Internet Appendix to
"Technological Change, Job Tasks, and CEO Pay"*

I. Theoretical Model

In this paper, I define skill-biased technological change as the technological shock that began in the 1970s with the invention of microcomputer technology. I take the price of computer capital as exogenous to the firm. To understand the connection between falling computer prices and executive compensation, I use the task framework developed by Autor, Levy, and Murnane (2003) combined with the CEO pay model laid out in Gabaix and Landier (2008). I assume that production consists of a combination of four types of tasks: routine cognitive, routine manual, nonroutine cognitive, and nonroutine manual. Tasks are defined as routine if they can be accomplished by an exhaustive set of programmable rules. Assembly line work is an example of a routine manual task, while balancing a firm's ledger is an example of a routine cognitive task. Nonroutine tasks, in contrast, do not have an exhaustive set of well-defined rules. An example of a nonroutine manual task is delivering packages, while an example of a nonroutine cognitive task is designing a new vaccine. The nature of routine tasks makes them particularly suited to be performed by a computer, while nonroutine tasks are not easily completed by current levels of computer technology.

This basic framework suggests that computers substitute for workers that perform routine cognitive and manual tasks, but complement workers that perform nonroutine cognitive tasks. For my purposes, I assume that nonroutine manual tasks and computers are neither strong substitutes nor compliments.[1] I combine this framework with the exogenous decline in the price of computers to create quasi-exogenous changes in executive compensation.

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[1]Current technology is not yet advanced enough to substitute for most nonroutine manual tasks, though for at least some tasks it is moving in that direction (e.g., computer-driven cars). Further, the extent to which computers can complement manual tasks is naturally limited by the physical limitations of human employees (e.g., even with a G.P.S. system, a single UPS driver can only deliver so many packages in a day.

To understand the effect of falling computer prices on CEO pay, I introduce a simplified model. I assume an aggregate production function of the form,

$$Q = F(n, r, c)(1 + A \times T),$$
$$F(n, r, c) = (r + c)^{1-\beta} n^{\beta}, \beta \in (0, 1),$$
$$A = F(n, \Phi), \tag{IA.1}$$

where T is the talent of the manager, A is the firm's organizational capital, r and n are routine and nonroutine labor inputs, and c is computer capital. All inputs are measured in efficiency units. $F(n, r, c)$ is a Cobb-Douglas production function as in Autor et al. (2003).[2]

The firm's organizational capital, A, quantifies the effect of CEO talent on production. Organizational capital is a function of nonroutine labor n, i.e. the skill level of the firm's workforce, and CEO specific traits, Φ, such as age, experience, and education. I assume that A is increasing in Φ; that is, I assume that some of the skills that make an effective CEO can be learned. I also assume that

$$\frac{\partial A}{\partial n} > 0. \tag{IA.2}$$

Eq. IA.2 is the key assumption of the model. In words, there are positive synergies between managers and nonroutine task employees. This can be viewed as a reduced form way of modeling the effect of CEO effort on employees; the assumption implies that CEO effort increases productivity (or reduces the cost of effort) of nonroutine employees more than routine employees. Since the validity of my empirical results rests on Eq. IA.2, it is important to carefully consider the plausibility of this assumption. Why should CEO effort matter more to skilled employees? I argue that the role of a manager is fundamentally different when managing routine tasks versus

[2]Eq. IA.1 can be modified as in Gabaix and Landier (2008) to allow decreasing returns to scale to manager productivity, i.e. $Q = F(n, r, c) + F(n, r, c)^{\gamma} \times A \times T$. γ is what Lustig, Syverson, and Van Nieuwerburgh (2011) refer to as the "span of control" parameter of the manager; if CEOs have less effect on big firms than small firms, then $\gamma < 1$. To simplify the exposition, I take $\gamma = 1$ which is consistent with the evidence in Gabaix and Landier (2008).

nonroutine tasks. As a manager of routine tasks, the CEO is essentially the "colonel" of the firm giving orders and ensuring that these orders are followed through. Managing nonroutine tasks this way, though, is inefficient. Instead, a manager of nonroutine tasks acts as a "coach", leading his employees but allowing them freedom to find innovative solutions to the task at hand.

To illustrate the switch from "colonel" to "coach", consider an academic professor. When the professor hires an undergraduate research assistant, it tends to be to perform routine tasks such as data collection. The relationship between the professor and the undergraduate is generally command and control; rarely is there two-way feedback. When the professor works with a PhD student on research, though, the relationship is often much different. Acting as a coach or mentor, the professor and student collaborate together on a project. In the process, new and innovative ideas often emerge. While a professor might get a single research project out of the work of an undergraduate research assistant, a skilled mentor will likely become a co-author on many projects with a PhD student. In this sense, nonroutine labor leverages the ability of the manager.

Given Eq. IA.2, the rest of the model is straightforward. Intuitively, a fall in the price of computer capital causes firms to substitute computers for routine task employees. Since computers compliment skilled workers, the firm demands and hires more skilled employees. This increase in employee skill makes it more beneficial to the firm to hire a more talented manager, and the firm is willing to pay more money to the CEO to convince her to take (or keep) the position.

Formally, as in Gabaix and Landier (2008), there are a continuum of firms and potential CEOs. CEO $m \in [0, N]$ has talent $T(m)$, where low m denotes a more talented manager: $T'(m) < 0$. Assuming perfect competition and normalizing the price of output to 1, the firm's optimization problem can be written as

$$\max_{m,n,r,c} F(n, r, c)(1 + A \times T(m)) - w_r r - \rho c - w_n n - w(m), \tag{IA.3}$$

where ρ is the price of computer capital. It is clear from Eq. IA.1 that that computer capital and routine labor are perfect substitutes.[3] Consequently, the wage for routine labor equals the price

[3]While this assumption simplifies the model, it is only necessary that computer capital is more substitutable for

of computer capital. First order conditions for productive efficiency require that

$$\begin{aligned} w_r = \rho = \frac{\partial Q}{\partial r} &= (1-\beta)\left(\frac{c+r}{n}\right)^{-\beta}(1 + A \times T(m)), \\ w_n = \frac{\partial Q}{\partial n} &= \beta\left(\frac{c+r}{n}\right)^{1-\beta}(1 + A \times T(m)) + (c+r)^{1-\beta} n^{\beta}(\frac{\partial A}{\partial n} \times T), \\ w'(m) = \frac{\partial Q}{\partial m} &= AF(n,r,c)T'(m). \end{aligned} \tag{IA.4}$$

Let $n \in [0, N]$ index the organizational capital scaled output of the firm, $S(n) = A \times F(n,r,c)$, with small n equal to the largest firms. Any efficient equilibrium involves positive assortative matching. In particular, if there are two firms with $S_1 > S_2$ and two CEOs with $T_1 > T_2$, then $S_1 \times T_1 + S_2 \times T_2 > S_1 \times T_2 + S_2 \times T_1$. As a result, the highest net surplus is achieved by assigning the most talented managers to the largest effective firms. Since there is associative matching,

$$w'(m) = S(m)T'(m). \tag{IA.5}$$

In effect, a modified version of the result from Gabaix and Landier (2008) holds. The most talented CEOs are hired by the largest effective firms, and consequently CEO pay is increasing in organizational capital scaled output of the firm.[4]

We are now in a position to examine the effect of an exogenous change in the price of computing power, ρ. Note that since computer capital and routine labor are perfect substitutes, $\rho = w_r$ and $\partial(\ln w_r)/\partial(\ln \rho) = 1$, and consequently

$$\frac{\partial \ln\left(\frac{c+r}{n}\right)}{\partial \ln \rho} = \frac{\partial \ln \frac{w_n}{w_r}}{\partial \ln \rho} = -\frac{1}{\beta} < 0. \tag{IA.6}$$

The basic results of Autor et al. (2003) hold: a decline in the price of computing power ρ increases

routine than for nonroutine tasks.

[4]I borrow the term "effective size" from Gabaix and Landier (2008), who also note that in cases where the CEO impact varies across firms pay is increasing in a scaled version of size (see Proposition 25 in their paper). Gabaix and Landier are able to use extreme value theory to obtain a functional form for manager compensation by assuming that A and $F(n,r,c)$ are independent. In my model, A and $F(n,r,c)$ are clearly not independent; additionally, the functional form of A is unknown. As a result, I do not attempt to model the exact functional form for CEO pay.

demand for routine input. Given that routine workers and computers are perfect substitutes, the firm will choose to meet this demand with an investment in computers.[5] Since routine tasks and nonroutine tasks are q-complements, the decrease in ρ also causes the demand for nonroutine tasks to rise. Consequently, marginal workers switch from supplying routine to nonroutine labor. This increases the nonroutine task level of the firm, n. The increase in skilled employees increases the effective size of the firm, since both output and manager effectiveness increase (i.e. $\partial S/\partial n > 0$). Now, Eq. IA.5 shows that an increase in effective size, $S(m)$ induces the firm to hire a more talented CEO at a higher wage. Consequently, a decline in the price of computers leads firms to optimally increase CEO pay. However, the extent to which a given firm increases executive compensation depends on how much the skill-level of the firm's workforce rises.

This model provides a mechanism through which an exogenous fall in the price of computers leads firms to optimally increase executive compensation. Importantly, it also provides a reasonable explanation for why CEO pay began to increase in during the 1970s. It is plausible that the organizational capital function, A, is structured such that the effective size, $S(m)$, is constant or even decreasing from the mid 1930s until the 1970s. This would reconcile the single largest discrepancy of Gabaix and Landier (2008)—that firm size steadily rose throughout the 1900s but that CEO did not rise until the 1970s. I do not have data available to test this relationship prior to the 1980s, but I provide empirical evidence consistent with this model from 1984 to 2010.

II. Additional Results

This appendix presents additional results and robustness tests. Table IA.I further investigates the channel driving the relationship between employee tasks and CEO pay. Using the successor to the DOT, O*NET, I am able to create a more up to date measure of occupation tasks. The O*NET task classifications allow me to separate nonroutine task intensity into analytic and interpersonal tasks. I estimate the model shown in Column 3 of Table VIII separately for each of these two measures. If the relationship between CEO pay and employee tasks is driven by an increased

[5] See Autor et al. (2003) for a formal proof of this statement.

importance in the role of the CEO, I expect this to effect to be concentrated in interpersonal tasks. These are the types of tasks that require teamwork; consequently, the corporate culture is likely to have a significant influence on the productivity of these workers. The CEO, along with the executive team, is responsible for the corporate culture.

[Table IA.I about here.]

The results in Table IA.I are consistent with this channel. The coefficient on analytical skill is statistically indistinguishable from zero, but the coefficient on interpersonal skill is statistically significant at the 1% level. The point estimate of 10.2 implies that the change in interpersonal skill from the 1980s to 2010 led to a 2.3 times increase in the level of total CEO pay. The magnitude of this result is consistent with my earlier estimates, and suggests that the increase in CEO pay is driven primarily by managing workers doing interpersonal tasks.

While the previous result is broadly consistent with optimal contracting, it is inconsistent with agency problems driving the increase in pay. Analytic tasks are likely to be much more difficult for outsiders to understand than interpersonal tasks; as a result, agency conflict theories would suggest that managers would extract more rents from firms that are analytic task intense. Table IA.I suggests that this is not the case.

Table IA.II presents additional evidence that agency problems do not drive the results in this paper. In this table, I re-estimate the difference in difference regression shown in Table V and the 2SLS regression shown in Table VIII controlling for firm exposure to offshoring and firm governance characteristics. The offshoring measure is created using the O*NET definitions of occupation tasks and is designed to reflect the potential for moving a given occupation offshore. This measure includes both routine tasks such as textile production and nonroutine tasks such as customer service. Higher values of offshoring reflect an industry that can more easily substitute foreign workers for domestic workers. As shown in Columns 1 and 2, controlling for offshoring does not alter the estimated effect of nonroutine task workers on CEO pay. Intriguingly, exposure to offshoring has a negative and statistically significant effect on executive compensation.

In columns 3 and 4, I include several measures designed to proxy for agency conflicts. CEO ownership reflects the extent to which shareholder and manager interests are aligned. Higher institutional ownership is likely correlated with better monitoring. A CEO who is also chairman has increased power which might exacerbate agency issues. The size and independence of the board reflect the ability of shareholders to monitor and discipline the CEO. While some of these proxies suggest that agency issues matter for executive pay (e.g., CEOs with high ownership are paid less and dual CEO/chairman are paid more), other proxies are inconsistent with agency theories (e.g., more independent boards and firms with higher institutional ownership pay more). In any case, including these proxies does not alter the statistical or economical significance of nonroutine employee skill.

[Table IA.II about here.]

REFERENCES

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Table IA.I

CEO pay and types of nonroutine tasks

I estimate the model shown in Column 3 of Table VIII with different measures of employee tasks. *Analytical skill* measures nonroutine tasks that require analytical skill to complete, while *Interpersonal skill* measures nonroutine tasks that involve relationships between people. I instrument for each task measure using *Original Routine Tasks* and *RAM price shock*. Definitions for each of the variables can be found in Table AI in the Appendix. Standard errors are clustered at the industry-year level. *** indicates significance at the 1% level, ** indicates significance at the 5% level, and * indicates significance at the 10% level.

	ln(Total pay)		
	(1)	(2)	(3)
Analytical skill	4.76**		0.05
	(2.30)		(0.02)
Interpersonal skill		2.37***	2.34
		(2.81)	(1.48)
ln(Revenue)	0.26***	0.23***	0.23***
	(10.47)	(11.71)	(10.01)
Tobin's *Q*	0.02***	0.02***	0.02***
	(4.31)	(4.51)	(4.51)
Income to assets	0.92***	0.74***	0.75***
	(5.61)	(6.33)	(5.01)
Shareholder return	0.15***	0.15***	0.15***
	(12.54)	(13.73)	(13.73)
Std. dev. return	1.00	0.81	0.81
	(1.11)	(0.94)	(0.93)
Beta	−0.00	0.01	0.01
	(−0.18)	(0.32)	(0.30)
CEO Tenure	−0.01	−0.01***	−0.01***
	(−1.61)	(−2.62)	(−2.59)
Age	0.00	0.01	0.01
	(0.59)	(1.38)	(1.33)
t	0.03***	0.04***	0.04***
	(2.59)	(4.61)	(4.29)
Original Routine Tasks	−0.16	0.00	
	(−1.22)	(0.02)	
Number of CEOs	5,216	5,216	5,216
Observations	30,856	30,856	30,856
First-stage F statistic	22.62	98.95	1.39
Hansen J statistic	0.00	0.00	0.00
p-value for J-statistic			

Table IA.II

Robustness tests

This table shows that the estimated effect of employee tasks on CEO pay is robust to controlling for firm exposure to offshoring and firm governance characteristics. Columns 1 and 3 estimate the difference in difference regression shown in Table V; Columns 2 and 4 estimate the 2SLS regression shown in Table VIII. Although the coefficients are not shown to conserve space, the specifications include all of the control variables used in the previous tables. Definitions for each of the variables can be found in Table AI in the Appendix. Standard errors are clustered at the industry-year level. *** indicates significance at the 1% level, ** indicates significance at the 5% level, and * indicates significance at the 10% level.

	ln(Total Pay)			
	(1) OLS	(2) 2SLS	(3) OLS	(4) 2SLS
Interaction	0.67***		0.71***	
	(5.27)		(4.95)	
Nonroutine tasks		14.14***		6.11***
		(4.45)		(3.35)
Offshorability	−0.20**	−4.86***		
	(−2.22)	(−4.48)		
Ownership			−1.99***	−0.19
			(−6.31)	(−0.56)
Institutional Ownership			0.10*	−0.18***
			(1.87)	(−3.19)
CEO is Chair			0.24***	0.02
			(13.36)	(0.67)
Board Size			−0.00	−0.01
			(−1.11)	(−1.30)
Pct. Indep. Directors			0.13**	−0.04
			(2.17)	(−0.46)
Industry FE	Yes	No	Yes	No
5-year FE	No	Yes	No	Yes
Number of CEOs	6,090	5,216	4,714	3,755
Observations	31,730	30,856	19,904	18,945
R^2	0.46	−1.10	0.52	−0.11