Abstract

I study how the distribution of CEO talent and that of CEO compensation vary across industries, and how product market characteristics affect these distributions. I develop a general equilibrium model that incorporates the competitive assignment of CEOs to firms in a framework in which firms engage in imperfect product market—specifically, monopolistic—competition. I use the model to address the following principal research questions: (i) How important is managerial talent when the product market environment in which firms operate is considered? (ii) How do product market characteristics, such as the entry cost and the elasticity of substitution between differentiated products, affect CEO compensation? (iii) How does the distribution of CEO talent vary across industries? (iv) To what extent can product market characteristics explain the wide variation in the levels and distributions of CEO compensation across industries?

Adopting the method of Terviö (2003, 2008) to identify the unobserved factor distributions, I calibrate my structural model to a sample of firm-CEO observations industry by industry. I then conduct several counterfactual experiments using the respective calibrated models. I find that the distribution of CEO talent does, indeed, vary dramatically across industries. More importantly, contrary to the conclusions of earlier studies that abstract away from product market characteristics (Terviö, 2008 and Gabaix and Landier, 2008), the impact of CEO talent on firm value appears to be quite significant. My estimates of the effect of CEO talent on firm value for the industries in my sample are two orders of magnitude higher than those obtained by Terviö (2008) and Gabaix and Landier (2008). Further, my estimates suggest that the compensation of CEOs is quantitatively in line with their contributions to firms. Broadly, my study shows that it is important to incorporate characteristics of the product market when assessing the contributions of CEOs to firms.

JEL Classification: D43, D59, G30, J24, J31, L11, L13, M52

Key Words: CEO Talent, Firm-CEO Matching, CEO compensation, Monopolistic Competition, General Equilibrium

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1 Introduction

In 2005, the average (median) CEO in the energy and telecom industries earned $10.22 (4.72) million and $7.48 (3.86) million, respectively, whereas the average (median) CEO in the consumer durable goods industry earned only $3.24 (2.68) million (based on data on S&P 1500 firms). The difference between the maximum and minimum CEO pay levels within an industry ranges from $12.63 million in the consumer durable goods industry to $92.20 million in the business equipment industry. Why do the levels and distributions of CEO pay vary so dramatically across industries? Are variations in industry characteristics largely responsible for the variations in the distributions of CEO pay or do inter-industry variations in the distributions of managerial ability/talent play an important role in explaining these findings? How important is managerial talent when industry characteristics and, more generally, the product market environment in which firms operate are considered? To what extent do product market characteristics affect the levels and distributions of CEO compensation and firm value across industries?

I address these questions by developing a general equilibrium model in which the competitive assignment of CEOs to firms and imperfect product market competition among firms interact to determine the distributions of firm value and managerial compensation. Managers of different talent levels are matched to firms of different qualities, and their match quality determines firm productivity. There exists a unique, stationary general equilibrium of the model in which CEO-firm matches and the distributions of firm market value and managerial compensation are endogenously determined. I calibrate the structural model to a sample of firm-CEO observations in each of twelve Fama-French industries (except for finance, regulated, and other miscellaneous industries). In addition to the key structural parameters of the model, I also indirectly infer the unobserved factor distributions—the distributions of CEO talent and firm quality—by matching the observed distributions of firm value and CEO compensation in each industry. I then conduct counterfactual experiments using the respective calibrated models to explore the quantitative effects of managerial talent and product market characteristics.

First, I show that there is substantial variation not only in the distributions of firm quality and managerial talent across industries, but also in their relative contributions to firm value. The dis-
persions of these attributes are much larger in high-tech industries—including business equipment, health care, and telecom—relative to traditional manufacturing industries. Second, in contrast with the strikingly small estimate obtained by Gabaix and Landier (2008), I find that, when product market characteristics are taken into account, CEO talent has a much more significant impact on firm value. My estimates of the impact of CEO talent are largely two orders of magnitude higher than that of Gabaix and Landier (2008). My results show that the incorporation of product market characteristics and intra-industry competition among firms plays a central role in generating the significantly different estimates. Third, again in contrast with the findings of Gabaix and Landier (2008) and Terviö (2008), my estimates of the impact of CEO talent on firm value are of the same order of magnitude as the ratio of CEO compensation to firm value. The finding suggests that the compensation of CEOs is, in fact, roughly in line with the marginal products of CEOs. Fourth, I analytically derive a number of novel implications for the effects of product market characteristics on the number of active firms in an industry as well as the distributions of managerial compensation and firm value.

I build a discrete time, infinite horizon model of an industry in which there is a continuum of heterogeneous firms engaged in imperfect product market—specifically, monopolistic—competition and heterogeneous managers. My model builds upon the framework of Plehn-Dujowich and Subramanian (2010) who examine how product market characteristics affect the distributions of CEO compensation and firm size using a general equilibrium framework in which firms are engaged in monopolistic competition (Dixit and Stiglitz, 1977). In their model, however, the assignment process between firms and managers is exogenous and they leave the relative contributions of CEO-specific and firm-specific characteristics to firm output unmodeled. Given the focus of my study, I explicitly incorporate heterogeneity in manager and firm attributes as well as the endogenous matching of CEOs to firms. In addition, unlike their study, I abstract away from incentive considerations as in Terviö (2008) and Gabaix and Landier (2008).

Managers are characterized by a variable referred to as talent, and firms are also characterized by a single variable—firm quality—which is open to various interpretations as discussed by Terviö (2008). Firms are established by entrepreneurs who make an initial sunk investment. Firm quality, which is a random variable drawn from a known distribution, is realized after entry. Consequently,
firms are identical ex ante (i.e. prior to entry), but differentiated ex post. Each firm then hires a manager. Firm qualities and managerial talents are observable to market participants. As in Terviö (2008), the match quality is a multiplicative function of CEO talent and firm quality. The match quality determines the firm’s productivity in each period. Firms are monopolistically competitive in that they take the aggregate price index—the weighted average of the prices charged by each firm—as given when they make their output and pricing decisions. A firm produces in each period unless it faces an exogenous shock that forces it to exit the market (Melitz, 2003).

I derive the unique, stationary equilibrium with free entry in which the matching of CEOs to firms as well as the distributions of firm value and CEO pay are endogenously determined. The equilibrium satisfies a number of conditions. First, the free entry condition implies that the value of an entering firm—which rationally anticipates the outcome of the matching process between firms and managers—equals the entry cost. Second, in the stationary equilibrium, exiting firms are exactly replaced by new entrants so that the mass of firms remains constant through time. Third, the market clearing condition is satisfied in equilibrium, that is, the aggregate revenue of firms equals the aggregate payoffs to entrepreneurs, managers and workers. The equilibrium of the model depends on product market characteristics—the entry cost, the elasticity of substitution between products, and the exit probability of firms—as well as the distributions of managerial talent and firm quality.

My structural approach requires the identification of the unobserved distributions of firm quality and managerial talent—that are unobservable to the econometrician—as well as the estimation of unknown model parameters such as the exit probability and the elasticity of substitution between products that determine the product market structure. I treat a sample of firm-CEO observations that belong to an industry as an industry equilibrium outcome. Thus, I choose a set of quantiles of the observed distributions of firm market value and CEO pay as the moments to be matched to the corresponding model-predicted statistics. In addition, I use the entire observed distributions to identify the unobserved factor distributions as in the analysis of Terviö (2003, 2008). This calibration process determines the set of parameter values and factor distributions that minimize the distance between the model-predicted and observed moments. Because I employ a general equilibrium model, the parameter values and factor distributions in the estimated model allow the
computation of counterfactuals about the quantitative effects of managerial talent and product market characteristics not only on the distributions of firm value and managerial compensation, but also on consumer welfare in the market.

There is significant variation in the inferred distributions of firm quality and managerial talent across industries. Consistent with what casual empiricism might suggest, the dispersions of CEO talent and firm quality are much larger in high-tech industries, such as business equipment, health care, and telecom, relative to traditional manufacturing industries. To examine whether this result is induced by inter-industry differences in compensation structure, I repeat the same procedure using CEO current compensation including only salary and bonus and obtain very similar results. Second, in line with anecdotal and empirical evidence (e.g., Daines, Nair, and Kornhauser, 2005; Pan, 2010; Falato, Li and Milbourn, 2010), I show that managerial talent is, indeed, an important factor in the production process as differences in managerial talent could make a significant difference to firm market value. Following Gabaix and Landier (2008), I measure the impact of talent as the benefit the median firm could obtain from the replacement of the current CEO with the best one in the same industry. My estimates for different industries in my sample, which are obtained by explicitly incorporating product market influences, are largely two orders of magnitude higher than the strikingly small estimate of Gabaix and Landier (2008), who abstract away from product market effects. For example, the median firm in the business equipment industry could obtain an about 2.9% increase in its market value if its CEO were replaced with the best CEO. It should also be noted that, while the ratio of extra compensation payments to be incurred if the firm had to provide the best CEO with his current level of compensation is larger than the CEO’s impact on the firm’s value, it is not orders of magnitude higher as in Gabaix and Landier (2008). For instance, for the median firm in the business equipment industry, the ratio of additional future compensation payments to firm value is 10.7%. For other industries too, the costs are about three or four times greater than the benefits. This finding suggests that the remunerations of CEOs are roughly in line with their relative contributions to firms.

Moreover, I find that the impact of CEO talent varies dramatically across industries. The median firm in the business equipment and health care industries could increase its market value by about 2.9% and 2.5%, respectively, whereas the sizes of the impacts in the chemical, consumer
durable goods, and manufacturing industries are only 0.85%, 1.15% and 1.16%, respectively.

Finally, I analytically derive the effects of product market characteristics on consumer welfare, the mass of active firms, and the distributions of firm market value and managerial compensation. A decline in the entry cost and/or the exit probability leads to more firms in the market and, therefore, tougher price competition, which in turn increases consumer welfare, but lowers the levels of firm market value and CEO pay. While the effects of a marginal increase in product substitutability depends on the values of other parameters, my counterfactual analysis of the calibrated models yields clear predictions. An increase in this parameter induces less firms to enter the market, which in turn lessens price competition. Thus, consumer welfare declines. Since the marginal return to managerial talent on average decreases with this parameter, so does the average managerial compensation. Furthermore, these effects of product market characteristics vary quantitatively across industries. Taken together, my results in this paper suggest that industry-related factors, including those linked to the CEO labor market and those linked to the product market, are very critical determinants of the levels and distributions of CEO compensation.

My work revisits the fundamental question of how important managerial talent is if competition for CEO talent in an efficient labor market exists, which is raised and explored by recent work of Terviö (2003, 2008) and Gabaix and Landier (2008). Both studies document that differences in CEO talent are very small and have little influence on shareholder value that is largely driven by firm-specific factors. The findings on the limited role of managerial talent run counter to the common notion that managerial competence is an important factor affecting firm performance, which is supported by recent empirical studies (Bertrand and Schoar, 2003; Daines, Nair, and Kornhauser, 2005; Bennedsen, Perez-Gonzalez, and Wolfenzon, 2006; Graham, Li, and Qiu, 2010; Pan, 2010; Falato, Li and Milbourn, 2010; Leverty and Grace, 2010). These studies find both statistically and economically significant impact of CEO characteristics, which are especially narrowed down to CEO talent for some studies, on CEO pay and firm performance, controlling for firm characteristics.

To reconcile the results from the competitive assignment models with the empirical evidence, I conjecture that industry matters in determining the level of CEO pay and in identifying the importance of CEO talent. There are three channels through which industry characteristics could affect the assignment process of CEOs to firms and, thereby, the distribution of CEO pay. First,
product market characteristics affect a firm’s gross profit that is generated and shared by the matched firm-manager pair. In other words, the effects of firm quality and managerial talent on the output can differ according to the nature of the product market environment. Second, different industries may be characterized by different degrees of firm heterogeneity, and the sources of firm heterogeneity can also differ across industries. Third, to the extent that markets for CEO talent are segmented by industry, industry-level talent distributions may differ, which suggests that the CEO talent distribution and the effects of CEO talent on firms should be estimated at the industry level rather than at the entire economy level.

Terviö (2008) and Gabaix and Landier (2008) abstract away from industry and product market effects in their models. They estimate their models using a full sample of the largest firms in different industries, that is, they aggregate firms across industries in their estimation exercises. By contrast, given the discussion above, I develop a single industry equilibrium framework in which the competitive assignment of CEOs to firms is incorporated and then estimate the structural model industry by industry. In the literature on CEO turnover, Parrino (1997) and Cremers and Grinstein (2010) report that a dominant portion of new CEOs are insiders of hiring firms or come from other firms in the same industry and that most of those from outside their industries still have some relevant industry experience such as business relationships. The latter study further documents cross-industry differences in CEO selection practices and their explanatory power when examining different CEO compensation practices, thereby providing the evidence of fragmented CEO talent pools across industries. These studies in part support my premise that there are CEO labor markets composed of senior managers within or outside firms in the same industry who have industry-specific skills.

The rest of this paper proceeds as follows. Section 2 reviews the related literature in more detail. In Section 3, I present the model with three stages. Section 4 characterizes the equilibrium of the model and provides some theoretical implications. In Section 5, I describe my data and estimation procedure. Section 6 presents the results of the model calibration, including the structural parameter estimates and the factor distributions implied by the data. Section 7 contains counterfactual exercises using the calibrated models, and Section 8 summarizes and concludes.
2 Related Literature

As discussed earlier, my work contributes to the recent literature initiated by Terviö (2003) that studies CEO pay levels in a competitive assignment framework. In Terviö (2003, 2008) and Gabaix and Landier (2008), the underlying idea is that, in a competitive and frictionless labor market for CEO talent, CEOs with different talents are competitively matched to heterogeneous firms at different pay levels. Both studies mainly argue that while talent differences between CEOs are very small, significant differences in firm quality, which is complementary to CEO talent and thus implies the marginal return to talent, can explain large pay dispersions for such small talent differences. In this study, I argue that when industry implications are taken into account, differences in talent themselves can justify different CEO pay levels. By changing the degree of complementarity between firm and managerial attributes in a business cycle model, rather than stressing inter-industry differences, Alder (2009) shows that managerial attributes actually play an important role in the determination of firm size and CEO pay.

My research is related to the literature that addresses how the distributions of firm size and CEO compensation change in response to economic conditions. Grossmann (2007) bases his analysis on the early job assignment model, which considers the allocation of heterogeneous managers across ex ante identical firms, so that ex post firm size and CEO pay differences across firms are solely attributed to the heterogeneity in managerial skills. Other studies, including Raith (2003), Falato and Kadyrzhanova (2007), Baranchuk, MacDonald, and Yang (2010), and Plehn-Dujowich and Subramanian (2010), mainly look at the effects of product market characteristics on optimal managerial incentives by incorporating agency conflicts arising from moral hazard in an industry equilibrium framework. Among these studies, Baranchuk, MacDonald, and Yang (2010) take into account firm and managerial heterogeneity and predict the effects of demand growth and/or production labor market conditions, but their assumption of perfectly competitive product markets is difficult to be applied to many industries. As noted previously, my model builds upon the general equilibrium framework with monopolistic competition in Plehn-Dujowich and Subramanian (2010), but the central mechanism to determine CEO pay in my model is the competitive assignment framework rather than managerial incentive contracts.
Recently, several studies have empirically examined the association between managerial characteristics, especially, managerial talent, and CEO pay and firm performance. Falato, Li, and Milbourn (2010) study the effects of CEO talent on firm performance using a media-based measure of CEO talent, the age of the executive when he took his first CEO job, and the selectivity of his undergraduate college. They document that replacing the CEO of median talent with the most talented CEO in their sample would improve firm operating performance by between 1.3% and 2.3%, which is two orders of magnitude greater than the estimate of Gabaix and Landier (2008) but largely consistent with my estimates for the industries in my sample. Daines, Nair, and Kornhauser (2005) define CEO skill as the persistence of positive performance and the reversal of poor performance and find a positive link between CEO skill and pay especially when pay is performance based and when there are large shareholders. Also, the link between skill and pay appears to be stronger in industries where pay dispersion is large, which supports my conjecture that CEO talent may matter more for firms in some industries than those in other industries. Focusing on the property-liability insurance industry, Leverty and Grace (2010) use several firm efficiency variables obtained from the Data Envelopment Analysis (DEA) as proxies for managerial ability and find that managerial ability plays an important role in reducing the duration of regulatory scrutiny, the likelihood of failure, and the cost of failure. Finally, Pan (2010) estimates an executive-firm matching model incorporating three matching dimensions, one of which is the usual complementarity between firm size and managerial talent, and finds that higher matching quality is associated with better subsequent firm performance.

3 The Model

I develop a discrete-time, infinite horizon model of an industry with dates $t = 0, 1, 2, \ldots$. The industry consists of a continuum of heterogeneous operating firms, heterogeneous managers, and identical production workers. The firms engage in Dixit-Stiglitz monopolistic competition with a constant elasticity of product substitution. Production requires raw labor supplied by production workers and specialized human capital provided by managers.

There are three stages of the model as follows:
• Stage 1: (Entry) A group of (identical) entrepreneurs drawn from the pool of workers establish a firm at date \( t \) by making an initial sunk investment. Subsequent to entry, the firm’s quality is realized. Firm quality is a random variable that is drawn from a known distribution and then remains constant through time. Firms are, therefore, identical ex ante, but differentiated ex post.

• Stage 2: (Assignment) The owners (entrepreneurs) of each firm hire a manager from a continuum of potential managers of various talent levels in a competitive executive labor market. Managerial talent is observable and is constant through time.

• Stage 3: (Production and Exit) In each period, each firm produces its good, generates profit, and pays its manager. It continues over an infinite time horizon unless it faces an exogenous negative shock that forces it to exit the market (Melitz, 2003).

Since each firm’s quality is realized ex post after entry, there is two-sided heterogeneity in the assignment process between firms and managers. I focus on a stationary general equilibrium with free entry in which exiting firms are exactly replaced by new entrants. Consequently, the equilibrium distributions of managerial talent and firm quality among active firms, and the equilibrium distributions of firm market value and CEO pay are stationary.

I solve the model by backward induction. First, I analyze an active firm’s (that is, a firm that matches with a manager) profit maximization problem in each period. Second, I study the competitive assignment problem between heterogeneous firms and managers. Finally, I examine the entry decision of a firm into the market.

3.1 Preferences, Market Demand and Production

There is a single, representative consumer with preferences for consumption of a continuum of goods in each period that are described by the utility function

\[
U = \left[ \int_{\Omega} q(\omega)^{\rho} d\omega \right]^{\frac{1}{\rho}}; 0 < \rho < 1,
\]

where \( \Omega \) is the set of available goods and \( \omega \) is a finite measure on the Borel \( \sigma \)-algebra of \( \Omega \). If
\( p(\omega) \) is the price of good \( \omega \), the following shows the consumer’s utility maximization problem that determines her demand for each good:

\[
\begin{align*}
\max_{q(\omega)} & \quad U = \left[ \int_{\Omega} q(\omega)^{\rho} d\omega \right]^{\frac{1}{\rho}} \\
\text{subject to} & \quad \int_{\Omega} p(\omega) q(\omega) d\omega = R,
\end{align*}
\]

(2)

In the above, \( R \) represents the total expenditure of the representative consumer on goods produced by the industry. It is natural to interpret \( R \) as the size of the industry.\(^1\)

As shown by Dixit and Stiglitz (1977), the optimal consumption of each good is

\[
q(\omega) = U \left[ \frac{P}{p(\omega)} \right]^{1/(1-\rho)},
\]

(3)

where \( P \) is referred to as the aggregate price index and given by

\[
P = \left[ \int_{\Omega} p(\omega)^{\frac{\rho}{\rho-1}} d\omega \right]^{\frac{\rho-1}{\rho}}.
\]

(4)

Further,

\[
R = PU.
\]

(5)

The optimal consumption (3) of each good represents the market demand that the firm producing this particular good faces in the market. From (3), we see that

\[
\frac{q(\omega)}{q(\omega')} = \left[ \frac{p(\omega')}{p(\omega)} \right]^{1/(1-\rho)},
\]

(6)

which implies that any two products in the market are substitutes, and the elasticity of substitution between these products is

\[
\sigma = \frac{1}{1-\rho} > 1.
\]

(7)

This is also the constant price elasticity of demand for each good as seen in (3).

\(^1\)To avoid complicating the analysis, I do not consider the representative consumer’s budgeting procedure that optimally allocates her income to different product markets (industries) with the consideration of interrelations between different groups of commodities. Instead, I treat \( R \) as exogenously given and analyze an industry equilibrium rather than the equilibrium of the whole economy.
I now turn to the production decision of each firm for any period after it has matched with a manager. I describe the assignment process of managers to firms in the next section. Production is driven by production labor supplied by production workers. The firm’s quality and the manager’s talent together determine the firm’s productivity. I normalize the labor wage rate to 1, that is, the labor wage is the numeraire.

More precisely, suppose that the firm has quality $x \in \mathbb{R}_+$ and its manager has talent $y \in \mathbb{R}_+$. As in Tervio (2008), there is complementarity between firm quality and managerial talent. Specifically, the match quality $\theta$ takes the multiplicative form

$$\theta(x, y) = xy.$$  

(8)

The firm’s productivity equals the match quality $\theta(x, y)$, that is, the inverse of the match quality is the firm’s marginal cost of production measured in units of labor.

At the beginning of each period, the firm chooses its price in order to maximize its net profit, that is, revenue net of variable production costs and managerial compensation. Suppose the manager’s compensation is $u$ (this is endogenously determined as the outcome of the matching process between firms and managers). The firm’s net profit is

$$\pi(x, y, u) = \max_p pq(p) - \frac{q(p)}{\theta(x, y)} - u,$$

(9)

where the market demand curve, $q(p)$, is given by (3) (I omit the argument $\omega$ to simplify the notation). Since there is a continuum of firms, each firm takes the aggregate variables $U$ and $P$ as given when it chooses its price and output quantity. The second term on the right hand side of (9) represents total labor wages received by production workers who are employed by the firm. The profit maximization condition equates the marginal revenue with the marginal cost of production, thereby yielding the firm’s optimal price,

$$p(x, y) = \frac{1}{\rho xy}.$$  

(10)
Consequently, the firm produces the following level of its good,

\[ q(x, y) = q(p(x, y)) = RP^{\sigma - 1}(pxy)^{\sigma}, \quad (11) \]

and its resulting revenue is given by

\[ r(x, y) = p(x, y)q(x, y) = R(Pxy)^{\sigma - 1}. \quad (12) \]

The firm’s gross profit (profit before managerial compensation), that is, the output generated by the firm-manager pair in each period that can be comparable with the simple multiplicative form in Terviö (2008), is given by

\[ \Pi(x, y) = p(x, y)q(x, y) - q(x, y)\theta(x, y) = R(Pxy)^{\sigma - 1}\frac{\sigma}{\sigma}, \quad (13) \]

where the impact of match quality on the output level can differ considerably depending on the product market characteristics. Finally, the firm’s net profit is given by

\[ \pi(x, y, u) = \Pi(x, y) - u = R(Pxy)^{\sigma - 1}\frac{\sigma}{\sigma} - u. \quad (14) \]

### 3.2 Assignment of Managerial Talent

I now describe the assignment of managers of different abilities to firms of different qualities and the determination of managerial compensation. Managerial abilities and firm qualities are constant through time. Since the distributions of CEO talent and firm quality are stationary, each firm continues to hire the same type of manager and pays the same remuneration. Hence, its productivity level remains constant over time, and so does its net profit. More specifically, if a firm of quality \( x \) hires a manager of talent \( y \) whose compensation is \( u \), the firm will earn net profit \( \pi(x, y, u) \), given by (14), in each period until it has to exit the market for some exogenous reasons. Denoting the probability of staying in the market for another period by \( \beta \), the firm’s market value, defined as
the present value of future earnings net of the payoffs to the manager, is

$$\phi(x, y, u) = \sum_{t=0}^{\infty} \beta^t \pi(x, y, u) = \frac{\pi(x, y, u)}{1-\beta} = \frac{1}{1-\beta} \left[ \frac{R(P\rho xy)^{\sigma-1}}{\sigma} - u \right].$$ (15)

Following the terminology of Legros and Newman (2007), I refer to the function \(\phi(x, y, u)\) as the bargaining frontier for this firm and denote the quasi-inverse function of \(\phi(x, y, u)\) by \(\psi(x, y, v)\): \(\phi(x, y, \psi(x, y, v)) = v\), where \(\psi(x, y, v)\) implies the maximum payoff to the manager when the firm expects \(v\) as its payoff. I apply the criteria identified by Legros and Newman (2007) to this framework in order to identify the matching pattern between firms and managers. Notice that matching in this perfect information situation is a case of transferable utility, in which the surplus generated from a match can be divided without any restriction, as the payoff \(u\) to the manager is separable from the other arguments in \(\phi(x, y, u)\). Then only the condition of increasing differences needs to be checked so as to show positive assortative matching (hereafter, \(PAM\)) in equilibrium: let \(S(x, y)\) be the total surplus generated by this firm-manager pair, which is the first term of \(\phi(x, y, u)\),

$$S(x, y) = \frac{R(P\rho xy)^{\sigma-1}}{(1-\beta)\sigma},$$ (16)

then it is easily seen that the condition, \(S(x, y) - S(x, y') \geq S(x', y) - S(x', y')\) whenever \(x > x'\) and \(y > y'\), holds.

Having confirmed the unique pattern of \(PAM\), I now describe the derivation of equilibrium matching payoffs to both parties. As in Terviö (2008), I index each side of the matching parties on the unit interval using their cumulative distribution functions, \(F_x(\cdot)\) and \(F_y(\cdot)\), respectively:

$$x[i] = x \quad \text{s.t.} \quad F_x(x) = i,$$

$$y[i] = y \quad \text{s.t.} \quad F_y(y) = i.$$ (17)

Consequently, \(x'[i] > 0\) and \(y'[i] > 0\) where \(i \in [0,1]\), that is, higher \(i\) denotes a more advantaged firm and a more talented manager. By \(PAM\), I can restrict attention to matches where firm \(i\) is matched with manager \(i\).

The total surplus, \(S(x[i], y[i])\) in (16), must be apportioned to the manager and the firm in a way
that ensures the stability of the matching correspondence. Let $u[i]$ be the equilibrium compensation of manager $i$ for each period and $v[i]$ be the equilibrium payoff to firm $i$, that is, its market value. To begin with, I consider participation constraints for both parties. The matching payoffs must be on the frontier of the maximum payoff to each party given its partner’s payoff, $\phi(x, y, \cdot)$ and $\psi(x, y, \cdot)$, respectively, and can never be less than their outside payoffs, $v_0$ and $u_0$, which are assumed to be identical for all types:

$$v[i] = \phi(x[i], y[i], u[i]); \quad v[i] \geq v_0,$$  \hspace{1cm} (18) \\
$$u[i] = \psi(x[i], y[i], v[i]); \quad u[i] \geq u_0.$$  \hspace{1cm} (19)

Note that, by (15), (16), and (18), the relation between $v[i]$ and $u[i]$ is given by

$$S(x[i], y[i]) = v[i] + \frac{u[i]}{1 - \beta} = \frac{R(P\rho x[i]y[i])^{\sigma - 1}}{(1 - \beta)\sigma},$$  \hspace{1cm} (20)

and that the outside payoffs, by definition, imply the payoffs of the lowest active firm-manager pair in the market:

$$S(x[0], y[0]) = v_0 + \frac{u_0}{(1 - \beta)} = \frac{R(P\rho x[0]y[0])^{\sigma - 1}}{(1 - \beta)\sigma}.$$  \hspace{1cm} (21)

The next set of constraints to be considered are incentive compatibility constraints. Each party needs to choose the best matching partner. Let $m(i)$ be firm $i$’s choice variable to choose its manager and $n(i)$ be manager $i$’s choice variable to choose his firm; then the conditions are given by

$$v[i] = \max_{m(i)} \phi(x[i], y[m(i)], u[m(i)]),$$  \hspace{1cm} (22) \\
$$u[i] = \max_{n(i)} \psi(x[n(i)], y[i], v[n(i)]).$$  \hspace{1cm} (23)

As one solves a usual screening problem, I show that a single crossing property holds in the framework analyzed here so that the set of incentive constraints above is equivalent to the following two sets of constraints: (i) Monotonicity and (ii) Local incentive compatibility (Bolton and Dewatripont, 2005). Here, I only describe the procedure for the firm’s constraint (22) because it is
analogous for the manager’s constraint (23). Firm $i$ faces a set of choices that can be described as $(m, u[m])$ and needs to choose the best one. From (15) and (22), it is easy to check the single crossing property that the indifference curve for a higher type has a greater slope, that is, the marginal payoff of partner type $m$ relative to that of payment $u$ rises with firm type $i$:

$$\frac{\partial}{\partial i} \left[ -\frac{\partial v}{\partial m} \right] > 0. \quad (24)$$

As a consequence, the set of incentive constraints can be replaced by the monotonicity condition,

$$\frac{dm(i)}{di} \geq 0, \quad (25)$$

and the local incentive condition,

$$\frac{d\phi(x[i], y[m(i)], u[m(i)])}{dm} \bigg|_{m(i) = i} = 0. \quad (26)$$

Since the monotonicity condition holds due to $PAM$, the firm’s global incentive compatibility is equivalent to the local incentive condition above. The same argument applies to the incentive compatibility for the manager. From the local incentive conditions, the following differential equations in $u[i]$ and $v[i]$ are derived:

$$u'(i) = -\frac{\phi_2}{\phi_3} y'[i] = RP^{\sigma-1} \rho^\sigma x[i]^\sigma - 1 y[i]^{\sigma-2} y'[i], \quad (27)$$

$$v'(i) = -\frac{\psi_1}{\psi_3} x'[i] = \frac{RP^{\sigma-1} \rho^\sigma x[i]^\sigma - 2 y[i]^{\sigma-1} x'[i]}{1 - \beta}, \quad (28)$$

where the second equation can also be obtained from (20). Integrating these slopes from the lowest to type $i$ in the rankings provides the equilibrium payoffs $u[i]$ and $v[i]$, respectively. These equations will be presented in the characterization of equilibrium in Section 4.

### 3.3 Market Entry

Given the distributions of managerial talent and firm quality, I have derived the distributions of firm market value and managerial compensation for active firms in the market. These distributions
are observed by prospective entrants (a group of entrepreneurs) into the market. The entrepreneurs want to establish a firm to enter the market, which requires a fixed investment cost of \( f_e > 0 \) that is nonrecoverable and becomes sunk thereafter. Since the quality \( x \) of a newly established firm is determined once it enters the market, the quality of the firm is an unknown random variable with cdf \( F_x \) in the stage of market entry. By (17), it can be shown that its rank, compared with incumbent firms, is also a random variable with cdf \( G(i) = i \). To decide whether to enter, entrepreneurs should compare the expected market value and the entry cost:

\[
V_e = E[v[i]] - f_e,
\]

where \( V_e \) is the net value of entry. If this value was negative, no one would open up a firm. As free entry to obtain a stationary market equilibrium drives \( V_e \) to zero, I rewrite (29) as

\[
E[v[i]] = \int_0^1 v[i]dG(i) = \int_0^1 v[i]di = f_e,
\]

where the second equality is obtained from \( G(i) = i \), and \( v[i] \) follows from (27) and (28) as will be specified in the next section. Note that \( v[i] \) reflects the possibility that active firms may be hit by bad shocks and forced to exit the market with probability of \( 1 - \beta \). Under the free entry condition (30), exiting firms are exactly replaced by entering firms, and the mass of active firms, to be denoted by \( N \), remains unchanged over time in equilibrium.

### 4 Equilibrium

An equilibrium is characterized by a mass \( N^* \) of active firms, a distribution \( x[i] \) of firm quality, a distribution \( y[i] \) of managerial talent, an aggregate price index \( P^* \), and payoff profiles—managerial compensation \( u[i] \) and firm market value \( v[i] \)—such that

1. Firm profit maximization: In any period, each active firm \( i \) sets its price at \( p(i) \) and produces \( q(i) \) of its good to maximize its net profit as described in (9) where

\[
p(i) = \frac{1}{\rho x[i]y[i]}; \quad q(i) = R P^{*\sigma - 1}(\rho x[i]y[i])^\sigma.
\]
2. Stability in the assignment of managerial talent: A manager ranked at $i$ is assigned to the equally ranked firm $i$, and either party of the matched pair prefers the assigned counterpart to any other assignment at the equilibrium payoff profiles satisfying
\[
v[i] = \frac{1}{1 - \beta} \left[ \frac{R(P^* \rho x[i] y[i])^{\sigma - 1}}{\sigma} - u[i] \right],
\]
\[
u[i] = u_0 + \int_{0}^{i} \left( R \sigma \rho x[j]^{\sigma - 1} y[j]^{\sigma - 2} y'[j] \right) dj.
\]

3. Free entry of firms: The free entry condition determines the aggregate price index $P^*$ as follows
\[
RP^* \sigma - 1 \left[ \frac{(\rho x[0] y[0])^{\sigma - 1}}{\sigma} + \rho^{\sigma} \int_{0}^{1} \left[ \int_{0}^{i} x[j]^{\sigma - 2} y[j]^{\sigma - 1} x'[j] dj \right] di \right] = u_0 + (1 - \beta) f_e.
\]

4. Market clearing: In any period, the aggregate revenue of firms producing in the market must equal the aggregate expenditure $R$ by the representative consumer, that is,
\[
R = \int_{0}^{1} r(x[i], y[i]) N^* di \Rightarrow N^* = \left( \int_{0}^{1} (P^* \rho x[i] y[i])^{\sigma - 1} di \right)^{-1},
\]
which is derived from the revenue function given by (12) and determines the equilibrium mass $N^*$ of producing firms.

It is evident that there exists a unique, stationary equilibrium in which the aggregate price index $P^*$ and the mass $N^*$ of active firms are uniquely determined by equations (34) and (35), respectively, and remain constant over time so that the distributions of firm market value and managerial compensation are also invariant over time.

Based upon the above equilibrium characterization, I analytically explore the effects of product market characteristics, including the entry cost, the likelihood of exit, the market size, and the elasticity of substitution, on the equilibrium outcome. Note that the general equilibrium framework enables me to draw some consumer welfare implications as well as those for firm size and CEO pay. Consumer welfare is measured by the equilibrium utility level of the representative consumer as
follows:

$$U^* = R/P^*.$$ \hfill (36)

Since the market size $R$ is exogenously fixed, consumer welfare in equilibrium is determined by the equilibrium aggregate price index $P^*$. The following proposition describes the effects of product market characteristics on consumer welfare.

**Proposition 1 (Product Market Characteristics and Consumer Welfare)**

- Consumer welfare decreases with the entry cost $f_e$ and the likelihood of exit $1 - \beta$, whereas it increases with the market size $R$.

- Consumer welfare decreases with a marginal increase in the elasticity of substitution $\sigma$ if the entry cost $f_e$ or the likelihood of exit $1 - \beta$ is smaller than their respective thresholds, denoted by $\tilde{f}_e(\sigma)$ and $1 - \tilde{\beta}(\sigma)$, respectively, and increases if $f_e > \tilde{f}_e(\sigma)$ or $1 - \beta > 1 - \tilde{\beta}(\sigma)$.

The impact of $f_e$, $1 - \beta$, or $R$ can be immediately seen from (34), as consumer welfare is inversely related to the aggregate price index. The effect of a marginal increase in $\sigma$ depends on other parameters. Keeping the aggregate price as it is, one can show that the left-hand side of (34) increases with a marginal increase in $\sigma$ when the price index is above a threshold and decreases otherwise. This observation in turn implies that, to satisfy the free entry condition for the new value of $\sigma$, the aggregate price index must decrease in the former case but increase in the latter case. Since there is a monotonically positive relation between the entry cost $f_e$ or the exit probability $1 - \beta$ and the aggregate price index as shown in (34), whether or not the original aggregate price index exceeds the threshold can be replaced by whether each of these parameters is above or below its threshold, which gives the second result of Proposition 1.

**Proposition 2 (Product Market Characteristics and the Mass of Firms)**

- The mass of active firms declines with the entry cost $f_e$ and the likelihood of exit $1 - \beta$, but increases with the market size $R$.

- The mass of active firms may decrease or increase with a marginal increase in the elasticity of substitution $\sigma$. 

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Proposition 2 shows how the mass of active firms is affected by the product market characteristics. While the first result is easily obtained from equations (34) and (35), the impact of product substitutability is ambiguous. I discuss the intuition underlying the observations in Propositions 1 and 2. First, an increase in either the entry cost or the exit probability deters potential firms from entering the industry because the expected value of entry, given by (29), is negative. Accordingly, there will be fewer firms operating in the market, which, in turn, dampens competition, resulting in a higher aggregate price index (lower consumer welfare). Second, an increase in the market size $R$ will first attract more entrants due to the expectation of a higher profitability. However, as price competition becomes severe, the aggregate price index will go down, thereby improving consumer welfare. Third, contrary to the other product market characteristics, the elasticity of substitution $\sigma$ affects the aggregate equilibrium outcome in a complex way. Notice that, if $\sigma$ is high, then products in the market are more substitutable so that firms face a more price-elastic market demand. As shown in (35), the effect of this measure of market competition on the mass of firms depends on the other product market characteristics and the factor distributions. I therefore empirically explore the effects of product substitutability after calibrating the model to data in the next section.

Proposition 3 (Product Market Characteristics, Firm Market Value, and CEO Pay)

- Managerial compensation increases with the entry cost $f_e$ and the likelihood of exit $1 - \beta$, but is not affected by the market size $R$.

- Firm market value increases with the entry cost $f_e$, but does not change with the market size $R$. However, the effect of the exit probability $1 - \beta$ is ambiguous.

- There exits a trigger $\bar{i}$ such that managerial compensation increases with a marginal increase in the elasticity of substitution $\sigma$ if $i > \bar{i}$, but decreases if $i < \bar{i}$.

Based upon the implications for the aggregate equilibrium variables in the previous propositions, Proposition 3 describes the firm-level effects of product market dimensions. Combining equation (34) with (32) and (33) gives the first two results in this proposition. In particular, an increase in the market size $R$ boosts each firm’s profit at the current price index, but the increase in the number of firms due to the expectation of a higher profitability drives the aggregate price index
down. Since these effects exactly cancel out, an individual firm’s market value and its managerial compensation do not change in response to the increase in the market size. The last result is obtained by differentiating the right hand side of (33) coupled with (34). This observation implies that a marginal increase in product substitutability \( \sigma \) affects CEO compensation differently across firms, which may lead to higher CEO pay dispersion within an industry.

5 Estimation

To quantitatively investigate the extent to which managerial talent and product market characteristics affect the distributions of firm size and managerial compensation, I calibrate the model to U.S. data. The theoretical model presented in the previous section represents a single industry framework. Accordingly, I calibrate the model industry by industry using a sample of firm-CEO observations belonging to the respective industry and then compare the calibrated models across industries.

5.1 Data

My sample includes S&P 1500 firms from the ExecuComp database. Firm-specific variables are obtained from the Compustat annual database, the U.S. GDP deflator is downloaded from the website of the Bureau of Economic Analysis (BEA), and the Fama-French twelve industry classification and industry portfolio returns are provided by Kenneth French’s website. I collect firm-CEO observations over the period 1992-2009 except for those in which sales or book value of equity is nonpositive. I partition the entire sample into different industry sectors. Among the twelve groups, financial firms (SIC = 6000-6999) are excluded because the model is applicable to conventional firms producing goods and services and selling them to consumers instead of financial intermediaries. In addition, I do not include regulated firms (SIC = 481 and 4900-4949) based on Loughran and Ritter (1997), because the assessment of monopolistic competition is difficult in regulated industries. By excluding telephone communications (SIC = 481) together with other regulated utilities, only unregulated firms are classified as belonging to the telecom industry. Further, firms in miscellaneous industries that are classified as “Other” in the Fama-French classification are not considered.
Accordingly, the final sample consists of 2,049 publicly traded U.S. companies and 20,635 firm-year observations, which are grouped into nine different industry sectors labeled as Consumer Non-durables, Consumer Durables, Manufacturing, Energy, Chemicals, Business Equipment, Telecom, Shops, and Health Care.\(^2\)

I now describe the variables used in the analysis. I define firm market value as total firm value (debt plus equity) computed as the market value of equity plus the book value of total assets minus the book value of equity.\(^3\) Consistent with the literature, the measure of CEO compensation is the total compensation variable, which includes salary, bonus, other annual, restricted stock grants, stock options (using the Black-Scholes formula), and long-term incentives. For the purpose of comparison, I also test with the CEO cash compensation variable (the sum of salary and annual bonus). In addition, as will be explained in detail later, I compute the price-cost margin for an industry as industry sales divided by industry operating costs. To do so, I obtain net sales and operating costs from the database. In particular, a firm’s operating costs include costs of goods sold, selling, general and administrative expenses, and depreciation, depletion, and amortization. All variables are converted to 2005 U.S. dollars using the GDP deflator provided by the BEA.

Since my model draws only cross-sectional implications, I take the averages of the above variables for each firm over the time period during which it was operating. Importantly, rather than using the actual CEO pay variables, I employ a Lowess (locally weighted regression scatter plot smoothing) curve to capture a smoothed pattern between CEO pay and firm market value from the actual noisy relation. As Terviö (2008) points out, it allows to calibrate the assignment model that involves a monotone matching correspondence. For each industry, I rank firms by firm market value and then perform a Lowess smoothing (bandwidth, 0.7) of the relation between CEO compensation levels and firm ranks. Hereafter, the observed distribution of CEO compensation refers to the smoothed levels.


\(^3\)Terviö (2003, 2008) uses market capitalization that is common shares outstanding multiplied by the share price (Compustat item MKVALT) as firm market value.
Table 1 provides the cross-industry summary statistics for these variables. It should be noted that there is wide variation across industries. First, the business equipment industry contains the largest number of firms. Given that this measure counts the number of firms that appeared in the sample even for a short time period, it could be because many new dot-com companies went public especially around the dot-com bubble period even though many of them failed shortly. Second, the mean value of CEO total compensation is especially higher in the energy, business equipment, and telecom industries, whereas the average CEO in the manufacturing industry earned the least. Third, differences in CEO pay levels across industries do not necessarily correspond to firm size differences across industries. For instance, the total market value of the average firm in the business equipment industry is $5.65 billion and that in the consumer durable goods industry is $12.10 billion, whereas the average CEO earned $4.88 million in the former industry but earned only $3.33 million in the latter industry. Gabaix and Landier (2008) provide a cross-sectional prediction that the compensation of a CEO is proportional to the size of his firm to the power of some parameter value. If CEO talent markets were integrated as presumed in their study and the average firm represented the firms in the same industry, their argument would suggest that the average firm with a larger size should pay more to its CEO, which is not consistent with the above observation. This might suggest either that the markets for CEO talent are segmented by industry (Gabaix and Landier (2008) leave the possibility open in their conclusion) or that the cross-industry variation in CEO pay cannot be fully explained by firm size differences. My study conjectures and addresses these possibilities by estimating the single-industry equilibrium model using the respective industry data in which the structure of CEO talent market and product market characteristics are incorporated.

5.2 Model Calibration

In this subsection, the calibration of the model is described in detail. As mentioned earlier, the underlying assumption in this analysis is that the observed outcome in the sample of firm-CEO pairs belonging to an industry, including the number of firms and the distributions of firm market value and CEO pay, can be treated as the unique industry equilibrium of the model. Accordingly, my calibration strategy is to identify the unknown parameter values and the unobserved distributions
of firm quality and CEO talent for which the equilibrium outcome of the model is very close to the observed one.

I mainly adopt the structural approach devised by Terviö (2003) that aims to infer the unobserved factor distributions from the observed distributions of firm market value and CEO pay. There are, however, two important distinctions. First, I do not make any adjustments for the observed firm market value. He defines the output in each period as the product of firm quality and CEO talent which does not capture the effects of adjustable inputs influencing the observed market value. For this reason, he uses the modified market value, which is the observed market value minus the value of adjustable capital, in his model calibration. In contrast, the fixed entry cost and variable production costs are already incorporated into the theoretical firm value in my model so that I use the observed firm market value without any adjustments. Second, the empirical approach in this study, as in Terviö (2003, 2008), requires a semi-parametric estimation whose results rely on unknown parameter values. He examines five different combinations of arbitrarily chosen parameter values, whereas I look for a reasonable set of baseline parameter values for the computation of counterfactuals by calibrating the model to a sample of firm-CEO observations. As noted earlier, I repeat the same procedure described below for each industry in the sample.

The set of parameters to be calibrated is

$$\Delta = \{\beta, R, \sigma, u_0\}, \quad (37)$$

which does not include another fixed parameter in the model, the entry cost, $f_e$, because the free entry equilibrium condition (30) determines its value immediately.

**The likelihood of Exit, $1 - \beta$:** As Melitz (2003) notes, $\beta$ can be viewed either as the likelihood that each operating firm will stay in the market for another period or as the time discount rate for this particular industry. The industry discount rate is usually calculated using the industry costs of equity, $r$, assuming annual compounding:

$$\beta = 1/(1 + r). \quad (38)$$
To estimate the cost of equity or the required (expected) rate of return \( r \), I employ the Capital Asset Pricing Model (CAPM) as in the literature, including Kaplan (1995) and Fama and French (1997). I use industry portfolio returns and excess returns on the market portfolio which are provided on Kenneth French’s website. Both sets of returns are value-weighted and monthly. I first compute the industry beta (using the data dated before the sample period: 1926-1991) by running a regression of the monthly industry excess returns on the monthly excess returns of the market index. And then I obtain the expected monthly industry returns using the CAPM equation for the sample period from 1992 to 2009. I annualize these monthly returns and take the averages over the sample period.

**Total expenditure by the representative consumer, \( R \):** As one of the equilibrium conditions, the aggregate revenue of all operating firms in the market must equal the aggregate expenditure \( R \) by the representative consumer that is exogenously given. Hence, I set \( R \) equal to industry sales, computed as the sum of net sales for firms operating in the industry.

I determine the remaining two parameters by matching several statistics from the model-predicted distributions of firm market value and managerial compensation with the corresponding observed statistics. More specifically, mean values, minimum and maximum values, and deciles are selected from these distributions. Let \( \text{Obs}_i \) and \( \text{Pred}_i \) be the observed and predicted values of each selected statistic; then the baseline values of \( \sigma \) and \( u_0 \) solve

\[
(\sigma, u_0) = \arg \min_{\bar{\sigma}, \bar{u}_0} \sum_i \left( \frac{\text{Pred}_i(\bar{\sigma}, \bar{u}_0) - \text{Obs}_i}{\text{Obs}_i} \right)^2.
\]

In what follows, I outline how to generate the model-predicted payoff distributions for a candidate parameter vector \( \Delta \). First, I identify the unobserved factor distributions (relative to the lowest values), following Terviö (2003, 2008).

**Unobserved factor distributions, \( x[i]/x[0] \) and \( y[i]/y[0] \):** Recall that the slopes of the payoff functions must follow (27) and (28), which guarantees matching stability. Dividing these slopes by the equation for the total surplus (20), respectively, yields the following equations for the rates of
increase in factors.

\[
\begin{align*}
    x'[i] &= \frac{v'(i)}{(\sigma - 1)[v(i) + u(i)/(1 - \beta)]}, \\
    y'[i] &= \frac{u'(i)}{(1 - \beta)[v(i) + u(i)/(1 - \beta)]}.
\end{align*}
\] (40)

I can then obtain the profiles of the unobserved factors relative to the lowest type by integrating these equations, respectively.

\[
\begin{align*}
    \frac{x[i]}{x[0]} &= \exp \left\{ \int_0^i \frac{x'[j]}{x[j]} dj \right\} = \exp \left\{ \frac{1}{\sigma - 1} \int_0^i \frac{v'(j)}{v(j) + u(j)/(1 - \beta)} dj \right\}, \\
    \frac{y[i]}{y[0]} &= \exp \left\{ \int_0^i \frac{y'[j]}{y[j]} dj \right\} = \exp \left\{ \frac{1}{(1 - \beta)\sigma - 1} \int_0^i \frac{u'(j)}{v(j) + u(j)/(1 - \beta)} dj \right\}.
\end{align*}
\] (42)

I calculate the relative factor values by numerically integrating the right-hand sides of equations (42) and (43). As in Terviö (2003, 2008), however, I cannot determine the constants \( x[0] \) and \( y[0] \).

Second, I need to consider the equilibrium aggregate price index \( P^* \). Treating the observed number of firms in the industry as the equilibrium mass \( N^* \) of firms, the equilibrium condition (35) can be rewritten as

\[
P^* = \frac{1}{\rho} \left[ \int_0^1 (x[i]y[i])^{\sigma - 1} N^* di \right]^{\frac{1}{1 - \sigma}}.
\] (44)

Since \( x[0] \) and \( y[0] \) are undetermined, I only can compute the relative aggregate price index, \( P_0 \), which is defined as

\[
P_0 = P^* \rho x[0]y[0] = \left[ \int_0^1 \left( \frac{x[i]}{x[0]} \frac{y[i]}{y[0]} \right)^{\sigma - 1} N^* di \right]^{\frac{1}{1 - \sigma}}.
\] (45)

Third, I generate the predicted distributions of payoffs by plugging the given parameter values, the inferred relative factor values \( x[i]/x[0] \) and \( y[i]/y[0] \), and the relative aggregate price index \( P_0 \) into (32) and (33). The selected statistics from the predicted distributions are compared with their observed counterparts. The above procedure is repeated until the optimal solution that minimizes the sum of squared percentage differences between the model-predicted and observed values of the statistics is obtained as described in (39).
6 Calibration Results

Through the calibration procedure illustrated in the previous section, I obtain the baseline parameter values and the factor distributions for each of the nine industries in my sample. Table 2 reports the estimates of the parameters in the first four columns. The first two parameters $\beta$ and $R$ are obtained directly from the data as described earlier. Notice that, according to the CAPM theory, firms in the business equipment and consumer durable goods industries are in particular more likely to exit the market than those in other industries.

The other two parameter values are obtained by matching the theoretical distributions of firm market value and CEO compensation to their observed distributions. It is worth noting that there are significant differences in product substitutability $\sigma$ across industries. The estimate is lower in the business equipment, health care, and telecom industries, whereas it is higher in the industries of consumer durable goods and shops. This result is intuitive given that, in high-technology-intensity sectors such as the former three industries, product innovation plays a critical role and products tend to display a high degree of product differentiation (Ioannidis and Schreyer, 1997; Anderton, 1999). Moreover, if one considers $\sigma$ to be the price elasticity for each good in the market, the finding of Tellis (1988) also supports my result. By reviewing econometric studies that estimate price elasticities from different brands and markets, he documents that price elasticity for pharmaceutical products is lower than all other product categories and the difference is particularly significant and larger for detergents and durable goods in comparison with pharmaceutical products. The very high value of $\sigma$ for the consumer durable goods industry is, in fact, consistent with a general consensus in the literature on industrial organization that in any durable good industry, even competition within oligopolies, will be more intense than in a similarly structured non-durable good industry (e.g., Coase, 1972).

To further validate the estimates for this key model parameter $\sigma$, I compare them with industry price-cost margin estimates, which are commonly used to capture the degree of product substitutability in an industry in the empirical literature (e.g., Nevo, 2001; Karuna, 2007). The underlying notion behind this variable is that the higher is the extent of product substitutability in an industry, the greater is the price elasticity of demand, and the less is the price-cost margin.
I calculate it as industry sales divided by industry operating costs. These industry variables are computed by taking the sum of net sales and operating costs for firms in a given industry. The last column of the table shows the estimates of the measure for different industries. Although the estimates are less widely dispersed across industries than my structural estimates are, it is still observed that the health care and telecom industries have relatively higher price-cost margins, whereas shops and consumer durable goods industries have lower values. Except for the business equipment industry, the baseline values of $\sigma$ obtained through the structural approach are consistent with the values of the usual empirical proxy.

In addition to the model parameter values, the model calibration infers the unobserved factor distributions indirectly. The two middle columns of Table 2 report the highest values of firm quality and managerial talent relative to their lowest ones. For any industry, it is obvious that differences in firm quality between the highest and lowest ranking firms are greater than those in managerial talent, which implies that the relative impact of firm quality on the resulting payoffs is higher than that of managerial talent. This finding is consistent with Gabaix and Landier (2008) and Terviö (2003, 2008).\footnote{Terviö (2003, 2008) does not report the inferred distribution of firm quality, but shows how a larger firm quality can lead to more significant variation in CEO pay. Also, it should be noted that the relative talent ratios from my calibration are largely consistent (but somewhat smaller) with those in Terviö (2008), which are between 1.03 and 1.08 over the period 1994-2004.} However, more importantly, it should be emphasized that intra-industry dispersions of the factors vary significantly across industries. Compared to other industries, the business equipment, health care, and telecom (with smaller values than the former two industries) industries have higher relative values of firm quality and managerial talent.

For more precise descriptions, I report the entire factor distributions for the business equipment, health care, telecom, and manufacturing industries in Figure 1. The first two industries have much more widely dispersed firm and managerial characteristics across firms. In particular, the distributions of firm quality tend to be highly skewed to the right (convex), whereas those of managerial talent tend to be monotonically increasing (concave). This observation seems intuitive because managerial talent (human capital) cannot be so much differentiated as shown in the distributions of firm quality. The telecom industry shows a similar pattern (albeit higher) of firm heterogeneity to that of the manufacturing industry, whereas its talent distribution is closer to the...
first two industries even though there is little dispersion at the top of the distribution. Finally, one can clearly see that firms and managers are very homogeneous in the manufacturing industry, which is also true for the other industries unreported in the graph.

Although my main focus is on the implications of managerial talent, I first discuss how to interpret the exogenous firm quality given that there are found significant inter-industry variations in the inferred distributions of firm quality. The three industries with higher firm heterogeneity (business equipment, health care, and telecom industries) are usually referred to as high-tech industries (Loughran and Ritter, 2004). Moreover, in the first two industries, it is observed that there are a small mass of firms that are much more significantly differentiated from other firms in the same industry. Terviö (2008) broadly interprets the dimension of firm heterogeneity that is complementary to CEO talent as the natural scale of a firm, that is, all exogenous determinants of the scope (niches) of a firm’s operations that are linked to technology and consumer preferences. The strategy literature also attributes intra-industry firm heterogeneity to the establishment of unique product market positions (e.g., Caves and Porter, 1977). Such an interpretation is enhanced by my finding that variations in the firm-side dimension appear to be much greater in high-tech industries that are characterized by a greater variety of business ideas and technological innovations (Andersson et al., 2009).

I now discuss the implications of the inferred distributions of managerial talent. In Figure 1, compared to the manufacturing and other unreported industries, greater intra-industry differences in CEO talent are observed in high-tech industries. This finding, which is obtained by conducting the same procedure for each industry without any a priori assumption, suggests differences in CEO talent pools across industries. Although my analysis cannot compare the absolute levels of managerial talent between industries because the lowest levels are undetermined, a higher degree of CEO talent dispersion within an industry implies higher competition for CEO talent among firms. In other words, firms put greater emphasis on CEO human capital in those industries with greater heterogeneity in managerial talent. It is intuitive in the sense that the success of high-tech firms, which need to continuously develop new products and manage technological innovation in a highly competitive environment with very low barriers to entry and very high risk, is very closely tied to the talents of the workforce (Andersson et al., 2009). Further, managerial rents models in the
management literature argue that managerial human capital is more emphasized in industries in the early stages of the product-life cycle (e.g., early biotechnology companies), relative to that in more mature industries, and in industries with characteristics that allow greater managerial discretion than industries with less latitude for managerial discretion (Castanias and Helfat, 2001). Given that industries producing a differentiable product or service and high-growth industries tend to provide more managerial discretion (Hambrick and Abrahamson, 1995), my finding of larger talent dispersions in high-tech industries is in line with these arguments.

One may argue that this finding might mainly be induced by the prevalence of equity-based compensation of CEOs in high-tech industries. To examine that possibility, I perform the same analysis using CEO cash compensation, containing only salary and annual bonus. Figure 3 shows that greater differences in CEO talent are still observed in high-tech industries, relative to other traditional industries, even though the relative talent levels are overall lower than those are in Figure 1. As another robustness check, I also test an extension in which the impact of management team (top senior executives) is taken into account. As a caveat on firm-CEO matching models, it is often pointed out that, upon CEO turnover, the top management team usually tends to be replaced together. An easier way to deal with this extension would be to assume that the quality of the management team is simply characterized by a one-dimensional variable and keep the current framework as it is except that the observed CEO compensation distribution should be replaced by the distribution of the average compensation of non-CEO executives. In Figure 4, one can observe similar patterns of firm quality and managerial talent distributions. However, a more concrete way would be to model the efficiency of a management team by considering the complementarities between the talents of executives (in a similar vein, Eeckhout and Pinheiro, 2010). However, I leave a more detailed analysis to future work.

7 Counterfactual Experiments

I now conduct counterfactual experiments using the respective calibrated models that consist of the estimated baseline parameter values and the implied distributions of firm quality and CEO talent. First, I discuss the impact of CEO talent by asking similar questions explored in Gabaix
Second, I examine how the model equilibrium changes in response to a change in one of the product market characteristics.

### 7.1 Implications of CEO Talent

I consider the experiment of Gabaix and Landier (2008) that examines the impact of CEO talent at the median-sized firm among the largest 500 firms. Suppose that the reference firm indexed by \( i = 1/2 \) could replace its manager by the best CEO indexed by \( i = 1 \) in the same industry. I assume that the aggregate market structure, such as the aggregate price index \( P^* \) and the equilibrium mass \( N^* \) of firms, remains unchanged with this event associated with only one firm. To begin with, using (20), I calculate the rate of increase in the total surplus \( S \) at this reference firm as

\[
\frac{\Delta S}{S[1/2]} = \frac{S(x[1/2], y[1]) - S(x[1/2], y[1/2])}{S(x[1/2], y[1/2])} = \left( \frac{y[1]/y[0]}{y[1/2]/y[0]} \right)^{\sigma-1} - 1. \tag{46}
\]

Next, how much the firm’s market value \( v \) would change due to this event with no extra costs can be estimated using (15). In fact, this measure captures the gross benefit from hiring the best CEO, that is, the present value of additional future gross earnings relative to the current market value as shown below:

\[
\frac{\Delta v}{v[1/2]} = \frac{\phi(x[1/2], y[1/2], u[1/2]) - \phi(x[1/2], y[1/2], u[1/2])}{\phi(x[1/2], y[1/2], u[1/2])} = \frac{R(P^*x[1/2])^{\sigma-1} - y[1/2]^{\sigma-1} - y[1/2]^{\sigma-1}}{v[1/2]}. \tag{47}
\]

For the purpose of comparison, I also consider the cost to be incurred if the firm was required to pay the best CEO his current compensation at the largest firm. It is computed as the ratio of the present value of future additional compensation payments relative to the current market value, that is,

\[
\frac{\Delta u/(1 - \beta)}{v[1/2]} = \frac{(u[1] - u[1/2])/(1 - \beta)}{v[1/2]}. \tag{48}
\]

Table 3 shows the results of this counterfactual experiment. Note that, since CEO compensation is relatively small compared to the firm’s gross profit, changes in surplus and those in firm market value are very similar. The percentage changes in firm market value in the second column should be compared to the result of Gabaix and Landier (2008), whose sample is the largest 500 firms
among S&P 1500 firms in different industries. In their estimation, replacing the median CEO by the number one CEO at no extra compensation payment could increase the firm’s market capitalization by only 0.016%. My estimates, by contrast, are almost two orders of magnitude greater than their estimate in most sectors.

More importantly, there is considerable variation across industries. The impact of better CEOs is, indeed, much more quantitatively significant in the business equipment and health care industries (about 2.9% and 2.5%, respectively), whereas the size of the impact in the chemical industry (0.85%) is the lowest. In particular, notice that industries with lower impact of managerial talent are the chemical, consumer durable goods, and manufacturing industries which are often viewed as old economy industries in contrast with new economy or high-tech industries. Since there is no much difference in talent between the highest and the median ranking CEOs in the telecom industry as shown in Figure 1, this industry shows a somewhat low impact of managerial talent, which might be different if the replacement of the lowest ranking CEO with the best one was considered.

Further, these ratios of the benefit from hiring the best CEO should be compared with the ratios of additional compensation payments relative to firm market value that are reported in the last column. Higher costs than benefits is a natural result of the competitive assignment process because otherwise the matching of the median firm-manager pair would not be sustained. As one can expect, the size of the additional cost is higher in the business equipment and health care industries (10.72% and 8.69%, respectively) in which the marginal returns to managerial talent are higher than in other industries. However, it is worth emphasizing that, for any industry, the size of the cost is roughly of the same order of magnitude as the size of the benefit, more precisely, the cost is about three or four times greater than the benefit. This result does contrast with the finding of Gabaix and Landier (2008) that the talent difference resulting in a mere 0.016% increase in firm market value implies 530% difference in CEO pay, which might be mainly attributed to the huge difference in firm size between the highest and median ranking firms, possibly, from different industries. Overall, my results show that when different industries are characterized by different structures of CEO talent and product markets, the impact of managerial talent is not negligible at all, and the compensation of CEOs is quantitatively in line with their contributions to firms.

In addition to the effects of the hypothetical employment only at a reference firm, I now estimate
the effects of counterfactual distributions, which is similar to the approach used by Terviö (2008). More specifically, I look at three cases in which all managers hypothetically have the same level of talent \( y[I] \) with \( I = 0, 1/2, \) and 1, respectively, while the existing distribution of firm quality is kept in place. Since there is no heterogeneity on the side of managers, the current levels of compensation (33) from the competitive assignment process cannot be applied. Following Terviö (2008), I assume that all the managers would earn the same level of compensation that manager \( I \) receives in the original equilibrium with managerial heterogeneity, \( u[I] \). All the product market characteristics are assumed to be the same, and I set the fixed entry cost \( f_e \) to the value of \( E[v[i]] \) in the current equilibrium, following the free entry condition (30). Under this structure, I derive a new equilibrium in each counterfactual, that is, a new set of the relative aggregate price index, \( P^I_0 \), and the mass of firms, \( N^I \), using (34) and (35).

\[
\frac{R}{\sigma} (P^I_0)^{\sigma-1} \int_0^1 \left( \frac{x[i]}{x[0]} \frac{y[I]}{y[0]} \right)^{\sigma-1} di = u[I] + (1 - \beta)f_e, \tag{49}
\]

\[
N^I = \frac{R}{u[I] + (1 - \beta)f_e}, \tag{50}
\]

\[
S([x[i], y[I]]) = \frac{R}{(1 - \beta)\sigma} \left( P^I_0 \frac{x[i]}{x[0]} \frac{y[I]}{y[0]} \right)^{\sigma-1}. \tag{51}
\]

I compare the results of each counterfactual with the original equilibrium outcome. Table 4 displays the percentage differences in consumer welfare, the mass of firms, and the mean value of the surplus. First, consumer welfare in each counterfactual is worse than in the original economy. The integral on the left-hand side of (49) represents the industry-wide productivity and has a greater value if \( I \) is bigger. \( u[I] \) on the right-hand side is also larger if \( I \) is bigger. When the hypothetical talent level of all managers is at the lowest level of \( y[0] \), the former effect is larger than the latter effect, resulting in a higher aggregate price and thus negatively affecting consumer welfare. Interestingly, even if all managers are of the highest type with \( y[1] \), that is, the industry-wide productivity in this counterfactual would be higher than in the original equilibrium, consumer welfare would be still worse (negative sign) because of the high value of \( u[1] \). Note that the mass of firms would decrease in this counterfactual. In other words, the high managerial compensation might attract less firms in the market and dampen market competition, thereby causing a deterioration in consumer welfare.
In particular, industries with higher levels of CEO compensation show greater consumer welfare losses.

### 7.2 Implications of Product Market Characteristics

Having identified the impact of managerial talent, I now examine the effects of different product market characteristics on the equilibrium outcome. In the monopolistically competitive product market, there are several dimensions influencing the market structure: the elasticity of product substitution $\sigma$, the exit probability $1 - \beta$, the entry cost $f_e$, and the market size $R$. I explore how each of these dimensions alters the equilibrium outcome, including consumer welfare (due to a change in the aggregate price index), the mass of firms, and the levels and distributions of CEO pay and firm market value, by varying that specific parameter over its plausible range. In other words, keeping the inferred factor distributions and other parameter values in place, I obtain a new equilibrium for the new parameter and then compare the new equilibrium outcome with the original one.

#### 7.2.1 Effects of Product Substitutability

Table 5 shows the effects of the elasticity of product substitution across industries. To begin with, it is observed that, for any industry, consumer welfare deteriorates and the mass of firms declines as product substitutability increases. According to Proposition 1, this observation implies that the entry cost and the exit probability are below their respective thresholds. In this case, at the current equilibrium aggregate price, a marginal increase in product substitutability implies more intense price competition and therefore lowers firms’ gross and net profits, which, in turn, adjusts the aggregate price upward to a new level for the free entry condition (34) to be met again. The ambiguous effect of product substitutability on the mass of firms turns out to be negative for any industry. Moreover, while the percentage change in the mass of firms seems to be similar across industries, the change in consumer welfare vary significantly across industries. In particular, consumer welfare (or, inversely, industry aggregate price) is more sensitive to the elasticity of product substitution especially in the business equipment and health care industries, for which the baseline value of the parameter is relatively lower as shown in Table 2. Hence, the observation
implies that these industries are not only heterogeneous in terms of product substitutability but also more vulnerable to some exogenous factors that would affect the degree of product substitutability. In contrast, the consumer durable goods industry has the least sensitivity of the aggregate price index. In fact, its least change in the consumer durable goods industry is also observed when any of other product market characteristics changes. This result might be explained by the argument of the price rigidity in this industry (Domowitz, Hubbard, and Petersen, 1986, 1988; Leith and Malley, 2007).

Next, I examine the implications of product substitutability for the equilibrium distributions of CEO pay and firm market value. CEO pay levels, measured by their mean values, decline with this dimension of market competition. In particular, CEO pay levels in the health care and business equipment industries are affected most by a change in this parameter. Roughly speaking, the average CEOs in these industries would face an about 8% pay cut in response to a 5% increase in product substitutability in the market.

In addition to the mean values of CEO pay, I further examine the shifts in CEO pay distributions in response to a 10% increase and a 10% decrease in product substitutability for the business equipment and telecom industries. Figure 2 displays the shifts in CEO pay distribution for these industries. As noted in the comparison of the mean values of CEO pay, the shifts in CEO pay distributions in the former industry are more noticeable than those in the latter industry. More importantly, the figure confirms the analytical result presented in Proposition 3 that an increase in the elasticity of product substitution affects managerial compensation differently across firms. That is, there is a certain rank such that managers below the rank get paid less than currently, whereas managers above that rank get paid more. While the trigger rank in the former industry is almost the highest one, it is lower ($\bar{r} = 0.9$) in the latter industry. This result implies that a change in product substitutability may induce a larger CEO pay dispersion within an industry.

Finally, while firms would face a more price-elastic demand in the market in response to an increase in product substitutability, they could also reduce CEO pay levels. It is shown in Table 5 that, due to these contrasting effects, product substitutability has a less significant quantitative effect on firm market value than it does on CEO pay.
7.2.2 Effects of the Exit Probability and Entry Cost

The exit probability $1 - \beta$ and the entry cost $f_e$ affect the equilibrium outcome mainly through the aggregate price index determined by the free entry condition (34). As either of them increases, the free entry condition implies that the aggregate price index also needs to increase in a new equilibrium, thereby resulting in a loss of consumer welfare. The other equilibrium condition (35) implies that this market change lowers the mass of firms in the market. The intuition is that an increase in the exit probability or the entry cost induces fewer firms to enter the market and, therefore, reduces price competition, resulting in a higher aggregate price index. Consequently, the marginal returns to talent, the integrand in (33), increase so that managers would get paid more.

Table 6 displays the effects of the industry discount rate $\beta$ instead of the exit probability $1 - \beta$, and the effects of the fixed entry cost $f_e$ are reported in Table 7. Notice that I consider smaller percentage changes in $\beta$ because of its upper limit, $0 < \beta < 1$. It is shown that the exit probability has much more significant quantitative impacts on the equilibrium outcome than any other parameters do. Since the parameter can be viewed as being negatively associated with industry risk that active firms face in the market, this observation suggests the important role of risk in determining the industry equilibrium outcome. In particular, the telecom industry is overall most sensitive to this factor. Specifically, a 5% increase in risk leads to a 65.3% increase in the mean value of CEO pay in the telecom industry. Moreover, one can observe that the changes in firm market value are relatively smaller than those in CEO pay and that their signs vary across industries, which in fact confirms the ambiguous effect of the discount rate on firm market value in Proposition 3. In contrast with the influence of the exit probability, that of the entry cost seems to be uniform across industries. Nonetheless, the price rigidity of the consumer durable goods industry still holds in response to a change in the exit probability and the entry cost.

7.2.3 Effects of the Market Size

Table 8 confirms the effects of the market size $R$ discussed in Section 4. At the current aggregate price, as the market size increases, the market demand each firm faces increases, and so does its profitability, which attracts more firms to the market. A greater mass of firms in the market induces
more intense price competition, thereby driving the aggregate price index down. In line with this intuition, consumer welfare and the mass of firms increase with the market size in any industry. As discussed in Proposition 3, it is also empirically observed that a firm’s market value and managerial compensation are not affected by the market size $R$ (therefore, unreported).

8 Conclusion and Future Work

This paper studies the assignment of CEO talent in a general equilibrium framework. The model enables the simultaneous analysis of the effects of managerial talent and product market characteristics on the determination of firm market value and CEO pay distributions. I characterize a unique, stationary equilibrium of the model and then calibrate the model to a sample of firm-CEO observations in each of the nine industry sectors based on the twelve Fama-French industry classification. Using the respective calibrated models for different industries, I perform several counterfactual experiments to investigate the quantitative effects of managerial talent and those of product market characteristics.

There are several main results obtained from the analysis of the paper. First, there is much variation in the distributions of firm quality and managerial talent across industries. As compared with other industries, high-tech industries are characterized by higher heterogeneity both in firm quality and in managerial talent. Second, contrary to the conclusions of Terviö (2008) and Gabaix and Landier (2008), the impact of CEO talent on shareholder value is, indeed, significant, as many empirical studies suggest, and it is roughly of the same order of magnitude as CEO pay difference. This finding is obtained because, unlike the earlier studies, I explicitly incorporate the product market environment in which firms operate and reflects inter-industry variations in the distributions of firm and managerial exogenous characteristics. Third, more importantly, the contribution of CEO talent varies significantly across industries. As one may expect from the inferred talent distributions, managerial talent is more important to firm value in high-tech industries so that more intense competition for CEO talent in those industries leads to higher pay dispersions. Fourth, the effects of different product market characteristics on the equilibrium outcome are analytically proved and confirmed through the counterfactual experiments using the respective
calibrated models. In particular, either the entry cost or the exit probability shifts the entire CEO pay distribution upward or downward, whereas the elasticity of product substitution may affect large and small firms differently, which leads to higher pay differences between CEOs in the same industry. Overall, my study shows that industry structures associated with CEO labor markets and product markets help explain the variations in the levels and distributions of CEO pay across industries.

In this paper, I abstract away from asymmetric information, risk and incentive provisions as in Gabaix and Landier (2008) and Tervio (2008). However, since a large body of research on CEO compensation is based upon agency problems, a natural next step would be to introduce asymmetric information stemming from moral hazard. I will explore the importance of risk and moral hazard in the endogenous matching of CEOs to firms and the determination of CEO compensation levels and incentives. I will then estimate agency costs arising from moral hazard across industries and obtain qualitative as well as quantitative implications for the effects of product market characteristics on managerial incentives and the inefficiencies arising from agency problems.

In future work, I plan to build further on the research framework that I am exploring in this paper. One potential direction I would like to pursue is to explicitly model the bargaining process between CEOs and boards, which could vary significantly by industry due to variations in CEO bargaining power. I could then explore the relative importance and complementarities of CEO power over boards and competition for CEO talent as determinants of CEO compensation. I would also like to study the dynamics of CEO labor market by distinguishing inter-industry turnovers from intra-industry turnovers. Such an analysis could lead to new predictions for the relationships among the characteristics of prior and subsequent industries, the product market conditions of these industries, and managerial skill sets.
Appendix: Proofs

Proof of Proposition 1
As the entry cost \( f_e \) or the likelihood of exit \( 1 - \beta \) increases, the right-hand side of (34) increases. Since the left-hand side of (34) is an increasing function of the aggregate price index, it follows that the equilibrium aggregate price must increase with \( f_e \) or \( 1 - \beta \) to satisfy the equilibrium condition (34). The market size \( R \) has an opposite effect because \( R \) is on the left-hand side of (34). Consumer welfare is inversely related to the aggregate price index as shown in (36), which, therefore, completes the proof of the first result of proposition 1.

The result above is used to show the second result about the effect of a marginal increase in \( \sigma \). Here, I only prove the result with the threshold of the entry cost, \( \bar{f}_e(\sigma, \beta) \) because the result with the threshold of the exit probability, \( 1 - \bar{\beta}(\sigma, f_e) \) can be similarly shown. First, define from (34)

\[
f(\sigma, P) = \frac{RP^{\sigma - 1}}{1 - \beta} \left[ (\rho x[0|y[0])^{\sigma - 1} \rho^\sigma \int_0^1 \int_0^1 x[j]^{\sigma - 2} y[j]^{\sigma - 1} x'[j] dy[j] dj \right] - \frac{\mu_0}{1 - \beta}.
\]

If \( P^*(\sigma) \) denotes the equilibrium aggregate price index when the elasticity of substitution is \( \sigma \),

\[
f(\sigma, P^*(\sigma)) = f_e.
\]

By taking the derivative of \( f \) with respect to \( \sigma \), one can observe that \( \frac{\partial f}{\partial \sigma} \) is greater than zero if \( P \) exceeds a threshold \( \bar{P}(\sigma) \) and is less than zero otherwise. In addition, note that \( \frac{\partial f}{\partial P} > 0 \). By (53) and the implicit function theorem, I can write

\[
\frac{dP^*(\sigma)}{d\sigma} = -\frac{\partial f/\partial \sigma}{\partial f/\partial P} \bigg|_{P=P^*(\sigma)}.
\]

In the proof of the first result of this proposition, the aggregate price index \( P^*(\sigma) \) has been shown to increase with the entry cost \( f_e \). It then follows that there exists a threshold level \( \bar{f}_e(\sigma) \) of the entry cost such that \( P^*(\sigma) > \bar{P}(\sigma) \) if \( f_e > \bar{f}_e(\sigma) \) and \( P^*(\sigma) < \bar{P}(\sigma) \) if \( f_e < \bar{f}_e(\sigma) \), which determines the sign of \( \partial f/\partial \sigma \). Taken together, \( \frac{dP^*(\sigma)}{d\sigma} < 0 \) if \( f_e > \bar{f}_e(\sigma) \) and \( \frac{dP^*(\sigma)}{d\sigma} > 0 \) if \( f_e < \bar{f}_e(\sigma) \). Q.E.D.

Proof of Proposition 2
In the proof of Proposition 1, I have showed that the equilibrium aggregate price increases with the entry cost \( f_e \) or the exit probability \( 1 - \beta \), whereas it decreases with \( R \). By the observation and (35), I immediately have the first result of this proposition. On the other hand, the impact of a marginal increase in \( \sigma \) cannot be unambiguously determined because the mass of firms, given by (35), depends on the factor distributions as well as other product market characteristics. Hence, I empirically explore the effect of \( \sigma \) after calibrating the model to data. Q.E.D.
Proof of Proposition 3

Equation (34) can be rewritten as an equation for \( RP^{\sigma-1} \). First, plugging the equation into (33) shows that CEO compensation increases with the the entry cost \( f_e \) and the likelihood of exit \( 1 - \beta \), whereas it does not change with the market size \( R \). Second, to prove the effects on firm market value, I plug the equation and (33) into (32) and perform a partial integration, which provides the following equation:

\[
v[i] = Q f_e + \frac{(Q - 1) u_0}{1 - \beta},
\]

where \( Q = \frac{(\rho x[j]y[j])^{\sigma-1} + \rho^\sigma f_0^j \int_0 x[j]^{\sigma-2} y[j]^{\sigma-1} x'[j]dj}{(\rho x[j]y[j])^{\sigma-1} + \rho^\sigma f_0^j \int_0 x[j]^{\sigma-2} y[j]^{\sigma-1} x'[j]dj} > 0 \). In the above, one can see that firm market value increases with the entry cost \( f_e \), but is not affected by the market size \( R \). It is also shown that firm market value increases with the exit probability \( 1 - \beta \) if \( Q < 1 \), but decreases if \( Q > 1 \). However, since the value of \( Q \) depends on the factor distributions, the effect of the exit probability should be empirically tested after the factor distributions are implied by data.

Finally, I show the effect of product substitutability on CEO pay. I first differentiate equation (33) with respect to \( \sigma \) as follows:

\[
\frac{\partial u[i]}{\partial \sigma} = \int_0^i \left( \frac{\partial h(j, \sigma)}{\partial \sigma} \right) dj = \int_0^i \left( h(j, \sigma) \frac{\partial \ln h(j, \sigma)}{\partial \sigma} \right) dj,
\]

where \( h(j, \sigma) = RP^{\sigma}(\sigma)^{\sigma-1} \rho^\sigma x[j]^{\sigma-1} y[j]^{\sigma-2} y'[j] \) and \( P^{\sigma}(\sigma) \) is the equilibrium aggregate price index when the elasticity of substitution is \( \sigma \). Taking the derivative of \( \ln h(j, \sigma) \), I obtain

\[
\frac{\partial}{\partial \sigma} \ln h(j, \sigma) = \ln P^{\sigma}(\sigma) + (\sigma - 1) \frac{\partial}{\partial \sigma} \ln P^{\sigma}(\sigma) + \ln \rho + \frac{1}{\sigma - 1} + \ln(x[j]y[j]).
\]

It then follows that there exists a trigger level \( \bar{j} \) of firm rank such that \( \frac{\partial \ln h(j, \sigma)}{\partial \sigma} > 0 \) for \( j > \bar{j} \) and \( \frac{\partial \ln h(j, \sigma)}{\partial \sigma} < 0 \) for \( j < \bar{j} \). Since \( h(j, \sigma) \) is positive, the integrand in (56) has the same sign as that of \( \frac{\partial \ln h(j, \sigma)}{\partial \sigma} \). Accordingly, it is evident that the right-hand side of (56) is negative unless \( i \) is sufficiently high. Note that the threshold for \( i \), to be denoted by \( \bar{i} \), is different from \( \bar{j} \) at which \( \frac{\partial \ln h(j, \sigma)}{\partial \sigma} = 0 \). Therefore, CEO pay level increases (decreases) with \( \sigma \) when the rank of a firm is above (below) \( \bar{i} \).

Q.E.D.

References


[19] Falato, Antonio, Dan Li, and Todd Milbourn, 2010, To each according to his ability? the returns to CEO talent, unpublished working paper.


[31] Legros, Patrick, and Andrew Newman, 2007, Beauty is a beast, frog is a prince: assortative matching with nontransferabilities, Econometrica 75 (4), 1073-1102.


Table 1: Cross-Industry Summary Statistics

I extract firm-specific variables and CEO compensation variables for 1992-2009 from the Compustat Fundamentals Annual database and ExecuComp database, respectively. CEO Total Compensation is ExecuComp item \textit{TDC1}, which represents the total compensation comprised of salary, bonus, other annual, total value of restricted stock granted, total value of stock-options granted (using Black-Scholes), long-term incentive payouts, and all other total, whereas CEO Cash Compensation (ExecuComp item \textit{TOTAL\_CURR}) is comprised of only salary and bonus. Total Firm Value (market value of common equity plus book value of debt) is computed as common stock price (item \textit{PRCCF}) times shares outstanding at the end of fiscal year (item \textit{CSHO}) plus total assets (item \textit{AT}) minus book value of equity, which is computed as common equity (item \textit{CEQ}) plus balance sheet deferred taxes (item \textit{TXDB}). Total Assets is item \textit{AT}, and Net Sales is item \textit{SALE}. Operating Costs contains costs of goods sold (item \textit{COGS}), selling, general and administrative expenses (item \textit{XGAS}), and depreciation, depletion, and amortization (item \textit{DP}). All nominal variables are converted to 2005 U.S. dollars (in millions) using the GDP deflator provided by the BEA. I take the averages of all of the above variables for each firm over the time period during which it was operating to construct a cross-sectional sample, and then group them into Fama-French’s 12 industries (except for finance, regulated, and other miscellaneous groups). CEO total compensation variables below are not the actual variables, but smoothed ones obtained by performing a Lowess (bandwidth, 0.7) on the relation between the actual compensation levels and the ranks of the firms in terms of total firm value. In this table, I report the means and standard deviations (in parentheses) of the variables by industry.

<table>
<thead>
<tr>
<th>Industry Sector</th>
<th>Number of Firms</th>
<th>CEO Total Compensation Mean</th>
<th>CEO Total Compensation SD</th>
<th>Total Firm Value Mean</th>
<th>Total Firm Value SD</th>
<th>Total Assets Mean</th>
<th>Total Assets SD</th>
<th>Net Sales Mean</th>
<th>Net Sales SD</th>
<th>Operating Costs Mean</th>
<th>Operating Costs SD</th>
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<tbody>
<tr>
<td>All</td>
<td>2,049</td>
<td>4.158</td>
<td>1.093</td>
<td>6,656.87</td>
<td>3,568.24</td>
<td>3,523.28</td>
<td>3,184.76</td>
<td>(3.183)</td>
<td>(0.575)</td>
<td>(20,878.71)</td>
<td>(12,479.35)</td>
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<td>7,733.62</td>
<td>3,826.24</td>
<td>3,797.87</td>
<td>3,270.09</td>
<td>(3.277)</td>
<td>(0.610)</td>
<td>(19,706.46)</td>
<td>(8,719.88)</td>
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<td>Consumer Durables</td>
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<td>7,955.60</td>
<td>7,463.66</td>
<td>6,571.27</td>
<td>(2.413)</td>
<td>(0.741)</td>
<td>(48,959.69)</td>
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<td>(3,400.51)</td>
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### Table 2: Parameter Estimates, Relative Factor Values, and Price-Cost Margin

<table>
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<th>Industry Sector</th>
<th>$\beta$</th>
<th>$R$</th>
<th>$\sigma$</th>
<th>$u_0$</th>
<th>$x[1]/x[0]$</th>
<th>$y[1]/y[0]$</th>
<th>Price-Cost Margin</th>
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</thead>
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### Table 3: Impact of CEO Talent at the Median-Sized Firm

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<th>$\Delta u/(1-\beta)$ (%)/$v_{[1/2]}$</th>
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Table 4: Effects of Hypothetical Talent Distributions

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Table 5: Effects of Product Substitutability σ

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<th>10%</th>
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<td>ΔN/δ (%)</td>
<td>ΔE[u]/δ (%)</td>
<td>ΔE[v]/δ (%)</td>
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### Table 6: Effects of Discount Rate $\beta$

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<th>$\frac{\Delta E[v]}{E[v]}$ (%)</th>
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### Table 7: Effects of Entry Cost $f_e$

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### Table 8: Effects of Market Size $R$

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### Figure 1: Inferred Distributions of Firm Quality and Managerial Talent
Figure 2: Shifts in CEO Pay Distributions due to Changes in $\sigma$ (Business Equipment and Telecom)

Figure 3: Inferred Distributions of Firm Quality and Managerial Talent (CEO Cash Compensation)
Figure 4: Inferred Distributions of Firm Quality and Managerial Talent (Non-CEO Total Compensation)