Informed Trading and High Compensation in Finance *

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We propose a model in which financial firms compete for skilled workers who can be assigned to over-the-counter trading or to more socially productive activities. Because of negative externalities they impose on rival firms, traders earn more than the profits they generate for their employer and more than what other workers with similar skills earn. However, when firms can easily interchange workers across tasks, high trader compensation can also drive up the compensation of other skilled workers in finance above their marginal product. We discuss the impact of restricting compensation on the efficiency of the allocation of workers.

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Compensation in the financial sector has been a controversial topic in recent years. One particular group of workers who tend to earn extraordinary rewards for their expertise are traders of complex securities. For instance, before the recent crisis managing directors trading exotic credit derivatives were making $3.4 million on average per year.[1] Since then, some Wall Street firms have gone as far as paying a few highly specialized traders more than the CEO to ensure they can retain them.[2]

We propose a labor market model that highlights the importance for financial firms to hire highly talented individuals as over-the-counter (OTC) traders by offering them seemingly excessive levels of pay. High compensation arises in our model even though: (i) the employment of these workers is concentrated among very few firms,[3] and (ii) these workers are hired only to strengthen their employers' position when bargaining with other firms over a fixed pie (hence creating no social value in the model).[4] In fact, we argue that it could be *because* of these circumstances that specialized traders are so highly compensated.

We model a financial firm as an entity that engages in two interlinked tasks that require the labor of financial experts. Firms compete for a limited supply of skilled workers they can deploy as *traders* or as *surplus creators*. Deploying some workers as traders allows a firm to obtain a more precise valuation of a security before agreeing to trade it over the counter with another firm. Deploying some workers as surplus creators, on the other hand, raises the total gains to trade that can be split between firms. This can be interpreted as resulting from expanded efforts to locate counterparties with large private benefits from trade or from designing new securities with improved risk sharing properties.

When the supply of workers is low enough that firms find it optimal to hire them all in equilibrium, traders earn a premium over the profits their expertise generates for the firm. Intuitively, when trading expertise improves firms' ability to extract the surplus in a *fixed-sum* trading game, hiring traders imposes a negative externality on rival firms (i.e., trading counterparties). This leads to defensive bidding by firms that offer traders a premium over the profits they produce for the firm.

[1] See "London trader bonuses top those in U.S. - survey" published March 26, 2007 on Reuters.com

[2] See "Traders Beat Wall Street CEOs in Pay" by Stephen Grocer and Aaron Lucchetti in the April 6, 2010 issue of The Wall Street Journal.

[3] Consistent with evidence of concentrated trading in credit and interest-rate derivative markets from Atkeson, Eisfeldt, and Weill (2012) and Begenau, Piazzesi, and Schneider (2012).

[4] Consistent with Scott Patterson's best selling book "Dark Pools" in which he alludes to how Wall Street insiders view quantitative trading as "war. Us against them. The market was the field of battle." (p. 17) or as "sharks devouring one another." (p. 181)

Without such a premium, traders would be hired by rival firms, who would then use this additional expertise against the firm in question. Thus, traders are paid what we call a "*defense premium*" over their *internal* marginal productivity — they extract some rents for the losses avoided by preventing trading counterparties from employing these workers to bargain against the firm. Trading, as a whole, may still be a very profitable activity for financial firms as long as the surplus it creates is large. However, traders are compensated above the rents their expertise allows their employer to extract from rival firms.

Our model not only sheds light on the elevated levels of compensation we observe for highly specialized traders but also on those we observe for the financial sector in general, even after controlling for workers' ability levels and hours worked (see Philippon and Reshef 2012). Many other skilled workers in finance may see their compensation increased by the participation of their employer to OTC trading. Equilibrium wages for non-traders, or surplus creators, are determined as follows in the model. When workers are offered contracts that are tied to a particular task, surplus creators may appear to be "underpaid" as they earn less than what they produce for the firm and a lot less than what traders earn. The nature of the trading game allows hiring for surplus creation to have positive externalities, thus reducing the temptation for firms to hire surplus creators away from rival firms. The strict inequality of pay levels in this case is guaranteed by the optimal assignment of workers within the firm; all workers generate the same internal marginal productivity but rival firms see more value in poaching a trader than a surplus creator. If, however, firms assign workers to tasks *after* the labor market has closed, the dispersion in compensation between traders and surplus creators disappears, with all workers now receiving the high, trader compensation. Financial firms thus need to pay all their experts far more than their internal marginal value, and labor appropriates an abnormally large share of any surplus available.

Naturally, high compensation requires the supply of capable financial workers to be relatively small. If the supply of workers is large enough that hiring fewer traders does not imply that rival firms will employ more traders, firms do not find it optimal to offer a defense premium and traders only receive their reservation payoff. As a result, our model highlights the non-monotonic effect that a market's concentration can have on workers' compensation. The less concentrated a sector is, the more excess demand there is for traders and the higher the likelihood is that firms will have to offer a premium over workers' reservation payoffs. However, as concentration decreases, the probability that a firm will trade with the firm that actually hires a given trader it covets becomes smaller; hence the cost of losing this trader to another firm and the compensation he is offered in equilibrium both decrease.

High trader compensation should therefore arise in markets where most of the trading takes place among a few firms and where very few qualified experts are able to value the securities being traded. For example, Begenau, Piazzesi, and Schneider (2012) show that three dealer banks overwhelmingly dominate the market for interest-rate derivatives, whose total notional value surpasses $160 trillion.[5] From a comparative perspective, trading concentration of U.S. interest-rate options is about two thirds greater than that of foreign-exchange options, as measured using the Herfindahl index by Cetorelli, Hirtle, Morgan, Peristiani, and Santos (2007). Consistent with the arguments in our paper, traders in the former market earn roughly twice as much, on average, as those in the latter market (see Options Group's 2011 annual compensation report).[6] Similar patterns in concentration and compensation can also be observed, for example, in credit derivative trading (whose concentration is empirically documented and theoretically rationalized by Atkeson, Eisfeldt, and Weill 2012).

Our results could also apply to traders working in burgeoning markets. Notable, albeit extreme, examples include Josh Levine who pioneered high frequency trading in the early 1990's and allowed the proprietary trading firm Datek to "out-trade the very best in the business. They could grind Goldman to a pulp. They could make Morgan cry" or algorithmic trader Haim Bodek, who was poached from Goldman Sachs by UBS in the early 2000's "to build an options-trading desk that could go head-to-head with the likes of Hull [Goldman's electronic trading arm]."[7]

From a welfare perspective, the cost of financial expertise takes the form of a transfer from firms to workers, but allocating workers to surplus extraction, rather than to surplus creation, still represents a social inefficiency. This inefficiency arises even though traders are, in equilibrium, "overpaid" from the perspective of the firm; firms would prefer not to hire traders at the prevailing compensation levels as efficient trade would take place without experts, but do so to prevent other firms from hiring them instead. We discuss, at the end of the paper, how restricting compensation

[5]The authors note that this concentration is also common for many classes of bonds.

[6]Options Group is an international executive-search company that advises banks on compensation, and its executives generously agreed to provide us with compensation statistics and discuss the ideas in the paper.

[7]See pages 100 and 32, respectively, in Patterson (2012).

in the sector, as done in the recent crisis, can improve or worsen the allocation of workers across and within firms.

Related Literature. Our paper directly contributes to the growing theoretical literature on the size of the financial sector, which accounts for 9.1% of U.S. GDP according to Shiller (2012),[8] and the associated high levels of compensation, which amounts to 40% of Wall Street firms' revenues according to the Office of the New York State Comptroller. Acharya, Pagano, and Volpin (2012), Axelson and Bond (2012), Bénabou and Tirole (2012), Bijlsma, Boone, and Zwart (2012), Bond and Glode (2012), and Thanassoulis (2012) all share with our paper the objective of modeling a labor market to understand equilibrium compensation in finance. Axelson and Bond (2012) and Bijlsma, Boone, and Zwart (2012) focus on the role moral hazard can play in determining optimal contracts in finance, while Bond and Glode (2012) focus on the competition among financial firms and regulatory bodies for a scarce supply of skilled workers. Acharya, Pagano, and Volpin (2012), Bénabou and Tirole (2012), and Thanassoulis (2012) highlight negative externalities that competition for workers can have on risk-taking, work ethic, and financial stability, respectively. None of these papers, however, studies the role workers' expertise plays when financial firms interact with each others and trade securities among themselves as we explicitly model in this paper. We believe it is important to do so given the impact that trading expertise has on financial institutions' profits, and stability — for example, the financial services firm J.P. Morgan recently reported to have lost $5.8 billion from one massive credit-default-swap trade gone awry (compared to profits of $5 billion in that quarter).[9]

A well-known model of high compensation has also been proposed by Rosen (1981) to rationalize the skewed reward distributions in some industries like show business. He shows that a "superstar" effect, defined as a convex revenue-to-talent function, can result from a technological indivisibility in the consumption of labor. Similar ideas are found in models in which managerial talent is assortatively matched with firm productivity or operational scale (see, e.g., Lucas 1978, Berk and Green 2004, Gabaix and Landier 2008, Terviö 2008).[10] While Gabaix and Landier (2008), Terviö

[8]See also Greenwood and Scharfstein (2012), who document the growth of the U.S. financial sector since 1980.

[9]See "JP Morgan Says Trading Loss Tops $5.8 Billion; Profit for Quarter Falls 9%" by Jessica Silver-Greenberg in the July 13, 2012 issue of The New York Times' DealBook.

[10]Terviö (2009), however, cautions that industries in which a worker's ability is learned over time may have low quality workers earning high wages and resembling superstars.

(2008) and Berk and van Binsbergen (2012) find supportive evidence in the compensation paid to CEOs of large U.S. corporations and equity mutual fund managers, Philippon and Reshef (2012) show that these effects only explain a small fraction of the elevated levels of compensation recently paid to financial executives on Wall Street. The huge compensation gap we describe above between interest-rate option traders and foreign-exchange option traders is also hard to rationalize using realistic arguments centered around differences in the scalability of trading these types of securities, or in agency conflicts for that matter. Our paper provides a simple explanation for this gap that relies on trading concentration. In any case, our goal here is not to argue that these other theories do not play any role in explaining compensation in the financial sector — in fact, we view these theories as complementary. Rather, our goal is to highlight that when firms bid strategically for the services of workers who impose negative externalities on rival firms, such as OTC traders, the *level* of compensation offered in equilibrium can *exceed* the value created for their firms, unlike what these other theories predict. This result and others we derive about the endogenous allocation of workers across tasks (some more socially productive than others) strike us as important for the current debates on the optimal size and compensation in the financial sector.

As a result, our model is closer in spirit to papers studying the social efficiency of resources allocated to different sectors of the economy, including finance. Philippon (2010), Biais, Foucault, and Moinas (2012), Bolton, Santos, and Scheinkman (2012), Fishman and Parker (2012), and Glode, Green, and Lowery (2012) all propose mechanisms that cause some financial activities to exist at levels that exceed the social optimum.[11] In particular, Glode, Green, and Lowery (2012) develop a model in which financial firms acquire high levels of expertise in OTC trading, even though this expertise impedes efficient trade among firms in rare high-volatility periods. The current model uses the same link between trading expertise and trading outcomes as in Glode, Green, and Lowery (2012), but the focus here is on firms' strategic interactions in the labor market and the allocation of talent within these firms, neither of which were considered there. This difference allows our model to make novel predictions about optimal compensation and allocation of workers in the financial sector. A few papers also study the decision by agents to perform rent-seeking activities; that is, activities for which the private rewards agents extract exceed the social value they create, just like

[11] See also Hirshleifer (1971), Allen (1984), and Diamond (1985) who compare the private and social benefits of acquiring information when valuing and trading financial securities.

informed OTC trading in our model. Murphy, Shleifer, and Vishny (1991) show theoretically that skilled workers prefer to enter sectors of the economy with the most elastic production functions and empirically that economic growth is slower in countries where rent-seeking activities reward talent more than entrepreneurship does. Acemoglu (1995) solve for the equilibrium allocation of talent between a productive sector and a rent-seeking sector that impedes production. Lockwood, Nathanson, and Weyl (2012) and Rothschild and Scheuer (2012) instead focus on how taxation schemes can reduce workers' incentives to enter a rent-seeking sector. In these papers, a continuum of workers choose whether to become rent seekers or entrepreneurs, based on private rewards available from both types of careers. Here, we model the competition by a few firms for the services of workers performing rent-seeking tasks, and it is the defensive bidding by firms resulting from this competition that allows workers to collect a defense premium in equilibrium. Not only do they earn more than what they contribute to society, as is standard in the rent-seeking literature, but they also earn more than what they contribute to their rent-seeking firms.

Our paper contributes more broadly to the literature on personnel economics (see Lazear and Oyer 2011, for a survey). In our model, similarly skilled workers are compensated differently based on how their work affects the firms that failed to hire them — workers earn abnormally high compensation when hired to perform tasks that impose negative externalities on rival firms. From a social point of view, this result can be alarming as socially unproductive tasks might become overly attractive for skilled workers. We show that in some cases this defense premium leaks also to other employees who are not performing rent-seeking activities but who have the necessary skills, potentially making socially valuable activities unprofitable for firms because of their linkage with rent-seeking activities. We apply our model to OTC trading of complex securities because it represents one of the few, though not unique, areas in which: (i) a small number of sophisticated firms compete for the services of workers whose unique skills are an important driver of firms' profits and (ii) one firm's success directly implies other firms' failure. The intuition we develop could, nonetheless, apply to a few other settings with fixed-sum game features such as divorce litigation where two ex-partners compete for the services of the best lawyer in town, professional sports where a few rival teams in the same division try to sign a star free-agent athlete, or innovation races where a few technology companies fight for the services of the most gifted scientists.[12]

[12]See Bhagwati (1982), Baumol (1990), or Scharfstein and Stein (2000) for more examples of rent-seeking activities.

Finally, the notion that traders impose negative externalities on rival firms links our paper to the small literature on optimal design of auctions for goods with externalities (see Jéhiel, Moldovanu, and Stacchetti 1996, Caillaud and Jéhiel 1998, Jéhiel, Moldovanu, and Stacchetti 1999, Jéhiel and Moldovanu 2000).[13] Our paper, however, differs significantly from these papers as it focuses on a fungible good (i.e., labor), which can be allocated by firms either to produce positive or negative externalities — the type of externality depending on the equilibrium allocation of the good within a production process (i.e., trading vs. surplus creation). We also consider a disaggregated labor market rather than a monopolist selling an indivisible good, and are concerned with the allocation of the labor market input among firms. Most previous work focuses on the allocation of an indivisible good, except for Eső, Nocke, and White (2010) who consider an auction for shares of production capacity to be divided among firms. Their model abstracts from the design of the auction for capacity, focusing on the efficient allocations, and considers Cournot competition in an oligopolistic product market. This focus generates substantially different implications than our labor market model in which concerns about adverse selection influence the demand for workers. Moreover, our model allows us to show that the price paid by firms for the resources that impose negative externalities (i.e., the traders) can affect the price paid for other resources (i.e., the non-traders) based on the interchangeability of these resources.

The rest of the paper is organized as follows. In the next section we describe the environment and how trading takes place among financial firms in our model. Section 2 studies the labor market for financial experts when firms only employ experts to value and trade securities. Section 3 generalizes the concept of financial expertise and considers the situation in which firms can hire experts as traders who compete with other firms for a fixed surplus or as non-traders who work on creating that surplus. Section 4 discusses the potential impact of restricting workers' compensation on the equilibrium allocation of workers and on welfare. The last section concludes.

[13]See also McCardle and Viswanathan (1994) in which a new firm chooses between directly entering an industry or bidding for the acquisition of an incumbent firm and the decision is based on the negative externalities that rival firms generate under Cournot competition in the product market.

1 Model

Our model has two stages. In the first stage, N financial firms compete for the hiring of a fixed supply of risk-neutral workers whose expertise is needed to value financial securities. In the second stage, firms are randomly matched with each others to trade a security of uncertain value. This section describes the trading game when firms' expertise levels are taken as given, which is identical to the trading game in Glode, Green, and Lowery (2012). The labor market for experts, which replaces the assumption of an exogenously given (low) cost for expertise from the earlier paper, is the main focus of the current paper and is studied in the following sections.

1.1 Trading Game

Each firm i meets a randomly assigned counterparty j, drawn with equal probability from a set of $N-1$ potential trading partners, to exchange a hard-to-value security through bargaining in an ultimatum game. One of the two parties is assigned the role of buyer, who we denote as firm j for now while firm i is the seller. The seller values the security at v while the buyer values it at $v+2\Delta$. The private value component, 2Δ, is the source of the gains to trade and could represent hedging motives, special access to a retail investor willing to overpay for the security, or any other source of value that is not shared by both parties. Without this, trade would break down in this setting due to the standard no-trade theorem. Gains to trade are common knowledge to both parties, but the common value v is uncertain: it can be high, v_h, or low, v_l, with equal probabilities. The spread $v_h - v_l$ is fixed and common knowledge to all parties. It measures the amount of uncertainty about the value of the security and will play an important role in identifying the optimal mass of experts firms want to hire and the resulting labor market equilibrium.

For simplicity, we give the buyer all the bargaining power in an ultimatum game as he makes a take-it-or-leave-it offer to buy the security at a price p. The buyer is uninformed about the value, v, and views the two possible outcomes as equally likely. Assuming an uninformed buyer dramatically simplifies the analysis while still allowing us to illustrate the incentives to hire experts because it eliminates the complications that arise when the first mover in the trading game is privately informed. Later we discuss why our results would survive if we allowed for two-sided asymmetric information.

The seller can use the experts hired in the first stage to gather information about the security before responding to the buyer's offer. Specifically, these experts can generate a signal, $s_i \in \{H, L\}$, that is informative about whether the security is worth v_h or v_l. The probability that firm i's signal is correct is $\mu_i = \frac{1}{2} + e_i$, where $e_i \in [0, \frac{1}{2}]$ denotes the mass of experts hired by firm i — its expertise. Such expertise is assumed to be observable by trading counterparties, as hiring highly specialized traders away from another firm is usually a visible activity on Wall Street.

The uninformed buyer considers offering one of two potential prices: the lowest price a seller would accept after receiving a low signal and the lowest price a seller would accept after receiving a high signal. These prices are, respectively, the seller's valuations given a low signal:

$$\begin{aligned} p^L &= E(v \mid s_i = L) \\ &= (1 - \mu_i)v_h + \mu_i v_l, \end{aligned} \tag{1}$$

and given a high signal:

$$\begin{aligned} p^H &= E(v \mid s_i = H) \\ &= \mu_i v_h + (1 - \mu_i)v_l. \end{aligned} \tag{2}$$

If the buyer offers the low price p^L, trade only takes place when the seller observes a low signal. The buyer's expected payoff is then:

$$\frac{1}{2}(2\Delta + E(v \mid s_i = L) - p^L) = \Delta, \tag{3}$$

and the seller's expected surplus is his reservation price of zero.

If the buyer offers the high price p^H, trade always takes place, preserving the whole surplus. The buyer, however, shares some of that surplus with the seller. The buyer's expected payoff is:

$$\begin{aligned} E(v) + 2\Delta - p^H &= 2\Delta - (v_h - v_l)\left(\mu_i - \frac{1}{2}\right) \\ &= 2\Delta - (v_h - v_l)e_i, \end{aligned} \tag{4}$$

and the seller's expected payoff (unconditionally, across both possible realizations of his signal) is:

$$\begin{aligned} E[p^H - E(v \mid s_i)] &= p^H - E(v) \\ &= (v_h - v_l)\left(\mu_i - \frac{1}{2}\right) \\ &= (v_h - v_l)e_i. \end{aligned} \tag{5}$$

Thus, hiring experts who generate a more accurate valuation of the security may allow a seller to force the buyer to make a better offer, even though the seller ends up not using the information acquired once the offer is received. The buyer's choice between the two prices depends on which offer yields the highest expected payoff to him. Defining $\sigma \equiv v_h - v_l$, we compare (3) and (4) and observe that the buyer offers the high price p^H if and only if

$$2\Delta - \sigma e_i \geq \Delta \tag{6}$$

or, equivalently,

$$e_i \leq \bar{e} \equiv \frac{\Delta}{\sigma}. \tag{7}$$

As in Hirshleifer (1971), the social value of information in this simple trading game is zero when expertise is low enough, that is: $e_i \leq \bar{e}$. However, our trading game also allows for expertise to trigger adverse selection and destroy social surplus whenever $e_i > \bar{e}$. The impact expertise has on adverse selection will play a key role in determining firms' demand for workers. In equilibrium, firms will optimally restrict the expertise they acquire to prevent adverse selection from destroying some of the surplus. Consequently, the trading game will be of *fixed-sum* nature.

1.2 Discussion

The trading game above is a relatively simple mechanism in which the benefits and costs of acquiring information are stark and straightforward to characterize. We are thus able to focus on the competition for labor that helps firms value securities given the tradeoff between a bargaining position improved by better information and the increased risk of surplus destruction due to adverse selection. These effects are, however, similar in spirit to those in more complex bilateral bargaining mechanisms. In Glode, Green, and Lowery (2012) for example, both bargaining parties receive signals of potentially different precision, which significantly complicates the analysis due to the signalling problem associated with the initial offer. For our purposes though, the only significant change in how the trading game proceeds in equilibrium is that, under the credible belief refinement of Grossman and Perry (1986), the maximum levels of expertise that allow for efficient trade become tighter when both parties are partially informed. Another example is Duffie, Malamud, and Manso (2012), in which the authors use a double-auction design to study the percolation of information in over-the-counter markets. Just like in our model, their agents face incentives to gather information that their trading counterparties do not have, which may, however, lead to trade inefficiencies. More generally, bilateral trade will have the characteristic that informational rents for an agent will increase in the precision of his signal over some region but will potentially drop when efficient trade becomes impossible (see, e.g., Moldovanu 2002, for a related discussion of bargaining mechanisms). Thus, the results we derive next about the competition by OTC firms for scarce talent that allows them to profit from trading counterparties should not be viewed as being specific to our simple trading game.

2 Hiring Traders

In the first stage, firms try to hire experts to help value the security traded in the second stage. There is a mass ξ of skilled financial workers, also known as *experts*, with a reservation payoff of β. Hiring a mass e_i of workers yields a probability $\mu_i = \frac{1}{2} + e_i$ that firm i's signal is correct.

The labor market for experts works as follows. Each firm submits a single wage offer w_i (per unit of workers) and a demand for workers $x_i \in [0,1]$, representing the fraction of the ξ workers that the firm i is willing to hire at w_i. Workers are then allocated to firms based on wage, with the firm offering the highest wage receiving its full demand for workers, the firm offering the second highest wage receiving the maximum of its demand and the residual mass of workers available, and so forth. If two (or more) firms offer the same wage but there are too few workers available to satisfy their total demand, workers are evenly divided among the firms offering the highest wage whose total demand cannot be satisfied. In later sections, we introduce ex-post and ex-ante heterogeneity over workers and the labor market triggers, effectively, worker-by-worker competition. In the current setup, the simpler labor market is adequate as results are equivalent with a setup in which firms compete separately for each infinitesimal worker.

To ensure that some traders are hired in equilibrium, we impose the condition that their reservation payoff is low, that is: $\beta \leq \frac{\sigma}{2}$. Note that, for now, hiring experts only serves to appropriate a larger share of the surplus 2Δ and does not create social value — in fact, hiring too many of them might destroy some of the gains to trade. In the next section, we generalize our model of financial expertise by allowing firms to also hire workers to perform surplus-creating tasks. This generalization will allow our model to have implications for the allocation of experts within the financial sector and how the tasks they perform impact their compensation.

Before knowing its role as a buyer or as a seller, firm i's expected payoff from participating in a trade with firm j is given by:

$$\frac{\sigma}{2} e_i I\left(e_i \leq \frac{\Delta}{\sigma}\right) + \frac{1}{2}\left[\Delta + (\Delta - \sigma e_j) I\left(e_j \leq \frac{\Delta}{\sigma}\right)\right], \tag{8}$$

where $I(\cdot)$ is an indicator function. It is obvious from this equation that no firm acquires expertise above the level $\bar{e} \equiv \frac{\Delta}{\sigma}$, even if unemployed workers are willing to work for free. Specifically, we know from Glode, Green, and Lowery (2012) that if the cost of expertise is low enough, all firms will want to acquire an expertise level of $\bar{e}$. The fixed supply ξ of experts will, however, determine how much financial firms have to compete for these workers through compensation. With a labor market, financial firms now strategically interact with each other not only at the trading stage but also at the hiring stage. The limits on firms' expertise that adverse selection imposes will imply equilibrium levels of (un)employment for financial workers.

Throughout the paper, we focus on symmetric equilibria for brevity. We first study the case in which the supply of workers binds, even when one firm decides to deviate from the equilibrium and hires no worker.

2.1 Low Supply of Experts

When the supply of workers is low enough, the N firms compete in the hiring of workers as the limited supply of workers binds. Further, if one firm chooses not to hire any workers, all workers can still be employed by the remaining firms without disrupting trade. Firm i's expected payoff from trade is given by:

$$\Delta + \frac{\sigma}{2}(e_i - E[e_j]), \tag{9}$$

since all firms hire no more than $\bar{e}$ traders, a condition that is optimal for all firms to satisfy and that ensures efficient trade. Equilibrium compensation is, obviously, affected by the binding supply of workers. However, our model highlights the impact of the fixed-sum game nature of trading on workers' compensation.

We now solve for the equilibrium demand for workers and their wages. If demand is fully satisfied for all firms, i.e., $x_i \leq \frac{1}{N}$, the wage offered must be no more than $\frac{\sigma}{2}$, since this is exactly what one unit of traders produces for the firm. If the wage is above this level, there is a profitable deviation to hiring fewer workers because the demand by other firms is fully satisfied and the workers will remain unemployed. But, if the wage is $\frac{\sigma}{2}$ or lower, then there is a profitable deviation to offering a slightly higher wage and demanding slightly more than a mass $\frac{\xi}{N}$ of workers. The benefit of hiring extra workers now includes the fact that they no longer work against the firm itself. When the supply of workers is low, all experts not hired by firm i end up working for some of the firm's counterparties, making the expected payoff from trade:

$$\Delta + \frac{\sigma}{2}\left[e_i - \left(\frac{\xi - e_i}{N-1}\right)\right]. \tag{10}$$

Thus, the (per-unit) benefit from deviating to an infinitesimally higher wage and to an infinitesimally higher demand is $\frac{\sigma}{2}\left(1 + \frac{1}{N-1}\right) = \frac{\sigma}{2}\left(\frac{N}{N-1}\right)$, which is greater than $\frac{\sigma}{2}$. This deviation is profitable as long as the wage is below $\frac{\sigma}{2}\left(\frac{N}{N-1}\right)$, so the equilibrium wage has to be:

$$w^* = \frac{\sigma}{2}\left(\frac{N}{N-1}\right). \tag{11}$$

At such a wage, it is profitable for a firm to deviate to hiring fewer traders only if it anticipates that some of the workers the firm does not hire will remain unemployed. Thus, in any symmetric equilibrium, the equilibrium demand of traders must satisfy $x^* \geq \frac{1}{N-1}$ because then each firm knows that deviating to hiring no traders would result in these traders working for rival firms. The marginal loss due to the hiring of traders by rival firms is positive only when the adverse selection limit on trading expertise does not bind. Hence, a deviation to hiring no trader and saving on the high wages that traders command cannot be profitable as long as the $(N-1)$ rival firms are expected to hire all traders without triggering trade breakdowns when bargaining with the deviating firm. This condition is satisfied only when $\xi \leq (N-1)\frac{\Delta}{\sigma}$.

To summarize these first results, the total benefit of hiring an additional trader depends on two things when the supply of experts is low. First, by hiring an expert firm i improves its ability to value securities, which increases its bargaining power when responding to an offer. This benefit is worth $\frac{\sigma}{2}$ to the firm. Second, by hiring an expert firm i ensures that this worker is not hired by any of the $(N-1)$ potential counterparties and thus lowers their bargaining power when responding to an offer from firm i. This benefit is worth $\frac{\sigma}{2}\left(\frac{1}{N-1}\right)$ to the firm. Hence, when hiring workers the firm does not only value the increase in its own trading expertise, but it also values the decrease in the expertise it needs to defend itself against. When the supply of workers is low enough given the number of firms, equilibrium compensation w^* is such that firms are indifferent about "poaching" workers from their counterparties, so it includes a defense premium. Traders are paid more than the value they create by improving their employers' ability to value securities as they also extract some rents from the fact that hiring them lowers the ability of their employer's trading counterparties.

Financial firms still make a positive profit despite "overpaying" for the expertise of their traders. A firm's expected profit can be written as

$$\Delta - \frac{\xi}{N}w^* = \frac{\sigma}{N-1}\left((N-1)\frac{\Delta}{\sigma} - \frac{\xi}{2}\right). \qquad (12)$$

This expression is positive in the region of interest, that is, when $\xi \leq (N-1)\frac{\Delta}{\sigma}$.

2.2 High Supply of Experts

We now study two cases that can arise when the supply of workers is too large for the equilibrium above to exist, that is when $\xi > (N-1)\frac{\Delta}{\sigma}$.

We start with the simple case in which the supply of workers is the highest, that is: $\xi \geq N\frac{\Delta}{\sigma}$. Then, the N firms do not hire all workers in equilibrium, even if workers are willing to work for free. The reason is that hiring more than a mass $\overline{e} = \frac{\Delta}{\sigma}$ of workers within one firm would result in a separating equilibrium in the trading stage and destroy some of the gains to trade. Thus, the supply of experts does not bind, financial firms only hire a mass $\overline{e}$ of workers by offering them the reservation payoff of β. A positive mass $(\xi - N\overline{e})$ of workers remain unemployed.

The second, and more complex, case has the supply of workers being small enough that the N firms are still able to hire all available workers without destroying gains to trade, i.e., $\xi < N\frac{\Delta}{\sigma}$. As with a low supply of workers, no equilibrium with some unemployment can exist because workers' reservation payoff is lower than their marginal productivity. The only wage that can make marginal deviations unprofitable is given by equation (11). However, at that wage it is optimal for a firm to deviate to hiring no traders. The wage in question makes firms indifferent between hiring or not these workers only if rival firms would hire and use against the firm all the workers that the firm does not hire. But if a firm does not hire any trader, its expected profit becomes:

$$\Delta - \frac{\sigma}{2}\frac{\Delta}{\sigma} = \frac{1}{2}\Delta, \tag{13}$$

which, in the current region of ξ, is greater than the expected profit from offering a wage $w = \frac{\sigma}{2}\left(\frac{N}{N-1}\right)$ and hiring $\frac{\xi}{N}$ of the workers:

$$\Delta - \frac{\sigma}{2}\frac{\xi}{N-1}. \tag{14}$$

Consequently, when $(N-1)\frac{\Delta}{\sigma} < \xi < N\frac{\Delta}{\sigma}$, no symmetric pure strategy Nash equilibrium exists. This non-existence is driven by the property that the value of trading expertise increases linearly in the mass of experts hired as long as trade is efficient, but the payoff drops discontinuously when expertise crosses the boundary where trade breaks down with positive probability.

As we show in the Appendix, there exists a unique symmetric, mixed strategy equilibrium over this region and such equilibrium implies, effectively, a continuous transition from the high-supply to the low-supply pure strategy equilibria. For ξ close to $(N-1)\frac{\Delta}{\sigma}$, the mass of wage offers becomes arbitrarily concentrated around $\frac{\sigma}{2}\left(\frac{N}{N-1}\right)$, the pure-strategy equilibrium wage offer for $\xi < (N-1)\frac{\Delta}{\sigma}$. Similarly, as ξ converges to $N\frac{\Delta}{\sigma}$, the mass becomes arbitrarily concentrated around β, the pure-strategy equilibrium wage offer for $\xi \geq N\frac{\Delta}{\sigma}$. In between, each firms demands a mass

$\frac{\Delta}{\sigma}$ of workers and mixes over an interval of wage offers $w \in [\beta, \overline{w}]$, where $\overline{w}$ is defined as:

$$\overline{w} = \beta + \left(\frac{\sigma}{2}\left(\frac{N}{N-1}\right) - \beta\right)\left(N - \frac{\xi}{\frac{\Delta}{\sigma}}\right). \tag{15}$$

The equilibrium wage offer is thus effectively continuous between the two regions over which the wage is determined as part of a pure strategy Nash equilibrium. Traders extract part of the surplus they would have extracted if the supply of experts was lower and a symmetric pure strategy equilibrium existed. Also, since this unique candidate for a symmetric mixed strategy equilibrium does not exist outside the intermediate region, the symmetric pure strategy equilibria we derive above represent the unique symmetric equilibrium that exists in each respective region.

2.3 Discussion

Uncertainty in asset value plays a key role in the demand for, and compensation of, traders. Studying the effects of changes in the uncertainty σ, while keeping the number of firms N and the supply of workers ξ fixed, highlights that highly volatile settings could be associated with lower demand for traders, but also with their higher compensation. A lower demand for traders usually means that these workers are less likely to earn a surplus over their reservation payoffs. However, conditional on witnessing excess demand for workers, which then drives wages higher than β, traders' compensation increases as the value of the security becomes more uncertain. This seemingly counterintuitive relationship results from trading expertise becoming more valuable while its limits due to adverse selection also become more restrictive as uncertainty increases.

Similarly, the degree of competition in the sector affects in a non-monotonic fashion the allocation and compensation of workers hired to perform tasks that impose negative externalities on rival firms. As we increase the number of firms but keep the supply of workers fixed, we are less likely to observe unemployment of experts and more likely to see compensation premia offered to them. As N increases, it becomes easier to satisfy the condition necessary for the defense premium, that is: $\xi \leq (N-1)\frac{\Delta}{\sigma}$. We also observe, however, that when the limited supply of experts binds, and therefore a premium is paid, the magnitude of this premium decreases with the number of firms. The reason for this is simple. As we increase the number of potential trading partners a firm has, hiring an expert still allows the firm to improve its own bargaining power but it also decreases the expected losses incurred by letting this expert work for another firm. At the margin, payoffs from trade are less sensitive to the exact allocation of workers, and these workers become less able to extract a compensation premium for the negative externality they impose. For a given ξ, workers' compensation is then non-monotone in the number of firms N. It is β for any $N \leq \frac{\xi}{\bar{e}}$, then increases to $\frac{\sigma}{2}\left(\frac{N}{N-1}\right)$ until $N \geq 1 + \frac{\xi}{\bar{e}}$, and then decreases and converges toward $\frac{\sigma}{2}$ as N grows.

In a more general model in which the probability of firms trading with each other depends on the pairing, the term $\frac{1}{N-1}$ in the defense premium paid to a worker would be replaced by the probability that its firm ends up trading with the second highest bidder for the services of this worker. For example, a large bank like Goldman Sachs would offer more to the specialized traders likely to defect to J.P. Morgan than to those likely to defect to a small hedge fund with which the bank trades less often. In the current model, we focus on the simple case in which firms meet randomly with equal probability, but ultimately the size of the negative externality a trader imposes on firms that fail to hire him is what determines his defense premium. Empirically, large defense premia can still exist in markets (e.g., securities, time periods, or regions) where the number of firms is large, as long as some firms with frequent trading interactions happen to target and bid for the same skilled workers. The high concentration in the interest-rate derivative market might help to explain why working as an interest-rate option trader for a top U.S. bank is roughly twice as lucrative as working as a foreign-exchange option trader (see Options Group's 2011 annual compensation report). And as illustrated in the introduction, our model can also speak to the compensation of traders in burgeoning markets.

The magnitude of the defense premium, which is also the difference between workers' compensation and internal marginal product, depends on how firms interact with each others in the industry. Changes in the structure of the industry (e.g., entries, exits, or mergers) should impact the compensation of workers, even after controlling for their effects on firms' actual profits. In that sense, our implications differ from other models we describe in the introduction where production functions are independent across firms and agents (which makes sense in models of generalist CEOs employed in various industries or for the huge pool of investment bankers, but not if we are modeling specialized OTC traders working for a very small set of financial firms). Unlike in those models, the workers who impose negative externalities on rival firms in our model can extract more than they create for their firms. This difference has important implications for recent policy debates on the optimal size and compensation for the financial sector. Our comparative statics also seem to fit well with survey evidence on the compensation of various types of traders (e.g., interest-rate option traders vs. foreign-exchange option traders). Still, one could combine in a more complicated model the industrial organization modeled in the current paper with mechanisms studied in these other papers and generate even more cross-sectional variation in rewards to skill than in those models, thanks to the amplification effect that our defense premium has on compensation. We leave such endeavor for future work and instead focus, in the next section, on showing how firms' defensive bidding for traders can affect the compensation offered to workers with virtually identical skills, but who occupy different jobs.

The current model is based on the most transparent trading game that allows us to study the competition for the scarce talent that gives firms an advantage when trading. However, if we were to allow for two-sided asymmetric information in the trading game, as done in Glode, Green, and Lowery (2012), equation (10) would still represent the expected payoff from hiring experts when the supply of workers is tight and thus expertise does not impede efficient trade. The equilibrium wage for traders would still be $w^* = \frac{\sigma}{2}\left(\frac{N}{N-1}\right)$. The only difference is that fewer traders could trigger adverse selection problems, leading to a condition for the occurrence of a defense premium that is tighter than $\xi \leq (N-1)\frac{\Delta}{\sigma}$.

3 Socially Valuable Expertise

In the last section, we showed that OTC traders, hired to extract some surplus away from rival firms, not only earn more than what they contribute to society, but also more than what they contribute to their rent-seeking firms. In this section, we generalize the concept of workers' expertise by allowing firms to assign some workers to a socially valuable task. We show that the "overcompensation" of traders not only survives this generalization, but may also leak to non-traders.

The mass ξ of experts can now be hired by the N financial firms to work on two different tasks — each worker can be hired to increase the accuracy of the firm's signal about the value of the security, which as before only affects the division of the surplus from trade between firms, or be hired to increase the size of the overall surplus available. This second task is socially valuable and could, for example, represent the creation of securities that allow for more efficient risk sharing or the search for better matching trade partners. Specifically, a firm will hire a mass e_i of workers to become trading experts who work on appropriating a larger share of the surplus 2Δ through bargaining and will hire a mass m_i of workers to become intermediation experts, or financial engineers, who work on increasing the available surplus 2Δ.

As before, employing a mass e_i of traders yields a probability $\mu_i = \frac{1}{2} + e_i$ that firm i's signal is correct. The ex-ante gains to trade when firm i proposes to buy from firm j are now denoted by $\Delta(m_i, m_j)$ and depend on m_i and m_j, the number of experts the two counterparties hire to work on surplus creation. For simplicity, we use a reduced-form characterization of $\Delta(m_i, m_j)$ and assume that it is strictly increasing and concave in its two arguments. We also assume that both the level of the gains to trade and the marginal productivity of surplus creation are more sensitive to a firm's own expertise than to that of its counterparty. First, we impose that $\Delta_1(m, m) > \Delta_2(m, m)$ to ensure that each firm captures more benefits from its own effort than from the efforts of other firms (since in our model the gains to trade accrue to the firm who is selected as the buyer rather than the seller). Second, we impose that $\Delta_{12}(m_i, m_j) = 0$, which greatly simplifies the analysis in subsection 3.2 but is not necessary for our results.[14] In the more complicated two-task setup below, we focus on the case in which the supply of workers would bind even if one firm were to deviate from the equilibrium and hire no traders. This region is the analog to the region in which our one-task model produced its most novel and interesting predictions. Finally, to ensure that surplus creators and traders are hired in equilibrium, we impose the boundary conditions that $\Delta_1(0, m_j) \to +\infty$ and $\Delta_1\left(\frac{\xi}{N}, \frac{\xi}{N}\right) < \frac{\sigma}{2}$.

The labor market operates as follows. There is a mass ξ of workers indexed by a continuous variable $h \in [0, 1]$, which will represent worker heterogeneity, and there is a parameter $\kappa > 0$ that determines the importance of such heterogeneity. Values of h, the worker's type, are uniformly distributed. Heterogeneity is modeled as some additive, orthogonal (per-unit) benefit κh of employing a worker as a surplus creator rather than as a trader. For example, some workers may be easier to train for certain tasks than others. Note, however, that nothing in our results depends on the specific role of worker heterogeneity. All that matters is that there is some ex ante difference between workers that makes some of them marginally more suited to one task versus the other.

[14] This condition is sufficient for the existence of a symmetric, pure strategy equilibrium, but such an equilibrium would exist under much milder conditions.

Furthermore, the equilibrium of the game with heterogeneity we describe in this section still exists in the limiting case with homogenous workers (where $\kappa \to 0$), but directly analyzing a model with $\kappa = 0$ can become more involved for reasons that will become clear later.

3.1 Rigid Assignment of Workers between Tasks

In this subsection, we assume that each of the N financial firms submits for each type of worker h a wage offer, a job type, and a measure for the quantity of workers demanded: $\{w_i(h), \tau_i(h), x_i(h)\}$. Here, $w_i(h) \geq 0$ is the wage offered by firm i to type h and $\tau_i(h) \in \{\text{Surplus Creation}, \text{Trading}\}$ is the task to which type h will be assigned. For now, we assume that the task offered, $\tau_i(h)$, is binding, in the sense that if firm i offers to a worker of type h to become a trader for a wage of $w_i(h)$, then firm i cannot later reassign the worker to surplus creation, or vice versa, as a response to an unanticipated strategy by a rival firm. We relax this assumption in subsection 3.2, where the assignment of workers to the two tasks takes place after workers have been matched to firms through the wage bidding process. Finally, $x_i(h) \in [0, 1]$ is the "fraction" of workers of type h that firm i is willing to hire at that wage.[15] Aggregate demand for workers of type h is then $\sum_{i=1}^{N} x_i(h)$. If this quantity is less than or equal to 1, all firms obtain the fraction of workers they desire. If aggregate demand exceeds the supply of workers, firms instead receive an allocation $\gamma_i(h) \leq x_i(h)$ of workers of type h. The functions $\{\gamma_i\}_{i=1}^{N}$ are determined as follows. Workers allocate themselves to the highest wage offers first. If several firms offer the same wage and demand more workers than available at that wage (which will be the case in equilibrium) the workers are divided evenly among these firms. No firm ever receives more workers than it requests.

A couple of examples of how the labor market works may prove helpful. If all firms offer the same wage schedule (i.e., $w_i(h) = w_j(h)$ for all $i, j \in \{1, \ldots, N\}$ and $h \in [0, 1]$), and all firms choose $x_i(h) = 1$ for all h, then $\gamma_i(h) = \frac{1}{N}$ for all h and for all firms. If one firm (say, j) were to deviate by offering a slightly higher wage than $w_i(h)$ to each type h with $x_j(h) = 1$, then the deviating firm would hire all workers. Less trivially, if all firms except j offered a wage $w_i(h)$, but firm j offered a wage very slightly below $w_i(h)$, then firm j would still obtain $\frac{\xi}{N}$ total workers if the other firms chose $x_i(h) = \frac{1}{N}$ for all h, but would obtain no workers at all if $x_i(h) \geq \frac{1}{N-1}$. If *all* firms,

[15] Here, we use quotation marks to highlight that notions of quantity, such as a fraction, are imprecise in a setting with atomistic workers.

including j, had offered $w_i(h)$, the allocation of workers would be the same regardless of whether all firms chose $x_i(h) = \frac{1}{N}$ or $x_i(h) = 1$; in both cases, $\gamma_i(h) = \frac{1}{N}$. Put simply, all demands for workers that can be satisfied are satisfied whenever possible. However, when aggregate demand cannot be satisfied, the demand of the highest bidding firms is satisfied first, then the demand of the second highest bidding firms is satisfied, and so on. As soon as the supply of remaining workers to be allocated to firms that are the n-th highest bidders is insufficient to satisfy their total demand, workers are evenly allocated among the n-th highest bidders. Given our focus on symmetric equilibria, solving for the quantity of workers hired and the wages paid to workers is relatively simple, but for completeness we describe in greater details how labor is allocated for general actions by firms in the Appendix.

While workers' heterogeneity described above allows for various distributions of type for the workers hired by each firm, it will not play a role in our analysis because we will focus on what happens as we let $\kappa \to 0$. Thus, when calculating payoffs, we will not account for the small benefits received from assigning a worker to surplus creation versus trading. The limit case as $\kappa \to 0$ will highlight that differences between workers' abilities do not drive the wage dispersion we obtain in this model. The only role worker type plays is that it allows firms to predict which workers will be assigned to each job by other firms. Absent this dispersion, the equilibrium we identify still exists, but the analysis becomes more complicated as the final allocation of workers cannot be predicted by other firms. The pseudo "coordination device" that workers' heterogeneity represents is a simple way to ensure that our static model captures the idea that, in reality, firms are able to target specific workers they want to poach from rival firms and set contract terms based on the jobs these workers currently occupy for their employer.

We now describe how firms pick the jobs they offer to workers, given the distribution of workers they expect to hire. Before knowing its role as buyer or seller, firm i's expected payoff from participating in a trade with firm j is:

$$\frac{\sigma}{2} e_i I\left(e_i \leq \frac{\Delta(m_j, m_i)}{\sigma}\right) + \frac{1}{2}\left[\Delta(m_i, m_j) + (\Delta(m_i, m_j) - \sigma e_j) I\left(e_j \leq \frac{\Delta(m_i, m_j)}{\sigma}\right)\right], \tag{16}$$

where $I(\cdot)$ is an indicator function. The highest bidder for a given worker can offer him a job in surplus creation or in trading. Since workers' heterogeneity, though potentially small, is nondegenerate, we can represent the optimal assignment of expertise within firm i as a threshold $h_i^* \in [0,1]$, where the mass of experts assigned to trading in firm i becomes $\int_0^{h_i^*} \gamma_i(h)\xi dh$. In a symmetric equilibrium with full employment, $\gamma_i(h) = \frac{1}{N}$ for each firm i, so the total mass of workers who receive and accept a job offer as traders is given by $\frac{\xi}{N}h^*$, and as surplus creators by $\frac{\xi}{N}(1-h^*)$, where the threshold h^* is the same for all firms.

We can now study equilibrium employment and wages for surplus creators and traders. An equilibrium wage requires that no firm would benefit from hiring more workers at that wage. Any wage offer infinitesimally above the equilibrium wage would permit employment of more workers, so the condition for equilibrium is that no firm would prefer to hire a larger mass of workers for either task at the prevailing wage. This is, however, not a statement about the demand for workers in equilibrium, $x_i(h)$; firms may still submit demands in excess of what they expect to hire on the equilibrium path, and in fact such demands play a crucial role in the equilibrium of the labor market. The requirement is rather that no firm would be willing to pay an infinitesimally higher wage in order to hire more workers of a given type.

It is immediate that wage dispersion among experts performing the same task must vanish as $\kappa \to 0$. If some surplus creators, for example, were to earn more than others, then whichever firm is hiring these workers could hire fewer workers at this high wage and replace them by offering lower wage workers from other firms a slightly higher wage. Thus, in any equilibrium, when $\kappa \to 0$ at most two wage levels, w_m for surplus creators and w_e for traders, can coexist.

In equilibrium, the wage schedule depends on the total supply of experts. In the situation we focus on, the mass of available workers is sufficiently small that there is no unemployment and firms are indifferent between hiring the marginal expert for surplus creation or for trading.[16] Equilibrium wages, nonetheless, differ depending on the task, even as we let workers' heterogeneity $\kappa \to 0$.

We first need to derive the optimal assignment of experts within a firm for a conjectured symmetric equilibrium with full employment. For the same reasons as before, we can focus on solving for a symmetric equilibrium where no breakdowns in trade occur. To find this equilibrium, we solve the maximization problem of a single firm, given that it is able to hire an equal fraction

[16] In the interest of space, we omit analysis of the game with a high or intermediate supply of skilled workers; this analysis proceeds largely along the lines of the analysis of the case in which only traders are hired but is more involved because of considerations involving allocations of workers between tasks following deviations. As in the model with traders only, there is a pure strategy equilibrium with low wages when the supply of experts is high and only a mixed strategy equilibrium in the intermediate region for supply.

of all worker types. At this stage the wage bill is fixed (taking as given how much the firm needs to pay to get the conjectured mass of workers) and therefore does not enter into the firm's decision problem.

The total mass of workers hired by the firm is $\frac{\xi}{N}$ by the conjecture that we are in a symmetric, full employment equilibrium. In that case, the threshold on h that differentiates workers who receive job offers as traders or as surplus creators is given by $\overline{m} \equiv (1-\overline{h})\frac{\xi}{N}$, where $\overline{m}$ satisfies:[17]

$$\Delta_1\left(\overline{m}, \overline{m}\right) + \kappa \overline{h} = \frac{\sigma}{2}. \tag{17}$$

The definition for $\overline{m}$ implies that, when all firms hire a mass $\overline{m}$ of workers as surplus creators, their marginal benefit is equal to that of hired traders, which remains constant as long as efficient trade is preserved. Note here that the marginal benefit of hiring surplus creators does not account for the fact that larger gains to trade reduce adverse selection problems and allow for the hiring of more traders. Therefore, this definition for an optimal m_i will only be relevant when the limit on e_i for efficient trade does not bind.

When the supply of workers is low, i.e., $\xi < N\left[\overline{m} + \frac{\Delta(\overline{m},\overline{m})}{\sigma}\right]$, and all workers are employed, each firm would like to hire a mass $\overline{m}$ of workers as surplus creators and the remaining mass $\frac{\xi}{N} - \overline{m}$ as traders. The supply of workers is small enough that all workers who are not hired as surplus creators are hired as traders and efficient trade still takes place. No allocation of workers other than $h^* = \overline{h}$ can be sustained in a symmetric pure strategy equilibrium with a sufficiently low supply of workers, because it would allow for a strictly profitable reassignment of workers, even without changing any of the wage offers. What remains to be derived are the wage and demand schedules that sustain this symmetric equilibrium assignment of workers for each firm. Since the intuition behind these derivations is similar to that developed in Section 2, except that now we added workers who create a positive externality rather than a negative one, we relegate these derivations to the proof of the proposition below, which can be found in the Appendix.

[17]Throughout, we denote the partial derivative of a function with respect to its nth argument, evaluated at the point $\{x_1, x_2, \dots\}$, as $f_n(x_1, x_2, \dots)$.

Proposition 1 *For $\xi \leq N\overline{m} + (N-1)\frac{\Delta(\overline{m},\overline{m})}{\sigma}$ and $\kappa \to 0$, the unique symmetric pure strategy equilibrium with rigid assignment of workers has each firm hiring a mass $\overline{m}$ of surplus creators at a wage of:*

$$w_m^* = \max\left\{\frac{\sigma}{2} - \frac{1}{N-1}\Delta_2(\overline{m},\overline{m}), \beta\right\}, \tag{18}$$

and a mass $\frac{\xi}{N} - \overline{m}$ of traders at a wage of:

$$w_e^* = \frac{\sigma}{2}\left(\frac{N}{N-1}\right). \tag{19}$$

Firms earn positive profits as long as $\Delta(\overline{m},\overline{m}) \geq \overline{m}w_m^* + \left(\frac{\xi}{N} - \overline{m}\right)w_e^*$, which simplifies to $\xi \leq 2(N-1)\frac{\Delta(\overline{m},\overline{m})}{\sigma} + \overline{m}\left(1 + \frac{2\Delta_2(\overline{m},\overline{m})}{\sigma}\right)$ when the reservation payoff does not bind.

In the limiting case in which workers' heterogeneity vanishes and the supply of workers is small, our model predicts that traders will be better compensated than surplus creators. Although surplus creators can also earn a premium over their reservation payoff β, their wage ends up being dominated by the wage paid to traders. This difference in wage is due to the fact that (efficient) trading is a fixed-sum game and surplus creation is not. When assigning potential workers between the two tasks, firms equate the payoffs of allocating workers to surplus creation and trading. But when competing with rival firms for the hiring of workers, firms compare the payoffs of employing a worker versus having a competitor employing him. If the gains to trade a firm can extract increase when counterparties hire surplus creators, surplus creation becomes a public good and reduces firms' incentives to retain these workers. Comparatively, "poaching" experts who would otherwise become traders for a counterparty is more profitable because of the fixed-sum game nature of trading. Outbidding other firms for the services of traders not only improves a firm's expertise in valuing a security but it also lowers the expertise of counterparties the firm trades with. Hence, the benefit of poaching experts depends on the externality they are imposing on the poaching firm when working for a counterparty. These predictions are consistent with evidence from Options Group that risk management officers are earning significantly less than interest-rate option traders, who operate in a highly concentrated market, and only slightly less than foreign-exchange options traders, who operate in a more diffuse market.

The equilibrium assignment of experts across tasks is socially inefficient, as some workers who could contribute to surplus creation are instead trying to appropriate a larger share of the surplus for the firm that employs them. As long as the gains to trade Δ are large enough for the supply of workers ξ, or equivalently, ξ satisfies the last inequality in Proposition 1, financial firms are able to make a positive profit despite paying traders more than their internal marginal product.

Note that the heterogeneity in workers' type delivers a unique equilibrium outcome in terms of worker allocation and wages in this setup. We have focussed our analysis on the limited case in which this heterogeneity converges to zero and the type of equilibria described above still exists. The crucial characteristic of these equilibria is that all firms anticipate and agree perfectly on which workers will be assigned to each task. But when experts are ex ante identical, other types of equilibria may also emerge. Any such equilibrium exists only in the knife-edge case with ex ante homogeneity, which is not the case for the type of equilibria we focus on. These other equilibria are unlikely to describe an actual labor market for financial experts, in which firms can target specific workers they want to poach from rival firms and find it optimal to set contract terms based on the jobs these workers currently occupy for their employer.

3.2 Flexible Assignment of Workers between Tasks

Up to this point, we have assumed that workers are hired for a specific task and such task cannot be changed in response to a deviation by a rival firm. This assumption is realistic if, for example, the different tasks are carried out by different divisions within a firm. This environment is particularly relevant in finance where regulations such as Sarbanes-Oxley or the Volcker rule require stark divisions of tasks across units of a single firm. It is also appropriate if we view the static model as an abstraction for a richer, dynamic environment in which workers develop task-specific skills as they engage in one task or the other and firms pay them just enough to discourage poaching in the future.

We can, alternatively, allow firms to choose how to assign workers within the firm *after* the labor market has closed. In equilibrium, the assignment of workers between the tasks will be identical to what we derived earlier, since firms correctly anticipate how they and their opponents will assign workers when making offers in the labor market stage. Wages, however, will differ dramatically. We show this by establishing the existence, when the supply of workers is low, of a pure strategy, symmetric equilibrium. When experts are essentially perfect substitutes for each other, each non-deviating firm responds to poaching by a rival firm by moving the threshold for assigning workers to surplus creation so as to exactly offset the loss of surplus creators. Consequently, as $\kappa \to 0$, traders and surplus creators get paid the same wage, which includes the defense premium, in equilibrium. Proof for the proposition below is relegated to the Appendix.

Proposition 2 *For $\xi \leq (N-1)\frac{\Delta(0,0)}{\sigma}$ and $\kappa \to 0$, the unique symmetric pure strategy equilibrium with flexible assignment of workers has each firm hiring a mass $\overline{m}$ of surplus creators and a mass $\frac{\xi}{N} - \overline{m}$ of traders, all at a wage of:*

$$w^* = \frac{\sigma}{2}\left(\frac{N}{N-1}\right), \tag{20}$$

and making positive profits, net of these compensation expenses.

With flexible assignment of workers, price dispersion collapses because, for small κ, deviating from the symmetric equilibrium by hiring more experts who would have otherwise been deployed as surplus creators by rival firms has the same effect on rival firms' trading expertise as deviating by poaching their traders. The near perfect substitutability of experts across tasks ensures that if a firm finds itself hiring fewer workers than expected due to a deviation by a rival firm, it will respond by reallocating workers until the returns to the two activities are again equalized. When $\kappa > 0$, this substitution effect is not complete; poaching workers expected to work as surplus creators in equilibrium from other firms will, in fact, lead to less surplus creation because any worker reassigned from trading to surplus creation to make up for the loss of surplus creators will have a lower idiosyncratic payoff κh than the poached workers. Thus, the level of surplus creation that equalizes the marginal value of surplus creation and the marginal value of trading will be lower. The wedge in compensation between surplus creators and traders diminishes, and even disappears completely, as $\kappa \to 0$ and workers can be redeployed within firms in response to a deviation by other firms. Since experts are essentially perfect substitutes for each other when $\kappa \to 0$, every firm responds to the poaching of a mass of workers by reallocating non-poached workers so as to exactly offset the loss of "would-be" surplus creators, whose internal marginal productivity (weakly) dominates that of traders.[18] Thus, poaching a surplus creator is just as

[18] Given the constant returns to trading expertise and the decreasing returns to surplus creation expertise, the

valuable as poaching a trader, since a trader will be moved out of trading and into surplus creation (to replace the poached surplus creator) following such a deviation. The implications of this new labor structure are markedly different than with rigid assignment of workers where traders, assumed to create no value, are paid a premium over what they bring in for the firm, and experts assigned to a socially productive task are paid less than their marginal product. When we allow for optimal reassignment of workers following a deviation, the presence of the fixed-sum trading task raises the wages of *all* experts.

3.3 Discussion

Obviously, in reality, distinctions between rent-seeking careers and surplus-creating careers are not as clean as in our model and most jobs involve different mixtures of these two types of activities. The perfect separation of these activities, however, allows our model to make stark predictions about the pecuniary incentives associated with the externalities workers impose on other firms. Specifically, the analysis of the two structures of the labor market has two potentially important implications which are outside of the model we consider but warrant comment.

First, if workers can take actions prior to the job market that influence their suitability for one type of activities versus the other (for example, through their choice of classes in an MBA program or any other mean to develop technical skills), the setup without immediate reassignment suggests that they would greatly favor investment in skills useful for surplus extraction rather than for surplus creation. The setup with optimal reassignment then ameliorates this effect as workers who develop skills associated with a socially useful task are now able to obtain some, if not all, of the wage premium that develops from the existence of fixed-sum game activities. The setup with optimal reassignment consequently generates a wage bill for the financial firms that is much higher than the wage bill without reassignment, even though the actual assignment of workers is identical. If financial firms face shocks to their capital, this higher wage bill could have a destabilizing effect on the financial sector.

Finally, our model also highlights that the ease with which workers can be reallocated between

equilibrium wage all workers receive is the trader wage from earlier sections. However, if we complicated the model by assuming that returns to trading expertise are decreasing as well, the defense premium would be smaller than with rigid assignment as firms would then *partially* replace their poached traders with surplus creators. Such a premium would, however, still apply to all workers for the same reasons as in the current setup.

tasks should be a consideration in light of recent debates surrounding the Volcker rule and the wisdom of separating proprietary trading activities from other activities within financial firms.

4 Discussion on Restricting Workers' Compensation

Even though the cost of financial expertise for a firm is a simple transfer from its owners to its workers in our model, optimal competition for workers among firms results in social inefficiencies. These inefficiencies originate from the incentives firms have to assign some workers to trading, and appropriate a greater share of the surplus, rather than to the tasks that create the actual surplus. A policymaker would naturally have an interest in promoting investment in surplus creation over trading expertise. Pigouvian taxation of profits from trading, potentially combined with subsidies for surplus creation, would be a standard approach to promote a more efficient outcome. Such a scheme would, of course, be difficult to implement either in our model or in reality. Profits from speculative trading and surplus creation (e.g., through market making) appear too interlinked for such a tax plan to work. Taxing the "bonus" that traders earn above the compensation of surplus creators would also not affect the efficiency of worker allocations. The defense premium puts traders well above their opportunity cost and these workers would continue to provide the same level of trading activity, with the tax serving only as a transfer from traders to the government.

We can, however, use some of the model's insights to analyze the effects of a type of policy interventions used during the recent crisis that will turn out to have implications for the efficiency of worker allocations: restricting the compensation a subset of financial firms can pay to their workers. Constrained firms could, for example, represent the financial firms that require extraordinary assistance from the government or central bank in times of crisis and that may be forced to limit workers' compensation until they have repaid taxpayers. To ease the exposition, we discuss the impact of these policies on the aggregate level of social surplus that financial firms create with more involved derivations available on request from the authors.

The corrective effect of limiting compensation in the financial sector will vary with the level of the wage cap as well as with the number of firms it constrains. In many cases, restraining wages does not affect the aggregate surplus that financial firms create for the economy, as all it does is move some experts from constrained firms to unconstrained firms and possibly transfer some of the rents from workers to unconstrained firms. It does not make constrained firms (e.g., those that owe taxpayers money) better off nor does it increase the aggregate surplus. In fact, if the limit on workers' compensation is low enough to affect the wages of non-traders, it might actually reduce the surplus firms create as some workers hired to create more surplus in the unconstrained equilibrium are instead hired by unconstrained firms to work as traders in the constrained equilibrium. On the other hand, imposing a high wage cap that only restricts trader wages paid by constrained firms can, in some cases, reduce the inefficiencies highlighted in our model. When the supply of experts is large enough that unconstrained firms cannot hire all the workers who would be traders in the unconstrained equilibrium without violating the efficient trade condition imposed on the mass of traders hired, the aggregate surplus can be greater with wage constraints than without wage constraints. The reason is that unconstrained firms now hire some or all of the experts who would otherwise work as traders for constrained firms and assign some of them to surplus creation. Effectively, the wage constraints reduce the number of firms able to hire traders in equilibrium and unconstrained firms then hire more than a mass $\overline{m}$ of surplus creators as they do not want to violate the condition that allows efficient trade to take place.[19]

5 Conclusion

We propose a labor market model that highlights the importance for financial firms of retaining their skilled traders. Firms bid for a limited supply of financial workers who can be assigned to information production in OTC trading or to more socially productive activities. When the supply of workers is sufficiently low, hiring an additional trader has two benefits. By hiring a trader a firm not only improves its own ability to value securities but also ensures that this worker will not be hired by trading counterparties. Equilibrium compensation for the trader is thus given by the difference between the firm's profits when hiring the worker and the firm's profits when losing the worker to a counterparty who is then better armed to bargain against the firm over the trade of a financial security. Because of the fixed-sum game nature of informed OTC trading among financial firms, traders extracts some rents from the fact that hiring them lowers the expertise of

[19] Acharya, Pagano, and Volpin (2012) and Bénabou and Tirole (2012) also find that capping compensation may improve social efficiency in some circumstances. In Acharya, Pagano, and Volpin (2012), salary caps serve to facilitate efficient risk-sharing between employees and firms, leading to better incentives and less excessive risk taking. In Bénabou and Tirole (2012), bonus caps help refocus the efforts of workers toward socially valuable tasks.

counterparties the hiring firm trades with. When substituting these workers with the firm's other workers is easy, the presence of the fixed-sum trading task can raise the wages of *all* workers who could potentially be poached away from the firm, making the overall compensation of financial workers higher than their marginal product.

Finally, although we apply our model to specialized trading in finance, our paper also provides a new rationale for why other types of jobs garner seemingly high levels of compensation. For example, highly skilled litigation lawyers, professional athletes in team sports, and Silicon Valley software engineers are all the object of a few parties' competition for their services and their work imposes negative externalities on the parties that fail to hire them. If we believe that their talents are scarce, we should not be surprised to observe that these workers earn what we call a defense premium.

References

Acemoglu, Daron, 1995, "Reward Structures and the Allocation of Talent," *European Economic Review*, **39**, 17-33.

Acharya, Viral, Marco Pagano, and Paolo Volpin, 2012, "Seeking Alpha: Excess Risk Taking and Competition for Managerial Talent," Working Paper, New York University.

Allen, Franklin, 1984, "The Social Value of Asymmetric Information," Working Paper, University of Pennsylvania.

Atkeson, Andrew G., Andrea L. Eisfeldt, and Pierre-Olivier Weill, 2012, "The Market for OTC Credit Derivatives," Working Paper, UCLA.

Axelson, Ulf, and Philip Bond, 2012, "Investment Banking (and Other High Profile) Careers," Working Paper, University of Minnesota.

Baumol, William J., 1990, "Entrepreneurship: Productive, Unproductive, and Destructive," *Journal of Political Economy* **98**, 893-921.

Begenau, Juliane, Monika Piazzesi, and Martin Schneider, 2012, "Banks' Risk Exposures," Working Paper, Stanford University.

Berk, Jonathan B., and Richard C. Green, 2004, "Mutual Fund Flows and Performance in Rational Markets," *Journal of Political Economy* **112**, 1269-1295.

Berk, Jonathan B., and Jules H. van Binsbergen, 2012, "Measuring Managerial Skill in the Mutual Fund Industry," Working Paper, Stanford University.

Bénabou, Roland, and Jean Tirole, 2012, "Bonus Culture: Competitive Pay, Screening, and Multitasking," Working Paper, Princeton University.

Bhagwati, Jagdish N., 1982, "Directly Unproductive, Profit-seeking (DUP) Activities," *Journal of Political Economy* **90**, 988-1002.

Biais, Bruno, Thierry Foucault, and Sophie Moinas, 2012, "Equilibrium High-Frequency Trading," Working Paper, HEC Paris.

Bijlsma, Michiel, Jan Boone, and Gijsbert Zwart, 2012, "Competition for Trader and Risk," Working Paper, Tilburg University.

Bond, Philip, and Vincent Glode, 2012, "Bankers and Regulators" Working Paper, University of Pennsylvania.

Bolton, Patrick, Tano Santos, and Jose A. Scheinkman, 2012, "Cream Skimming in Financial Markets," Working Paper, Columbia University.

Caillaud, Bernard, and Philippe Jéhiel, 1998, "Collusion in Auctions with Externalities," *RAND Journal of Economics* **29**, 680-702.

Cetorelli, Nicola, Beverly Hirtle, Donald Morgan, Stavros Peristiani, and João Santos, 2007, "Trends in Financial Market Concentration and Their Implications for Market Stability," *FRBNY Economic Policy Review*, March 2007, 33-51.

Diamond, Douglas W., 1985, "Optimal Release of Information by Firms," *Journal of Finance* **40**, 1071-1094.

Duffie, Darrell, Semyon Malamud, and Gustavo Manso, 2012, "Information Percolation in Segmented Markets," Working Paper, Stanford University.

Eső, Péter, Volker Nocke, and Lucy White, 2010, "Competition for Scarce Resources," *RAND Journal of Economics* **41**, 524-548.

Fishman, Michael J., and Jonathan A. Parker, 2012, "Valuation, Adverse Selection, and Market Collapses," Working Paper, Northwestern University.

Gabaix, Xavier, and Augustin Landier, 2008, "Why Has CEO Pay Increased so Much?," *Quarterly Journal of Economics* **123**, 49-100.

Glode, Vincent, Richard C. Green, and Richard Lowery, 2012, "Financial Expertise as an Arms Race," *Journal of Finance* **67**, 1723-1759.

Greenwood, Robin, and David Scharfstein, 2012, "The Growth of Modern Finance," Working Paper, Harvard University.

Grossman, Sanford, and Motty Perry, 1986, "Perfect Sequential Equilibrium," *Journal of Economic Theory* **39**, 97-119.

Hirshleifer, Jack, 1971, "The Private and Social Value of Information and the Reward to Inventive Activity," *American Economic Review* **61**, 561-574.

Jéhiel, Philippe, and Benny Moldovanu, 2000, "Auctions with Downstream Interactions among Buyers," *RAND Journal of Economics* **31**, 768-791.

Jéhiel, Philippe, Benny Moldovanu, and Ennio Stacchetti, 1996, "How (Not) to Sell Nuclear Weapons," *American Economic Review* **86**, 814-829.

Jéhiel, Philippe, Benny Moldovanu, and Ennio Stacchetti, 1999, "Multidimensional Mechanism Design for Auctions with Externalities," *Journal of Economic Theory* **85**, 258-293.

Lazear, Edward, and Paul Oyer, 2011, "Personnel Economics," in the *Handbook of Organizational Economics*, edited by R. Gibbons and J. Roberts, forthcoming, Princeton University Press.

Lockwood, Benjamin B., Charles G. Nathanson and E. Glen Weyl, 2012, "Taxation and the Allocation of Talent," Working Paper, University of Chicago.

Lucas, Robert E., Jr., 1978, "On the Size Distribution of Business Firms," *Bell Journal of Economics* **9**, 508-523.

McCardle, Kevin F., and S. Viswanathan, 1994, "The Direct Entry versus Takeover Decision and Stock Price Performance around Takeovers," *Journal of Business* **67**, 1-43.

Moldovanu, Benny, 2002, "How to Dissolve a Partnership," *Journal of Institutional and Theoretical Economics* **158**, 66-80.

Murphy, Kevin M., Andrei Schleifer, and Robert W. Vishny, 1991, "The Allocation of Talent: Implications for Growth," *Quarterly Journal of Economics* **106**, 503-530.

Office of the New York State Comptroller, 2012, "The Securities Industry in New York City," Report 9-2013, October 2012, New York City, NY.

Options Group, 2011, "2011-2012 Global Financial Market Overview & Compensation Report," New York City, NY.

Patterson, Scott, 2012, *Dark Pools,* New York, NY: Crown Business.

Philippon, Thomas, 2010, "Engineers vs. Financiers: Should the Financial Sector be Taxed or Subsidized," *American Economic Journal: Macro* **2**, 158-182.

Philippon, Thomas, and Ariell Reshef, 2012, "Wages and Human Capital in the U.S. Financial Industry: 1909-2006," *Quarterly Journal of Economics*, forthcoming.

Rosen, Sherwin, 1981, "The Economics of Superstars," *American Economic Review* **71**, 845-858.

Rothschild, Casey, and Florian Scheuer, 2012, "Optimal Taxation with Rent-Seeking," Working Paper, Stanford University.

Scharfstein, David S., and Jeremy C. Stein, 2000, "The Dark Side of Internal Capital Markets: Divisional Rent-Seeking and Inefficient Investment," *Journal of Finance* **55**, 2537-2564.

Shiller, Robert J., 2012, *Finance and the Good Society,* Princeton, NJ: Princeton University Press.

Terviö, Marko, 2008, "The Difference that CEOs Make: An Assignment Model Approach," *American Economic Review* **98**, 642-668.

Terviö, Marko, 2009, "Superstars and Mediocrities: Market Failure in the Discovery of Talent," *Review of Economic Studies* **76**, 829-850.

Thanassoulis, John, 2012, "The Case for Intervening in Bankers' Pay," *Journal of Finance* **67**, 849-895.

A Appendix

A.1 Equilibrium with Intermediate Supply of Workers

We solve for the mixed strategy equilibrium that prevails in the region where no symmetric pure strategy equilibrium exists. As in the main text, we focus on the case with $\beta < \frac{\sigma}{2}$.

We claim that the following is a symmetric, mixed-strategy Nash equilibrium. Each firm demands a mass $\bar{e} = \frac{\Delta}{\sigma}$ of experts, which is the maximum quantity of experts a firm can hire without creating adverse selection. Using notation from the main text, this means that each firm demands a fraction $x^* = \frac{\Delta}{\sigma}/\xi$ of the total supply of workers. The wage offer is random, as firms draw the offer w from a cumulative distribution function (CDF) given by:

$$G(w) = 1 - \left[\frac{\left(\frac{\sigma}{2}\left(\frac{N}{N-1}\right) - \beta\right)(N\Delta - \xi\sigma) - \Delta(w-\beta)}{\left(\frac{\sigma}{2}\left(\frac{N}{N-1}\right) - w\right)(N\Delta - \xi\sigma)} \right]^{\frac{1}{N-1}}. \tag{21}$$

Since we consider only the range $\xi \in \left((N-1)\frac{\Delta}{\sigma}, N\frac{\Delta}{\sigma}\right)$, the CDF in (21) is strictly positive for $w > \beta$, equal to zero at $w = \beta$, and implies an upper bound on wage of

$$\overline{w} = \beta + \left(\frac{\sigma}{2}\left(\frac{N}{N-1}\right) - \beta\right)\left(N - \frac{\xi}{\frac{\Delta}{\sigma}}\right). \tag{22}$$

Thus, $\overline{w} < \frac{\sigma}{2}\left(\frac{N}{N-1}\right)$ since $\left(N - \frac{\xi}{\frac{\Delta}{\sigma}}\right) \in (0,1)$ in the region of interest and G is a well defined distribution function for a mixed strategy with support $w \in [\beta, \overline{w}]$.

Given the demand for experts by all firms, a firm hires $\frac{\Delta}{\sigma}$ if it turns out to outbid at least one rival firm and $\xi - (N-1)\frac{\Delta}{\sigma}$ otherwise. The payoff for any wage offer $w \in [\beta, \overline{w}]$ is thus:

$$\begin{aligned}(1-(1-G(w))^{N-1})&\left[\Delta + \frac{\sigma}{2}\left(\frac{\Delta}{\sigma} - \frac{N-2}{N-1}\frac{\Delta}{\sigma} - \frac{1}{N-1}\left(\xi - (N-1)\frac{\Delta}{\sigma}\right)\right) - w\frac{\Delta}{\sigma}\right] \\ &+(1-G(w))^{N-1}\left[\Delta + \frac{\sigma}{2}\left(\xi - (N-1)\frac{\Delta}{\sigma} - \frac{\Delta}{\sigma}\right) - w\left(\xi - (N-1)\frac{\Delta}{\sigma}\right)\right]. \end{aligned} \tag{23}$$

Differentiating the above expression with respect to w gives 0 for all $w \in (\beta, \overline{w})$, implying that the firm is indifferent among any interior wage offer. When the wage offer is either β or $\overline{w}$, the firm obtains a mass of experts $\xi - (N-1)\frac{\Delta}{\sigma}$ and $\frac{\Delta}{\sigma}$, respectively, with probability 1. Payoffs are thus continuous around $w = \beta$ and $w = \overline{w}$, and firms are indifferent between the endpoints of the distribution of wages and interior wage offers. It remains to check whether there is a profitable deviation outside of the interval $w \in [\beta, \overline{w}]$ and whether there is a profitable deviation to a different quantity of demand for workers. First, it is immediate that there is no value to deviating to a higher wage offer, as an offer of $w = \overline{w}$ guarantees that the firm can hire $\frac{\Delta}{\sigma}$ workers with probability 1. Thus, any higher wage is wasted. A deviation to a wage lower than β implies that the deviating firm hires zero experts. But, for $\beta < \frac{\sigma}{2}$, always offering β instead dominates this deviation.

Next, we consider deviations on quantity. Any demand of workers between $\xi - (N-1)\frac{\Delta}{\sigma}$ and $\frac{\Delta}{\sigma}$ makes the deviating firm strictly worse off since its realized expertise is unchanged when it turns out to offer the lowest wage of all firms, but it is lower otherwise. The workers who are not hired by the deviating firm now end up working for the firm that made the lowest wage offer, which implies a decrease in trading profits of $\frac{\sigma}{2}\left(\frac{N}{N-1}\right)$ times the size of the deviation. But, since wage is lower than $\frac{\sigma}{2}\left(\frac{N}{N-1}\right)$, this is an unprofitable deviation. If the firm instead deviates by demanding fewer than $\xi - (N-1)\frac{\Delta}{\sigma}$ workers, the firm is then guaranteed to have its demand fullfilled. Therefore, the firm should choose to offer a wage of β because this is the lowest wage that workers will accept. But, we know that at a wage of β, which is lower than $\frac{\sigma}{2}$, the firm would strictly prefer to hire $\xi - (N-1)\frac{\Delta}{\sigma}$ workers rather than fewer workers. Hence, deviating to a demand for less than $\xi - (N-1)\frac{\Delta}{\sigma}$ workers generates a lower payoff than the payoff the firm gets on the equilibrium path. This confirms that no deviation on quantity can be profitable at any wage offer.

Thus, the posited G and demand of $\frac{\Delta}{\sigma}$ is a mixed-strategy Nash equilibrium of the game, and in fact is the only symmetric Nash equilibrium. We have already shown that no symmetric pure-strategy equilibrium exists. Consequently, uniqueness can be proved using standard arguments that establish that the wage distribution must be atomless, and the fact that the posited distribution is the only distribution that satisfies the required indifference over wages. That is, any symmetric mixed strategy of the game must be the solution to a differential equation given by setting the derivative of equation (23) with respect to w equal to zero. The lower bound of the distribution of wage must be β; otherwise, there would be a profitable deviation from the lowest wage offer to β. These two conditions imply a unique solution for G, which also pins down a unique equilibrium since the demand posited is the only possible equilibrium demand.[20] Any higher demand would generate

[20]To be strictly formal, we note that there are equilibria that differ from the posited equilibria for events that

adverse selection losses whenever the demand is satisfied and would imply a reduced payoff. A lower demand could be improved upon for reasons symmetric to why there is no profitable deviation to a lower demand from the demand $\frac{\Delta}{\sigma}$.

These arguments also establish that the pure strategy equilibrium derived for the high and low supply of workers is the unique symmetric equilibrium. Otherwise, the mixed strategy equilibrium would have the same form described here. From equation (22), the upper bound on wages in the region where a pure strategy exists either falls below β, which implies zero employment and cannot be an equilibrium, or exceeds $\frac{\sigma}{2}\left(\frac{N}{N-1}\right)$, which also cannot be an equilibrium since any firm employing traders at such a wage would prefer to hire zero traders.

The mixed strategy equilibrium has the following characteristics. For ξ close to $(N-1)\frac{\Delta}{\sigma}$, the mass of wage offers becomes arbitrarily concentrated around $\frac{\sigma}{2}\left(\frac{N}{N-1}\right)$, the pure strategy wage offer for $\xi < (N-1)\frac{\Delta}{\sigma}$. Similarly, as ξ converges to $N\frac{\Delta}{\sigma}$, the mass becomes arbitrarily concentrated around β, the high expertise wage offer. In between, each firm mixes over the interval of wage offers. Thus, the equilibrium wage offer is effectively continuous between the two regions over which the wage is determined as part of a pure strategy Nash equilibrium.

A.2 Formal Description of Labor Market in Section 3

Here, we present a formal description of the allocation of workers in the labor market. We describe how to calculate the distribution of wages and worker types within a firm for any arbitrary set of actions taken by firms. These quantities are necessary to calculate the payoffs for any set of strategies employed by firms. The payoffs simplify greatly both along the equilibrium paths studied and for all unilateral deviations from these equilibria, so the general expressions do not play a role in our main analysis. We include them here only for completeness.

Allocation functions $\gamma_i(h)$ depend on demand functions $x_i(h)$ for firm i and worker type h. Since each worker type represents only an infinitesimal share of the mass of workers, the quantities demanded and allocated are meaningful only as they determine the total mass of workers allocated to a firm and the distribution of worker types within that allocation.

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occur with zero probability. For example, playing G as posited with a demand of $\frac{\Delta}{\sigma}$ whenever the wage offer is greater than β, but submitting a demand between $\xi-(N-1)\frac{\Delta}{\sigma}$ and $\frac{\Delta}{\sigma}$ when the wage offer turns out to be β, is also an equilibrium. As is standard, we ignore such alternative, but payoff equivalent, equilibria when describing the uniqueness of our equilibrium.

Now, we define rules for the allocation of workers for any wage/demand pairs submitted by firms. These rules state mathematically the allocation rules mentioned in the main text. They ensure that all demands that can be satisfied are satisfied, and that when total demand cannot be satisfied the available supply of workers is allocated evenly among the high demanders. In such instance, a firm receiving its full allocation must receive weakly less than the partial allocation going to firms that posted a higher demand and offered the same wage, and firms posting identical demands and wages must receive identical allocations.

The mass of workers of type less than y allocated to firm i is given by:

$$\int_0^y \gamma_i(h)\xi dh.$$

where $\gamma_i(h)$ is given by:

- If $\sum_{j=1}^N x_j(h)\mathbf{1}_{\{w_j(h)\geq w_i(h)\}} \leq 1$, then $\gamma_i(h) = x_i(h)$. That is, if the total demand for workers by firms offering a wage greater than or equal to the wage offered by the firm in question leaves enough of the type of worker to satisfy the firm's demand, then that firm receives all the workers it demands.

- If $\sum_{j=1}^N x_j(h)\mathbf{1}_{\{w_j(h)>w_i(h)\}} < 1$, but $\sum_{j=1}^N x_j(h)\mathbf{1}_{\{w_j(h)\geq w_i(h)\}} > 1$
  - If we define $N_{w_i(h)}$ as the number of firms offering $w_i(h)$ and $x_j(h) > \frac{1-\sum_{j=1}^N x_j(h)\mathbf{1}_{\{w_j(h)>w_i(h)\}}}{N_{w_i(h)}}$ for all j such that $w_j(h) = w_i(h)$, then $\gamma_i(h) = \frac{1-\sum_{j=1}^N x_j(h)\mathbf{1}_{\{w_j(h)>w_i(h)\}}}{N_{w_i(h)}}$.
  - Otherwise, ordering the firms j offering $w_j(h) = w_i(h)$ by $x_j(h)$ such that $x_1 \leq x_2 \leq \ldots x_k \leq \ldots$, find the largest k such that k is the highest index assigned to a given demand and:

$$\frac{1-\sum_{j=1}^N x_j(h)\mathbf{1}_{\{w_j(h)>w_i(h)\}} - \sum_{j=1}^k x_j(h)}{N_{w_i(h)} - k} \geq x_k(h).$$

    For $j \leq k$ under the reordering, $\gamma_i(h) = x_i(h)$. For $j > k$, $\gamma_i(h)$ is equal to the left-hand side of the above inequality.

- For all other firms, $\gamma_i(h) = 0$. Supply is completely exhausted by firms offering higher wages, so these low bidders receive no workers.

In order to calculate firms' payoffs, we need to be able to calculate the total wages paid to a worker of type less than y:

$$\int_0^y \gamma_i(h) w_i(h) \xi dh.$$

In equilibrium, there will be at most two levels of wages for the case with $\kappa \to 0$, so the calculation of the wage bill is quite simple. However, the expressions for the distribution of worker types and wages is necessary to fully specify the payoff functions of the game.

A.3 Proofs of Propositions

Proof of Proposition 1: First, as explained in the body of the paper, the internal optimal assignment condition in equation (17) needs to be satisfied in equilibrium, hence $h^* = \overline{h}$. And similar to Section 2, if the demand for an expert expected to be hired as a trader is fully satisfied for all firms, i.e., $x_i(h) \leq \frac{1}{N}$, the wage offered must be no more than $\frac{\sigma}{2}$, since this is exactly what the trader produces for the firm. But, if the wage is $\frac{\sigma}{2}$ or lower, then there is a profitable deviation to offering a higher wage and demanding more than a mass $\frac{\xi}{N}$ of that type of worker. This deviation is profitable as long as the wage is less than $\frac{\sigma}{2}\left(\frac{N}{N-1}\right)$, so the equilibrium wage schedule for traders must be:

$$w_e^* = \frac{\sigma}{2}\left(\frac{N}{N-1}\right), \tag{24}$$

and includes the defense premium we observed in the model with trading jobs only. With such wage schedule, it is profitable for a firm to deviate to hiring marginally fewer traders only if it anticipates that other firms would not hire anyone whom the firm in question does not hire. Thus, in any symmetric equilibrium, the total demand for traders must at least exceed supply, i.e. $x^*(h) > \frac{1}{N}$ whenever $h < \overline{h}$.

The wage of the surplus creator, on the other hand, turns out to be potentially less than the value he creates for the firm. If the wage offered to surplus creators is below $\Delta_1(\overline{m}, \overline{m}) - \frac{1}{N-1}\Delta_2(\overline{m}, \overline{m}) + \kappa h$, then firms will prefer to hire more workers of the types expected to engage in surplus creation by paying an infinitesimally higher wage. Assume for now that β is lower than this level, then if the wage exceeds this level, firms will want to reduce their employment of these workers. However, if the aggregate demand for workers equals their supply, a firm will recognize the profitable deviation of offering a wage equal to the reservation payoff β instead (since any worker who rejects such offer would become unemployed). Hence, in equilibrium, demands for workers expected to become surplus creators, i.e., with $h \geq \overline{h}$, must exceed the supply and the wage must therefore be:

$$w_m^*(h) = \Delta_1(\overline{m}, \overline{m}) - \frac{1}{N-1}\Delta_2(\overline{m}, \overline{m}) + \kappa h. \tag{25}$$

These conjectured equilibrium wages rule out most possible discrete deviations by construction. First, at these wages hiring significantly more than the equilibrium levels of traders and surplus creators is not an attractive deviation given the concavity of $\Delta(\cdot,\cdot)$ and the linearity of trading payoffs. Similarly, if a firm is thinking of hiring fewer surplus creators, the concavity of $\Delta(\cdot,\cdot)$ and the restriction on the sensitivity of payoffs to own hiring versus counterparty's hiring make this deviation strictly suboptimal. Now, given the linear payoff function from trading (as long as $e_j \leq \frac{\Delta(m_i,m_j)}{\sigma}$), hiring fewer traders could imply that rival firms would hire all these otherwise unemployed traders and the savings in wages from this deviation would equal the loss in trading profits. Therefore, if not hiring these traders implies that rival firms will hire them and still satisfy the efficient trade condition on trading expertise, hiring fewer traders cannot be a profitable deviation.

However, if hiring fewer traders means that rival firms, who have excess demand for these workers, will end up with so many traders that the conditions for efficient trade are violated or that these workers will become surplus creators in rival firms or unemployed, then the deviation can be profitable. Hence, in equilibrium the demand for workers who become traders, those with $h < \overline{h}$, must be greater or equal to $\frac{1}{N-1}$, and the resulting level of trading expertise by rival firms cannot prevent efficient trade, i.e.,

$$\xi \leq N\overline{m} + (N-1)\frac{\Delta(\overline{m}, \overline{m})}{\sigma}. \tag{26}$$

This condition rules out the remaining discrete deviations and is more restrictive than the condition imposed on ξ earlier in the subsection.

In the case where β is greater than the equilibrium wage mentioned above for surplus creators, firms just pay surplus creators β without changing the allocation of workers. Equilibrium wages still fall below what surplus creators produce for the firm; wages are depressed by the fact that experts produce positive externalities when they are hired by other firms. Since a worker would exit the sector entirely in favor of his reservation payoff if the firm were to pay him a wage lower than β, then the incentive to decrease wages below β disappears. This holds as long as $\beta \leq \frac{\sigma}{2}$, which is the parameter range of interest for our model. The positive profit condition (trivially) imposes: $\Delta(\overline{m}, \overline{m}) - \left(\frac{\xi}{N} - \overline{m}\right) w_e^* - \overline{m} w_m^* \geq 0.$ ∎

Proof of Proposition 2: We start by conjecturing a symmetric, pure strategy equilibrium with full employment where optimal expertise levels do not reach their adverse selection boundary. As before, the marginal value of surplus creation must equal the marginal value of trading, hence $h^* = \overline{h}$. To ensure that no firm deviates from this equilibrium, we must determine the allocation of workers by all firms after a deviation by one firm. This is the major distinction between this setup and the earlier one. It is immediate that, if a firm deviates to offering an infinitesimally higher wage to a small mass of experts of the type deployed as traders by other firms on the equilibrium path, the deviating firm will deploy the new experts it hires as traders. Furthermore, rival firms will choose exactly the same level of surplus creation as they would have without the deviation. Thus, traders must be paid a wage $\frac{\sigma}{2}\left(\frac{N}{N-1}\right)$ to prevent poaching, as previously.

On the other hand, a deviation to hiring a small mass of additional workers who would have been deployed as surplus creators by other firms results in a reassignment of workers both within the deviating firm and within the other $(N-1)$ firms. When the poached surplus creators come from the interior of $[h^*, 1]$, the deviating firm will assign the poached workers to surplus creation but will also reassign some of the marginal surplus creators to trading. The firms facing the deviation, on the other hand, will respond by partially compensating for the lost surplus creators by moving marginal traders to surplus creation. Defining $\tilde{h}$ as the new threshold for the deviator and $\hat{h}$ as the new threshold for the non-deviators, the deviator and non-deviators solve the following two maximization problems in response to a deviation to poach an additional ε surplus creators from other firms:

1) For the deviator:

$$\max_{\tilde{h}} \Delta(\overline{m} + \varepsilon - \frac{\xi}{N}(\tilde{h} - h^*), \overline{m} - \frac{\varepsilon}{N-1} + \frac{\xi}{N}(h^* - \hat{h})) + \frac{\sigma}{2}\frac{\xi}{N}(\tilde{h} - h^*) - \frac{\xi}{N}\int_{h^*}^{\tilde{h}} \kappa h dh + W, \quad (27)$$

where W is a constant that does not depend on $\tilde{h}$.

2) For each of the $(N-1)$ non-deviators:

$$\max_{\hat{h}} \frac{1}{N-1}\Delta(\overline{m}-\frac{\varepsilon}{N-1}+\frac{\xi}{N}(h^*-\hat{h}),\overline{m}+\varepsilon-\frac{\xi}{N}(\tilde{h}-h^*))$$
$$+\frac{N-2}{N-1}\Delta(\overline{m}-\frac{\varepsilon}{N-1}+\frac{\xi}{N}(h^*-\hat{h}),\overline{m}-\frac{\varepsilon}{N-1}+\frac{\xi}{N}(h^*-\breve{h}))$$
$$+\frac{\sigma}{2}\frac{\xi}{N}(\hat{h}-h^*)-\frac{\xi}{N}\int_{h^*}^{\hat{h}}\kappa h dh+V, \tag{28}$$

where V is a constant that does not depend on $\hat{h}$, and $\breve{h}$ denotes the reaction of the other non-deviating firms.

Recalling that $\Delta_{12}(m_i,m_j)=0$, we can define $\widehat{\Delta}'(m)\equiv\Delta_1(m,m_j)$ and $\widehat{\Delta}''(m)\equiv\Delta_{11}(m,m_j)$ for all m_j. This produces the following system of first-order conditions:

$$\widehat{\Delta}'(\overline{m}+\varepsilon-\frac{\xi}{N}(\tilde{h}-h^*))+\kappa\tilde{h} = \frac{\sigma}{2} \tag{29}$$
$$\widehat{\Delta}'(\overline{m}-\frac{\varepsilon}{N-1}+\frac{\xi}{N}(h^*-\hat{h}))+\kappa\hat{h} = \frac{\sigma}{2} \tag{30}$$

From equation (30), we can derive the rate at which $\hat{h}$ changes with ε in a neighborhood of 0. This is given by

$$\frac{d\hat{h}}{d\varepsilon}=-\left(\frac{\frac{1}{N-1}\widehat{\Delta}''(\overline{m})}{\frac{\xi}{N}\widehat{\Delta}''(\overline{m})-\kappa}\right). \tag{31}$$

As $\kappa\to 0$, then $\frac{\xi}{N}\frac{d\hat{h}}{d\varepsilon}=-\frac{1}{N-1}$, meaning that when experts are essentially perfect substitutes for each other every non-deviating firm responds to poaching by moving the threshold for assigning workers to surplus creation so as to exactly offset the loss of surplus creators. Consequently, as $\kappa\to 0$ traders and surplus creators get paid the same wage in equilibrium.

For $\kappa>0$, a deviation to hire slightly more surplus creators leads to a partial offsetting of the loss of surplus creators by non-deviating firms, and thus the discount for surplus creators from the baseline setup survives partially. Poaching surplus creators rather than traders leads to a decrease in positive externalities and is thus easier to prevent. As a result, surplus creators' wages are adjusted downward to account for the fact that poaching them is not as attractive to rival firms as poaching traders is because poaching surplus creators does not decrease trading expertise as much as poaching traders does (and it also reduces the gains to trade generated by rival firms).

The conditions on wages described here must hold in any symmetric, pure strategy equilibrium, or a firm will have an incentive to deviate to hiring a slightly different level of experts. We have yet to rule out larger deviations. A firm may profit by reducing surplus creation sufficiently that the adverse selection boundary binds for the other firm. Once the adverse selection boundary binds, workers hired away from the firm deviating to lower employment are not deployed as traders, and thus the loss in profits from reducing employment decreases for large enough deviations. It is clear, however, that as long as the supply of workers ξ is sufficiently small relative to the gains to trade, the equilibrium demands for workers can sufficiently exceed their supply and no deviation by a single firm can lead to the adverse selection boundary binding for other firms. In fact, the condition $\xi \leq (N-1)\frac{\Delta(0,0)}{\sigma}$ is sufficient to ensure that such symmetric equilibrium exists, is unique, and leads to positive profits by firms. ∎