $a^*(\ell, \tilde{c}, C^* \cup \tilde{c}) = 0$ so that $\tilde{c}$ never attracts low-productivity workers in any equilibrium at the acceptance stage.

We show next that there exists no equilibrium at the acceptance stage after market entry in which contract $\tilde{c}$ attracts no workers. Suppose $\tilde{c}$ attracts nobody. Then Property 4 requires $a^*(\theta, c, C^* \cup \tilde{c}) = a^*(\theta, c, C^*)$ for all $\theta \in \Theta$ and $c \in C^*$. High-productivity workers get $u(h, y^*(h, n, C^*), \hat{c})$ in equilibrium. Then $y^*(h, n, C^*) < h$ and $u_y(h, y, c) < 0$ imply that $u(h, h, \tilde{c}) > u(h, y^*(h, n, C^*), \hat{c})$ for small ϵ. A worker who alone accepts $\tilde{c}$ determines the average type attracted by $\tilde{n}$ such that $y^*(h, \tilde{n}, C^* \cup \tilde{c}) = h$. Rejecting $\tilde{n}$ thus cannot be optimal for high-productivity workers.

Since we only look at pure strategies, this implies that in any equilibrium at the acceptance stage, the market entrant attracts all high-productivity workers. By the optimality of previous contract choices, it then forms an equilibrium at the acceptance stage that low-productivity workers stick to their previous contract choice, while high-productivity workers are attracted by the market entrant. Firm $\tilde{n}$ makes strictly positive profits from entering the market, because $v_w < 0$, $v_y(h, y, \tilde{c}) \geq 0$, and $y^*(h, n, C^*) < h$ together imply $v(h, h, (\hat{t}, \hat{w} - \epsilon, \tilde{n})) > v(h, y^*(h, n, C^*), (\hat{t}, \hat{w}, n)) \geq 0$. This completes the proof. *Q.E.D.*

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