Process Intangibles and Agency Conflicts

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What are process innovations?

"This is the year ... that AI becomes better than humans at competitive code forever."

— *OpenAI chief product officer Kevin Weil*

"Leading industry figures say LLMs have sped up the software development process by generating entire blocks of code based on a few text instructions."

— *Financial Times, April 18, 2025*

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OECD define process and organization innovation:

"...implementation of a new or significantly improved production or a new organizational method in the firm's business practices, workplace organization or external relations..."

Process intensity and intangibility

$$\text{Process Intensity}_{f,t} = \frac{\text{Process patent claims}_{f,t}}{\text{Total patent claims}_{f,t}}$$

Process patent claims from Bena and Simintzi (2023)

Increased by 8.8% (manufacturing) and 20.3% (services) from 1975-2010

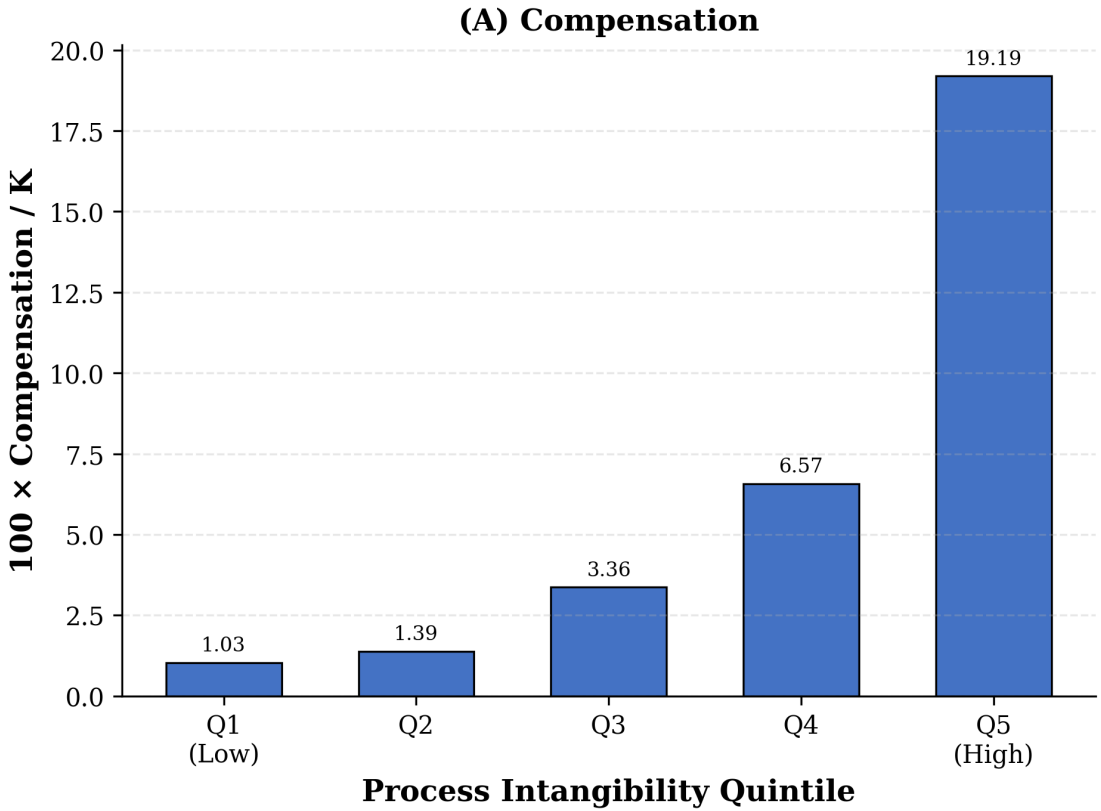
Process intangible $O^P_{f,t}$ (Peters and Taylor (2017)):

$$O^P_{f,t} = \text{After depreciation}(O^P_{f,t-1}) + \text{Process Intensity}_{f,t} \times \text{Intangible Investment}_{f,t}$$

$$\text{Process Intangibility}_{f,t} = \frac{\text{Process intangible}_{f,t}}{\text{Physical capital}_{f,t}}$$

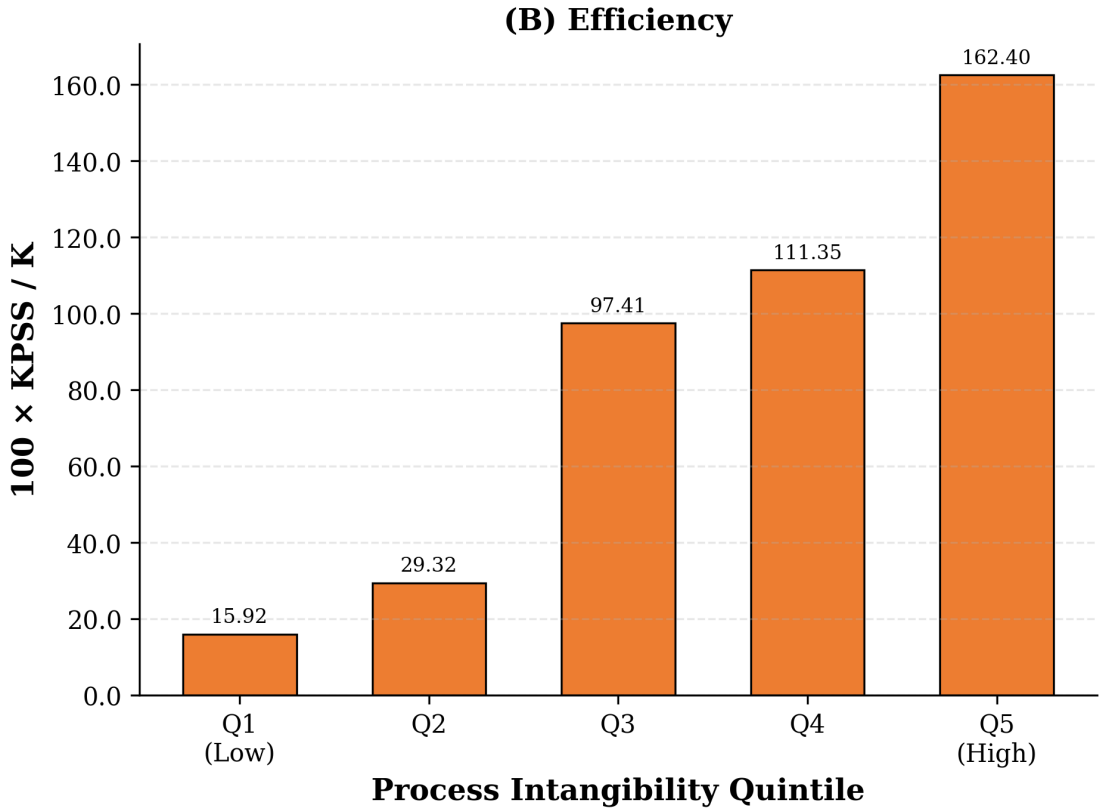
Higher process intangibility, higher pay

Intangibles and human capital are entwined (Eisfeldt and Papanikolaou (2013))



Higher process int., higher efficiency growth

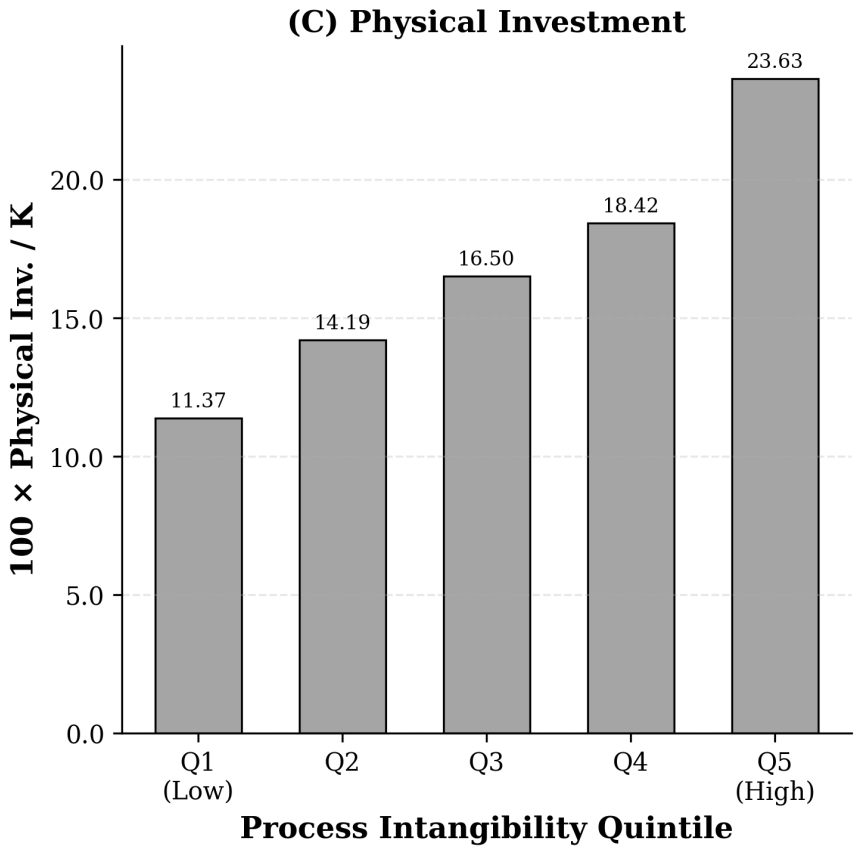
Patent value: Kogan, Papanikolaou, Seru, and Stoffman (2017)

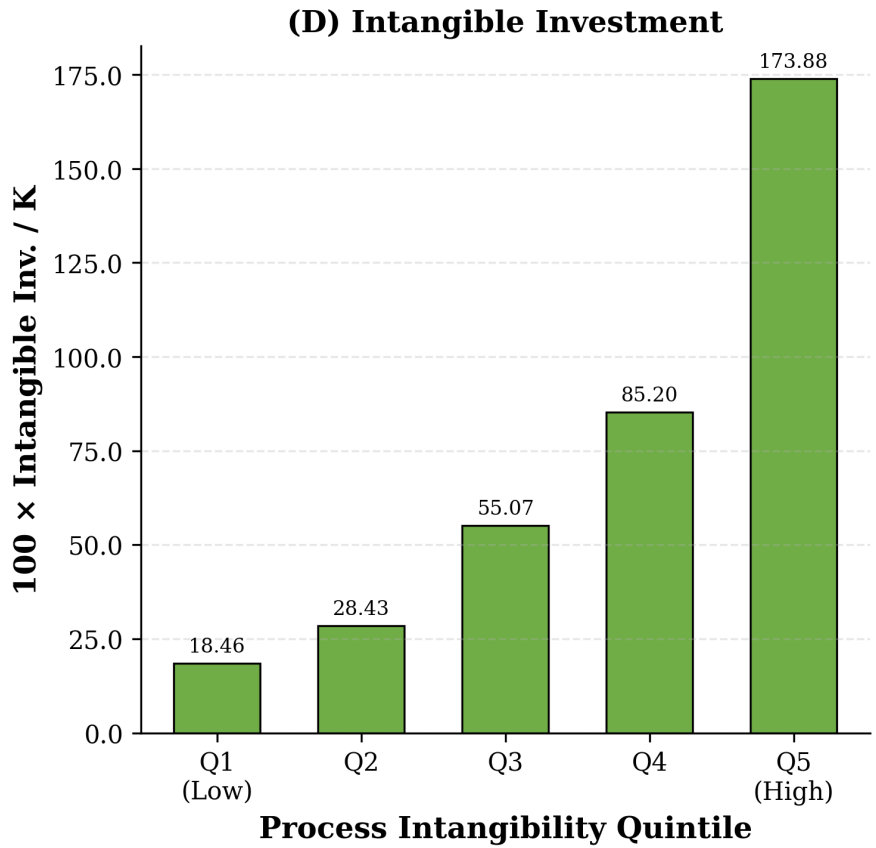


$$Y = XF(K, O) = XKF\left(1, \frac{O}{K}\right)$$

Future marginal product of $O/K \uparrow \implies X$ grows faster

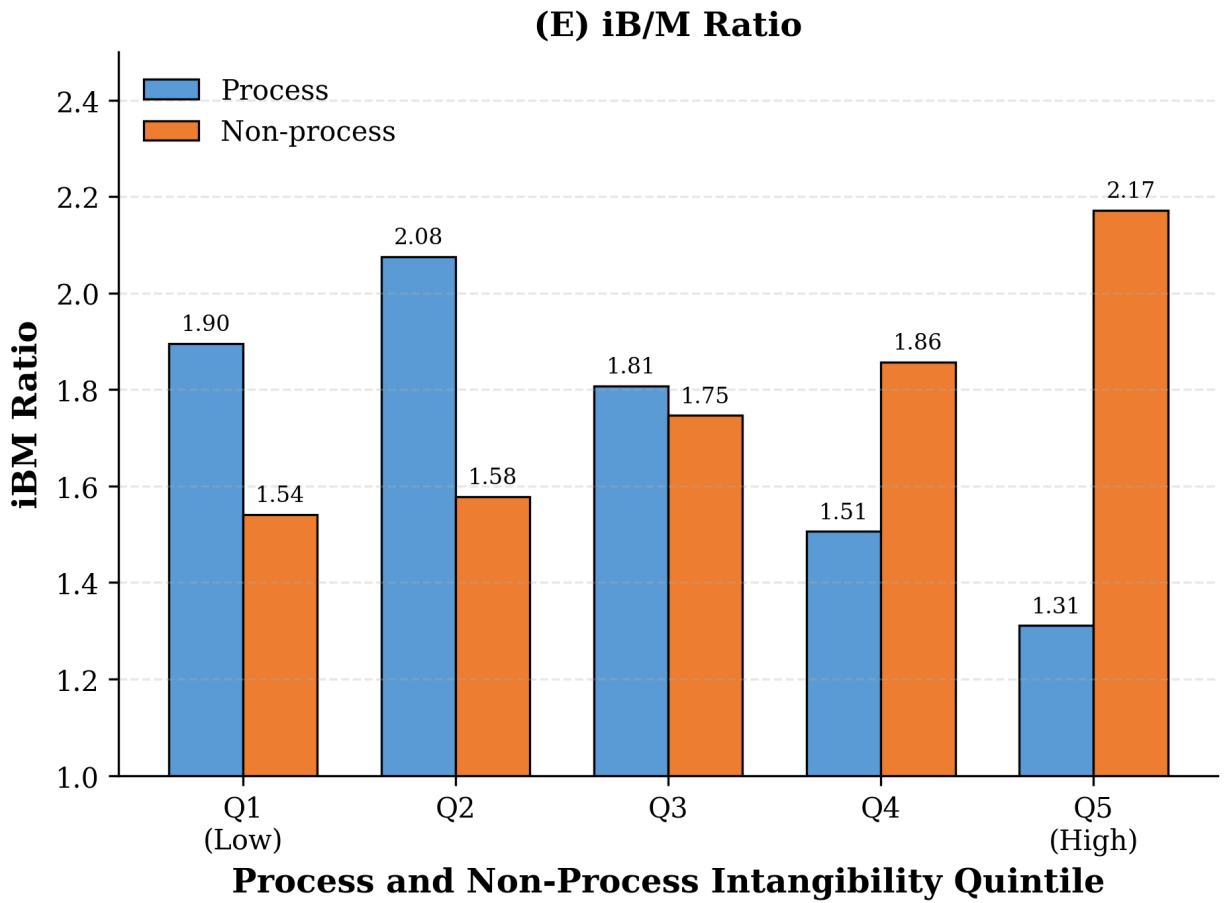
Higher process int., more investment





Higher process int., lower iB/M

$$\text{iB/M} = \frac{\text{Book Equity} + \text{Intangible Capital}}{\text{Market Value}}$$



Key results

- Heterogeneity in intangibles is associated with heterogeneity in pay and investment
- Propose a dynamic principal-agent model to rationalize the empirical facts
  - Process intangibles enhance productivity growth
  - Agent's shirking effort hampers it
- Implications on pay
  - *Level effect*: positive association between process measure and pay
  - *Slope effect*: association is stronger as process measure (or investment) increases
- Empirical support for model implications in executive pay and skilled worker wage

Literature

- Intangibles and finance (Eisfeldt and Papanikolaou (2013), Kogan, et al (2017), Crouzet and Eberly (2018), Peters and Taylor (2017), Ward (2022), etc)
- Dynamic Agency (Biais, et al (2007), DeMarzo and Sannikov (2006), Sannikov (2008), DeMarzo et al (2012), etc)
- Process vs product intangibles (Ganglmair, et al (2022), Angenendt (2018),Bena and Simintzi (2023), Bena, et al (2022))

Baseline model

- Firm-specific efficiency and productivity X_t:

$$dX_t = A(\theta o - e_t)X_t\,dt + X_t\sigma\,dZ_t^e,$$

  - θ: process intensity
  - $o_t = O_t/K_t$: intangibility (assumed constant in baseline)
  - e_t: shirking effort

- Physical capital K_t

$$dK_t = (i_t - \delta_K)K_t\,dt$$

- Flow profits Y_t:

$$Y_t = X_t\left\{\mu\Big[(1-\phi)K_t + \phi O_t\Big] - i_t K_t - \frac{Q_K}{2}i_t^2 K_t\right\}$$

Firm's problem

Value function (constant shirking effort e)

$$V(K_t, X_t; \theta, o, e) = \max_i \mathbb{E}_t\left[\int_t^\infty e^{-r(s-t)} Y_s \, ds\right]$$

Limiting case $Q_K \to \infty$, then $i = 0$

Firm's (normalized) value:

$$v(\theta, o, e) := \frac{V}{KX} = \frac{\mu(1 - \phi + \phi\, o)}{r + \delta_K - A(\theta o - e)}$$

Three properties:

$$\partial_e v < 0, \quad \partial^2_{\theta e} v < 0, \quad \text{and} \quad \partial^3_{\theta\theta e} v < 0$$

Impact of agency

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  $\Longrightarrow$ Level effect: compensation increases with θ

- $\partial^3_{\theta\theta e} v < 0$:

$$\partial^2_{\theta e} v(\theta_{\text{high}}, o, e) < \partial^2_{\theta e} v(\theta_{\text{low}}, o, e) < 0$$

  Agency friction deteriorates at a faster rate when θ increases from a high level

  $\Longrightarrow$ Slope effect: sensitivity of compensation in θ increases with θ

Agency model

Agent receives compensation dC_t and gains private benefit from shirking $B(e_t)$

Agent's continuation utility U_t

$$dU_t = ...dt + \varphi_t dX_t - dC_t.$$

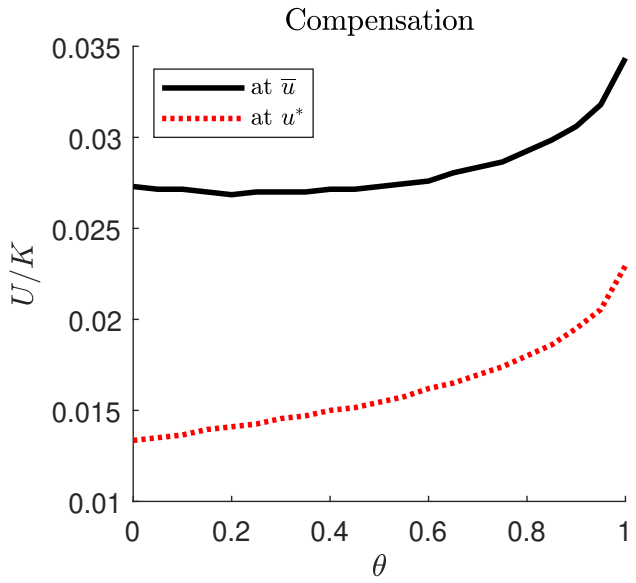
No shirking if the contract sensitivity φ_t is sufficiently large

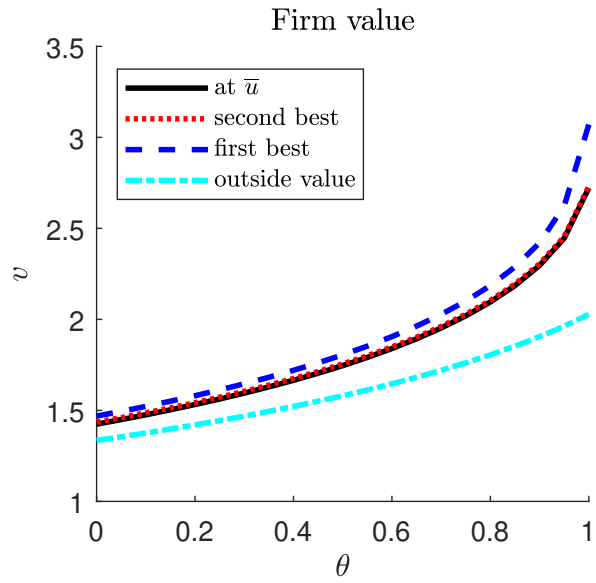
$u_t = U_t/K_t$ is principal's state variable
(DeMarzo, Fishman, He, and Wang (2012))

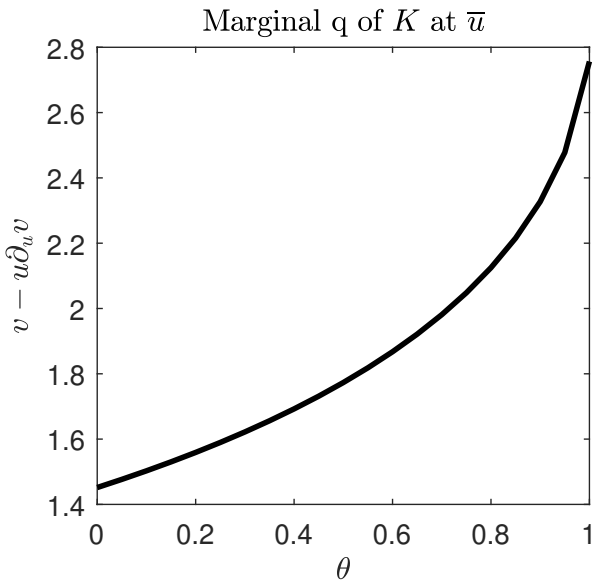
$$V(K_t, U_t) = K_t X_t \, v(u_t)$$

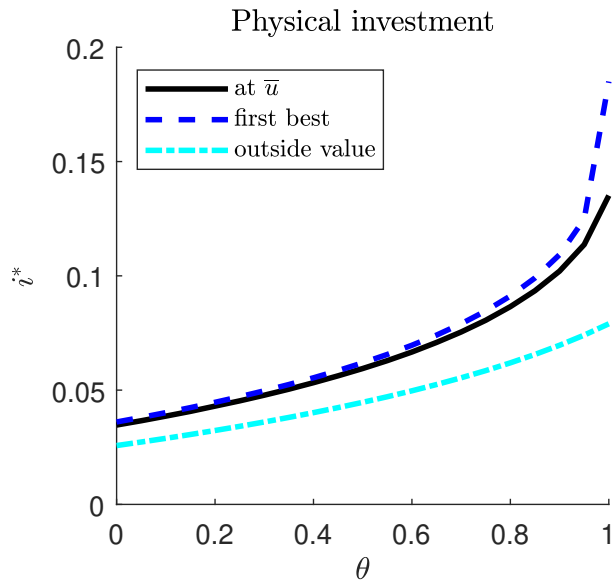
Compensation boundary $\overline{u}$, compensation is a "reflection" type, firm's value is maximized at u^*

Compensation and physical investment









Extended model

Incorporate intangible investment

(u_t, o_t) becomes principal's state variables

Model parameters calibrated to empirical moments of intangibility, investment (physical and intangible), and compensation

Conditioning on quintiles of O/K, compensation, investment, and marginal q of intangible capital increase in θ, both in data and in model

Empirical specifications

$$\begin{aligned}\text{Dep. Var}_{ft} =& \beta_1 \text{Process Intangibility}_{ft} + \beta_2 \text{Non-Process Intangibility}_{ft} \\ &+ \boldsymbol{\gamma} \boldsymbol{X}_{ft} + \varepsilon_{ft}\end{aligned}$$

$$\text{Dep. Var}_{ft} = \beta_1 \text{Process Intensity}_{ft} + \beta_2 \text{Total Intangibility}_{ft} + \boldsymbol{\gamma} \boldsymbol{X}_{ft} + \varepsilon_{ft}.$$

Controls $\boldsymbol{X}_{ft}$: size, iB/M, profits over total capital

Fixed effects: Industry + Year

Mechanism: efficiency growth

	Dependent variable:			
	KPSS Value (t+1) / Total Capital			
	(1)	(2)	(3)	(4)
Process Intangibility	0.481**	1.678***		
	(0.203)	(0.497)		
Non-Process Intangibility	0.206	1.160***		
	(0.198)	(0.349)		
Process Intensity			0.154***	0.170***
			(0.050)	(0.057)
Total Intangibility			0.509***	1.050***
			(0.085)	(0.198)
Controls ?	N	Y	N	Y
Fixed effects ?	Y	Y	Y	Y
R^2	0.056	0.165	0.041	0.089
Adjusted R^2	0.045	0.153	0.036	0.084

Mechanism: physical investment

	Dependent variable:			
	Physical Investment (t+1) / Physical Capital			
	(1)	(2)	(3)	(4)
Process Intangibility	0.308***	0.281***		
	(0.035)	(0.029)		
Non-Process Intangibility	0.244***	0.253***		
	(0.050)	(0.056)		
Process Intensity			0.031**	0.019**
			(0.012)	(0.009)
Total Intangibility			0.264***	0.243***
			(0.020)	(0.017)
Controls ?	N	Y	N	Y
Fixed effects ?	Y	Y	Y	Y
R^2	0.057	0.061	0.049	0.063
Adjusted R^2	0.047	0.049	0.045	0.058

Compensation: level effect

	Dependent variable:		
	Total Comp.	Def. Comp.	Frac. Def.
	(1)	(2)	(3)
Process Intensity	0.348***	0.130***	4.109***
	(0.115)	(0.042)	(0.984)
Total Intangibility	2.665***	0.661***	8.251***
	(0.188)	(0.078)	(1.528)
Controls ?	Y	Y	Y
Fixed effects?	Y	Y	Y
R^2	0.078	0.227	0.572
Adjusted R^2	0.072	0.222	0.569

Compensation: slope effect

Process Intensity = H if Process Intensity$_{f,t}$ > median

	Dependent variable:		
	Total Comp.	Def. Comp.	Frac. Def.
	(1)	(2)	(3)
Process Intensity	−0.407	−0.078	13.300***
	(0.596)	(0.084)	(2.868)
(Process Intensity = H)	−0.788***	−0.145***	9.462***
	(0.149)	(0.048)	(1.745)
Total Intangibility	2.772***	0.681***	6.957***
	(0.188)	(0.081)	(1.545)
Process Intensity x (Process Intensity = H)	1.738***	0.382***	−20.989***
	(0.659)	(0.125)	(3.938)
Controls ?	Y	Y	Y
Fixed effects?	Y	Y	Y
R^2	0.079	0.228	0.572
Adjusted R^2	0.073	0.223	0.569

Summary

- Is compensation related to the **composition** of intangibles?
  - Yes: Process focused intangibles associated with higher compensation, ceteris paribus
- Why? Agency friction
  - Process intangibles enhances firm-specific productivity growth
  - Agency problem introduces a hold up problem
- Implications
  - Level effect: a positive relation between process intangibility and pay
  - Slope effect: the association is stronger among high process intensity (or high investment) firms

Compensation: slope effect (indirect)

Inv. = H, if Physical investment$_{f,t}$ > median

	Dependent variable:		
	Total Comp.	Def. Comp.	Frac. Def.
	(1)	(2)	(3)
Process Intensity	0.239**	0.041	1.667
	(0.109)	(0.041)	(1.313)
(Inv. = H)	0.377***	0.052*	0.383
	(0.117)	(0.028)	(0.771)
Total Intangibility	2.452***	0.606***	7.237***
	(0.190)	(0.082)	(1.537)
Process Intensity x (Inv. = H)	0.123	0.154**	4.548***
	(0.197)	(0.062)	(1.671)
Controls ?	Y	Y	Y
Fixed effects?	Y	Y	Y
R^2	0.080	0.231	0.569
Adjusted R^2	0.074	0.226	0.566

Compensation: slope effect (indirect)

Inv. = H, if Intangible investment$_{f,t}$ > median

	Dependent variable:		
	Total Comp.	Def. Comp.	Frac. Def.
	(1)	(2)	(3)
Process Intensity	0.158	0.044	3.419**
	(0.104)	(0.031)	(1.389)
(Inv. = H)	0.434***	0.085***	1.139
	(0.114)	(0.032)	(0.792)
Total Intangibility	2.581***	0.639***	8.024***
	(0.184)	(0.076)	(1.498)
Process Intensity x (Inv. = H)	0.342*	0.156**	1.231
	(0.201)	(0.069)	(1.641)
Controls ?	Y	Y	Y
Fixed effects?	Y	Y	Y
R^2	0.083	0.234	0.570
Adjusted R^2	0.076	0.229	0.567