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# SELECTION VERSUS TALENT EFFECTS ON FIRM VALUE

Briana Chang
Harrison Hong

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## ABSTRACT

Measuring the value of labor-market hires for stock prices, be it underwriters when firms go public (IPOs) or chief executive officers (CEOs), is difficult due to selection. Opaque firms with higher costs of capital benefit more from prestigious underwriters, while productive firms benefit more from talented CEOs. Using assignment models, we show that the importance of talent (or agent heterogeneity) relative to selection (or firm heterogeneity) is measured by wage increases across agents of different compensation ranks divided by changes in output across their firms. The median of this ratio is 0.5% for underwriters and 2% for CEOs.

Briana Chang
Department of Finance, Investment and Banking
University of Wisconsin - Madison
bchang@bus.wisc.edu

Harrison Hong
Department of Economics
Columbia University
1022 International Affairs Building
Mail Code 3308
420 West 118th Street
New York, NY 10027
and NBER
hh2679@columbia.edu

# 1. Introduction

Measuring the value of labor market hires for stock prices is a fundamental question in financial economics. Two labor markets are particularly important and widely studied. The first is the market for underwriters when firms issue equity. Firms compete and spend significant resources to hire reputable underwriters (typically investment banks with track records of successful placements) for their initial public offerings (IPOs) so as to alleviate adverse selection (see, e.g., Allen and Faulhaber (1989), Carter and Manaster (1990), Welch (1989)). Measuring the value of prestigious underwriters is a long-standing goal in the IPO literature (for reviews, see, e.g., Ritter and Welch (2002)). The second is the market for Chief Executive Officers (CEOs). There is a large literature on the value-added of a CEO (see, e.g., Bertrand and Schoar (2003)). In particular, valuing different attributes of a CEO, be it intelligence or other personality attributes, remains a widely researched topic (see, e.g., Kaplan et al. (2012), Graham et al. (2013)).[1]

Regardless of the situation, quantifying these hires' impact on stock prices is difficult due to selection or sorting in competitive labor markets (Becker (1973) and Rosen (1974)). Firms that hire better underwriters might have more opacity or information asymmetry and higher costs of capital to begin with. So correlating a firm's stock valuation with the status of the underwriter it hired is potentially problematic due to this selection. Indeed, recent empirical work suggests that such competitive selection effects between firms and underwriters (Fernando et al. (2005), Akkus et al. (2013)) might inform the long-running debate on IPO underpricing, the first-day return thought to compensate investors for adverse selection. Prestigious underwriters were associated (correlated) with less underpricing before the Internet period but became associated with more underpricing during and after the Internet period. This change in the sign of this underpricing-prestige correlation remains puzzling. Selection effects arising from assortative matching in a competitive labor market

[1]Due to CEO wage inequality, this question continues to be important in the popular press and across various disciplines such as strategy and management (see, e.g., "Do CEOs Matter?" by *The Atlantic* in the June 2009 issue which surveyed a variety of contrasting views of whether CEOs add any value.).

for CEO talent are also problematic. Terviö (2008) and Gabaix and Landier (2008) point to a positive assortative matching between managerial talent and firm productivity due to complementarities in firm production functions.

To understand the role of selection from the direct effect of agent talent, we develop an assignment model where firms compete to hire a talented agent, be it an underwriter or a CEO, to raise their stock valuations. Specifically, the value of the match depends on the role of the agent in the asset market. In the labor market for underwriters when firms go IPO, our asset market follows the classical IPO underpricing set-up (Rock (1986), Benveniste and Wilhelm (1990), Habib and Ljungqvist (2001)), in which adverse selection generates underpricing. More prestigious underwriters are assumed to be able to bring in more uninformed investors and hence alleviate the need for underpricing. In the labor market for CEOs, a talented CEO raises long-term fundamental value as in Terviö (2008) and Gabaix and Landier (2008).

We characterize the assignment equilibrium that maps (assigns) these multiple dimensions of firms into agent talent and solve for the wage function and stock price. There are two effects that shape the relationship between firm value, be it the underpricing or fundamental value, and agent talent, be it a prestigious underwriter or a talented CEO. The first is the "direct effect" of hiring a more talented agent: all else equal, a firm with a better agent will have a lower cost of capital or higher value since the more prestigious underwriter will bring more uninformed investors to the IPO or the more talented CEO will lead to a greater increase in firm profitability. The second is the "selection effect". Firms with greater opacity or more productivity benefit more and pay more for a better agent.

The strength of the selection effect increases with heterogeneity across firms (be it opacity or firm productivity) relative to the talent distribution of agents. For instance, if firm opacity is tightly distributed in the population, the highly opaque firms still hire the most talented agents and so the direct effect dominates and firms with better agents have lower costs of capital. As dispersion of firm types increases this association flips signs from negative to positive; i.e. firms with better agents have higher costs of capital. This selection effect can potentially explain the change in the underpricing-prestige relationship during Internet period to the extent there is greater dispersion in firm opacity as young Internet firms with little cashflows went IPO. In the labor market for CEOs, the selection effect driven by the desire of firms with high fundamental value to hire talented CEOs gives rise to a positive correlation between firm size and CEO talent.

But dispersion in underlying opacity or productivity and heterogeneity in agent talent are typically unobservable to the econometrician, which results in the challenge of separating selection from talent effects. The key result of our paper is that we provide a decomposition of these unobservable quantities using observable firm outcomes (underpricing or firm profit) and agent wages.

Since the most talented workers work for the firms with the most opacity or productivity and make the most compensation, we can rank agents based on their wages. We show that the relative strength of the talent effect (or agent heterogeneity) can then be measured by the ratio of the change in wages across agents divided by the change in output (underpricing or profit) of the firms that these agents work for. Intuitively, suppose that workers are homogeneous in talent, then their wages will be similar and this ratio is close to zero. In the other extreme, suppose firms are similar, then the change in wages and output move one for one across agents of different percentiles, i.e. the ratio is close to 1. This ratio is invariant to scale effects, that is if all firms become equally more opaque or productive, it would not affect this ratio.

Given that firm profits and wage distributions are often observable, empirical researchers can use this decomposition to measure the relative strength of selection versus direct effects.[2] We apply our decomposition to the IPO and CEO settings. The time variation in IPO underpricing patterns has spawned competing explanations of selection effects versus structural

[2] Adjusting for selection (see, e.g., Heckman (1977), Roberts and Whited (2012)) is empirically challenging since it generally requires instrumental variables for the selection equation. Moreover, important firm characteristics that might drive the selection, such as investors' information asymmetry or uncertainty, are also unobservable to econometricians and at a minimum difficult to measure.

changes in underwriter technology or incentives (Loughran and Ritter (2002)). Using data on IPO underpricing from 1990-2015, we find that the relative strength of talent or prestige heterogeneity is for the median IPO in a typical year around 0.05% to 1%, a small fraction in comparison to selection effects or firm heterogeneity. Moreover, we find a significant decline in talent relative to selection effects from the early nineties into the dot-com period. That is, the change in signs of underpricing and prestige is likely driven by the increasing importance of selection effects due to time-variation in the heterogeneity of firm opacity.

Scale effects have been argued to explain the rise of CEO wages since the 1980s. The main test is to show that the increase in the average size of the firm in the stock market (i.e. a scale effect) can explain the rise in CEO wages (Gabaix and Landier (2008)). But there is debate on whether this coincident trend is causal as Frydman and Saks (2010) find that in the pre-1980s period wages of CEOs did not rise even though the average size of the firm in the stock market rose. One way to frame alternative explanations is the level of CEO wages in assignment models increase with both firm and talent heterogeneity as well as the scale. Since our decomposition is invariant to scale, we can use it to see if the rise of CEO wages might also be due to changing heterogeneity.

Using CEO wage data and firm value data from 1993-2014, we find that the relative strength of talent effects is for the median firm in a typical year 2%. It peaks at 4% during the Internet period, pointing to the importance of selection effects overall. We also find that the relative strength of talent effects rose from the early nineties to the early 2000's and has declined subsequently. That is, the rise in CEO pay since the 1980s is not just simply due to scale effects but also the changing composition of talent over the Internet period.[3]

Finally, we show that this decomposition can be thought of as a diagnostic test of the relative strength of talent versus selection effects in other labor markets such as venture capitalists who can affect both fundamental value and underpricing, i.e. the cost of capital.

[3] A simultaneous fall in the heterogeneity of talent effects along with an increase in scale effects during the pre-1980s might then explain why the average firm size rose in this period but CEO wages did not as we discuss in more detail below.

Notably Sørensen (2007) uses a structural model to point to the talent effects of venture capitalists in improving firm fundamental value, while Megginson and Weiss (1991) point to venture-capital backed IPOs having lower underpricing. A number of literatures in corporate finance involving the effect of talent on firm value have evolved largely separately but they are united, as we have hoped to show, in fundamental ways through the role of selection in labor markets.

Our paper proceeds as follows. We describe our assignment model in Section 2. We provide the solution in Section 3. We derive the decomposition of talent versus selection effects in the traditional multiplicative setting in Section 4. We provide some estimates of this decomposition for IPO underpricing and CEO compensation in Section 5. We consider more general settings in Section 6. We conclude in Section 7.

## 2. Model

The model lasts for three dates. There is a unit measure of heterogeneous firms that issue equity through the stock market. Firms can hire agents (e.g., underwriters or executives) via a competitive labor market at date 0. These agents, who differ in their ability, affect the share price of the firm at date 1. Finally, at date 2, the cash flow is realized, and all players in the economy consume their realized gains.

To proceed, we first introduce a general framework for the labor market. Firms, which differ in multiple dimensions, choose the optimal agent to maximize the firm's expected payoff. They rationally anticipate how different agents affect their stock price at date 1. We then specify the relationship between agents' talents and share prices by considering two classical models.

*Agents:* There is a distribution of heterogeneous agents whose ability is indexed by $h \in H \equiv [h^L, h^U]$. Let $G^A(h)$ denote the talent distribution. This ability in the context of underwriters is prestige bringing in more uninformed investors to an IPO. In the context of

CEOs, this talent increases fundamental value.

*Firms:* Each firm owns a risky project with capital stock $k$, which can be interpreted as firm productivity or size. The payoff of the project for the firm with capital $k$, is given by $k\theta$, where $\theta$ is a firm-specific payoff with mean $\hat{\theta}(h)$. The mean $\hat{\theta}(h)$ aims to capture firms' long-term fundamental, which can potentially be affected by the type of agent a firm hires. The riskiness of the project is indexed by $\sigma$. A firm originally owns $(1+\psi)$ measure of shares and wants to raise capital by issuing one measure of its equity to investors at date 1. In general, firms can differ in their size, volatility, or their proportion proportion of issued shares. Let $y \subseteq \mathbb{R}^n$denote the characteristics of a firm. The types of firms are distributed according to a probability measure $\nu^F$ on $Y$, which is assumed to be absolutely continuous with respect to the Lebesgue measure.

*Labor Market:* At date 0, each firm can hire at most one agent assuming it hires any at all. The fee paid to the agent is denoted by $\omega(h)$, which will be determined competitively in equilibrium, and is paid at the end-of-period. The end-of-period cash flows for firm $y$ are then the profit from its project minus the fee that it commits to pay: $k\theta - \omega(h)$. All equity holders are thus bearing the cost of fees.

At date 0, given the fee required to hire agent $\omega(h)$, a firm of type $y$ chooses the optimal agent to maximize its expected payoff. Let $\tilde{p}_{hy}$ denote the realized share price at date 1 for firm $y$ if it hires agent $h$. Given that the firm is issuing one share, he receives the share price $\tilde{p}_{hy}$ at date 1, and retain$\left(\frac{\psi}{1+\psi}\right)$ shares of the end-of-period profit, $k\theta - \omega(h)$. The expected profit of firm $y$ who hires agent $h$ is then given by

$$U(y,h) = \mathbb{E}_\theta \left[\tilde{p}_{hy} + \left(\frac{\psi}{1+\psi}\right)(k\theta - \omega(h))\right] \tag{1}$$

The exact relationship between agents' talents and share prices, $\tilde{p}_{hy}$, depends on the specified environment. Nevertheless, given the price function, the (unconditional) expected asset return for investors is given by $R(y,h) \equiv \mathbb{E}_\theta \left[\left(\frac{k\theta-\omega(h)}{1+\psi}\right) - \tilde{p}_{hy}\right]$. Thus, Equation (1) can be rewritten as

$$U(y,h) = \left\{ k\hat{\theta}(h) - R(y,h) - \omega(h) \right\}. \tag{2}$$

Thus, the agent can affect firms' expected profit through two channels: The first term reflects how talent affects the expected payoff (i.e., firms' long-term fundamental). The second term can be interpreted as the firm's cost of capital, which depends on both the firms' characteristics and the talent effect. Hence, the firm's expected profit when hiring agent $h$ can be conveniently rewritten as simply the value generated by the agent minus the agent's fee.

Note that, since the investors ultimately bear the hiring cost $\frac{\omega(h)}{1+\psi}$ at the end-of-period, such cost is reflected in the share price at period 1. This explains why, from a firm's view point, the total cost is simply the agent's fee. To fix the ideas, we now consider two classical applications to show how they can be nested in our setup:

**Labor Market for Underwriters:** In the setting of Rock (1986), Benveniste and Wilhelm (1990), and Habib and Ljungqvist (2001), the key friction is the asymmetric information among investors, where informed investors know the quality of the firm, while uninformed investors do not. As the winner's curse increases in proportion to the fraction of informed investors, so does the necessary amount of underpricing.

The main value of the underwriters is to reduce the cost of capital by attracting uninformed investors. One can thus interpret agents as the underwriters in this setting, who differ in terms of their ability to attract uninformed investors. Specifically, let $\beta(h)$ denote the fraction of uninformed investors that are attracted by underwriter $h$. We assume that the higher is $h$, the more prestigious the underwriter, the higher fraction of investors will be uninformed participating in the IPO: $\beta'(h) > 0$. We further set $\hat{\theta}(h) = \bar{\theta}$, which captures the fact that underwriters do not affect the fundamental and thus only increase the value of forms by reducing the cost of capital.

Specifically, the payoff of the project is given by $\theta \in \{\bar{\theta} - \sigma, \bar{\theta} + \sigma\}$ with equal probability.

Informed investors know the realized value of $\theta$, but uninformed investors do not. For any given fraction of uninformed investors, the price at which shares are sold to investors must be such that uninformed investors expect to break even. The expression for the expected return, which is interpreted as underpricing in the IPO literature, yields [4]

$$UP(y,h) \equiv R(y,h) = \left(\frac{k\sigma}{1+\psi}\right)\frac{(1-\beta(h))}{(1+\beta(h))}. \tag{3}$$

Note that $\frac{\partial UP(h,y)}{\partial h} = -\left(\frac{k\sigma}{1+\psi}\right)\frac{2\beta'(h)}{(1+\beta(h))^2} < 0$. Since a better (more prestigious) underwriter can attract more uninformed investors, a better agent helps reduce the amount of underpricing by more than a worse agent.

**Labor Market for CEOs:** In (Terviö (2008), Gabaix and Landier (2008)), the role of CEO is to increase the firm's fundamental. To capture this, it can be nested in our model by assuming that (1) a better CEO increases the average payoff of the project, i.e., $\hat{\theta}(h) = \bar{\theta}h$, and (2) a perfectly competitive and frictionless stock market. Thus, the share price is the expected fundamental value given by $\tilde{p}_{hy} = \mathbb{E}_\theta\left[\frac{k\theta-\omega(h)}{1+\psi}\right] = \frac{k\bar{\theta}h-\omega(h)}{1+\psi}$.

Given that the price is simply the fair value of the share, the expected return $R(y,h)$ is thus always zero. Hence, Equation (2) then collapses to the standard CEO setting, $U(y,h) = k\bar{\theta}h - \omega(h)$, where a CEO only affects the firm's fundamental.

**Other Applications:** Our uniform model can be further applied to other labor markets as well, such as the labor market for venture capitalists. In particular, venture capitalists may affect both the firm's fundamental as well as the underpricing. In this case, one can set $U(y,h) = k\bar{\theta}h - UP(y,h) - \omega(h)$. That is, both forces identified above will affect firms' hiring decision.

*Equilibrium:* Given any price function, the equilibrium in the labor market consists of an assignment $\mu(y)$: $Y \to H \cup \{\emptyset\}$ and competitive fee for agents $\omega(h) : H \to \mathbb{R}^+$ such

[4] See Appendix A.1 for detailed derivation.

that (1) the optimality conditions for both firms and agents are satisfied, i.e. given wage $\omega(h)$, $\mu(y)$ is the type of agent that firm $y$ optimally chooses to hire. That is, $\mu(y) \in \arg\max_{h \in H \cup \{\emptyset\}} U(y,h)$. And (2) the market-clearing condition holds for the labor market.

# 3. Labor Market Hiring

Taking into account how the agent affects the price in the asset market, we now characterize the assignment function and wage function. The surplus between firm $y$ and agent $h$, which is the sum of their payoff minus their outside option, yields

$$\begin{aligned} \Omega(y,h) &\equiv U(y,h) - U(y,\emptyset) + \omega(h) \\ &= k\left(\hat{\theta}(h) - \hat{\theta}(\emptyset)\right) + R(y,\emptyset) - R(y,h), \end{aligned} \tag{4}$$

where $\emptyset$ denotes the case in which a firm hires no agent (i.e., the firm's autarky value) and the workers' unemployed value is normalized to zero. The first two terms thus represent the gain of firm $y$ when it hires agent $h$ relative to no hiring. The third term represents the payoff of a worker, which is the fee. Thus, the surplus is simply the change in fundamental plus the reduction in the cost of capital (relative to no hiring).

Technically, given the multiple characteristics of a firm, our environment is a multidimensional-to-one matching problem. As established in Chiappori et al. (2016), given our surplus function in (4) and that the measure of firms $\nu^F$ is absolutely continuous with respect to the Lebesgue measure, stable matching exists and the assignment function $\mu(y)$ is unique and pure. That is, each firm hires a unique agent instead of using mixed strategies.

**Sorting** Proposition 1 first establishes the property of the assignment function in terms of firms' characteristics.

**Proposition 1.** *In the IPO setting, all else equal, a firm with a riskier project ($\sigma$), greater productivity or size ($k$), and a higher proportion of issued shares ($\frac{1}{1+\psi}$) hires a more talented* *agent. That is,* $\mu_\sigma(k, \psi, \sigma) > 0$*,* $\mu_k(k, \psi, \sigma) > 0$ *and* $\mu_\psi(k, \psi, \sigma) < 0$*. In the CEO market, a more productive firm hires a more talented agent.*

These results can be seen from the firms' optimization problem. Specifically, given that all firms face the same cost function $\omega(h)$, a firm that has a higher marginal benefit for talent must hire a better agent in equilibrium. For example, in the IPO setting, given the underpricing expression in Equation (3), the added value of talent $h$ for firm $y$ yields

$$\frac{\partial U(y, h)}{\partial h} = \left(\frac{k\sigma}{1+\psi}\right) \frac{2\beta'(h)}{(1+\beta(h))^2} - \omega_h(h). \tag{5}$$

In other words, there is a *complementarity* between the prestige of an agent and firms' scale and riskiness. Thus, firms with a higher scale or more volatility benefit more from hiring a prestigious underwriter. Similarly, as standard in the market for CEO (Terviö (2008), Gabaix and Landier (2008)), there is complementarity between the size or productivity of the firm and talent; hence, a more productive firm hires a better CEO.

**Characterization** Observe that, for the market for underwriters, Equation (5) suggests that firms' marginal value for hiring can be simply summarized by the one-dimensional index

$$a(y) = \left(\frac{k\sigma}{1+\psi}\right). \tag{6}$$

Thus, two different firms will choose the same agent in equilibrium if they have same index $a(y)$. With this particular feature, the model can be solved similarly as in the standard model with one-dimensional heterogeneity, where firms with a higher $a$ is matched with a more talented agent.

In the market for CEO, the only firm heterogeneity is firm productivity or size. And, a larger firm has a higher marginal value of hiring a more talent agent. That is, the one-dimensional index for firm is given by $a(y) = k$.

In both cases, the assignment function $\mu(y)$ must then satisfy the familiar market clearing condition:

$$G^F(a(y)) = G^A(\mu(y)), \tag{7}$$

where $G^F(a)$ denotes the measure of firms with an index lower than $a$. Furthermore, as shown in Terviö (2008), for any agent $h$, his marginal gain in equilibrium (represented by $\omega_h(h)$) is his contribution to the surplus within the match, given his optimal assignment:

$$\omega_h(h) = \Omega_h(\mu^{-1}(h), h), \tag{8}$$

where $\mu^{-1}$ denotes the inverse of $\mu$, representing the type of firm assigned to agent $h$. Note that the continuity assumption is important for Equation (8). In a continuous model, all agents and firms have arbitrarily close competitors. As a result, they do not earn rents over their next best competitor.[5]

More generally, the sorting can be multidimensional. For example, when venture capitalists affect both the firm's fundamental as well as the cost of capital, the sorting can no longer can be reduced to one-dimensional index. In Section 6, we provide an algorithm to characterize the assignment function and wages when type spaces are multidimensional and discuss its implications.

## 4. Selection and Talent Effects in Multiplicative Setting

Given that firm value depends on both the characteristics of firms and talents, the existence of sorting suggests that quantifying the impact of talent on firm value is fundamentally difficult. Below, we consider an environment where the output of a firm is multiplicatively separable in the characteristics of firms and agents, and establish how one can use both wage and firm output information to disentangle these two effects.

[5] In a discrete model, on the other hand, there would be a match-specific rent left for bargaining.

## 4.1. Joint Effects on Firm Output

The output function for a firm (underpricing outcome for IPOs or fundamental value) depends on the talent of the agent (underwriters or CEOs) can be written as $V(a,b) = ab$, where $a$ represents the aggregate index of a firm's type and $b$ represents the effective type of agent. That is, $b$ can be understood as a monotonically increasing function in agent's ability $h$ (i.e., $b = f(h)$, where $f'(h) > 0$).

Let $a[j]$ represent the $j$th percentile firm sorted based on the one-dimensional index $a$ and let $b[i]$ represent the value generated by the $i$th percentile agent, where $a'[j] > 0$ and $b'[i] > 0$.[6] Due to sorting and labor market clearing in Equation (7), positive sorting implies that an $i$-th percentile agent thus match with an $i$-th percentile firm: $j^*(i) = i$. Hence, the output created by the $i$th percentile agent can be expressed as

$$V[i] = a[j^*(i)]b[i] = a[i]b[i]. \tag{9}$$

In our underpricing environment, for example, output is measured by underpricing $V[i] = -UP[i]$, where $a[i]$ represents the $i$-th percentile firm sorted based on the one-dimensional index of firm opaqueness given by Equation (6), and $b[i] = -\left(\frac{1-\beta(h[i])}{1+\beta(h[i])}\right)$ represents the value generated by underwriter of prestige $h[i]$. In the standard CEO literature (e.g., Gabaix and Landier (2008)), $a[i] = k[i]$ represents the firm size and $b[i] = \bar{\theta}h[i]$ represents the ability of the $i$th percentile CEO.

In either case, given that the output and wage depend on the characteristics of firms and agents, it is thus difficult to tell whether the change in output/income is driven by either talent or selection effects. Formally, $V'[i] = a'[i]b[i] + a[i]b'[i]$, thus the percentage change of

[6] As explained in Terviö (2008), a central feature of the assignment is that the characteristics $a$ and $b$ are essentially ordinal. It is thus without loss of generality to consider a simple multiplicative function $V(a,b) = ab$. Any separable function, for example, $Aa^{\gamma}b^{1-\gamma}$, can be nested in this expression.

output as function of the rank $i$ yields

$$\frac{V'[i]}{V[i]} = \frac{a'[i]}{a[i]} + \frac{b'[i]}{b[i]}. \tag{10}$$

The first (second) term is the selection (talent) effect, which captures the characteristics of firms (agents).[7]

## 4.2. Decomposition

In either event, accurately assessing worker contribution to the surplus is challenging because of selection effects. To separate selection from talent effects, we make use of the wage distribution.

Let $\omega(b)$ denote the wage schedule with respect to the effective type $b$. According to Equation (8), the marginal wage increase for an agent with type $b$ is given by his contribution to the surplus within the match, given his optimal assignment. That is, $\omega_b(b) = \Omega_b(\mu^{-1}(b), b)$.

The wage for the $i$-th percentile agent is thus given by $\omega[i] \equiv \omega(b[i])$. Given that the optimal assignment for agent $b[i]$ is the firm with index $a[i]$ (i.e., $\mu^{-1}(b[i]) = a[i]$), the slope of the wage profile as a function of the $i$-th percentile agent can then be rewritten as

$$\omega'[i] = \omega_b(b[i])b'[i] = \Omega_b(a[i], b[i])b'[i] = a[i]b'[i]. \tag{11}$$

Recall that the surplus function defined in Equation (4) is given by the change in firm's output when the firm hire agent $b$ relative to no hiring: $\Omega(a, b) = V(a, b) - V(a, \emptyset)$. Thus, the last equality follows from the fact that $\Omega_b(a, b) = V_b(a, b) = a$.

Observe that, unlike the change in the firm output $V'[i] = a'[i]b[i] + a[i]b'[i]$, the wage slope $\omega'[i]$ depends on the change in the characteristic of agent $b'[i]$ but not the change in

[7] If agents and firms are matched randomly, then $a[i]$, which represents the expected type of firm that hires the $i$th agent, will be the same across all agents (i.e., $a'[i] = 0$). In other words, the first term in Equation (10) no longer exists. That is, the expected value generated by the $i$th agent is driven by the talent effect only.

firm's characteristic $a'[i]$. The reason is that, in the competitive market, the slope of the wage for worker $i$ in equilibrium is pinned down to keep the firm $a[i]$ from wanting to hire the next best individual. This explains the economics behind Equation (11): the marginal cost of hiring the $i$th agent is simply the marginal benefit of firm $a[i]$.

This observation thus implies that underlying heterogeneity of firms and talents will affect these two variables in different ways. Specifically, the proportion driven by talent's heterogeneity can be measured by the ratio of the slope of the wage to the change in firms' output:

$$\phi[i] \equiv \frac{\omega'[i]}{V'[i]} = \frac{a[i]b'[i]}{a'[i]b[i] + a[i]b'[i]} = \frac{\frac{b'[i]}{b[i]}}{\frac{a'[i]}{a[i]} + \frac{b'[i]}{b[i]}}. \tag{12}$$

Since the talent (selection) effect is more important when talent's (higher) heterogeneity is higher, $\phi[i]$ thus measures the strength of the selection vs. talent effects, which can be seen from Equation (12). One can see that $\phi[i] = 0$ if and only if all workers are homogeneous (i.e., $b'[i] = 0$), and $\phi[i] = 1$ if and only if all firms are homogeneous. The general relationship is summarized by Proposition 2.

**Proposition 2.** *The measurement $\phi[i]$ decreases with the strength of the selection effect (i.e., the heterogeneity of firms $\frac{a'[i]}{a[i]}$) and increases with the talent effect ( i.e., heterogeneity in agents $\frac{b'[i]}{b[i]}$)*

This quantity is robust to how we specify the outside option of agents as long as it is constant across agents. To the extent these outside options vary across agents, this would change the slope of the wage function.

It is this quantity that we will estimate in the data. Moreover, this ratio simply gives us a sense of how important relatively are talent versus selection effects. Even if talent heterogeneity is small, it can still give rise to large economic differences in output and wages as we highlight below. Before we turn to implementing this decomposition, it is worth highlighting what drives this quantity.

**Determinants of the Relative Strength of Talent versus Selection Effects** We now formalize how the heterogeneity of the underlying distributions of firms and agents affect the observable wages, output, and the strength of the selection effect. First of all, Proposition 2 immediately implies that the scaling effect of firms does not change the strength of the selection.

**Corollary 1.** *When all firms are scaled by some constant* $\lambda > 1$, *that is,* $\tilde{a}[i] = \lambda a[i]$, *both wage and output also change by the same multiple:* $\tilde{\omega}[i] = \lambda\omega[i]$ *and* $\tilde{V}[i] = \lambda V[i]$. *But the strength of the selection effect (i.e.,* $\phi[i]$*) remains the same.*

Such an effect is considered in the CEO setting of Gabaix and Landier (2008), who show that when all firms become bigger, the level of wage increases. Our result provides an additional test for this hypothesis. If this were true, then the strength of the selection effect (i.e., $\phi[i]$) should stay constant.

In the underpricing setting, on the other hand, this means that when all firms become uniformly more opaque, underpricing is scaled up by the same constant. Intuitively, the demand for prestige increases when all firms become more opaque. However, since the increase is uniform across firms, it will not change the matching pattern. That is, all firms match with exactly the same underwriter, but the matching surplus within each pair is simply scaled up by the same constant $\lambda$.

As a result, such a uniform change will not affect the strength of the selection effect. Thus, our model predicts that the observable correlation between prestige and under-pricing (i.e., $\frac{UP'[i]}{UP[i]}$) must remain the same. In other words, the scaling effect cannot explain why the sign of the underpricing-prestige correlation changed signs from negative pre-Internet to positive during and after the Internet period.

Hence, the change of the signs must be driven by the change of underlying distribution of talents or firms, as it affects the strength of the selection effect. In particular, the strength of the selection effect depends on $a'[i]$. Intuitively, a steep $a'[i]$ means that an $i$-th quantile firm has a higher $a$ index relative to the competitor right below it. Similarly, the strength of the direct effect depends on $b'[i]$. As a result, which effect dominates crucially depends on the ratio of these two, which can be mapped onto the ratio of the density function:

$$\frac{a'[i]}{b'[i]} = \frac{dG^A(b[i])}{dG^F(a[i])}. \tag{13}$$

A higher (lower) ratio means that firms are relatively dispersed (homogeneous) relative to the talent distribution, resulting in a stronger (weaker) selection effect. For the sake of illustration, consider a simple case where both firms and agents' effective types (summarized by $a$ and $b$, respectively) follow a uniform distribution. This term is then a constant ratio of the density function (i.e., $\frac{a'[i]}{b'[i]} = \frac{(a^U - a^L)}{(b^U - b^L)}$). This shows transparently that the selection effect is stronger whenever firms are dispersed relative to the talent. The same intuition holds for more general distributions: for any given distribution of talent, the selection effect is stronger when firms are more heterogeneous in the sense that there is a smaller mass for a given $a$. The proposition below formalizes this effect.

**Corollary 2.** *Consider two distributions, where the heterogeneity of firms is higher under* $\tilde{a}[i]$ *in the sense that* $\tilde{a}'[i] \geq a'[i]$ *for* $i$ *and* $\tilde{a}[1] = a[1]$. *For any* $a[i] \geq 0$ *and* $b[i] \geq 0$, $\phi[i]$ *is lower (and thus selection effect is stronger) under* $\tilde{a}[i]$. *On the other hand, an increase in the heterogeneity of agents leads to a weaker selection effect and thus a higher* $\phi[i]$.

# 5. Estimates

The appealing part of this decomposition is that we do not need to measure underlying firm and agent characteristics per se. By comparing the change in firm output and work wages, we can deduce the relative strength of talent versus decomposition effects. This is an alternative diagnostic test to the literature that tries to measure the sorting relationship based on underlying firm and agent characteristics. In this section, we implement this decomposition for IPO underpricing and CEO compensation. Since the data is better for CEO compensation, we start with CEOs first and then consider IPO underpricing.

## 5.1. Time Variation in CEO Wages

Implementing this decomposition for CEO compensation is relatively straightforward since CEO wages are readily available. The data set with CEO compensation runs from 1993 to 2014. Data for CEO compensation typically covers firms in the S&P 1500, with less coverage in the beginning of the sample and more at the end. Following the literature, we focus on the top 1000 firms in terms of market capitalization (where capitalization includes market equity plus book value of debt).

The only key decision variable is what constitutes firm output, which can be measured using net income, firm sales or even market capitalization. We focus on net income but results are similar using other metrics. More specifically, for each firm/year observation, we average a firm's net income for the five previous years including the year of the observation.[8] This intertemporal smoothing reduces measurement errors as annual fluctuations in net income might be due to idiosyncratic capital expensing or other accounting choices.

In general it is hard to know exactly what is firm output in the context of assignment models and hence any proxy we use is necessarily subject to measurement error. As a result of this measurement error, one challenge of measuring $\phi$ for any given $i$-th percentile agent is that the change in net income across agents might be close to zero or negative and hence create ill-behaved estimates. With this caveat in mind, we propose a robust way of estimating $\phi_t$.

We sort each year CEOs and the firms that hire them into decile bins based on compensation ranks ($n = 1$ is the top compensation bin and $n = 10$ the bottom compensation bin). We take the median compensation and median smoothed net income in each bin. We then calculate $\omega'$ and $V'$ across these decile bins and obtain

$$\phi_t = \frac{\omega_t(n) - \omega_t(n+1)}{V_t(n) - V_t(n+1)}.$$

[8] If the firm does not have five years of net income information, we use four years. If it does not have four years, then we use three years.

In other words, we are shrinking compensation $\omega$ and $V$ to the decile bins based on compensation rank before calculating $\phi_t$. It does not matter much whether we bin at deciles or demi-deciles. An alternative which we have also tried is kernel smoothing of wage and net income for each $i$-th percentile agent. This yields qualitatively similar results to this decile-binning approach.

There is debate on whether selection effects due to firm productivity and CEO talent can explain the rise of CEO wages since the 1980s in the CEO literature. The main test in the literature thus far is to show that the increase in the average size of the firm in the stock market can explain the rise in CEO wages (Gabaix and Landier (2008)). But Frydman and Saks (2010)) find that in the pre-1980s period wages of CEOs did not rise even though the average size of the firm in the stock market rose. They point out concerns regarding coincident trends. Alternative explanations such as managerial talent might also be part of the story (see Frydman and Jenter (2010) for a review).

Our decomposition offers an alternative test in Figure 1. In this figure, we plot the median $\phi$ for each year along with bootstrap standard error bands for the 5-th and 95-th percentiles. The standard error bands can be wide in some years but for most of the years, we get a fairly sharp estimate of $\phi$ that is between 4% and 1%. The median estimate is 2%. There does appear to be some trends. For instance, between 1997 and 2001, we see a near doubling of our estimate of $\phi$ from 2% to nearly 4%. Whereas the 5-th percentile during this sub-sample is around 1%, the 95-th rises to nearly 8%. That is, talent heterogeneity or relative importance of talent effects seems to have nearly doubled during the Internet boom of 1997-2001. But this is then followed by a steady drop in the importance of talent effects post the Internet boom. In the recent period our estimates place talent effects at around 1.5% with 5-th and 95-th confidence intervals of 1% and 3.5%, respectively. Our decomposition suggests that part of the rise in CEO wages is due to time variation in talent effects but clearly selection effects play a large role.

Moreover, the coexistence of a scaling effect and a decrease in talent heterogeneity can result in an increase in firm value but the level of wage remains the same.[9] To see this, when all firms become larger, the level of all firm value increases. However, from the wage Equation (8), a mean-preserving shrink in talent's distribution decreases the wage slope. It can then offset the scaling effect of firm size, leaving the wage function the same. Such a scenario might then explain why the average firm size in the stock market rose pre-1980s but CEO wages did not. We leave verifying this possibility for future research. We have emphasized the time variation in $\phi$ but our analysis provides a first estimate of the levels of $\phi$. Our results show that the heterogeneity in firm is much higher than the one in talent. However, a relative small change in talent can still have large effect on firm firm value, as its impact will be amplified by firms' characteristics as pointed out by Gabaix and Landier (2008).

## 5.2. Time Variation in IPO Underpricing-Prestige Relationship

We now implement our decomposition to understand time variation in the IPO underpricing-prestige relationship. The stylized facts are well summarized in various review papers (see, e.g. Ritter and Welch (2002), Loughran and Ritter (2002)). First, underpricing before the Internet era of the late nineties averaged a few percent and firms that hired prestigious underwriters had lower underpricing. Second, the underpricing became much larger after the late nineties, averaging nearly 20% and coverage by a prestigious underwriter is associated more underpricing. Explanations have typically centered on structural changes in firm objective functions, such as firms underpricing to benefit friends or family in the late nineties, and changes in underwriter strategies, such as underpricing to pay buy-side clients.

We use our model to examine the extent to which selection effects induced by competitive sorting in the labor market for underwriters can account for these stylized facts. Given that

[9]For example, consider that all firms are scaled up by $\lambda > 1$ (i.e., $\tilde{a}[i] = \lambda a[i]$). Assume talents follow uniform distribution $U \sim [\bar{h} - \frac{\Delta}{2}, \bar{h} + \frac{\Delta}{2}]$ with mean $\bar{h}$. Thus, $h[i] = \left(\bar{h} - \frac{\Delta}{2}\right) + i\Delta$. Suppose that the dispersion of talent decreases $\tilde{\Delta} = \frac{\Delta}{\lambda}$ but the mean $\bar{h}$ remains the same. This thus implies that the wage level remains the same as $\tilde{\omega}[i] = \int_0^i \tilde{\omega}'[\tilde{i}]d\tilde{i} = \int_0^i \lambda a[\tilde{i}]\frac{\Delta}{\lambda}d\tilde{i} = \omega[i]$. However, the value of firm increases since $\tilde{V}[i] = \lambda a[i]\left(\left(\bar{h} - \frac{\Delta}{2\lambda}\right) + i\frac{\Delta}{\lambda}\right) = a[i](\lambda - 1)\bar{h} + V[i] > V[i]$.

the Internet period produced a sizeable Internet (new technology) sector that had little cashflows before going IPO, a plausible hypothesis is that the opacity ($a$) distribution most likely has a higher mean, i.e. the average firm becomes more opaque, and also more dispersed or heterogeneous. Indeed, as shown in Ritter and Welch (2002), the composition of firms that go IPO changed during the Internet period. In particular, during this period, firms are much younger and many of them have negative earnings, which thus leads to a higher level of heterogeneity in opacity. While opacity is itself difficult to measure, we can evaluate the importance of each of these changes to the firm distributions using our decomposition, i.e. to estimate the $\phi$.

We follow Loughran and Ritter (2002) and IPO literature in using the IPO underpricing from SDC Platinum from 1990 through 2015. There are several years during that period when there are a very small number of IPOs, so we only include years when there are at least 100 IPOs. This gives us 18 years of IPOs. For each IPO in our sample, we can calculate the underpricing for each IPO offering following the literature as:

$$Underpricing = (ClosingPriceofOffering - OfferPrice) \times NumberofShares.$$

In the IPO underpricing setting, to implement our decomposition, we ideally need the underpricing data and the wages of security analysts working at the bank that the firm hired for underwriting the IPO. While such detailed wage data are not readily available, we can nonetheless gather financial analysts wages data for each year $t$ using the American Community Survey produced by the Census Bureau. We get information on the income of analysts from the March supplements of the Current Population Survey. People sampled in that supplement are asked to report their yearly income the previous calendar year. We gather together the CPS data sets from 1991 to 2016. This gives us income information for the years 1990 through 2015. The income variable we use is total personal wage and salary income.

We limit our sample in three ways. First, we look at people classified as being in the occupation "Securities and financial services sales occupations" using the 1990 Census occupation codes. Next, we look at only at men since we want to compare time trends over time and do not want other trends in terms of men-women pay differentials influencing our comparisons. Finally, we only look at observations that have income above the median for the year. We think the analysts that deal in any way with IPOs would be at the upper half of the income distribution, suggesting that we should not look below the median.

With this sample, we collapse the data into quartiles each year. In contrast to the CEO sample where we have more data in each cross-section, we have a smaller sample of wages (around several hundred wages per year) and hence use quartiles to bin observations rather than deciles. That is, we take the median total income of analysts by quartile for each year. This gives us a data set with four observations each year. We can then use this data set to calculate the $\omega'$. That is, sorting on income quartile we calculate:

$$\omega' = MedianIncome(n) - MedianIncome(n+1),$$

where $n$ corresponds to the income quartile. (Lower $n$ is higher quartile.) We have also tried smaller and larger binning groups. The primary difference is that bootstrap standard errors. The median estimates are similar but the standard errors are the tightest when we bin by quartiles.

While we do not know the underwriters that they work for, we know from earlier work that underwriters with high Carter and Manaster (1990) prestige rankings (i.e. bulge-bracket banks like Goldman, JP Morgan, Morgan Stanley) pay higher wages that lower tiered firms (Stickel (1992)). From data from Jay Ritter, we have a dataset that includes IPO underpricing and the Carter-Manaster ranking of investment bank prestige. We then collapse the data by Carter-Manaster rankings into quartiles by year. That is, for each year/Carter-Manaster ranking quartile, we calculate the median *Underpricing* of the IPOs in that bucket. With this data set, we can then calculate the change in the *Underpricing* across Carter-Manaster ranking quartiles. Then $V'$ is:

$$V' = MediumUnderpricing(n) - MedianUnderpricing(n+1),$$

where $n$ corresponds to the Carter-Manaster quartile rank of the observation within the year (lower n corresponds to higher Carter-Manaster quartile rank).

We then calculate the median $\phi$ for each year along with the bootstrap standard error bands. The graph of this ratio is presented below in Figure 2. The bootstrap standard error bands at the 5-th and 95-th percentile can be quite wide in certain years. But they are precise over the period of interest, during the 1997-2000 Internet period. Notice that $\phi$ is around 0.5% before 1997. It then drops to close to zero in 2000. That is, during the peak of the Internet period in 2000, $\phi$ is close to zero when underpricing is highest and the correlation between underpricing and prestige becomes positive. So it is likely that the flip in the sign of the IPO underpricing-prestige is associated with much lower talent effects or equivalently, much larger selection effects.[10] Right after the Internet boom, the relative talent effect rises again. It then falls as we enter into the recent period of 2013-2015 when there are again many new IPOs with social media.

As in the CEO discussion, we have emphasized the time variation in $\phi_t$. Our analysis here, as in the CEO setting, gives a first estimate of the importance of selection effects. While the proportion of talent effects is also small in this setting it does not mean that the heterogeneity in talent cannot generate enormous differences in value as in the CEO context. Moreover, our analysis focuses on just analyst wages but if wages for investment bankers were

[10]To see why, according to Equation (10), by setting $V[i] = -UP[i]$, the percentage change of underpricing for the $i$th quantile underwriter yields:

$$\frac{UP'[i]}{UP[i]} = \frac{a'[i]}{a[i]} - \frac{2\beta'(h[i])h'[i]}{((1-\beta(h[i])^2)}. \tag{14}$$

Under competitive sorting, we have have $a'[i] > 0$. And thus $UP'[i] > 0$ if the selection effect dominates (i.e., $\frac{a'[i]}{a[i]}$ is large enough). On the other hand, without the sorting effect, underpricing is always negative associated with prestige. To see this, under random matching $a'[i] = 0$ and thus $UP'[i] < 0$.

available, this could also be used to re-estimate $\phi$. Our qualitative conclusions are unlikely to change since wages of bankers and analysts are both higher at higher Carter-Manaster ranking firms.

# 6. General Settings

More generally, the output function can be non-multiplicative and the sorting can be multi-dimensional. Below, we highlight our prediction in a more general environment and discuss how our measurements remain robust. For example, venture capitalists may affect both the firm's fundamental as well as the underpricing, so that we have

$$U(y,h) = k\bar{\theta}h - \left(\frac{k\sigma}{1+\psi}\right)\frac{(1-\beta(h))}{(1+\beta(h))} - \omega(h).$$

This is then an example where the output function is then non-multiplicative and the sorting can no longer be reduced to one-dimensional index.

**Characterization** In Appendix A.2, we thus provide an algorithm to characterize the assignment function and wages when type spaces are multidimensional. Intuitively, similar to one-dimensional assignment model, the equilibrium wage $\omega(h)$ must be such that it is indeed optimal for firm $y$ to hire agent $\mu(y)$. Thus, the wage schedule $\omega(h)$ together with the assignment function $\mu(y)$ must be such that a firm's first-order condition is satisfied: if firm $y$ chooses to match with agent $\mu(y)$ in equilibrium, then his marginal benefit of precision must equal the marginal cost. As illustrated in Figure 3, each line represents the set of firms such that, given the wage schedule, $\omega_h(\mu(y)) = \Omega_h(y, \mu(y))$.

Furthermore, to make sure that the market-clearing condition is satisfied, $\omega_h(h)$ must be chosen so that the measure of firms below the line coincides with $G^A(h)$. That is, the wage schedule must be constructed in a way so that the measure of firms that find a particular talent type $h$ too expensive coincides with the measure of agents below $h$. As long as this condition is satisfied, Chiappori et al. (2016) establishes that the constructed algorithm guarantees a stable matching equilibrium.[11]

**Robustness** We now discuss how our measures change in the general setting. When firms' types are multi-dimensional, there is no obvious ordering of the firms' types. Thus, unlike the one-dimensional case, firms can no longer be ranked by one index $a$. However, agents can still be ranked by their skill index $b[i]$. So, the equilibrium solution still describes the matching for any agent $i$. Specifically, when the characteristics of firms are $m$ dimensional, $\boldsymbol{a}[i] = (a_1[i], a_2[i], ..., a_m[i])$ is now defined as the vector that describes the characteristics of the firm that is matched with $i$-th percentile agent. The output of the firm associated with $i$-th percentile agent is then given by $V[i] = V(\boldsymbol{a}[i], b[i])$.

Furthermore, analogous to Equation (11), in the multidimensional environment, the slope of the wage schedule for the $i$-th percentile agent is his marginal contribution to the surplus within the match: $\omega'[i] = \Omega_b(\boldsymbol{a}[i], b[i])b'[i]$, where the only difference is that $\boldsymbol{a}[i]$ is now a vector. Given that $\Omega_b(\boldsymbol{a}, b) = V_b(\boldsymbol{a}, b)$, $\phi[i]$ in the general setting thus becomes:

$$\phi[i] = \frac{\omega'[i]}{V'[i]} = \frac{V_b(\boldsymbol{a}[i], b[i])b'[i]}{\Sigma_{n=1}^{m} \left(V_{a_n}(\boldsymbol{a}[i], b[i])a'_n[i]\right) + V_b(\boldsymbol{a}[i], b[i])b'[i]}. \tag{15}$$

Similar to the one-dimensional sorting setting, this ratio captures the importance of talent heterogeneity, as it increases with the marginal benefit of hiring the $i$-th agent relative to the next best individual, captured by the term $V_b(\boldsymbol{a}[i], b[i])b'[i]$. On the other hand, the first term in the denominator captures the effect of firms' heterogeneity, which is now multidimensional. Notice that the result for the separable one-dimensional case can be understood as a special case of this general setting by setting $m = 1$ and $V_{a_1}(\boldsymbol{a}[i], b[i]) = b[i]$ and $V_b(\boldsymbol{a}[i], b[i]) = a[i]$, which gives the simpler expression in Equation (15). In other words, the $\phi_t$ measure even in a general setting is a diagnostic of the relative strength of talent to selection effects.

[11] Chiappori et al. (2016) refers this nested condition. See Appendix A.2 for a detailed discussion.

## 7. Conclusion

Firms hire in labor markets, be it underwriters when going public or executives on an ongoing basis, to improve firm value. But assessing the value of these hires for stock prices is challenging because of selection since more opaque firms with higher costs of capital and lower valuations to begin with might hire better agents. By developing an assignment model, where matching surpluses, firm valuation, and wages emerge from a stock-market equilibrium, we derive a decomposition of selection from the direct effect of agent talent. We find that talent of underwriters and CEOs account for 0.5% and 2% of the heterogeneity in firm values, respectively. We also use this decomposition to understand changes over time in IPO underpricing and the surge in CEO wages since the 1980s. This decomposition is easy to implement when there is wage and firm profit data and can potentially applied in many other settings as a diagnostic test for selection versus talent effects.

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# A. Appendix

## A.1. Detailed Derivation for Underpricing

For any given fraction of uninformed investors, the price at which shares are sold to investors must be such that uninformed investors expect to break even on average. Thus $\tilde{p}_{hy}$ must solve

$$0 = \frac{1}{2}\beta(h)\left(\frac{k(\bar{\theta}+\sigma)-\omega(h)}{1+\psi} - \tilde{p}_{hy}\right) + \frac{1}{2}\left(\frac{k(\bar{\theta}-\sigma)-\omega(h)}{1+\psi} - \tilde{p}_{hy}\right).$$

To interpret this break-even condition, if $\beta(h) = 1$, and all investors are uninformed, there is no winner's curse since the uninformed investor will with 50% chance get the asset when the valuation is low and 50% chance get the asset when the valuation is high. But if $\beta(h) < 1$ and hence some fraction of the investors are informed, the informed investors will only buy when the valuation is good. That is, from the viewpoint of an uninformed investors, when the project has a high valuation, the probability that an order is filled is $\beta(h) < 1$. Hence, the share price for firm $y$ that hires an underwriter with ability $h$ is then given by

$$\tilde{p}_{hy} = \frac{k\left(\beta(h)(\bar{\theta}+\sigma)+(\bar{\theta}-\sigma)\right)}{(1+\beta(h))(1+\psi)} - \frac{\omega(h)}{1+\psi}.$$

This then gives us the expression in Equation (3).

## A.2. Characterization for Multidimensional Sorting

As discussed in Chiappori et al. (2016), when type spaces are multidimensional, it is generally not possible to derive a closed-form solution for the assignment function. Nevertheless, one can see that the characteristics of firms can be further reduced to aggregated indices in our setting, thereby simplifying our characterization. Facing equilibrium fee $\omega(h)$, $\omega_h(h)$ represents the marginal cost of a particular precision from the view point of firms. From the first-order condition, if firm $y$ chooses to match with agent $\mu(y)$ in equilibrium, then his marginal benefit of precision must equal the marginal cost. That is, $\Omega_h(y, \mu(y)) = \omega_h(\mu(y))$.

In other words, once we have figured out the value of $\omega_h(h)$, one can then find the set of firms matched to agent $h$. Note that when firms differ in multiple dimensions, two different types of firms may have the same marginal value of $h$. To facilitate the analysis, define the set of firms $y$ whose marginal benefit of $h$ is given by a value of $m$ :

$$\Upsilon(h, m) \equiv \{y \in Y \mid \Omega_h(y, h) = m\}.$$

That is, if the marginal cost of hiring agent $h$ is given by $\omega_h(h)$, then $\Upsilon(h, \omega_h(h))$ is the set of firms matched to agent $h$.

Clearly, $\omega_h(h)$ is an equilibrium object that depends on the underlying distribution. We now consider the following algorithm that allows us to construct an explicit solution for this multi-dimensional environment. The basic idea of the equilibrium construction is the following.

First, for each $h$, we will need to choose some level $m \in R$ that satisfies the following condition:

$$\underline{Y}(h, m) \equiv \nu^F (\{y \in Y \mid \Omega_h(y, h) \leq m\}) = G^A(h). \tag{16}$$

By choosing $m$ properly for each agent $h$, the measure of firms whose marginal benefit of $h$ is lower than $m$ exactly coincides with the measure of agents below $h$. Intuitively, if $m$ were the price for ability $h$, all firms within (outside of) the set $y \in \underline{Y}(h, m)$ find this type of agent to be too expensive (cheap).

Choosing $m$ for each $h$ is thus as if we are choosing the price for any given ability. Equation (16) requires that, in equilibrium, the price for any particular ability must be chosen in a way so that the measure of firms that find this type of agent to be too expensive exactly coincides the measure of agents below this agent.

As established in Chiappori et al. (2016), this algorithm works only in the environment where the constructed $\omega_h(h)$ in the above procedure satisfies the following *nested* condition:

$$\underline{Y}(h, \omega_h(h)) \subset \underline{Y}(h', \omega_h(h'))\, \forall h' > h. \tag{17}$$

The construction of the fee schedule is such that if a firm finds that hiring agent $h$ is too expensive, then it must find a better agent $h' > h$ to be too expensive as well.

Observe that Condition (17) together with Condition (16) guarantee that (1) the set of firms that found $h$ to be too expensive are always matched to firms below agent $h$ and (2) the market clears in the sense that the measure that firms that hire agents below $h$ coincides with the measure of agents below $h$. As a result, the optimality condition of firms and market-clearing condition are satisfied. The following Lemma summarizes the characterization.

**Lemma 1.** *Let $\omega_h(h)$ be the value that solves $\underline{Y}(h, \omega_h(h)) = G^A(h)$. Under nested matching (i.e., if condition (17) holds), the optimal assignment is characterized by $\mu^{-1}(h) = \Upsilon(h, \omega_h(h))$.*

*Proof.* By construction, Equations (16) and (17) guarantee that the market clearing condition is satisfied: the measure of agents below $h$ is the same as the measure of firms that hire agents whose precision is lower than $h$. We now examine firms' optimality condition.

Recall that $\Upsilon(h, \omega_h(h))$ is the set of firms that are matched to agent $h$,

$$\Upsilon(h, \omega_h(h)) \equiv \{y \in Y \mid \Omega_h(y, h) = \omega_h(h)\}.$$

Since $U(y, h) = \Omega(y, h) - \omega(h)$, it thus shows that the FOC of firms is satisfied as $U_h(y, \mu(y)) = \Omega_h(y, \mu(y)) - \omega_h(\mu(y)) = 0$.

We now show that $\mu(y)$ is indeed the *maximum* of $U(y, h)$. Condition (17) suggests that, for any $h' > \mu(y)$, $y \in Y(\mu(y), \omega_h(\mu(y)) \subset Y(h', \omega_h(h'))$. That is, the marginal cost of a hiring a better agent $h'$ is too high:

$$\Omega_h(y, h') < \omega_h(h)\, \forall h' > \mu(y).$$

That is, $U(y, h)$ decreases with $h$ for $h > \mu(y)$. Similarly, hiring an agent with lower precision is too cheap:

$$\Omega_h(y, h') > \omega_h(h) \, \forall h' < \mu(y).$$

Thus, $U(y, h)$ increases with $h$ for $h < \mu(y)$. Hence, the constructed $\mu(y)$ solves the firm's optimization problem. □

## A.3. Omitted Proofs

### A.3.1. Proof for Proposition 1

*Proof.* From Equations (5), observe that $U_h(k, \psi, \sigma, h)$ increases with $k$, $\sigma$, and $\frac{1}{1+\psi}$. According to Milgrom and Segal (2002), $\mu(k, \psi, \sigma)$, the solution to $\max_h U(y, h)$, must increase with $k$, $\sigma$, and $\frac{1}{1+\psi}$. Since $U_h(y, h) = \Omega_h(y, h) - \omega_h(h)$, this is equivalent to looking at the complementarity of the surplus function, as is standard in matching models. Similarly, for CEO case, $U_h(k, h)$ increases with $k$. Thus, the firm with higher $k$ will hire a more talented CEO. □

### A.3.2. Proof for Proposition 2

*Proof.* This follows immediately from Equation (12). □

### A.3.3. Proof for Corollary 1

*Proof.* Given that $\tilde{a}[i] = \lambda a[i]$, $\tilde{V}[i] = \tilde{a}[i]b[i] = \lambda V[i]$ and $\tilde{\omega}[i] = \int \tilde{a}[j]b[j]dj = \lambda\omega[i]$. Furthermore, given that

$$\frac{\tilde{a}'[i]}{\tilde{a}[i]} = \frac{\lambda a'[i]}{\lambda a[i]} = \frac{a'[i]}{a[i]},$$

according to Equation (12), $\tilde{\phi}[i] = \phi[i] \, \forall i$. □

#### A.3.4. Proof for Corollary 2

*Proof.* For a change in the distribution that implies a higher heterogeneity (i.e., a higher $a'[i]$) with the same maximum, it thus implies that $\tilde{a}[i] < a[i]$ $\forall i < 1$. And hence, for any $a[i] \geq 0$, $\frac{\tilde{a}'[i]}{\tilde{a}[i]} > \frac{\tilde{a}'[i]}{\tilde{a}[i]}$, and thus, by Proposition 2, a stronger selection effect (lower $\phi[i]$). Similarly, for any $b[i] \geq 0$, an increase in $b'[i]$ leads to a higher $\frac{b'[i]}{b[i]}$ and thus higher $\phi[i]$. □

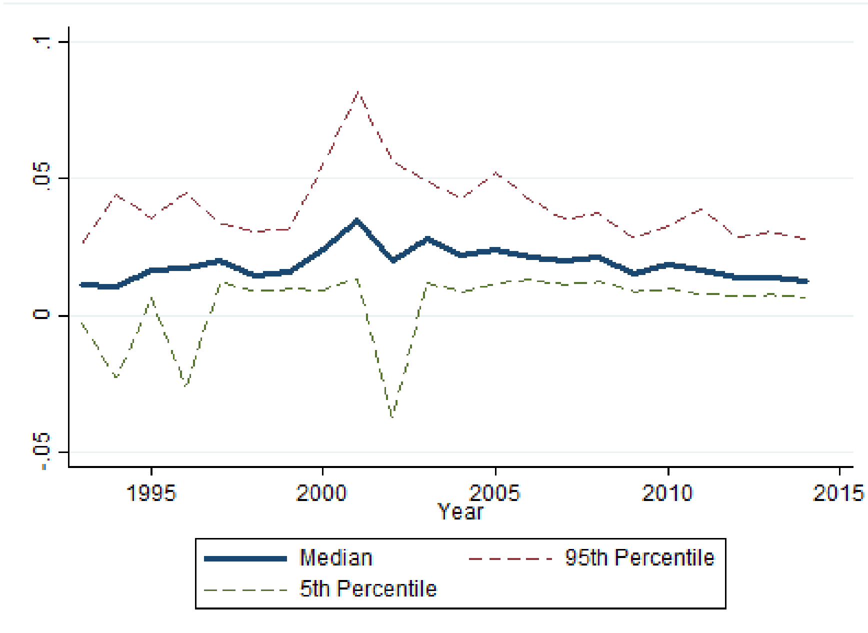


Figure 1: **Proportion of Talent Effect ($\phi$) for CEOs**. Sample period: 1993-2014. Each year we place CEOs and firms into decile bins based on CEO compensation. We take the median values for compensation and net income within each decile bin. We then calculate $\phi$ defined as the change in wage divided by the change in net income across bins. We report the median value of the $\phi$'s for each year along with bootstrap standard errors at the 5-th and 95-th percentiles.

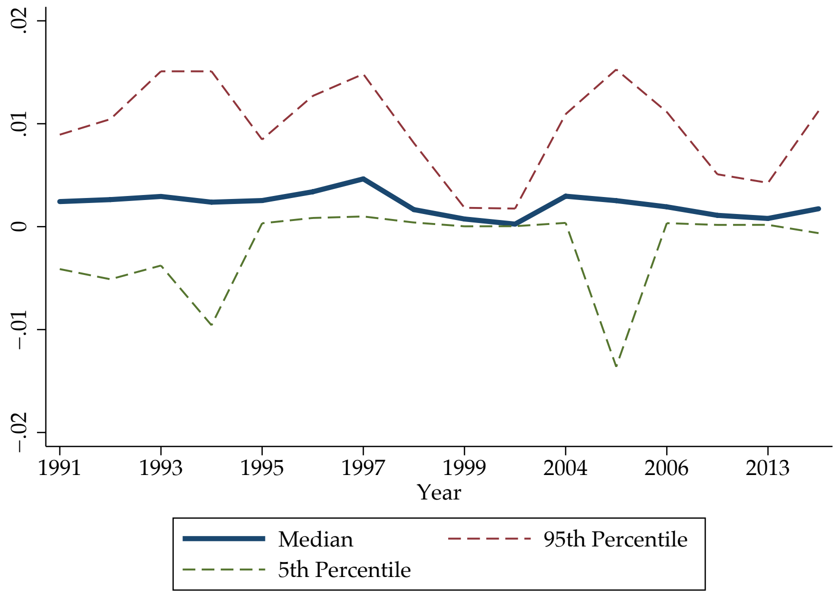


Figure 2: **Proportion of Talent Effect ($\phi$) for IPO Underpricing**. Sample period: 1990-2015. Each year we sort analysts into quartiles based on compensation. We take the median compensation of analysts in each quartile and calculate the change in these medians across quartiles. Each year we sort IPOs into quartiles based on Carter-Manaster rankings of the underwriters. We calculate the median IPO underpricing for each quartile and the change in these medians across quartiles. We calculate $\phi$ by taking the ratio of the changes in wages and changes in underpricing across quartiles. We report the median $\phi$ each year along with bootstrap standard errors at the 5-th and 95-th percentiles.

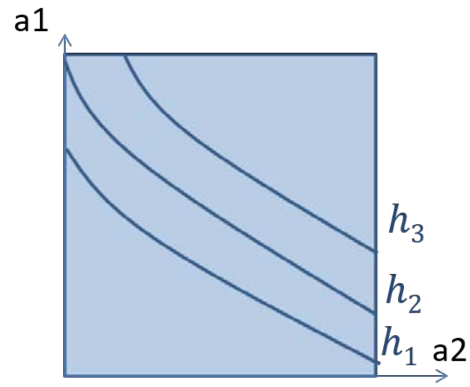


Figure 3: **Characterization for Multidimensional Sorting**: Consider agents with ability $h_i$, where $h_3 > h_2 > h_1$ and firms' type are two-dimensional, summarized by two indices $y = (a_1, a_2)$. Assume that $\Omega_{13}(a_1, a_2, h) > 0$ and $\Omega_{23}(a_1, a_2, h) > 0$, so firms with higher index $a_1$ or $a_2$ will hire a better agent. Each line represents the set of firms $y$ that hires agent $h_i$. The construction of the wage schedule schedule $\omega(h)$ together with the assignment function $\mu(y)$ must satisfy (1) firms' optimality condition: $\Omega_h(y, \mu(y)) = \omega_h(\mu(y))$ for any firm $y$, and (2) the market-clearing condition: the measure of firms below the indifferent set for agent $h_i$ is equal to the measure of agents below $h_i$.