CEO PAY AND INFORMATION TECHNOLOGY

PRELIMINARY AND INCOMPLETE

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Abstract

Compensation for CEO's and other top executives has drawn increasing scrutiny from researchers and policy-makers. We find that information technology (IT) intensity predicts the CEO pay levels, the dispersion of CEO pay, and the turnover of top executives and explore three possible explanations.

1. IT may facilitate "winner-take-most" markets that increase the size and dispersion of firms' market value. This in turn translates in to comparable changes in CEO compensation.
2. For any given firm size, IT may increase the "effective size" of the firm by making performance more sensitive to CEO decisions.
3. IT may increase the generality of skills required to be an effective CEO by converting tacit knowledge into more explicit, data-driven decision-making.

We examine panel data from 3413 publicly traded firms over 23 years, controlling for other types of capital, number of employees, market capitalization, industry turbulence, firm or industry fixed effects, and other factors and find the strongest evidence for the first and third hypotheses.

Keywords: CEO pay, IT impacts, decision-making, centralization, income inequality, executive compensation

"The mountains are high and the Emperor is far away."
– Chinese Proverb

"The [IT] dashboard is the CEO's killer app, making the gritty details of a business that are often buried deep within a large organization accessible at a glance to senior executives. ... Managers can see key changes in their businesses almost instantaneously -- and take quick, corrective action."
– Ante (2006)

Introduction

This paper examines the relationship between information technology (IT) and top executives' pay. A substantial rise in top executives' pay in the 1990s has been well-documented (Bebchuk & Fried, 2005; Bebchuk & Grinstein, 2005; Frydman & Jenter, 2010; Frydman & Saks, 2007; Hall & Liebman, 1998; Hall & Murphy, 2003). For instance, the ratio of CEO pay to average worker pay increased from 60 in 1990 to 380 in 2000. Less publicized is that fact that the top CEO pay subsequently fell and has been relatively flat since 2002 while the median CEO pay has been still increasing (Figure 1). Since early 2000s, the ratio of CEO pay to median work pay has fluctuated between 180 and 350 (Mishel and Davis 2014).

What explains this pattern? While increases in the market value of firms may explain a part of the increase (Figure 2), another part of the story may be the changes in IT intensity over the same period. Corporations can be thought of as information processors. Hence, large declines in the costs of digital information processing are likely to affect monitoring and control capabilities. In particular, the increases in the quality and quantity of IT have changed the types of skills needed to be an effective CEO and radically affected the ability of top executives to keep informed about activities throughout their organizations and to respond more quickly and precisely with instructions. This may have affected the level and dispersion of CEO pay, as well as their turnover. Our study provides a first look at the potential role of IT in CEO compensation and mobility.

Role of IT

We explore three hypotheses that would link IT intensity to CEO pay.

<u>1. IT and firm size</u>

IT may affect the size or value of firms by changing monitoring costs (Garicano and Rossi-Hansberg 2004, 2006; Garicano 2000), increasing the span of control (Guadalupe, Wulf, and Boston 2008; Rajan and Wulf 2006) or affecting firm boundaries (Brynjolfsson, Malone, Gurbaxani, & Kambil, 1994). In addition to the value or size of individual firms, the size distribution of firms within industry may be affected by IT. If IT facilitates winner-take-all markets (Brynjolfsson, McAfee, & Spence, 2014), then it may increase the Gini coefficient of firm size.

In turn, many researchers have reported that CEO pay is highly correlated with firm size and market value (Barro & Barro, 1990; Gabaix & Landier, 2008; Kostiuk, 1990; Roberts, 1956; Rosen, 1992). Gabaix and Landier (2008) and Tervio (2008) each propose a model in which the best CEO manages the largest firm at competitive equilibrium as this maximizes the CEO impact. In other words, the CEO of the largest firm has the highest marginal productivity and thus receives the highest pay.

Thus, IT may indirectly lead to changes in the level and dispersion of CEO pay by changing the size and dispersion of firm size.

<u>2. IT and *effective* firm size</u>

Even if nominal firm size is held constant, IT may increase the "effective" firm size relevant to CEO pay by increasing the CEO's influence and control. We define the concept of effective firm size as the extent of the firm that the CEO can effectively influence and control. The ability of CEO to manage large firms depends on technology for communicating instructions, replicating processes and monitoring employees. The less perfect the communication between top managers and employees is, the less effective the CEO's monitoring and influence becomes. For instance, if a CEO's instructions are accurately propagated throughout only a part of the firm, then the effective size is not as great as it would be if the instructions were accurately and precisely propagated to every part of the firm. Similarly, the ability of the CEO to use IT to better monitor compliance with instructions will also increase the effective size of the firm. The benefits of having a "superstar" CEO will be greater the larger the effective size of the firm. If IT increases the effective size of firm, then IT-intensive firms might pay their CEOs more than those of the same nominal size but with less IT.

3. IT and the generality of managerial skills

Information technology (IT) may be correlated with the increasing generality of the required managerial skills. In turn, as argued by Frydman (2005), an increase generality of skills can lead to higher compensation for top CEOs.

Managerial decisions are increasingly becoming based on data more than experience. Data-driven decision-making practices are likely to make the managerial skills transferrable across firms and industries, increasing the generality of the required managerial skill. For instance, Gary Loveman, CEO of Harrah's Entertainment Corp. successfully transformed that company by bringing to bear a set of analytical methods and quantitative "rocket scientists" from outside the industry (Becker 1993). He had no special knowledge of that industry, and has said that he could just as easily have brought the same techniques to any other industry.[1] There is some evidence that firms practicing data-driven decision-making tend to perform better (Brynjolfsson, Hitt, & Kim, 2011). This is consistent with the arguments that the increase in CEO pay may be due to the increased generality of the required managerial skills (Frydman, 2005; Murphy & Zabojnik, 2004).

Related Research

Our study is related to three streams of literature; one is the effect of IT on centralization and decentralization of decision-making, the second is the effect of IT on income inequality, and the third is the rise of CEO compensation.

1. IT and Organization

A large stream of literature studies effects of IT on command, control, coordination, and organization of firms. In theory, IT could shift power either toward the center or away from it, leading to centralization or decentralization of a firm. In the former case, IT makes local knowledge available to top managers and management can be more centralized. In this case, one might expect higher CEO relative pay. On the other hand, in the latter case, IT makes local knowledge of one department available to employees (as well as to top managers) in other departments and employees can coordinate tasks among themselves more easily with the need for CEO involvement. In this case, one might expect less CEO relative pay. Ultimately, the net effect is an empirical question. Previous studies have found evidence of both effects, albeit during earlier time periods where the technology and institutions were different than those that prevail more recently (See e.g. Attewell & Rule, 1984; Bresnahan, Brynjolfsson, & Hitt, 2002; Brynjolfsson, Malone, Gurbaxani, & Kambil, 1994; Brynjolfsson & Mendelson, 1993; Gurbaxani & Whang, 1991; Leavitt & Whisler, 1958). Changes in firm size induced by IT have been also studied based

[1] Presentation at "Economics of Information" class (15.567) at MIT, October 14, 2009.

on the economic theories of Coase (1937) and Williamson (1973, 1981). IT may change equilibrium firm size or the correlation between CEO compensation and IT or both.

2. IT and wage inequality

The second related stream of literature is the role of IT in leading to the wage inequality in the whole economy (e.g. Autor, Katz, & Krueger, 1998). This can lead to effects of IT on CEO pay in two ways. The first is closely related to those of Garicano and Ross-Hansberg (Garicano and Rossi-Hansberg, 2006; Garicano, 2000). They argue that knowledge has hierarchy; some knowledge attached to lower-ranked employee is used to solve a routine problem while other knowledge attached to top managers to process a convoluted non-routine problem. As the cost of communication among agents decreases, the complicated problems that lower-ranked employees cannot solve can be more easily passed to their superiors. Once solved, the solution can be disseminated easily with the lowered cost of communication. This can lead to the dependency of the problem-solving on a few "superstars" (Rosen, 1981) and thus a higher wage for the superstars. Their explanation is consistent with our view that IT increases the effective size of a firm by easily passing non-routine problems to a few problem solvers and then disseminating the solution to the entire firm. Therefore, the dependency of the IT-intense firm on the few problem solvers and thus the sensitivity of the IT-intense firm to those few superstars become greater, leading to a higher compensation for those superstars in IT-intense firms.

Another thread in this literature is that IT often firm-specific knowledge more general. For example, companies in virtually every industry have adopted Enterprise Resource Planning (ERP). According to one estimate, spending on these enterprise IT platforms already accounted for over 50% of all U.S. corporate IT investment in 2001 (McAfee, 2002). ERP makes sales, inventories, and many other resource data to be stored and readily available in distance and thus reach top managers or personnel whom top managers grant access to. Moreover, computers have codified technological knowledge and made high-level problem solvers increasingly important in steel, semiconductor and mechanical sectors (Balconi 2002). Then, optimal resource management can be done by a few data analysts who may not necessarily have firm-specific or even industry-specific knowledge. However, they do have general skills to process and analyze the codified technological knowledge or the stored data. The use of data in the management, therefore, increases the demand for the general skills more than firm- or industry-specific skill. The CEOs may or may not be the problem solvers but they are a key to recognize, place, and reward the superstars in their firm. Our model does not necessarily imply that a greater wage inequality *within* the same firm. Some firms or industries can concentrate many problem-solvers or superstars for the whole economy. The wage inequality within such firms may not be as great as in the whole economy. Our study focus is the differences of CEO pay across time and industry, not the wage inequality within the same firm, as a result of the increased IT intensity.

3. CEO pay

The third stream of literature relevant to our study examines CEO compensation more broadly. There have been many theories and explanations for the rise of CEO pay in academia as well as mass media. The rise in CEO pay has been viewed in wide spectrum. One end of the spectrum is a rent extraction view in which CEOs can set their own pay and extract rents from their firms (Bebchuk, Fried, & Walker, 2002; Bebchuk & Fried, 2005; Bertrand & Mullainathan, 2001; Hall & Murphy, 2003; Yermack, 1997) while the other end of the spectrum is an efficient labor market view in which firms optimally compete for managerial talent. While there is good evidence for both views, and they are not mutually exclusive, in this paper we more closely pursue the second view and refer to other papers to review the first view (e.g. Frydman & Jenter, 2010; Gabaix & Landier, 2008).

In turn, the competitive market view can be categorized in four sets of theories (Frydman & Jenter, 2010) that we recapitulate here. The first is the scale effects: the rise in CEO pay is due to the increase in firm sizes. The marginal productivity of CEO is larger for larger firms and a larger firm is willing to pay for a larger pay for CEO even with smaller incremental talent compared to the next talented CEO (Gabaix and Landier 2008; Himmelberg, Hubbard, and Palia 1999; Rosen 1981, 1996; Tervio 2008).

The second market-based explanation is the change in the type of managerial skills from firm or industry-specific to general (Frydman & Saks, 2010; Murphy & Zabojnik, 2004). This change increases firms' competition for talent and consequently the CEO pay.

The third set of theories is an agency view (Baker & Hall, 2004; Dow & Raposo, 2005; Himmelberg et al., 1999; Holmstrom & Kaplan, 2001; Hubbard & Palia, 1995; Jensen & Murphy, 1990) In order to give incentives or reward to CEOs to cope with more volatile and uncertain business environments and globalization, raise the CEO optimal effort, prevent moral hazard, and bring more innovative idea in the business strategy, firms have to link CEO pay more closely to performance, which in turn can lead to higher levels and dispersion of CEO pay.

Finally, a fourth market-based theory argues that a stricter corporate governance and a better monitoring of CEOs decrease their job stability. Firms optimally respond by increasing the CEO pay (Hermalin 2005).

Our paper investigates the correlation between IT and CEO pay via three distinct mechanism. First, IT may affect the size and size distribution of firms and market value. If IT increases the equilibrium size of firms, or the dispersion in the size of firms, then CEO pay may change in a similar way.

Second, the marginal productivity of CEO may depend not on nominal firm size but on its *effective* size. Effective size may be an increasing function of IT intensity of the firm because the more IT-intensive environment a firm has, the lower the cost of communication and access of knowledge as articulated by Garicano and Rossi-Hansberg (2006). As a result, the relationship between CEOs performance and firm performance becomes stronger, that is, the marginal productivity of CEO increases. Changes in CEO pay may be, therefore, at least in part a manifestation of changes marginal productivity of CEO.

Third, we consider the idea that IT can facilitate an increase of the generality of managerial skills. A previous study (Brynjolfsson, Hitt, & Kim, 2011) found that firms are more productive when they managerial decisions are data-driven rather than intuition-driven. CEOs' ability to make decisions based on quantitative data are likely more portable across industries than their ability to make decisions based on local knowledge, experience or intuition. As CEOs' skills become more general, talented CEOs have more options outside their firms or even their industries. Therefore, firms compete more for such a talent and consequently pay more for the talent.

These three hypotheses have different predictions about the *level* vs. the *dispersion* of CEO pay. The first hypothesis attributes changes in CEO pay to commensurate changes in the level and in dispersion to the firm size and dispersion, respectively. In other words, changes in the dispersion among CEO pay and the average CEO pay should be fully explained by changes in the dispersion among firm sizes and the average firm size. The effective size story predicts that increases in IT would be important for the level of CEO pay even after controlling for firm size. Finally, the general skill hypothesis predicts that the demand for generality skills in CEO market will increase the dispersion among CEO pay, not just its level. The top CEO will be much more paid than less talented CEOs beyond what can be explained by the firm size dispersion.[2]

To examine the robustness of our models, we included the industry turbulence as a control variable. Some researchers have reported that IT-intensive industries tend to be more turbulent than others (Brynjolfsson, McAfee, Sorell, & Zhu, 2007). It may be that firms in turbulent industries face more competitive business environments and benefit disproportionately from hiring more talented and thus more expensive CEOs.

[2] These hypotheses are illustrated in Figure 4 in the results section.

The increased CEO pay due to IT intensity may be a result of the more competitive business environment that the firm faces in her industry not the increased effective size of her firm. The industry turbulence, as defined as the average of rank changes of firms from year to year over industry, was included as a control variable to explore this possibility.

Data Sources and Variables

IT intensity at industry level

We followed a method similar to one described in a previous study (Brynjolfsson, McAfee, Sorell and Zhu, 2007) to estimate IT intensity at industry level. In summary, IT intensity was defined to be IT capital stock divided by the sum of Structure, Equipment and Intellectual property. The capital stock data for IT, Structures, Plant, and Intellectual Property are available from the Bureau of Economic Analysis's (BEA) "Fixed Assets Table" for 63 industry sectors at approximately three-digit NAICS level from 1947 to 2014. We compiled how IT was defined in more detail in the appendix. We used two variables for IT intensity; one is the IT intensity in the whole economy each year and the other is the IT intensity of each industry each year. As IT intensity is either at industry-level or at the whole economy, our firm-level analysis uses the industry-level IT intensity data.

CEO compensation and firm-level company data

We used two Compustat databases, *Industrial* and *Executives*, for the period from 1992 to 2014. Compustat provides commercially available databases for public companies. The Industrial database provides firm characteristics such as physical assets, employee numbers, common stock and sales, while the Executives database provides data on compensation of the top executives up to 13 from each company. The Executives database is compiled from proxy statements filed by the companies in compliance with Securities and Exchange Commission (SEC) regulations and covers S&P 1500 companies starting in 1992.

The CEO compensation, *w*, was the variable, *tdc1*, from Compustat Executives data set. The *tdc1* includes salary, bonus, other annual, restricted stock grants, LITP payouts, all other, and value of option grants. We selected companies with at least three executives included in the database.

As a firm size variable, we used market capitalization of firm, following GL definition (Gabaix and Landier 2008). They reported that the market capitalization was the best proxy for firm size. It was calculated by the equation, *data199* x *abs(data25) + data6 – data60 – data74*, where *data199* is the share price of closing at fiscal year, *data25* is Common Shares Outstanding, *data6* is Total Assets, *data60* is Total Common Equity, and *data74* is Deferred Taxes. All nominal quantities were converted into 2000 dollars using the GDP deflator from the BEA.

Excluding the observations with missing variables, we examine panel data from 3413 publicly traded firms over 23 years.

Results and Discussion

IT and Total CEO pay

CEO pay increased dramatically in the 1990s, but Execucomp data suggests that top CEO pay is no longer "exploding". When using 2000 dollars, it is relatively flat after 2002 (Figure 1).

In the following charts, we compare trends in total CEO pay (the sum of the pay of all CEOs in Execucomp) with trends in firm size, defined as the sum of market values of their firms (Figure 2) and market value with trends in IT intensity, as computed from BEA data as detailed above (Figure 3).

Figure 1: CEO Pay over time

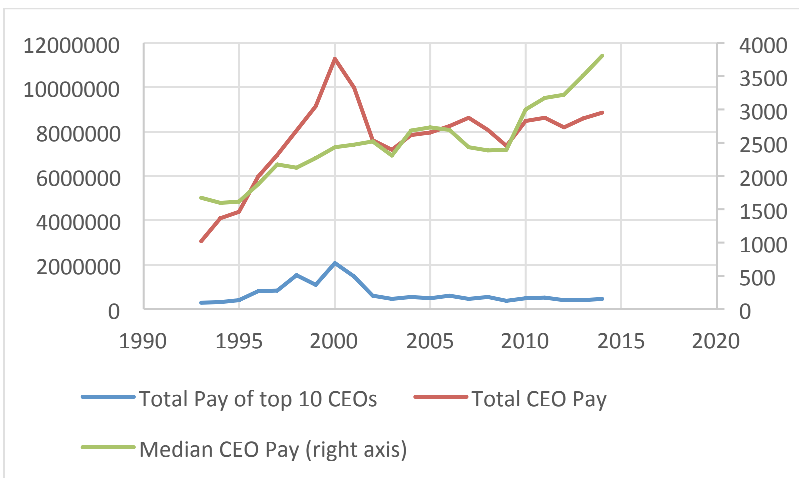
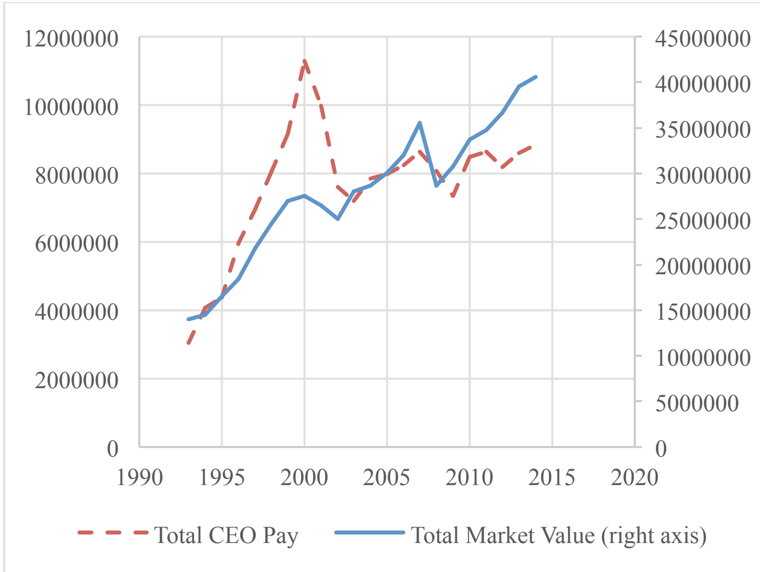
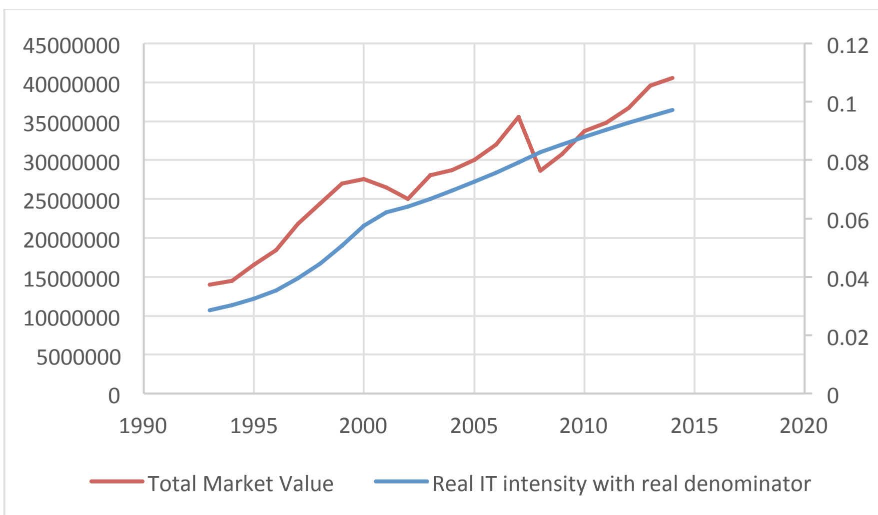


Figure 2 Total CEO Pay vs Total Market Value



Total CEO pay as well as top CEO pay seems to be leveling off after 2002, whereas median CEO pay has been steadily increasing in real terms, as have IT intensity and total market values of firms in the sample (Figure 3).

Figure 3 Total Market Value vs Real IT Intensity



As previous studies have reported (e.g Gabaix & Landier, 2008), total CEO pay is partly explained by the total market value of firms. We find that total CEO pay is also partly explained by the growth rate of real IT intensity, even after controlling for market value (Table 1).

Table 1: Economy-wide regression of growth rate of IT intensity and Market value on CEO Pay

	Dependent variable:

	log(Total CEO Pay)
Growth rate of real IT intensity	4.176***
	(0.771)
log(Total Market Value)	0.936***
	(0.094)
Constant	-0.421
	(1.628)
Observations	21
R^2	0.847
Adjusted R^2	0.831
Residual Std. Error	0.098 (df = 18)
Note:	*p<0.1; **p<0.05; ***p<0.01

We explore this relationship further via a variety of regressions using industry data on IT intensity. The effects of market value are significant (Table 2), consistent with previous research (Gabaix and Landier 2008). In addition to the firm size variables, IT intensity both in the whole economy and at industry level are consistently positive in each of the specifications (Table 2). Note that our IT intensity measure is at the industry-wide or economy-wide level while the CEO pay is at firm level. This reflects the fact that most theories of CEO pay argue that it is largely determined at the industry-wide or economy-wide level.

Table 2. Firm-level regression: CEO Pay vs. IT Intensity

	Dependent variable:			
	log(CEO Pay)			
	(1)	(2)	(3)	(4)
log(Market Value)	0.362***	0.362***	0.367***	0.369***
	(0.027)	(0.027)	(0.026)	(0.026)
log(Market Value of 250th firm)	0.666***	0.363***	0.357***	
	(0.095)	(0.078)	(0.077)	
IT Intensity (Whole Economy)		3.244**	2.643*	
		(1.325)	(1.454)	
IT Intensity (Industry)			0.255**	0.252**
			(0.110)	(0.110)
Year Dummies	No	No	No	Yes
Observations	36,531	36,531	36,531	36,531

R^2	0.410	0.411	0.416	0.422
Adjusted R^2	0.410	0.411	0.416	0.422
Residual Std. Error	0.749 (df = 36528)	0.747 (df = 36527)	0.745 (df = 36526)	0.741 (df = 36506)
Note:				*p<0.1; **p<0.05; ***p<0.01
				Errors Clustered By Industry

When industry turbulence and median worker wage are included as additional control variables, the IT intensity is still significant (Table 3). The effect of industry-level IT intensity is positive and significant except in the industry fixed effect specification, suggesting that most of the relevant variation is between industries, rather than over time.

Table 3. CEO Pay vs. IT intensity with more controls

	Dependent variable:			
	log(CEO Pay)			
	(1)	(2)	(3)	(4)
log(Market Value)	0.368***	0.371***	0.371***	0.417***
	(0.022)	(0.027)	(0.023)	(0.009)
log(Market Value of 250th firm)	0.375***	0.330***	0.342***	0.303***
	(0.094)	(0.078)	(0.122)	(0.066)
IT Intensity (Whole Economy)	2.253	2.931**	2.671	4.052***
	(2.050)	(1.490)	(2.585)	(1.234)
IT Intensity (Industry)	0.274**	0.297**	0.308*	-0.310
	(0.133)	(0.136)	(0.165)	(0.190)
Industry Turbulence	-0.002		-0.001	
	(0.003)		(0.005)	
log(Median Wage in Industry)		-0.158	-0.151	
		(0.112)	(0.119)	
Industry Fixed Effects	No	No	No	Yes
Observations	36,478	35,711	35,658	36,531
R^2	0.417	0.415	0.415	0.488
Adjusted R^2	0.416	0.415	0.415	0.487
Residual Std. Error	0.744 (df = 36472)	0.742 (df = 35705)	0.742 (df = 35651)	0.698 (df = 36466)
Note:				*p<0.1; **p<0.05; ***p<0.01
				Errors Clustered By Industry

IT and Dispersion in CEO pay

Any or all of the three theories (IT changing firm size, IT changing effective firm size, and IT changing skill generality) could explain the above correlation between IT and CEO pay. However, as outlined below, we may be able to distinguish among them by their distinct predictions for the relationship between IT and the dispersion, or variance, of CEO pay.

Using the framework of Gabaix and Landier (GL), we drive the following equation as detailed in the appendix.

$$w = D_* c_*^{\alpha} I_*^{\alpha\delta} S_*^{\alpha} c^{\beta} I^{\beta\delta} S^{\beta} = A_*^{\mu} I_*^{\varepsilon} S_*^{\alpha} c^{\beta} I^{\rho} S^{\beta} \quad (1)$$

where *w* is CEO pay, D_* is a function of the marginal talent of CEO, $T'(n_*)$ of the reference firm and the size of the reference firm, c is a constant, I is the IT intensity, S is the firm size, and α and β are positive constants. The ratio of one CEO pay, w(i) and the other CEO pay, w(j), is the ratio of the firm size and the IT intensity.

$$\frac{w(i)}{w(j)} = a(\frac{I(i)}{I(j)})^{\rho}(\frac{S(i)}{S(j)})^{\beta} \quad (2)$$

where *a* is a constant.

In GL's framework without the IT terms, the distribution of income maps directly into the distribution of firm size. As such, a shift in all firm sizes is expected to shift all CEO salaries by the same amount, leaving inequality among CEOs unchanged. That is, the ratio of CEO pay will be explained only by the ratio of firm size. We articulate that IT plays an additional role in the dispersion of CEO pay.

First, IT affects the inequality in CEO pay indirectly through the distribution of firm sizes. In the other words, the firm size is determined partly by IT. In the equation (2), the firm size, S(i), is a function of IT intensity, I(i). However, it is possible for IT intensity to affect firm size differentially at the top and at the bottom of the size distribution, which would indirectly lead, according to G&L's framework, to an increase in CEO pay inequality. Similarly, it is possible for firm size to affect IT intensity, a smaller firm being easier to manage without large IT investments.

Second, IT can have a direct effect on CEO pay inequality. In the equation (2), the CEO pay ratio, $w(i)/w(j)$, can be the ratio of the IT intensity, $I(i)/I(j)$, as well as the ratio of firm size. However, an average of IT intensity of the whole economy or the industry would not necessarily affect the ratio of the CEO pay. If the two firms, i,and j, increase their IT intensity as well as their firm size by the same factor, this framework predicts the ratio of CEO pay should remain unchanged.

On the other hand, the average IT in the whole economy or industry wide has a different effect on the dispersion of CEO pay. Following Frydman(2005), we formulate the variance and level of CEO pay in function of the importance of general skill as the followin:

$$q_{CEOi,k} = \theta_k(g^* + g_i + s_i)$$

Where $q_{CEOi,k}$ is the total output by CEO,i, at firm k, θ_k is the size of firm k, g* is the general skill of CEO,i, before entering firm k, g_i is the general skill of CEO, i, acquired at firm, s_i is the firm-specific skill of CEO,i, acquired at firm k. The firm, k, pays its CEO, i, the wage as the following:

$$w_{CEOi} = (1-\rho)\theta_k(g^* + g_i + s_i)$$

$(1-\rho)$ is the fraction of the value of the marginal product of labor of the CEO that the firms can have where firms extract some rents from the productivity of CEOs ($0<\rho<1$) or free entry and no profits for firms ($\rho=0$).

The CEO, i, leaves firm k for k' if

$$(1-\rho)\theta_{k'}(g^* + g_i) > (1-\rho)\theta_k(g^* + g_i + s_i)$$

The CEO's wage becomes that::

$$w_{CEOi} = (1-\rho)\theta_{k'}(g^* + g_i) = (1-\rho)\theta_{k'}(g^* + \alpha a_i)$$

With the assumption that $g_i = \alpha a_i$ where α is the relative importance of general skill and $a_i$is the ability of CEO, i. The difference in CEO pay with high and low ability is smaller when α is smaller but the difference in CEO pay with different ability is magnified with α.

The variance of CEO pay becomes that:

$$Var(w_{CEOi}) = Var[(1-\rho)\theta_{k'}(g^* + g_i)] = Var[(1-\rho)\theta_{k'}(g^* + \alpha a_i)]$$

$$= Var[(1-\rho)\theta_{k'}g^*)] + Var[(1-\rho)\theta_{k'}\alpha a_i)] + 2cov[(1-\rho)\theta_{k'}g^*, (1-\rho)\theta_{k'}\alpha a_i]$$

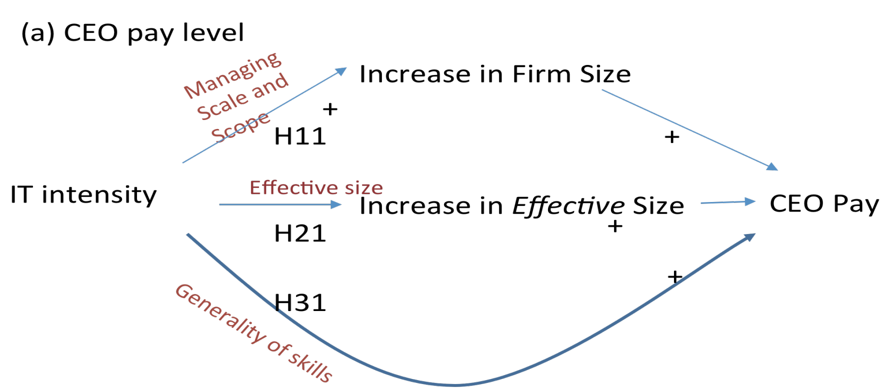
$$= Var[(1-\rho)\theta_{k'}g^*)] + ((1-\rho)\alpha)^2 Var[\theta_{k'}a_i)] + 2(1-\rho)^2\alpha\, g^* Cov(\theta_{k'},\theta_k a_i)$$

$Cov(\theta_{k'},\theta_{k'}a_i)$ is positive because managers with higher ability, a, self-select into larger firms (i.e., higher θ) (Frydman 2005). Therefore, the variance of CEO pay increases with increasing α. We articulate that α is a function of IT, in that, the industry with a high IT intensity has a higher value of α.

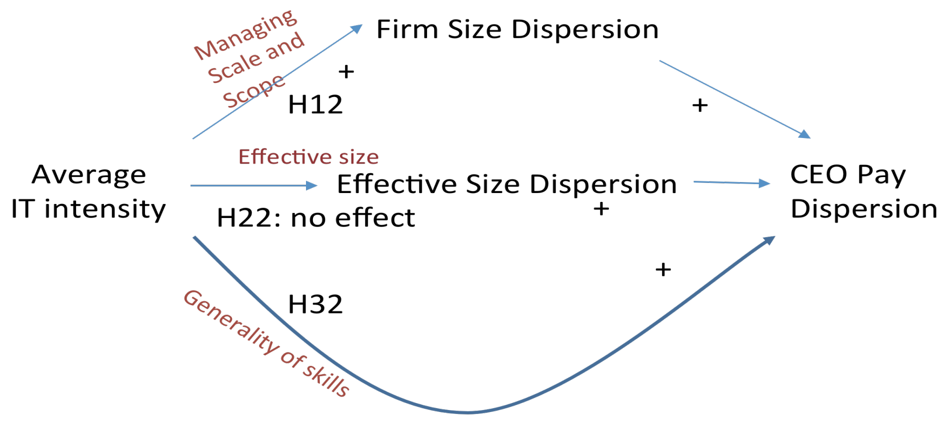
In other words, if the average IT intensity in the whole economy or industry wide increases the demand for the general skill of CEOs, the average IT can have a direct effect on CEO pay inequality (i.e. without going through nominal firm size or effective firm size). If IT-intensive firms can be managed by general managers (who are not necessarily experts in the specific sector of the firm), one can expect CEO pay inequality to increase, as hiring boards now have access to a larger external pool of CEO candidates (Frydman, 2005).

Figure 4 summarizes the hypothesized causal channels between the average IT intensity, CEO pay level, and the dispersion of CEO wages and we examine H12, H22, and H32 for the role of IT in the dispersion of CEO pay.

Figure 4. The role of IT in the change in CEO pay. (a) and (b) illustrate the hypotheses of the role of IT in the changes in CEO pay level and CEO pay dispersion, respectively.



(b) CEO pay dispersion



Does the average IT increase the dispersion of firm size and consequently increase the dispersion of CEO pay? (H12)

Earlier research found that investments in IT can explain a significant portion of a firms market value (Brynjolfsson, Hitt, & Yang, 2002) or firm size by other metrics, at least in manufacturing (Brynjolfsson et al., 1994). Our result suggests that the industry with higher IT density also increase the *variance* of firms market value.

The regressions shown in

Table 4. IT Intensity and Dispersion of Firm Size

	Dependent variable:				
	Variance of Log Market value within industry				
	pooling	pooling (clustered)	Fixed Effects (industry)	Year Dummies	Fixed Effects (industry) +year dummies
	(1)	(2)	(3)	(4)	(5)
IT Intensity (industry)	0.847^{***}	0.847^{***}	0.628^{**}	0.859^{***}	0.464^{*}
	(0.084)	(0.253)	(0.307)	(0.272)	(0.270)
log(SalesTurbulence)	0.023	0.023	-0.034	0.014	-0.040
	(0.023)	(0.068)	(0.058)	(0.078)	(0.068)
log(Mean Market Value (industry))	0.668^{***}	0.668^{***}	0.493^{***}	0.688^{***}	0.587^{***}
	(0.023)	(0.079)	(0.115)	(0.083)	(0.138)
Observations	1,030	1,030	1,030	1,030	1,030
R^2	0.558	0.558	0.800	0.577	0.816
Adjusted R^2	0.557	0.557	0.789	0.567	0.801
Residual Std. Error	0.645 (df = 1026)	0.645 (df = 1026)	0.446 (df = 973)	0.638 (df = 1005)	0.432 (df = 952)
Note:					*p<0.1; **p<0.05; ***p<0.01

*p<0.1; **p<0.05; ***p<0.01. Column (1) uses heteroscedasticity robust SEs. All others are clustered by industry provide evidence of a correlation between IT intensity at the industry level and the dispersion of market values within that industry (as measured by the variance of log of market value within industry). This is evidence for H12 in Figure 4b.

Table 4. IT Intensity and Dispersion of Firm Size

	Dependent variable:				
	Variance of Log Market value within industry				
	pooling	pooling (clustered)	Fixed Effects (industry)	Year Dummies	Fixed Effects (industry) +year dummies
	(1)	(2)	(3)	(4)	(5)
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Note:					*p<0.1; **p<0.05; ***p<0.01

*p<0.1; **p<0.05; ***p<0.01. Column (1) uses heteroscedasticity robust SEs. All others are clustered by industry

Does the average IT intensity increase the dispersion in CEO pay directly? (H22 and H32)

Does IT explain dispersion in CEO pay above and beyond the effect through dispersion in market values? According to the generality of skills argument (H32), it should, while the other hypotheses do not predict such an effect.

In order to gain insight into this, in each industry, we regress the variance of logs of CEO pay on the variance of logs of markets values (

Table 5). At the industry level, higher IT intensity leads to higher dispersion in CEO pay (as measured by the variance of log of CEO pay), even after controlling for dispersion in firm sizes (measured as market values) (

Table 5).

It is possible that the industry with a higher average IT intensity may have a higher degree of dispersion in IT density as well. However, we do not have the data on the dispersion of IT intensity among firms within industry and we cannot examine the dispersion of IT. However, regardless of the degree of the dispersion of IT intensity within the industry, the “generality of skills” argument, which is illustrated in H32 of Figure 4b, would predict that the increase in the average IT intensity should increase the dispersion of CEO pay.

The results shown in Table 5 and Table 6 are an evidence for the generality of skills argument.

Table 5. IT Intensity and Dispersion in CEO Pay

	Dependent variable: Variance in Log CEO Pay			
	(1)	(2)	(3)	(4)
log(Industry Average Market Value)	0.153**	0.144**	0.103*	
	(0.074)	(0.069)	(0.061)	
IT Intensity (Whole Economy)		2.565	0.356	
		(2.721)	(2.164)	
IT Intensity (Industry)			1.642***	1.700***
			(0.402)	(0.410)
Year Dummies	No	No	No	Yes
Observations	978	978	978	978
R^2	0.011	0.012	0.074	0.095
Adjusted R^2	0.010	0.010	0.071	0.073
Residual Std. Error	1.457 (df = 976)	1.456 (df = 975)	1.411 (df = 974)	1.409 (df = 954)
Note:	*p<0.1; **p<0.05; ***p<0.01; Errors Clustered by Industry			

Table 6. Dispersion of CEO pay vs. IT intensity with more controls

	Dependent variable:			
	Variance in Log CEO Pay			
	(1)	(2)	(3)	(4)
log(Industry Average Market Value)	0.105	0.173**	0.179**	0.509***
	(0.064)	(0.083)	(0.090)	(0.168)
IT Intensity (Whole Economy)	0.283	0.424	0.188	-5.796***
	(2.082)	(2.203)	(2.046)	(2.189)
IT Intensity (Industry)	1.648***	1.707***	1.726***	2.770***
	(0.406)	(0.346)	(0.359)	(0.446)
Industry Turbulence	-0.001		-0.002	
	(0.002)		(0.005)	
log(Median Wage in Industry)		-0.444**	-0.447**	
		(0.196)	(0.200)	
Industry Fixed Effects	No	No	No	Yes
Observations	977	954	953	978
R^2	0.074	0.083	0.083	0.431
Adjusted R^2	0.070	0.079	0.078	0.396
Residual Std. Error	1.412 (df = 972)	1.421 (df = 949)	1.422 (df = 947)	1.137 (df = 921)
Note:				*p<0.1; **p<0.05; ***p<0.01
				Errors Clustered By Industry

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IT and mobility of executives

Another way to distinguish among the hypothesis is by looking at turnover among CEOs and other executives. The more important the general skill of CEOs becomes, the more executives' turnover there would be (Frydman 2005; Murphy and Zabojnik 2004). Some researchers examined CEO turnover in correlation with firm performance (Kaplan and Minton 2012) and industry performance (Eisfeldt and Kuhnen 2013). We discussed how IT increases the demand for managerial general skill. Consequently, it may increase executives' turnover. In fact, we do find a significant correlation between IT intensity and executives' turnover in this section.

Let S_t^i be the set of executives employed by firm *i* at time *t*. Inflow is defined as the number of executives who are part of the firm in year *t* but were not part of year in year t-1. This value is normalized by the number of executives in the firm in year *t.* Similarly, outflow is the number of executives present in year t-1 but not in year t, normalized by the number of executives at time t. Finally, turnover is the average of these two values. Turnover is computed at the firm level.

$$\mathrm{Inflow}_t^i = \frac{\#(S_t^i \setminus S_{t-1}^i)}{\#S_t^i}$$

$$\mathrm{Outflow}_t^i = \frac{\#(S_{t-1}^i \setminus S_t^i)}{\#S_t^i}$$

$$Turnover_t^i = \frac{\mathrm{Inflow}_\mathrm{i}^t + \mathrm{Outflow}_i^t}{2}$$

In our empirical analysis, we focus on executive turnover instead of CEO turnover because Execucomp has few instances of documented CEO mobility (only about 300 CEOs changed jobs in our sample). We averaged the IT intensity and the executives turnovers over 22 years from 1993 to 2014 and examined the correlation (Figure 5 and Table 7). The industries with higher IT intensity have higher degree of executive turnover (Figure 5). The IT intensity is significantly correlated with executive turnover (Table 7).

Figure 5 Executive turnover and IT intensity. Each group indicates a quartile with regards to the average IT intensity level over 22 years. The group, 4, is the group of industries that has the top quartile in the average IT intensity.

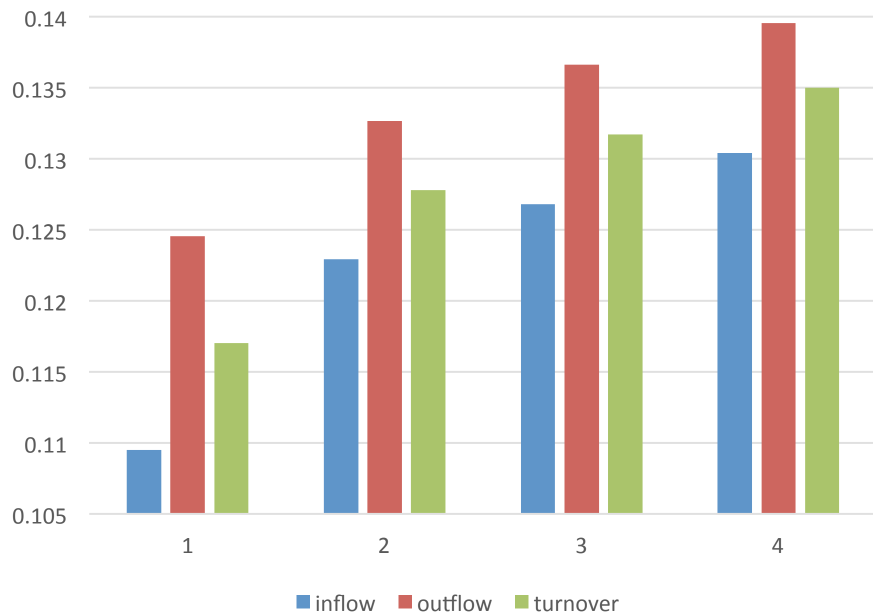
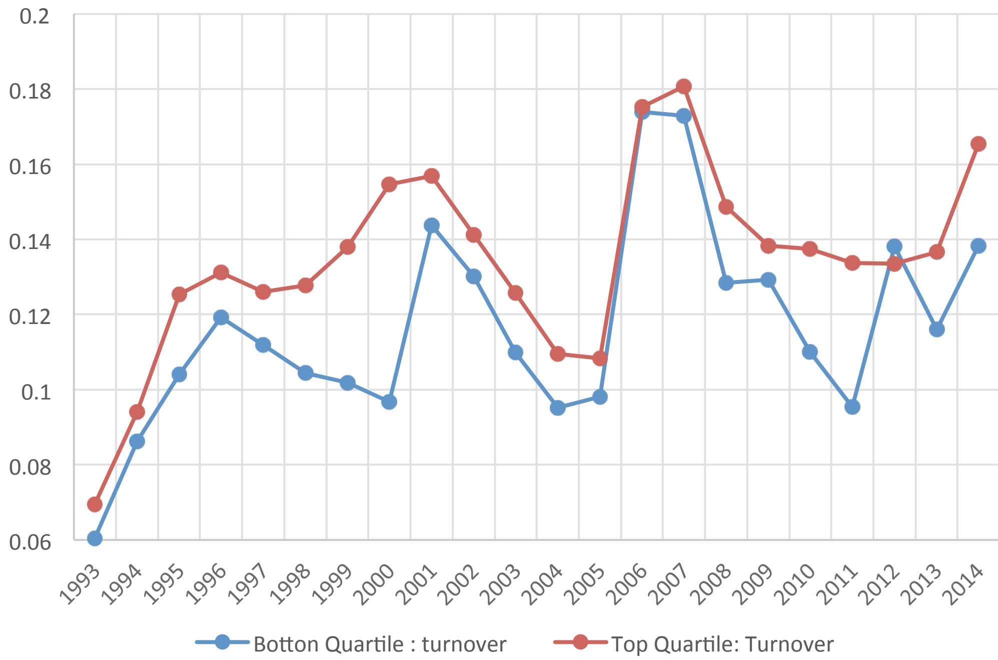

0.14
0.135
0.13
0.125
0.12
0.115
0.11
0.105
1
2
3
4
inflow
outflow
turnover

Table 7. IT intensity and Executive turnover (industry level)

	Dependent variable:		
	inflow	outflow	Turnover
	(1)	(2)	(3)
IT Intensity	0.077***	0.071***	0.074***
	(0.022)	(0.026)	(0.023)
Constant	0.117***	0.129***	0.123***
	(0.003)	(0.003)	(0.003)
Observations	61	61	61
R^2	0.168	0.115	0.148
Adjusted R^2	0.154	0.100	0.134
Residual Std. Error (df = 59)	0.019	0.022	0.020
	*p<0.1; **p<0.05; ***p<0.01		
Note:	Both dependent variables and IT intensity variable are the average over the period from 1993 to 2014.		

Executive turnover has increased over the period from 1993 to 2014 (Figure 6), consistent with other reports (Frydman 2005; Kaplan and Minton 2012). We find that the industries with high IT investment have higher executive turnover over the sample period (Figure 6).

Figure 6. Executive turnover in top and bottom quartile industries in terms of IT intensity from 1993 to 2014. Each quartile of industries based on IT intensity was calculated every year and an industry may not stay in the same quartile group over the sample period.



To further explore this relationship, we regressed (executives turnover)$_{it}$ where *i* is industry and *t* is year, on (IT intensity)$_{it}$. IT intensity is still significant when industry and year fixed effects are included (Table 8) and other industry characteristics are controlled (Table 9).

Table 8. Executive Turnover vs. IT Intensity

	Turnover (industry level)				
	pooling	pooling (clustered)	Fixed Effects (industry)	Year Dummies	Fixed Effects (industry) +year dummies
	(1)	(2)	(3)	(4)	(5)
IT Intensity	0.091^{***}	0.091^{***}	0.235^{***}	0.073^{***}	0.060^{**}
	(0.010)	(0.015)	(0.032)	(0.013)	(0.029)
Observations	1,286	1,286	1,286	1,286	1,286
R^2	0.024	0.024	0.121	0.150	0.243
Adjusted R^2	0.024	0.024	0.077	0.135	0.191
Residual Std. Error	0.063 (df= 1284)	0.063 (df= 1284)	0.062 (df= 1224)	0.060 (df= 1263)	0.058 (df= 1203)
Note:					*p<0.1; **p<0.05; ***p<0.01

Column (1) uses heteroscedasticity robust SEs. All others are clustered by industry

Table 9. Executive turnover vs. IT intensity with more controls.

	turnover			
	pooling (clustered)	Fixed Effects (industry)	Year Dummies	Fixed Effects (industry) +year dummies
	(1)	(2)	(3)	(4)
IT Intensity	0.090***	0.204***	0.067***	0.085**
	(0.016)	(0.026)	(0.015)	(0.036)
log(Industry Turbulence)	-0.003	-0.003	0.0002	0.0001
	(0.002)	(0.004)	(0.002)	(0.006)
log(Median Salary in industry)	-0.002	0.011	-0.0002	0.010
	(0.004)	(0.009)	(0.005)	(0.012)
log(Mean Market Value in industry)	-0.0004	0.011	-0.003	0.003
	(0.003)	(0.009)	(0.003)	(0.014)
log(Total Employment in industry)	0.003	-0.002	0.002	-0.008
	(0.003)	(0.010)	(0.003)	(0.008)
Observations	1,207	1,207	1,207	1,207
R^2	0.044	0.153	0.223	0.320
Adjusted R^2	0.040	0.107	0.205	0.269
Residual Std. Error	0.051 (df = 1201)	0.049 (df = 1143)	0.046 (df = 1180)	0.045 (df = 1122)
Note:				*p<0.1; **p<0.05; ***p<0.01 Errors clustered by industry

We also examined the executives' turnover at firm level vs. IT intensity. (Executives turnover)$_{ijt}$, where i is industry, j is firm, and t is year, was regressed on (IT intensity)$_{it}$ at industry level and other variables at firm level (Table 10). As other researchers reported that poor firm performance increases the executives' turnover (Kaplan and Minton 2012), we find that the market value of the firm is negatively correlated with executives' turnover (Table 10). However, IT intensity at industry level still explains a part of increased executives' turnover (Table 10).

Table 10. Executive turnover at firm level vs. IT intensity

	Turnover (firm level)				
	pooling	pooling (clustered)	Fixed Effects (firm)	Year Dummies	Fixed Effects (firm) +year dummies
	(1)	(2)	(3)	(4)	(5)
IT Intensity	**0.066*****	**0.066*****	**0.282*****	**0.055*****	**0.041**
	(0.005)	(0.008)	(0.031)	(0.008)	(0.036)
log(Market Value)	-0.006***	-0.006***	-0.007***	-0.006***	-0.015***
	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)
log(Average Pay of top 5 executives)	0.020***	0.020***	0.014***	0.018***	0.008***
	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)
Observations	36,067	36,067	36,067	36,067	36,067
R^2	0.017	0.017	0.201	0.042	0.231
Adjusted R^2	0.017	0.017	0.119	0.042	0.151
Residual Std. Error	0.130 (df = 36063)	0.130 (df = 36063)	0.123 (df = 32697)	0.129 (df = 36042)	0.121 (df = 32676)

Note: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Column (1) uses heteroscedasticity robust SEs. All others are clustered by firm

Conclusion

The compensation of a CEO will depend in part on the size of the firm, the CEO's information gathering and control capabilities, and the alternative options the CEO has for employment. Information technology can potentially influence CEO pay through all three of these mechanisms.

We find the strongest evidence for the first and third stories. IT is correlated not only with higher CEO pay, but also with increased dispersion in firm size, which is in turn reflected in increased dispersion in CEO pay. Furthermore, even controlling for changes in firm size, IT remains correlated with increased dispersion in CEO pay.

We also find a strong correlation between IT and CEO mobility. The higher IT intensity an industry has, the more executives' turnover it has. This is further evidence that IT increases the demand for general skill of top managers and top managers become more mobile. This is consistent with the theory that CEOs in IT intensive industries have more general skills, leading to higher relative pay for top CEOs.

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TECHNICAL APPENDIX I

Merging Compustat/Execucomp data with BEA data

The final industry classification used in this paper is made of 63 "BEA" industries, whereas Compustat data contains NAICS codes. NAICS codes are therefore converted to BEA industries using the below table:

INDUSTRY TITLE	BEA CODE	1997 NAICS Codes	2002 NAICS Codes	2007 NAICS Codes
Agriculture, forestry, fishing, and hunting	--------	**11**	**11**	**11**
Farms	110C	111,112	111,112	111,112
Forestry, fishing, and related activities	113F	113,114,115	113,114,115	113,114,115
Mining	--------	**21**	**21**	**21**
Oil and gas extraction	2110	211	211	211
Mining, except oil and gas	2120	212	212	212
Support activities for mining	2130	213	213	213
Utilities	**2200**	**22**	**22**	**22**
Construction	**2300**	**23**	**23**	**23**
Manufacturing	--------	**31-33**	**31-33**	**31-33**
Durable goods	--------	--------	--------	--------
Wood products	3210	321	321	321
Nonmetallic mineral products	3270	327	327	327
Primary metals	3310	331	331	331
Fabricated metal products	3320	332	332	332
Machinery	3330	333	333	333
Computer and electronic products	3340	334	334	334
Electrical equipment, appliances, and components	3350	335	335	335
Motor vehicles, bodies and trailers, and parts	336M	3361-3	3361-3	3361-3
Other transportation equipment	336O	3364-9	3364-9	3364-9
Furniture and related products	3370	337	337	337
Miscellaneous manufacturing	338A	339	339	339
Nondurable goods	--------	--------	--------	--------
Food, beverage, and tobacco products	311A	311,312	311,312	311,312
Textile mills and textile product mills	313T	313,314	313,314	313, 314
Apparel and leather and allied products	315A	315,316	315,316	315, 316
Paper products	3220	322	322	322
Printing and related support activities	3230	323	323	323
Petroleum and coal products	3240	324	324	324
Chemical products	3250	325	325	325
Plastics and rubber products	3260	326	326	326
Wholesale trade	**4200**	**42**	**42**	**42**
Retail trade	**44RT**	**44-45**	**44-45**	**44-45**
Transportation and warehousing	--------	**48-49**	**48-49**	**48-49**
Air transportation	4810	481	481	481
Railroad transportation	4820	482	482	482
Water transportation	4830	483	483	483
Truck transportation	4840	484	484	484
Transit and ground passenger transportation	4850	485	485	485

Pipeline transportation	4860	486	486	486
Other transportation and support activities	487S	487,488,492	487,488,492	487,488,492
Warehousing and storage	4930	493	493	493
Information	**--------**	**51**	**51**	**51**
Publishing industries (including software)	5110	511	511, 516 (pt.)	511
Motion picture and sound recording industries	5120	512	512	512
Broadcasting and telecommunications	5130	513	515, 517	515, 517
Information and data processing services	5140	514	516 (pt.), 518, 519	518, 519
Finance and insurance	**--------**	**52**	**52**	**52**
Federal Reserve banks	5210	521	521	521
Credit intermediation and related activities	5220	522	522	522
Securities, commodity contracts, and investments	5230	523	523	523
Insurance carriers and related activities	5240	524	524	524
Funds, trusts, and other financial vehicles	5250	525	525	525
Real estate and rental and leasing	**--------**	**53**	**53**	**53**
Real estate	5310	531	531	531
Rental and leasing services and lessors of intangible assets	5320	532,533	532,533	532,533
Professional, scientific, and technical services	**--------**	**54**	**54**	**54**
Legal services	5411	5411	5411	5411
Computer systems design and related services	5415	5415	5415	5415
Miscellaneous professional, scientific, and technical services	5412	541 ex. 5411,5415	541 ex. 5411,5415	541 ex. 5411,5415
Management of companies and enterprises	**5500**	**55**	**55**	**55**
Administrative and waste management services	**--------**			
Administrative and support services	5610	561	561	561
Waste management and remediation services	5620	562	562	562
Educational services	**6100**	**61**	**61**	**61**
Health care and social assistance	**--------**	**62**	**62**	**62**
Ambulatory health care services	6210	621	621	621
Hospitals	622H	622	622	622
Nursing and residential care facilities	6230	623	623	623
Social assistance	6240	624	624	624
Arts, entertainment, and recreation	**--------**	**71**	**71**	**71**
Performing arts, spectator sports, museums, and related activities	711A	711,712	711,712	711,712
Amusements, gambling, and recreation industries	7130	713	713	713
Accommodation and food services	**--------**	**72**	**72**	**72**
Accommodation	7210	721	721	721
Food services and drinking places	7220	722	722	722
Other services, except government	**8100**	**81**	**81**	**81**

Note: to make this process easier, the authors have an R function (NAICStoBEA), which support most variants of NAICS, available upon request.

Measures derived from Execucomp and Compustat

We restrict our attentions to full-year CEOs, [CEOANN='CEO'] in execucomp. We then merge the execucomp dataset with the Compustat Fundamentals database, downloaded in 2015. Compustat offers various levels of aggregations. We use **C**, the highest available level of aggregation. Compustat and Execucomp are straightforwardly merged using the GVKEY variable.

As our measure of CEO pay, we use TDC1 in Execucomp, which includes the current value of non-pay compensation (such as stock options).

As our measure of firm value, we use the same formula as in Gabaix and Landier:

data199 x *abs(data25) + data6 – data60 – data74,* where *data199* is the share price of closing at fiscal year, *data25* is Common Shares Outstanding, *data6* is Total Assets, *data60* is Total Common Equity, and *data74* is Deferred Taxes. Note that using 2015 Compustat variable names, this equation becomes:

csho x abs(prcc_f) + at - ceq- txdb

Industry turbulence: We use the SALE and the EBIDTA variables from compustat. For each year and within each industry, we rank firms by their sales and EBITDA. We then compute, for each industry, the average absolute value rank change from on year to the next. This serves as our measure of industry turbulence, which is used as a control in some tables.

All nominal quantities were converted into 2000 dollars using the GDP deflator from the BEA.

In our regression tables, restrict our attention to CEOs with pay > $200,000 (in 2000 dollars). This removes a negligible fraction of the sample.

Building Industry-Level IT measures

As of 2015, the BEA reports the following asset classes in its survey of tangible wealth. For each class, we report whether it was included in measure of IT spending. The denominator used to convert IT capital into IT intensity is the sum of the equipment and structures categories below. HW indicates the asset code was included in "hardware only" variables, and SW indicates it was included in "software only" variables. The general "IT" variable in our paper includes both hardware and software.

Asset Codes	NIPA Asset Types	Included in IT variable
EQUIPMENT	**TOTAL EQUIPMENT**	
EP1A	**Mainframes**	**Yes-HW**
EP1B	**PCs**	**Yes-HW**
EP1C	**DASDs**	**Yes-HW**
EP1D	**Printers**	**Yes-HW**
EP1E	**Terminals**	**Yes-HW**
EP1F	**Tape drives**	**Yes-HW**
EP1G	**Storage devices**	**Yes-HW**
EP1H	**System integrators**	**Yes-HW**

EP20	**Communications**	**Yes-HW**
EP34	**Nonelectro medical instruments**	
EP35	**Electro medical instruments**	
EP36	**Nonmedical instruments**	
EP31	**Photocopy and related equipment**	
EP12	**Office and accounting equipment**	
EI11	**Nuclear fuel**	
EI12	**Other fabricated metals**	
EI21	**Steam engines**	
EI22	**Internal combustion engines**	
EI30	**Metalworking machinery**	
EI40	**Special industrial machinery**	
EI50	**General industrial equipment**	
EI60	**Electric transmission and distribution**	
ET11	**Light trucks (including utility vehicles)**	
ET12	**Other trucks, buses and truck trailers**	
ET20	**Autos**	
ET30	**Aircraft**	
ET40	**Ships and boats**	
ET50	**Railroad equipment**	
EO11	**Household furniture**	
EO12	**Other furniture**	
EO30	**Other agricultural machinery**	
EO21	**Farm tractors**	
EO40	**Other construction machinery**	
EO22	**Construction tractors**	
EO50	**Mining and oilfield machinery**	
EO60	**Service industry machinery**	
EO71	**Household appliances**	
EO72	**Other electrical**	
EO80	**Other**	
STRUCTURES	**TOTAL STRUCTURES**	
SOO1	**Office**	
SB31	**Hospitals**	
SB32	**Special care**	
SOO2	**Medical buildings**	
SC03	**Multimerchandise shopping**	
SC04	**Food and beverage establishments**	
SC01	**Warehouses**	

SOMO	**Mobile structures**	
SC02	**Other commercial**	
SI00	**Manufacturing**	
SU30	**Electric**	
SU60	**Wind and solar**	
SU40	**Gas**	
SU50	**Petroleum pipelines**	
SU20	**Communication**	
SM01	**Petroleum and natural gas**	
SM02	**Mining**	
SB10	**Religious**	
SB20	**Educational and vocational**	
SB41	**Lodging**	
SB42	**Amusement and recreation**	
SB43	**Air transportation**	
SB45	**Other transportation**	
SU11	**Other railroad**	
SU12	**Track replacement**	
SB44	**Local transit structures**	
SB46	**Other land transportation**	
SN00	**Farm**	
SO01	**Water supply**	
SO02	**Sewage and waste disposal**	
SO03	**Public safety**	
SO04	**Highway and conservation and development**	
IPP	**TOTAL INTELLECTUAL PROPERTY PRODUCTS**	
ENS1	**Prepackaged software**	**Yes-SW**
ENS2	**Custom software**	**Yes-SW**
ENS3	**Own account software**	**Yes-SW**
RD11	**Pharmaceutical and medicine manufacturing**	
RD12	**Chemical manufacturing, ex. pharma and med**	
RD23	**Semiconductor and other component manufacturing**	**Yes-HW**
RD21	**Computers and peripheral equipment manufacturing**	**Yes-HW**
RD22	**Communications equipment manufacturing**	**Yes-HW**
RD24	**Navigational and other instruments manufacturing**	
RD25	**Other computer and electronic manufacturing, n.e.c.**	**Yes-HW**
RD31	**Motor vehicles and parts manufacturing**	
RD32	**Aerospace products and parts manufacturing**	
RDOM	**Other manufacturing**	

RD70	**Scientific research and development services**	
RD40	**Software publishers**	**Yes-SW**
RD50	**Financial and real estate services**	
RD60	**Computer systems design and related services**	**Yes-SW**
RD80	**All other nonmanufacturing, n.e.c.**	
RD91	**Private universities and colleges**	
RD92	**Other nonprofit institutions**	
AE10	**Theatrical movies**	
AE20	**Long-lived television programs**	
AE30	**Books**	
AE40	**Music**	
AE50	**Other entertainment originals**	

These IT, Software, Hardware measures are built at the industry level for each year, and at the level of the whole economy for each year.

Technical Appendix II: A Model of Effective Firm Size

Our model extends the model of Gabaix and Landier (2008), that can be summarized as the following:

1) CEOs have different levels and managerial talent and are matched to firms competitively;

2) in equilibrium, the best and thus the highest paid CEO manages the largest firms, as this maximizes their impact and economic efficiency; and

3) the CEO pay also increases with the average size of firm in the economy.

In other words, this theory states that, if there are two firms of different sizes and two managers of different talent, a competitive equilibrium exists in the way that the larger firm hires the more talented manager at a higher pay than the smaller firm does. Our contribution is to extend the concept of firm size in their theory to an "effective" size of firm, defined as the firm size that top managers can control and reach as information technology has integrated firm data and enabled a replicable, speedy, and firm-wide business process aided by an enterprise IT system, and test the theory with empirical analysis.

We briefly walk through Gabaix and Landier's model here. Consider the problem of hiring a CEO with talent, *T*, faced by a particular firm. The firm has "baseline" earnings of a_0. At t=0, it hires a manager of talent *T* for one period. The manager's talent *T* increases the firm's earnings according to

$$a_1 = a_0(1 + C\times T) = a_0 + a_0\times C\times T \qquad (1)$$

for some $C > 0$, which quantifies the effect of talent on earnings. Consider one extreme case that the CEO's actions at date 0 impact earnings only in period 1. The firm's earnings are $(a_1, a_0, a_0, \ldots.)$. The other extreme case is that the CEO's actions at date 0 impact earnings permanently. Then the earnings become $(a_1, a_1, a_1, \ldots)$. In both cases, the firm's problem can be written as the following:

$$\max_T S\times(1 + C\times T) - W(T) = \max_T S + S\times C\times T - W(T) \qquad (2)$$

where $S = \frac{a_0}{1+r}$ for the former (where CEO's talent impacts the firm's earnings only the first period) or $\frac{a_0}{r}$ for the latter (where CEO's talent impacts the firm's earnings permanently), *r* is the discount rate, and $W(T)$ is the wage of CEO with talent, T. Eqn (1) can be generalized as $a_1 = a_0 + C{a_0}^{\gamma} + independent\ factors$, for a non-negative γ. The maximization problem of (2) becomes that:

$$\max_T(S + S^{\gamma}\times C\times T - W(T)) \qquad (3)$$

Let's call $w(m)$ the equilibrium compensation of each CEO with index *m* which can be thought of the CEO's ranking or quantile in talent. The problem of (3) can be rewritten as that:

$$\max_m(CS(n)^{\gamma}T(m) - w(m)) \qquad (4)$$

A competitive equilibrium consists of:

i. a compensation function $W(T)$, which specifies the market pay of a CEO of talent T, and

ii. an assignment function $M(n)$, which specifies the index $m = M(n)$ of the CEO heading firm n in equilibrium,

such that

iii. each firm chooses its CEO optimally: $M(n) \in arg \max_m(CS(n)^{\gamma}T(m) - W(T(m))$, and

iv. the CEO market clears, that is each firm gets a CEO.

As in equilibrium there is associative matching: $m = n$,

$$w(n) = \int_N^n CS(u)^\gamma T'(u)du + w(N)$$
(5)

Assuming a specific functional form for $T'(u)$ with the use of the extreme value theory, Gabaix and Landier provided the solution for a CEO pay in terms of the size of a reference firm as well as the CEO's firm. The most relevant equation for our study is expressed in terms of the effective size of firm as following[3]:

$$w = D_*\widehat{S_*}^\alpha \hat{S}^\beta$$
(6)

where w is CEO pay, $\hat{S}$ and $\widehat{S_*}$ are the effective size of the CEO's firm and a reference firm, respectively, and α and β are positive constants. D_* is a function of the marginal talent of CEO, $T'(n_*)$ of the reference firm and the size of the reference firm. In all equations, the subscript * indicates attributes for a reference firm.

The effective size of a firm in Gabaix and Landier's model is a function of the sensitivity of the firm to CEO talent and the nominal size of the firm. We extend this concept further; CEO may be able to reach a greater portion of her firm if her firm is more integrated through its IT system. In other words, we hypothesize that the effective size (that CEO can affect) increases as a firm is more integrated through an information technology (IT) system. This hypothesis reflects that IT reduces, to name a few, the cost of communication between top managers and employees, the cost of implementing new business processes, and the cost of monitoring employee performances. For example, a large retailer such as Wal-Mart has adopted an enterprise IT system and the inventories and sales data from approximately 4,000 retail stores in the USA alone can be accessed and analyzed in its headquarter on real-time. Therefore, the effective size that top managers in its headquarter can reach has been widened with the centralized IT system allowing the global access to the data only local managers were accessible to in the past without such a centralized IT system. Therefore, we assume that the effective size is an increasing function of both IT and nominal size.

$$\hat{S} = cI^\delta S \qquad (7)$$

where c is a constant, I is the IT intensity, δ is a constant, and S is the nominal size of the firm.

The nominal size can be of various measures; they usually include employee numbers, sales, market capitalization, and assets. Following Gabaix and Landier's agnostic approaches, we used employee numbers, physical capital assets, and market capitalization as the nominal size and empirically chose the best proxy. As shown in the result section, the market capitalization turned out to be the best proxy for the nominal size. This is also what Gabaix and Landier found. The equations (6) and (7) yield that:

$$w = D_* c_*^\alpha I_*^{\alpha\delta} S_*^\alpha c^\beta I^{\beta\delta} S^\beta = A_*^\mu I_*^\varepsilon S_*^\alpha c^\beta I^\rho S^\beta$$
(8)

where $A_* = D_* c_*$, and μ, ε, and ρ are constants.

The resulting empirically testable equation is the following:

$$\ln(w_{i,t}) = \beta_1 + \beta_2 \ln(A_{*t-1}) + \beta_3 \ln(I_{*t-1}) + \beta_4 \ln(S_{*t-1}) + \beta_5 \ln(I_{i,t-1}) + \beta_6 \ln(S_{i,t-1})$$
(9)

where *i* and *t* indicate an index for firm and time, respectively. This equation implies that the compensation for a CEO this year ($w_{i,t}$) is determined by the effective size of a reference company (I_{*t-1} and S_{*t-1}) as well as the CEO's firm ($I_{i,t-1}$ and $S_{i,t-1}$) in the previous year along with other characteristics

[3] This is the equation (25) of Proposition 3 on p.85 by Gabaix and Landier.

associated with the reference company (A_{*t-1}). This time lag lessens the potential simultaneity problem between CEO pay and the effective firm size.

We tested this model in both firm-level and industry-level. The concept of the model lies at firm-level; however, as we argue that an IT-intensive firm may increase its effective size and thus the marginal productivity of its CEO but we do not have firm-level but industry-level IT intensity data, the industry level analysis may be more consistent with our measures of IT intensity. Therefore, we present both firm-level analysis more consistent with our model and industry-level analysis more consistent with our empirical measures.

A_* is a variable relevant to a reference company such as the marginal talent of CEO of the reference company and the sensitivity of the reference firm to its CEO talent (not captured by the effective size). This measure captures business environments that the CEO's firm of interest is under, on the assumption that the CEO's firm would face a similar environment as its reference firm. For example, a firm in a highly-competitive industry may reward its CEO's talent more because it takes more talent to win over the competition; a firm in the industry where more educated workers belong may also reward its CEO because it needs a CEO to understand the complexities of the tasks that the workers of his firm may have to deal with. Therefore, we used two measures for A_* which can capture the business environment to some degree: industry turbulence and industry-median worker income. To compare our results with Gabaix and Landier's results, we conducted our analysis with and without the variable, A_* as Gabaix and Landier assumed that A_* may be the same for all firms and dropped it in their empirical analysis. In both cases, IT intensity was statistically significant.

In our test, we used IT intensity, defined as the ratio of IT capital stock to the total capital stock of plant, equipment and IT capital, as the IT variable. I_{*t-1} is IT intensity for a reference company in year t-1. Whether we choose a median-sized firm or the 250th-ranked firm[4] in year t-1 as a reference firm, I_{*t-1} depends mostly on the year variable as IT intensity has substantially grown as time. The variation in IT intensity over time for a reference firm was not very different from the variation in IT intensity over time for the whole economy. Therefore, we used the IT intensity for the whole economy in year t-1 for I_{*t-1}except the models with fixed year effect. In the models with fixed year effect, the IT intensity for the whole economy was not included because there is no variation within a fixed year. The model with fixed year effect resolves the issue not whether the difference in the firm-level IT intensity explains the differences in CEO pay within an industry at a given year, but whether the differences in CEO pay for the same sized firm across industry are explained by the differences in the industry-level IT intensity at a given year.

We used industry-level IT as our measure of $I_{i,t-1}$ in the equation (9). This stems from two reasons, one practical and the other theoretical. The practical reason is that high quality firm-level IT data does not exist for the full period we seek to consider. Accordingly, industry-level IT intensity can serve as a noisy measure of firm-level IT intensity. The second reason for this approach is that using the industry-level IT intensity can mitigate a potential endogeneity problem; suppose that for some reason highly paid CEOs tend to spend more on IT investments in their own firms, leading to a positive correlation between CEO pay and firm-level IT intensity. By taking the IT intensity at the industry level and by also using the previous year's data as a covariate in the regression to determine the current year's CEO pay at firm level, the endogeneity problems are reduced.

The variables, S_{*t-1} and $S_{i,t-1}$, are the nominal size of a reference company and the CEO's firm of interest in the previous year, respectively. For firm-level analysis, we chose the 250th-ranked firm in the previous year as the reference firm following Gabaix and Landier's model. For industry-level analysis, there is no difference between a reference firm and a firm of interest and we treat those as one industry

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[4] The 250th-ranked firm was a reference firm in Gabaix and Landier's empirical analysis.

size variable. We used the total labor cost and the total net value of physical capital in each industry in the previous year for the industry size variable (S_{*t-1} and $S_{i,t-1}$).

For the firm-level analysis, two models, one using employee number and net value of physical capital and the other using market capitalization, were compared to select a better proxy for firm size in the context of CEO pay. As shown in Table 1, the market capitalization captured the firm size better, consistent with Gabaix and Landier's result. For all other models at firm level, we used the market capitalization as the firm size variable.

For the industry-level analysis, the model was assessed in three ways. First, all of the CEO compensations available from the data source were regressed only on the firm size variables (labor cost and net value of physical capital). Then, IT intensity variables were added as in the equation (9). Thirdly, other potential variables, median worker wage and industry turbulence, which may concur with IT intensity, were included to check the robustness of our model. Models with fixed effects of industry, firm, and year were also examined.