Public Listing Choice with Persistent Hidden Information

By Francesco Celentano and Mark Rempel

We argue that intangible assets amplify persistent private information and their growing prevalence simultaneously increased public CEO pay and reduced stock market listings in the US. Uninformed investors pay information rents to firm insiders to mitigate agency conflicts. Private specialist investors can directly monitor firm's intangible cash-flows and thereby avoid paying information rents, but have limited resources. Thus, competition between public and private investors induces more intangible and volatile firms to be privately funded, and private funds size to increase with the aggregate level of firm intangibility. We empirically validate and quantify our model predictions for US non-financial firms. (JEL: E02, G24, D21, D22)
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The number of US publicly listed firms has been in decline in the US since 1997 and has subsequently been followed by many other advanced economies including Germany, UK, Canada and France (Doidge et al. (2017), Gao et al. (2013b) or Stulz (2020)). This declining usage of public financing has been substituted by a boom in private equity (PE), with world-wide PE fund commitments growing from \$38 billion to over \$460 billion between 1995 and 2013 (Kaplan and Sensoy (2015)). Preceding this substitution away from public funding, median public CEO pay increased by over a factor of 7 since 1970 and moved in conjunction with a shift away from primarily cash-based pay towards restricted stock and option grants (Frydman and Jenter (2010), Edmans and Gabaix (2016), Edmans et al. (2017)).

In the backdrop of these seemingly disparate trends, an information communications technological (ICT) revolution has occurred and changed the way business is conducted (Corrado and Hulten (2010), Corrado et al. (2005) and Crouzet and Eberly (2018a)). In particular, there has been a pronounced increase in the reliance on intangible assets like patented innovations, information technology infrastructure and brand-management with recent record \$1 trillion USD valuations for four of the so-called 'Big Tech' firms (Alphabet, Amazon, Apple, and Microsoft). The concordant accumulation of intangible assets and shift in CEO pay is suggestive. For example, patent activity at the United States Patent and Trademark Office (USPTO) began its meteoric rise around 1980 (see Hall (2004)) which conforms almost exactly with the shift in cash-based to equity-based CEO compensation. Although muddied slightly by the exuberance in the Dot-com bubble, private equity importance has also coincided with this rise (Kaplan and Stromberg (2009)).

Despite their importance, the exact source of value and their durability in the face of evolving competitive pressures is difficult to ascertain for those without intimate knowledge of the assets and expertise in that particular product market.[1] Even with the requisite expertise, communicating proprietary information is difficult given the possibility that rival firms may replicate their intangible assets if the assets precise schematics are known and not sufficiently protected by intellectual property rights.[2] We thus tie the rise in intangible capital with an increasing informational wedge between specialist firm insiders and uninformed outside investors. Moreover, we argue that private information tied to these assets is persistent since innovations in firms cash-flows arising from intangible sources (like new consumer marketing datasources, new discoveries from R&D or improvements in inventory management) often persist for long-periods of time without being discernible from inspection of the balance-sheet (even after many years). Persistence substantially increases the information rents public investors must pay to the inside specialists to mitigate agency frictions and makes CEO compensation increasingly performance sensitive and backloaded. Private financiers, like Venture Capitalists (VC), are endowed with specialized expertise and can access privileged information on the firm (for instance, via signing non-disclosure documents), thereby avoiding the agency friction costs, but have limited resources and hence rationed on the set of firms they can finance. Competition between public and private financiers then induces a selection of firms for whom an uninformed financier would have to pay the largest information rents to be privately financed.

We formalize this argument by embedding Williams (2011) optimal (continuous time) contracting framework with persistent private information into a market setting with competing financiers.[3] The model is analytically tractable and yields closed form solutions for CEO compensation and a firm-level private equity premium (i.e. the relative value of a private financier funding the firm) and provides a novel mechanism through which technological change can simultaneously generate observed dynamics in CEO compensation and firm listing. We empirically validate the model's testable implications using balance sheet data on over 8,000 public and 6,000 private US firms from 1993 to 2016 which is linked to CEO

[1]See Blair and Wallman (2000), Kamiyama et al. (2006), and Mann (2018) for documentation on these trends. Rampini and Viswanathan (2013), Eisfeldt and Papanikolaou (2014) and Falato et al. (2020) examine economic channels linked to the relative lack of tradability of intangible assets.

[2]Many other papers have examined information frictions arising from intangible asset beginning with Aboody and Lev (2000).

[3]Continuous time contracting frameworks have become increasingly popular recently due to their tractability beginning with DeMarzo and Sannikov (2006), Biais et al. (2007), Sannikov (2008) and He (2009), but have largely focused on agency issues of the variant in Holmstrom and Milgrom (1987) of exerting private effort and in environments with independent and identically distributed private information. Garrett and Pavan (2012) extend this framework to have persistent private information through unknown initial conditions, but do not have new sources of private information arrive through time, leading to a single state variable. Bolton et al. (2019) considers a particular facet of intangible assets–inalienable human capital–and examines how it affects debt capacity and may increase CEOs risk exposure.

compensation data from 2001 - 2016, as well as historical data of balance sheets, firm patent portfolios and CEO pay packages for the largest public firms going back to 1950.[4] Further, we use analytical solutions of the model to identify and structurally estimate its key parameters separately using CEO compensation and listing moments to test our single common underlying mechanism driving both the US stock market listing decline and the rise in public CEO compensation.

We find that our estimate of the persistence of private information across the firm listing and CEO compensation moments is statistically indistinguishable from each other providing strong evidence of our common underlying mechanism. Furthermore, our estimates on size and persistence of private information substantially outweigh our estimates of the observable components of the cash-flow evolution. Moreover, we find that (1) firm intangibility, persistence and volatility of cash-flow innovations can substantially explain cross-sectional variation in CEO compensation and listing patterns (even above that of firm-size), (2) firm's reliance on patenting closely tracks firms' use of options and restricted stock grants in CEO pay since 1950 and (3) although average firm intangibility has increased, the degree of persistence of private information has declined since the 1990s.

We use our model and the combined time-series and cross-sectional patterns in firm listing, PE premia and CEO pay to evaluate the effects of major policies including (1) the introduction of increased disclosures for public firms through Sarbones-Oxley Act (SOX) after the Enron scandal and (2) the relaxation of funding restrictions for private equity in 1996 through National Securities Market Improvement (NSMIA) Act of 1996 as emphasized by Ewens and Farre-Mensa (2020).[5] Our results suggest that SOX did not meaningfully reduce information asymmetry but reduced the average benefit of being public across all firms, while the relaxation of funding restrictions did meaningfully reduce aggregate information frictions in the economy.

The remainder of the paper is structured as follows. In the next section we review the related literature. In Section II, we outline the model and present analytical expressions linking firm intangibility, cash-flow volatility and persistence to the level and pay-sensitivity of CEO compensation and firm listing decisions. In Section III, we describe our data on public and private firms and use proxies on firm's private information cash-flow characteristics to test the model's sorting and compensation predictions. In Section IV, we structurally estimate the model separately on listing moments and CEO compensation moments and test the similarity in the parameter estimates on the implied distribution of firm private

[4]We follow the convention of Doidge et al. (2017) and refer to public firms as those with common equity traded on one of the largest three US stock exchanges, NYSE, AMEX, and Nasdaq, while private firms consist of any firm with equity either not traded on a domestic exchange or traded solely through OTC markets.

[5]A number of papers have attempted to estimate the PE premia from either household data or flow of funds data like Moskowitz and Vissing-Jorgensen (2002), and Kartashova (2014), or directly from PE funds like Harris et al. (2014).

information characteristics. In Section V, we examine model extensions and counterfactual policies pertaining to the flow of funds to private equity and the private equity premia. We provide discussion of the limitations and areas deserving of further exploration in Section VI.

I. Related literature

To our knowledge, our paper is the first to quantify the effects of persistent private information arising from intangible assets on CEO compensation and firm listing decisions and as well as provide a credible estimate for the level of persistent private information. Most examinations of optimal CEO compensation contracts have focused on hidden actions, despite recent evidence by Gayle and Miller (2015) that these so-called 'pure moral hazard' models generate predictions which are rejected in their data, while hybrid moral hazard models with hidden information (e.g. like ours where cash-flows are not verifiable) are supported in their data. In perhaps the closest paper empirically examining firm agency-inducing characteristics, Cheng et al. (2015) shows persistent firm-specific (lagged or origin) risk induces higher levels of CEO pay in order to compensate the CEO for the magnified pay sensitivity risk faced under a variant of a two-period variant of the pure moral hazard model of Holmstrom and Milgrom (1987). In quantitative exercises on (dynamic) pure moral hazard models, the estimated size of the private information shock is found to be relatively small and dwarfed by effects based on firm size (e.g. Ai et al. (2016), Gayle and Miller (2009) and Gayle et al. (2015)).[6] Consequently, leading theories on the rise in the level of CEO compensation have tended to focus on size-driven mechanisms like Tervio (2008) and Gabaix and Landier (2008). Our work complements these size-based stories by examining the evolution of other persistent firm characteristics which helps rationalize the longer historical CEO compensation trends extending to the 1950s where firm size was growing while CEO compensation remained flat (see Frydman and Saks (2010)).

Our paper is not the first to examine exogenous technological change driving the growth in CEO compensation levels. Beginning with Lustig et al. (2011), a number of papers have examined how retention of high-skilled employees who can influence the innovation and growth potential of the firm (e.g. Sun and Xiaolan (2019), Frydman and Papanikolaou (2018) and Kline et al. (2019)). To the extent executive human capital is embedded in the private information component of the firm, the reduced form predictions on the level of CEO pay are the same. However, in our context performance sensitivity is an intentional effect to rather than a by-product of evolving outside options, and rationalizes the initial popularity in the 1980s of option-based compensation rather than simply deferred stock grants.[7]

[6]In a hybrid agency model like ours, for a given level of private information shocks, persistence magnifies the aggregate size of private information and introduces a mixture of moral hazard and adverse selection considerations within the contracting environment which substantially alters the firm financing and compensation structures.

[7]Of course, there are other suggested mechanisms in the literature for the overall rise in option-based

Spurred by the documentation of the decline in US public listings (see Gao et al. (2013b), Doidge et al. (2017), and Grullon et al. (2019)), a number of recent papers have posited explanations largely focused on US regulatory and institutional features increasing the compliance costs of being public like the implementation of SOX (Leuz (2007), Iliev (2010)), regulatory changes in private equity funding (e.g. Ewens and Farre-Mensa (2020), Kwon et al. (2020)) or some combination of the two like Davydiuk et al. (2020). More classical theories on decisions to go public have focused on the timing of the go-public decision based on either (i) tradeoffs in the illiquidity premia demanded by private financing against the monitoring and transaction costs (e.g. Chemmanur and Fulghieri (1999), Pástor et al. (2009), Gupta and Rust (2017)), (ii) the amount of financing relative to size of the firm (Holmstrom and Tirole (1997)), or (iii) by the type of investment needing financing (Clementi (2002), Ferreira et al. (2014), Spiegel and Tookes (2013)).[8] Our paper fits closest to the first motivated by Doidge et al. (2017) finding that firm listing propensities have declined across all sizes and industries suggesting that neither the amount of capital or the type of investment projects undertaken across industries are the core driver.[9] Our argument of rising agency frictions due to an increase in intangible assets is shared also by a contemporaneous paper, Ward (2019). His paper however addresses the recent investment behavior and market valuation dynamics of public firms and frames the agency friction as a pure moral hazard friction (that is with iid private information shocks).[10]

Due to a historical dearth of data on private firms empirical testing of theories on listing decisions have been relatively scarce. Three notable exception examine the 'going public' angle, Lerner (1994) studies the timing of IPOs by venture-capital backed biotechnology firms between 1978 and 1992, Pagano et al. (1998) study IPO decisions of over 2,000 Italian firms from 1982-1992, and Chemmanur et al. (2010) who study the timing of IPOs for US manufacturing firms. A number of recent studies have used our main data source, Capital IQ, to study observable differences in private and public firms including Gao et al. (2013a), Gao and Li (2015) and Acharya and Xu (2017), but none to our knowledge examine firm listing status or CEO pay in relation to firm intangibility.

compensation (for a survey, see Murphy (2013)).

[8]There is also a relatively smaller literature on the effects of delisting, see for example Bakke et al. (2012).

[9]Unlike Spiegel and Tookes (2013), Clementi (2002) or Ferreira et al. (2014) which predicts the highest productivity projects will be privately funded, our theory of sorting is not predicated on differences in firm's profitability which is important as in our large sample of US firms we find public firms have on average slightly higher markups and statistically indistinguishable differences in levels of productivity.

[10]His theory, tailored to public firms, predicts a positive correlation of productivity and firm intangibility based on public firms, while in our theory firm intangibility and profits or total factor productivity (TFP) need not be. This prediction is inconsistent with our broader sample of both public and private firms where we obtain a -13.8% correlation between firm intangibility and estimated firm productivity.

II. Model

We study the menu of optimal compensation contracts offered by competing financiers to a unit mass of heterogeneous firms and the resulting selection of firms into being privately or publicly funded. At time 0, each firm is wholly owned by a risk-averse agent (entrepreneur) with constant absolute risk aversion (CARA) utility, $-e^{-\psi c}$, where ψ the risk-aversion coefficient, and has time discount rate ρ, but lacks the initial capital A to operate the firm. For time $t > 0$, a firm of size (scale) A produces (net) cash-flows $Y_t = y_t A$ where y_t is the scale-free profits of the firm. This profitability rate is given by $y_t = (1-\tau)z_t + \tau x_t$, that is, is comprised of a share τ of tangible components, x_t, and share $1-\tau$ of intangible components, z_t. Since the channel we wish to highlight does not depend on size, we will from hereon abstract from size considerations and set $A = 1$.

Both x_t and z_t evolve as Ohrnstein-Uhlenbeck processes (that is the continuous time equivalent of autoregressive of order 1, AR(1), with persistence λ_i, drift μ_i and volatility σ_i for $i \in \{x, z\}$, that is,

$$dx_t = \frac{1}{\lambda_x}(\mu_x \lambda_x - x_t) + \sigma_x dW_t^x \tag{1}$$

and

$$dz_t = \frac{1}{\lambda_z}(\mu_z \lambda_z - z_t) + \sigma_z dW_t^z. \tag{2}$$

We assume the tangible cash-flows x_t are publicly observable but the intangible components z_t are directly observed only by the agent. As such, the agent of a firm has persistent private information on the total cash-flows Y_t and provides opportunity for moral hazard by diverting cash-flows.

Two representative, risk-neutral financiers (with common discount rate ρ) compete to fund each firm by offering compensation contracts in exchange for ownership of the firm. The public financier, P, has deep pockets but lacks a monitoring technology to observe the intangible cash-flows z_t and so must restrict their offered contracts to those which induce truthful reporting of the agent. The private financier, S, is assumed to be a specialist and so is able to expend monitoring effort to observe the intangible cash-flows, thereby avoiding the information friction, but is rationed in the amount of funds she has to invest by a budget $B^S < \infty$.

A. Agent's Reporting Problem

At the time of entering into a contract, the agent and financier are both fully informed as to the firm's cash-flow characteristics $\theta = (\{\mu_i, \lambda_i, \sigma_i\}_{i \in \{x,z\}})$ and initial conditions x_0, z_0, however, for every $t > 0$ the realized cash-flows y_t are not common knowledge given z_t is only privately observed by the agent (and by the private financier after paying the monitoring cost). We assume that at each instant the agent hands over any cash-flows reported to the financier (e.g. cash-flows are deposited into a monitored bank account) who then returns compensation c_t to the agent. Consequently, the agent has the opportunity to under-report the realized cash-flows and divert the residual for their own instantaneous consumption. Due to knowledge of θ and continuous reporting of the agent to the financier, any discontinuous jump in reported cash-flows reveals that the agent has lied and be punished. Consequently, feasible mis-reports are restricted to biasing downwards the drift of the reported cash-flows by $\Delta_t \geq 0$. Further, since the financier has perfect recall, the agent must make his report history consistent with his diversion history, so that his reports follow the process:

$$d\hat{y} = \tau dx_t + (1-\tau)dz_t - \frac{m_t}{\lambda_z}dt \tag{3}$$

where $m_t = \int_0^t \Delta_s ds$ is the accumulation (history) of past diversions.

Denoting $\bar{x}$ and $\bar{z}$ as the sample paths of x and z respectively (formally $\bar{x} : C[0,T] \to C[0,T]$, for $T \to \infty$), the agent seeks to maximize his value under a contract with compensation $c(\hat{y}, \bar{x})$ using a diversion strategy Δ, subject to the prescribed evolutions above:

$$\max_{\Delta_s \geq 0} V(\Delta; c) = \max_{\Delta_s \geq 0} \mathbb{E}_0^{\Delta}\left[\int_0^{\infty} e^{-\rho t} u(c_t + m_t)dt\right] \tag{4}$$

subject to (1) - (3) as well as a prescribed evolution for consumption c_t given report history $\hat{y}_t$, initial conditions on the tangible and intangible components x_0, z_0 and $m_0 = 0$. From hereon, where there is little chance of ambiguity we drop the subscript for the private information volatility parameter σ since the observable volatility component σ_x doesn't appear in the contract.

B. *Financier's Contracting Problem*

Lacking a monitoring technology, the public financier in designing an optimal compensation contract must take into account the agent's optimal reporting decision rules given by (4). By the Revelation Principle, we can restrict to contracts which induce truth-telling so that $\Delta_t = 0$ is optimal for all t. As is established formally in Appendix (and originally established for $\tau \in \{0, 1\}$ in Williams (2011)), using a change of variables and appealing to a stochastic maximum principle, truthful revelation imposes the following evolution in the agent's promised utility and (negative of) promised marginal utility under a contract.

LEMMA 1: *Any compensation contract with truthful (or complete) reporting of the cash-flows imposes the following evolution in the agent's promised utility, q_t and (negative of) promised marginal utility, p_t:*

$$dq_t = [\rho q_t - u(c_t)]dt + \gamma_t \sigma dW_t^z \tag{5}$$

$$dp_t = [\rho p_t + (1-\tau)u'(c_t) - \lambda_z^{-1}\gamma_t]dt + Q_t \sigma dW_t^z \tag{6}$$

for some processes γ_t, Q_t and c_t specified in the contract.

Notice first that here because the persistence of private information introduces an additional state variable m_t, a truthful revelation contract must control separately the evolution of promised utility and promised marginal utility through q_t, p_t.[11] Second, observe that since we have assumed all the private information of the agent is associated with the intangible cash-flows only the innovations of the intangible cash-flows dW_t^z matter for the dynamic incentives pertaining to private information of the state of the firm.

Further, to ensure truth-telling locally under a contract with truthful revelation thus-far, (γ_t, Q_t) is restricted to satisfy the following incentive compatibility constraint.

LEMMA 2: *Under a truthful revelation contract (i.e. satisfying evolution in Lemma 1), truth-telling is incentive compatible for an agent at time t if*

$$p_t + \gamma_t \geq 0. \tag{7}$$

That is to induce truth-telling, the public financier is restricted in how low he can adjust the volatility of future promised utility γ_t by the level of promised marginal utility today $(-p_t > 0)$.

As a final constraint on the financier's feasible contracts, we assume that the initial level of promised utility is constrained at some fixed level q_0. In light of these constraints, to determine the optimal contract, the public financier can dynamically tune the contract using Q_t, γ_t, c_t and adjust the initial levels of promised utility and marginal utility p_0, q_0 as follows:

$$J^P(q_0, z_0, x_0) = \max_{p_0 \leq 0} \max_{c_t, \gamma_t \geq -p_t, Q_t} E_0\left[\int_0^\infty e^{-\rho t}(y_t - c_t)dt\right] \tag{8}$$

s/t the evolution of cash-flows (1) - (2), the evolution for promised utility / marginal utility and IC constraint (5) - (7), as well as the transversality conditions $\lim_{T\to\infty} e^{-\rho T} q_T = \lim_{T\to\infty} e^{-\rho T} p_T = 0$.

Endowed with the costly monitoring technology (per project cost ν), the (private) specialist financier can avoid these information frictions.[12] Thus, they solve the following relaxed version of the public financier's problem:

[11] For example, a contract could specify q_t constant over time meaning total lifetime compensation is fixed, but have the timing of the consumption stream vary with the reported cash-flows.

[12] We assume that the specialist always elects to use their monitoring technology at the start of the contract. This is without loss of generality as, without the use of the technology, competition with the public financier will generate zero profits.

$$J^S(q_0, z_0, x_0) = \max_{\gamma \geq 0, c_t} E_0\left[\int_0^\infty e^{-\rho t}(y_t - c_t)dt\right] - \nu \tag{9}$$

subject to (1) - (6), that is the evolution of cash-flows dy_t, dz_t, dx_t, promised utility and marginal utility dq, dp and the transversality conditions $\lim_{T\to\infty} e^{-\rho T} q_T = \lim_{T\to\infty} e^{-\rho T} p_T = 0$.

C. *Initial Financing Problem*

Before a contract is initiated, financiers compete with each other for entrepreneurs projects through bids of initially promised utility to the entrepreneur, q_0. Since in this context q_0 is a sufficient statistic for an agents preference over contracts, agents observing a pair of contracts, one from each financier, simply choose whichever contract yields the highest initial promised utility q_0.

We assume that each project θ is drawn from a distribution $G(\theta)$ and for simplicity that all agents have the same outside option V^A. Further, we abstract from firm differences in initial conditions by assuming all projects cash-flows are initiated at their unconditional means.[13] Financiers therefore maximize their net profits from contracting with the various firm types by (implicitly) selecting the firms they will finance through bids of promised utility and subject to their budget constraint. That is, a financier of type $f \in \{P, S\}$ solves the following project bidding problem, given the bidding strategy of their opponent financier q_0^{-f}, firm listing choice selection rule, $i^f(q_0^f, q_0^{-f}; \theta)$ and the financier's own budget constraint B^f

$$W_0^f = \max_{q_0(\theta)} \int_\theta [J^f(p_0(\theta), q_0(\theta), z_0(\theta), x_0(\theta); \theta) - 1] i^f(q_0^f, q_0^{-f}; \theta) dG(\theta) \tag{10}$$

s/t

$$q_0^f(\theta) \geq V^A \tag{11}$$

$$\int i^f(q_0^f, q_0^{-f}; \theta) dG(\theta) \leq B^f \tag{12}$$

where in the case of the public financier $B^P \to \infty$ (reflecting deep pockets) while the specialist financier has $B^S < \infty$. From hereon since the budget constraint of the public financier never binds, we will drop the superscripts and refer to B as the private financiers budget.

[13] To the extent that private information persistence λ_z is taken as common across all firms, this assumption boils down to assuming all firms have the same expected level of cash-flows.

Finally, the firm's (agent's) listing choice selection rules, (i^P, i^S), $i^P(q_0^P, q_0^S; \theta) + i^S(q_0^S, q_0^P; \theta) \leq 1$, is simply the highest of the promised initial lifetime payoffs under the contract q_0^P, q_0^S and their outside option V^A. A public listing equilibrium then is a sub-game perfect Nash-equilibrium, where the financier's bids are best-responses to their rivals, the agent's selection rules are best-responses to the bids and the compensation contracts are optimal conditional on the agent type contracted for financing.

D. *Equilibrium Outcomes*

We solve the model by backward induction, first solving for the optimal compensation contract for the public and private financiers, then solving for the optimal bidding and selection rules in the financing competition market. The optimal contract for $\tau \in \{0, 1\}$ is solved in Williams (2011), details on the solution for $\tau \in (0, 1)$ are given in the appendix.

The optimal compensation contract for an agent with firm of type θ financed by a public and private financier respectively is summarized in the next theorem.

THEOREM 1 (Optimal compensation contracts): *The optimal compensation contract for an agent of type θ financed by a public financier is*

$$c_t^P = c_{base}(q_0) + c_{growth}(\theta)t + c_{pp}(\theta)W_t \tag{13}$$

while the compensation contract for a private financier it evolves as

$$c_t^S = c_{base}(q_0) \tag{14}$$

where $c_{base}(q_0) = -\frac{log(-\rho q_0)}{\psi}$ is the base compensation, $c_{growth}(\theta) = \rho^2 \pi(\theta)$ is the average drift in pay and $c_{pp}(\theta) = \rho\sqrt{\frac{2\pi(\theta)}{\psi}}$ is the pay-performance sensitivity of pay and what we refer to as the information premium $\pi(\theta)$,[14]

$$\pi(\theta) \equiv \frac{(1-\tau)^2 \sigma^2 \psi}{2(\rho + \frac{1}{\lambda_z})^2}. \tag{15}$$

Here we see that compensation for an agent of type θ with a fixed initial level of promised utility q_0 is fully stabilized under the private financier's contract reflecting the risk-premium the risk-neutral private financier can extract from insuring the risk-averse agent of the cash-flow risks. The public financier is precluded from offering this contract due to having to incentivize the agent to report the full cash-flows in each instant. To do so, the public financier must introduce some

[14]The rationale for this label will be made clear later in this and the following subsection.

performance pay component c_{pp} which is sensitive to the reported performance of the firm W_t^z, but because of the risk-aversion of the agent, to compensate the agent for this additional risk in their compensation the financier must raise and backload the expected compensation given by c_{growth}.

The expected difference in compensation paid to a given agent with firm θ between the public and private financier is simply $\frac{E[dc_t^P|\theta]-E[dc_t^S|\theta]}{dt} = c_{growth}(\theta)$. This difference in expected compensation translates into an information premium $\pi(\theta)$ the public financier must forgo in return for financing the same project as the private financier.[15] However, because the private financier must pay a monitoring cost ν to avoid having to incentivize the agent to truthfully report the private equity premium is then as stated in the next corollary.

COROLLARY 1.1: *The private (specialist) equity premium is*

$$J^S(\theta; q_0) - J^P(\theta; q_0) = \pi(\theta) - \nu. \tag{16}$$

With this information premium, for any θ such that $\pi(\theta) - \nu > 0$ is positive the private financier can bid the public financier's total surplus on the firm and still earn a positive profit. As a consequence, the private specialist will prioritize their investment to firms with higher information rents $\pi(\theta)$ and allow the public financier to fund the firms with relatively low information premia. That is, in equilibrium, firm financing by the specialist is characterized by the set $(\sigma, \lambda_z, \tau)$: $\pi(\theta) \geq \underline{\pi}(B, \nu)$ where $\underline{\pi}$ is some threshold information premium which is pinned down by some lower-bound cutoff on σ ($\underline{\sigma}$) or upper bound cutoff on τ ($\bar{\tau}$).

THEOREM 2 (Equilibrium firm sorting): *Let $\underline{\pi}$ denote the minimal information premium financed by the private financier in equilibrium. The optimal sorting of firms into being privately funded for a given λ_z is given by*

$$\underline{\sigma}(\tau; \underline{\pi}) \equiv \sqrt{\frac{2\underline{\pi}}{\psi} \frac{(\rho + \frac{1}{\lambda_z})}{1 - \tau}} \tag{17}$$

A graphical depiction of the sorting predictions of the model in tangibility / volatility space is provided in Figure 1a. All else equal, more volatile cash-flows and more persistent deviations in cash-flows provide more cover for an executive to hide mis-behaviour and hence is more costly for optimally designed compensation contracts to preclude for an uninformed financier.

INSERT FIGURE 1

[15] Note that here over a sufficiently long time horizon, the financier may have to actually subsidize the compensation of the manager from his own funds. This can be easily precluded with the introduction of stochastic project destruction. We solve the model in the appendix with a poisson arrival of job-destruction (arrival rate η) which yields the same results as above but with a modified discount rate $\tilde{\rho} = \rho + \eta$.

We have thus-far pinned down the equilibrium sorting and compensation by heterogeneously informed principals and heterogeneous projects in terms of the degree, volatility and persistence of private information for a given cutoff $\underline{\pi}$. The optimal information cutoff $\underline{\pi}$ is pinned down either by the budget constraint B if there is sufficient mass of information premia above their net costs of private equity financing ν. For convenience, rather than track the distribution of τ, σ, λ_z, define $G_\pi(\pi)$ to be the (univariate) distribution of the information premium $\pi(\theta)$ where $\theta \sim G(\theta)$. Then taking $\bar{G}_\pi$ to be the survivor function (the right tail of the distribution), $\bar{G}_\pi = 1 - G_\pi(\pi)$ the information premium cutoff is

$$\underline{\pi}(B, \nu) = \max\{\bar{G}_\pi^{-1}(B), \nu\}. \tag{18}$$

The mass of of firms funded by the private financiers is then given by

$$\underbrace{\mathbb{M}(B, \nu)}_{\text{Mass of specialist (private) financed firms}} \quad = \quad \bar{G}_\pi(\underline{\pi}(B, \nu)). \tag{19}$$

E. *Extending to General Equilibrium*

Up until now we have taken the amount of funds allocated to the private financier as exogenous. In this subsection we provide a simple extension of the model to make funding into the private equity and public markets endogenous.

We assume there is a continuum of households of mass H, each endowed with a dollar of funds and assigned a present-value (possibly non-pecuniary) monitoring cost $\nu \sim F(\cdot)$ with support on the positive reals. Each household can purchase a share from the public financier at competitive price s to earn a unit of the expected lifetime proceeds of the investment

$$D = \mathbb{E}[J^P(\theta) | \pi(\theta) < \underline{\pi}].$$

Alternatively, a household may choose to become a private equity investor by supplying their dollar of funds to a firm directly but also paying their private monitoring cost ν, thereby receiving revenues of

$$R(\nu) \equiv \pi(m(\nu)) - \nu + J^P(q_0^P, m(\nu))$$

where $m(\nu)$ is some bijective matching function of firm type θ to investor of cost ν. Recalling that $J^P(q_0^P, \theta) = 1$ in equilibrium for any firm the private financier finances, the revenues simplify to $R(\nu, m(\nu)) = \pi(m(\nu)) - \nu + 1$.

Let $d = \frac{D-s}{s}$ denote the (net) return on a dollar invested in public equity and $r(\nu) = \frac{R(\nu)-1}{1}$ the (net) return from a dollar invested in private equity for a household of type ν. Naturally households with $d > r(\nu)$ will supply their funds to the public markets while those with $d < r(\nu)$ will become private equity financiers.

To determine the matching function $m(\cdot)$ we will assume private equity investors may transfer projects amongst themselves in the set $\pi(\theta) \geq \underline{\pi}$ and use the notion of a competitive matching equilibrium (see Chade et al. (2017) or Becker (1974)) then since the trade surplus function is $\max\{\pi(\theta) - \nu, 0\}$ is by inspection submodular we have that equilibrium sorting features Negative Assortative Matching (NAM) so that the lowest cost matches with the highest information premium firm.[16]

Funds to private equity are then pinned down by the marginal private equity financier with $d = r(\nu)$. Denote this investor's monitoring cost by ν^*. From the definition of $\underline{\pi}$ and the NAM, we have $\nu^* = \underline{\pi}$. Consequently, the equilibrium private equity funds is given by the mass of households with $\nu \leq \nu^*$, $H \cdot F(\nu^*)$.

Furthermore, since we assumed that investing in the public market portfolio consists of a continuum of projects of each type θ, a law of large numbers applies so that D is obtained with probability of one and hence, lacking any risk or heterogeneity in investment opportunities, the public equity return d must be zero. Thus, the definition of the marginal investor we have that $r(\nu^*) = 0$ and so thus an equilibrium in this context is pinned down by ν^* which solves

$$\nu^* = \bar{G}_\pi^{-1}(H \cdot F(\nu^*)). \tag{20}$$

where $\bar{G}_\pi = 1 - G_\pi(\pi)$ is the survivor function of the distribution of the information premium $G_\pi(\pi)$.

Note that for $\nu^* \to 0$, the RHS of (20) $\bar{G}_\pi^{-1}(HF(\nu^*)) \to \infty$ by the assumptions on π having no finite upper bound, and that $\nu^* \to \infty$ implies $\bar{G}_\pi^{-1}(H \cdot F(\nu^*)) \to 0$, thus since $G_\pi^{-1}(\nu)$, $F(\nu)$ are continuous functions by the Intermediate Value Theorem a root ν^* exists. Furthermore, since $\bar{G}_\pi^{-1}(HF(\nu^*))$ is a monotonically decreasing function of ν the solution ν^* is unique. We summarize this result in the next theorem.

THEOREM 3: *Assume the mass of households H is sufficiently large and assume that $\tau \in [0, 1]$, $\sigma \in [0, \infty)$. A unique equilibrium to the GE extension outlined above exists with equilibrium funds given by*

$$B = H \cdot F(\nu^*) \tag{21}$$

and the marginal PE investor's monitoring cost implicitly given by

$$\nu^* = \bar{G}_\pi^{-1}(HF(\nu^*)).$$

[16]The optimal assignment problem is $\max_{m(\nu)} \int_\nu \int_\theta [\pi(m(\nu)) - \nu]_+ dG(\theta) H \cdot dF(\nu)$ where $[u]_+ = \max\{u, 0\}$ is sub-modular.

It is important to note that although the marginal PE investor earns zero profits, all other PE investors earn strictly positive returns and the average PE investor's return premium over public market returns is:

$$\text{Average PE Return premium, } \Pi = \mathbb{E}[\pi(\theta)|\pi(\theta) \geq \nu^*] - \mathbb{E}[\nu|\nu \leq \nu^*]. \tag{22}$$

F. Comparative Statics and Policy Counterfactuals

In this subsection, we examine through the lens of our model how various policy experiments and changes in fundamentals will affect the listing propensity, public CEO compensation makeup, average private equity premium and overall funds into private equity. In particular, we examine: (i) an increase in the average intangibility of firms, (ii) a relaxation of funding impediments to private equity firms as argued by Ewens and Farre-Mensa (2020) and (iii) the impact of costly public disclosure like the 2002 Sarbanes-Oxley (SOX) act (Engel et al. (2007)).

All of these comparative statics involve a shift in the threshold(s) determining listing status. As such the magnitude and direction of effects depend crucially on the curvature of the distribution of the information premium $G_\pi(\pi)$ and the distribution of the monitoring costs, $F(\nu)$. We define the partial equilibrium setting of sub-section II.D as the short-run, where the funds to PE are fixed at $B = HF(\nu^*)$, and the long-run to be where the marginal cutoff ν^* adjusts. We establish in the following Lemma how the information premium and average public CEO compensation awards respond to an exogenous increase in the cutoff ν^*.

LEMMA 3: *Suppose the survival function of the information premium, $\bar{G}_\pi(\pi) = 1 - G_\pi(\pi)$ and the distribution of monitoring costs $F(\nu)$ are log convex (log concave) then (i) the average PE information premium above the marginal cutoff ν^*, $E[\pi|\pi \geq \nu^*] - \nu^*$, is increasing (decreasing) in ν^*, (ii) the mean difference of the marginal PE finance monitoring cost and the average, $\nu^* - E[\nu|\nu \leq \nu^*]$, is decreasing (increasing) in ν^* and (iii) the average PE premium is increasing (decreasing) in ν^*.*

From the above lemma, we have the comparative static that aggregate funds to PE, B (corresponding to an increase in ν^*), can have an unambiguous increase or decrease in the average PE premium if the distributions fall within the class of log concave or log convex distributions. These classes are fairly large and are discussed in detail in Bagnoli and Bergstrom (2005), but for distributions which do not fall within this set, or where $\bar{G}_\pi(\pi)$ and $F(\nu)$ have opposite log concavity properties, the sign is ambiguous and can depend on the level of aggregate funds B (or equivalently the cutoff ν^*).

To examine the effects of increasing firm intangibility we will have to impose some assumptions on the underlying distribution of firms. If τ, σ, λ are independent then it follows that an increase in average intangibility corresponds to an increase in the average information premium, $E[\pi(\theta)]$. Interpreting the partial equilibrium setting of sub-section II.D as the short-run aftermath of the regulation change, the total private investment funds remain unchanged while the Average PE return premium will increase. Now in the long-run, where the amount of private investment funds may adjust, the threshold private financiers ν^* will increase and hence from (21) the net funds supplied to PE will increase to B'. The net effects on the average private equity premium is ambiguous in general, but can be signed with restrictions on the shape of the distributions. In contrast, average public CEO annual awarded pay, $\bar{c} \equiv E[\frac{dc_t(\theta)}{dt}|\pi \leq \nu^*] = E[\pi(\theta)\rho^2|\pi \leq \nu^*]$, will increase with rising intangibility of the pool if the distribution of the information premium $G_\pi(\pi)$ is log convex, but is otherwise ambiguous.

COROLLARY 3.1: *Suppose across the entire distribution firm intangibility is scaled up by $\xi > 1$, so that $\pi' = \xi\pi$. Then the information premium distribution $G_{\pi'}(\pi)$ first order stochastically dominates the original distribution $G_{\pi'}(\pi)$, i.e. $G'_{\pi'}(\pi) \leq G_\pi(\pi)$ for all π. In the short-run, funds are constant (since $\partial B/\partial\xi = 0$), while the average PE premium increases, $\partial\Pi/\partial\xi > 0$. In the long-run, unambiguously total funding $B = HF(\nu^*)$ and the monitoring cutoff ν^* increases. Further, if the survival function $\bar{G}_\pi(\pi)$ and the CDF $F(\nu)$ is log convex then in the long-run $\partial\Pi/\partial\xi > 0$. Finally, while public firms whose listing status is unchanged by the shifting intangibility will have average public compensation unambiguously increase, the aggregate long-run public CEO compensation $\bar{c}$ is in general ambiguous with the exception of $G_\pi(\pi)$ being log convex wherein $\bar{c}$ also increases in the long-run.*[17]

We now move to our first policy counterfactual inspired by the relaxation of funding restrictions to private equity in the '90s as studied by Ewens and Farre-Mensa (2020). In our setting, we interpret the relaxation of funds to private equity as a level scaling down in the distribution of net (pecuniary) monitoring costs $\nu\frac{1}{\xi}$, with $\xi > 1$. In this case, since $\partial\nu^*/\partial\xi > 0$, the amount of funds available to the private equity financiers immediately increases. The net effect on the average private equity premium and average CEO pay is again in general ambiguous and depends on the curvature of $G_\pi(\pi)$ and $F(\nu)$ as presented in the next corollary.

COROLLARY 3.2: *If funding restrictions on private financiers are relaxed so that $\nu' = \frac{1}{\xi}\nu$ for some $\xi > 1$, then the mass of privately financed firms increases, i.e. $\frac{\partial\nu^*}{\partial\xi} > 0$. The average PE premium, Π and CEO compensation in the long-run will behave just as in Corollary 3.1 if $\bar{G}_\pi(\pi)$ and $G_\pi(\pi)$ are log convex. On the other hand, if $\bar{G}_\pi(\pi)$ and $G_\pi(\pi)$ are log concave then the average PE premium and average public CEO pay will decrease.*

Finally, the passage of the SOX act in 2001 was a response to the Enron scandal involving persistent mis-leading reporting of financials to public investors and

[17]Note in particular that as we will find evidence from the structural estimation that $G_\pi(\pi)$ is log concave and while $\bar{G}_\pi$ log convex.

sought to increase transparency through increased disclosure. Substantial concern about the financial costs and efficacy of this disclosure has been widely discussed in the literature. One interpretation is that the increased compliance and disclosure costs for public firms have done little to reduce information asymmetry between firm insiders and outsiders (i.e. disclosure does not include divulging trade secrets or other proprietary information). Denote the costs of disclosure and compliance for public firms as ι. In this interpretation, the net revenues for the public financiers for a given project $J^P(\theta) - 1$ is reduced by ι, but without any dilution of the information premium. In this case, the disclosure is a deadweight loss and in the short-run, the private equity premium will increase as this additional cost just reduces the level of promised utility a private financier must offer a given project to woo away from public financing. If the costs are sufficiently large so that $J^P(\theta) - \iota - 1 < 0$ for some $\pi(\theta) \leq \nu^*$ then after the imposition of this policy, in the short-run, some firms will lose financing from both public and private financiers, resulting in delists / exits. In the long-run, additional funding will flow to private financiers to expand the set of firm types they finance. Assuming that the disclosure costs ι are such that for some firm type θ the net value of public financing becomes negative, $J^P(\theta) - \iota - 1 < 0$, but the net surplus of private financing, $J^S(\theta) - J^P(\theta) - 1$, is positive (as has been maintained throughout) then the full set of firms with $J^P(\theta) - \iota - 1 < 0$ will be absorbed by the private financiers in the long-run.

COROLLARY 3.3: *Suppose the public financier faces an additional cost ι with no effect on π where $J^P(\theta) - \iota - 1 < 0$ for some $\tilde{\pi}(\theta) \leq \nu^*$, then in the short-run, (i) some measure ε of public firms will delist and not receive new private injections,(ii) if $G_\pi(\pi)$ log convex (log concave), then average public CEO pay will decrease (increase), and (iii) the private equity premium will unambiguously increase. In the long-run, private financing will expand to fully absorb the delisted firm types, with an ambiguous effect on the average PE premium,* Π, *while public CEO pay will remain un-changed from the short-run.*

An alternative interpretation of SOX is that while it did increase compliance costs ι, the increased disclosure has helped reduce some of the information uncertainty so that $G'_\pi(\pi) = G_\pi(\pi) - \xi$ for some $\xi > 0$.[18] In this case, both the short and long-run effects are ambiguous, depending on whether the cost side or the information provision side dominates. In the extreme where the costs ι are negligible relative to the information provision, the set of publicly financed firms will increase, average CEO pay will decrease (assuming that the treatment on existing public firms of ξ is larger than the increase in CEO pay coming from the additional new firms being publicly funded).

[18]We evaluate the differential predictions from this costly but productive and unproductive disclosure in Section IV.C.

COROLLARY 3.4: *Suppose public financier faces an additional cost ι with some positive effect ξ on every public firm's level of information premium $\pi' = \pi - \xi$. If ι is sufficiently small so that $J^P(\theta) - \iota - 1 > 0$ for all $\pi(\theta) \leq \nu^*$ then in the short-run (ν^* fixed), (i) average public CEO pay will decrease (ii) the set of public firms will increase and (iii) the average PE premium will decrease (increase) if $\bar{G}_\pi(\pi)$ is log convex. The long-run leaves the sorting unchanged from the short-run.*

III. Data and Variables

The data for our empirical analysis comes from three sources. Our primary data source is S&P Capital IQ and provides us with balance sheet on US firms who file with the Securities Exchange Commission (SEC) either a Form 10-K, Form 10-Q or Form S-1 from 1993 - 2016.[19] This includes firms listed on the NYSE, AMEX or Nasdaq and firms with a reporting requirement to the SEC typically due to either having public debt, equity listed on minor or OTC exchanges, or having more than 500 shareholders or \$10 million in assets.[20] As Capital IQ only provides the current listing status of firms, to give historical classifications of public and private we merge the data with Compustat Snapshot to obtain the historical financing source for each firm through time if available.[21] We drop from the sample all firms listed on minor stock exchanges. Thus, our private firms consist of those firms indicated to be not listed on a top 3 or minor stock exchange or which could not be linked to Compustat Snapshot through the Capital IQ to Compustat linking table provided on WRDS.

We also obtain data on executive compensation from Capital IQ starting in the fiscal year 2001. Again, due to the CEO descriptor being a header variable, we identify which of the listed executives for a firm was the CEO in a given year using Capital IQ data on firm events as done by Gao et al. (2018) and cross-check with Execucomp data for the S&P 1500 firms. Where ambiguity remains in the identify of the CEO for a given firm-year (occurred in 6.5% percent of observation) we take the highest paid executive in terms of total compensation. For the longer historical analysis of CEO compensation in Section IV.C we use Execucomp and Frydman and Saks (2010) historical data.

[19]S&P Capital IQ is the same data provider as Compustat but with broader coverage of private firms. While the SEC reporting requirements are the same for both the listed and non-listed firms, there are still two key distinctions between top U.S. exchanges and the non-listed firms. First, the listed firms have more comprehensive reporting requirements in the SEC and receive much more analyst attention than those with stocks tradable in an OTC market or without a trading platform. Second, by the nature of these markets having less market depth (and implicitly fewer shareholders), the ease of communicating private information to long-term consolidated shareholders while avoiding divulging to the broader public should be higher than that of the firms listed on the top 3 US stock exchanges exchanges. Finally, the lower frequency of trade implies price adjustments of firm value should be lower than that of the top exchanges, so the information sensitivity of stock prices and CEO compensation should lie on a continuum between the totally private firm and the top 3 exchanges.

[20]Prior to the enactment of the 2012 JOBS Act, Section 12(g), any U.S. firms with \$10 million or more of total assets and more than 500 shareholders are required to provide balance sheet and compensation data through the annual 10-K and quarterly 10-Q reports. After the JOBS Act 2012, the shareholder threshold increased to more than 2000 shareholders

[21]We also used CRSP and Capital IQ listing information to validate our classification.

Our key variables of interest relate to firm listing status on a top 3 exchange, the level, and performance sensitive components of CEO pay, and firm-level proxies of: (i) the share of cash-flows with information frictions $1-\tau$, (ii) the persistence of private information shocks λ_z, and (iii) the volatility of the private information component of firm's profit stream σ.

Our proxy of firm's intangible share of net cash-flow innovations uses the perpetual inventory measure of intangible capital computed by Peters and Taylor (2017) but with the procedure adapted for private and public firms in Capital IQ and uses the year of foundation provided by either Capital IQ or Field-Ritter dataset begun by Field and Karpoff (2002) and completed by Loughran and Ritter (2004). The measure combines Research and Development (R&D) expenses, 30% of Sales, General and Administrative (SG&A) expenses and balance sheet intangible ('other intangible') and goodwill line items on the balance sheet as investment flow into intangible assets.[22] Our scale free measure of a firm's degree of intangibility $1-\hat{\tau}$ is then the share of this intangible stock to book value of assets plus intangibles.

We consider two mappings for the private information cash-flow process from which we construct our proxies for λ_z and σ. For our first proxy, we ascribe all of a firm's earnings (EBITDA) scaled by total assets to be private information (implicitly setting $\sigma_x = 0$). Since the discretized Ohrnstein-Uhlenbeck process is an AR(1), we estimate a firm-level proxy for λ_z using Han and Phillips (2010) estimator. Finally, we compute a firm-year proxy for the private information volatility, σ_{it} (earnings volatility), using the standard deviation of the scaled earnings over the previous three years.

The level of a firm's market power is by its nature not directly observable, but is known by firm insiders. Markups, as a manifestation of a firm's market power, also have the potential to be private information for inside firm management. As our second proxy we compute annual markups (revenues over marginal costs) for each firm following the estimation procedures by De Loecker et al. (2020) and Flynn et al. (2019). The estimation procedure is done in two stages. We first estimate a neoclassical Cobb-Douglas production function for each Fama-French 48 industry and year using Cost of Goods Sold (COGS) and SG&A as variable factors and Plants, Property and Equipment Gross Total (PPEGT) as a measure of physical capital and then use the output elasticity on COGS divided by the ratio of COGS to revenues. We estimate the production function using the estimator by Wooldridge (2009).[23] Just as with our earnings proxy, we estimate λ_i, from firm-level AR(1) estimates using Han and Phillips (2010) estimator and compute σ_{it} as the standard deviation of the previous three-years lagged markups for a firm.

We consider only firm-year observations with positive and non-missing book

[22]Details on the computation are available in Appendix A.

[23]Due to a severe sample restriction when we utilized Ackerberg et al. (2015), we relied on Wooldridge (2009) estimator used by for instance Andrews et al. (2016). Differences in TFP estimation methods have been found to in general be fairly small, see for instance Van Beveren (2012).

value of total assets.[24] We exclude from our analysis financial firms (SIC codes from 6000 to 6999), utilities (SIC codes from 4900 to 4999) and quasi-governmental firms (SIC codes from 9000). All variables are normalized in 2016 U.S. dollars. We annually winsorize variables without clear upper or lower bounds at the 1% and 99% level.

Summary statistics on both firms publicly listed on a top 3 US stock exchange ('public') and firms in the sample not listed on a top 3 ('private') as well as the compensation paid to their CEO is given in Table 1. Public firms are on average older, and larger than the private firms in our sample (both in the book value of assets, and the number of employees).[25] Size (Asset)-scaled performance measures of EBITDA, sales or markups are also weakly higher for public firms but the difference is much less pronounced than size differences. In particular, using Kolmogorov-Smirnov (KS) one-sided test with a null-hypothesis that public firms' performance distribution first order stochastically dominates the privates, we reject the null for earnings, and TFP and fail to reject the null for markups (with $KS = 0.016$, 0.018 and $1.5e^{-16}$ respectively). That is, public firms are substantively better at generating markups than private firms, but do not demonstrate a consistent performance advantage in productivity or earnings to assets.[26]

Public firms are on average 8 percentage points (p.p.) more tangible, have less volatile earnings and show higher persistence of earnings than the private firms. The volatility and persistence profiles of TFP and markups differ substantially from those of earnings. First, in terms of TFP, we are unable to reject the null that average firm volatility or persistence is different across the two sub-samples. Second, within firm markups are much more volatile for public firms than private, although the persistence of markups is very similar.

Private firms carry a similar fraction of gross physical property, plants and equipment (PPEGT) on their book assets as well as similar physical investment levels.[27] On the other hand, the median private firm conducts more R&D, has higher SG&A expenditures and holds more goodwill on their balance sheet but all three measures appear to exhibit substantial skew (with the mean levels for each measure falling well below the public level). Despite having slightly higher markups, public firms cost of goods sold are roughly 13 percentage points higher.

Total CEO compensation (in millions USD) is substantially higher for public firms than private firms, with salary accounting for 42% of public CEOs pay as opposed to 70% for private CEOs.[28] Public CEOs are compensated for the lower salary with more stock options, restricted grants and larger bonuses. Although our sample is broader than that of Execucomp and our sample period extends

[24] We also exclude 42 observations with negative cost of goods sold to facilitate our markups calculation.

[25] Number of employees is obtained in Capital IQ from the IRS Form 5500 provided publicly by the Department of Labour.

[26] The empirical distributions of log markups, TFP and earnings by listing status can be found in the appendix.

[27] All firm characteristic variables (excepting intangibility which is scaled by the sum of book and intangible assets) are scaled by book assets.

[28] CEO compensation components are scaled by total pay.

later, the levels and distribution of pay are similar to those found in Edmans et al. (2017). For instance, median public CEO pay is \$1.63 million in our sample versus \$1.2 million in Edmans et al. (2017). Similarly they find options to be 49% of pay for large cap firms by 2000 compared with $\approx 39\%$ here.

INSERT TABLE 1

IV. Empirical Results

Our theoretical results in Section II.D Theorem 1 and 2 suggest firm listing choice and CEO compensation is driven by a firm-level information premium, $\pi(\theta)$, which in logs is linearly increasing in (i) firm intangibility, (ii) firm private information volatility and (iii) the private information persistence. We validate these predictions using private information process proxies for the cross-section of public and private firms in our data.[29] We first examine the cross-sectional listing predictions of Theorem 2 in subsection IV.A. We then move on to assessing the cross-sectional CEO compensation predictions of Theorem 1 on the level and the performance-pay components in subsection IV.B. We conclude this section by considering some of the time-series and policy predictions in Section II.F.

A. Testing Cross-Sectional Firm Sorting Predictions

In Figure 2a we compute the average firm tangibility and earnings volatility within each Fama-French 12 industry and separately for publicly listed firms (triangles) and not listed firms (circles).[30] We superimpose the sorting rule predicted by Theorem 2 (and depicted in Figure 1a) with $\underline{\sigma}(\tau) = \frac{0.07}{1-\tau}$ which predicts that private firms are to the north-west and public to the south-east of this line. With the exception of the Medical Equipment industry, the within industry average for public and private firms falls along the patterns predicted by this sorting line. Although a single sorting line does not hold across all industries simultaneously, the predicted sorting patterns hold within each industry separately.

We produce the same figure for the first half of the sample from 1993 - 2003 in Figure 2b. We again plot the theoretical sorting line which minimizes the misclassification of public and private firms for this early sample and for comparison plot the sorting line from Figure 2a (dashed). Comparing the sorting patterns across the two figures we see that the firm sorting patterns are less pronounced. In particular, the Business Equipment and Oil / Gas industry segments cannot fit under one common industry sorting line for this early sample, but do still fit the predicted sorting pattern within industries. We also see that average intangibility and earnings volatility within industries has increased over our sample

[29]Proxies of private information are by their nature fraught and our theory contains different predictions for volatility coming from private info or publicly observable components. We avoid these problems in Section V where we estimate the parameters governing a firms information premium through the structure imposed by our model via a GMM structural estimation.

[30]We exclude firms with less than a million in assets to preclude the smallest firms from skewing the (unconditional) averages depicted even more in our favour.

period, especially for the private firms, suggesting higher information rents. On the other hand, the theoretical sorting line for this new sample falls below the full sample sorting line, $\frac{0.04}{1-\tau} < \frac{0.07}{1-\tau}$ so a back of the envelope calculation based on the functional form of $\underline{\sigma}(\theta)$ implies that the persistence of private information was in fact larger in the years around 2000 than for the years in the aftermath of the financial crisis.[31] This is consistent with the theory that the intensity of competition within product markets has increased shortening the window of profits for all but the most productive firm's (Autor et al. (2020)) and / or some sort of market-wide learning of the drivers of profitability for the new ICT firms.[32]

INSERT FIGURE 2

In Table 2 we present the results from regressing a firm's listing status against firm tangibility, private information volatility ($\hat{\sigma}$) and persistence ($\hat{\lambda}_z$) after controlling for firm size, age and industry / year effects.[33] The regression specification takes the following form for a firm i, in industry k and year t:

$$g(\text{Listed}_{i,t}) = \beta_0 + \beta_1 \log(\text{Tangibility}_{i,t-1}) + \beta_2 \log(\text{Volatility}_{i,t-1}) \\ + \beta_3 \log(\text{Persistence}_i) + \Gamma X_{i,t-1} + \zeta_{t,k} + \varepsilon_{i,t}, \tag{23}$$

where the outcome function $g(\cdot)$ is either the identity mapping, or the log odds ratio (i.e. linear and logistic regression respectively), $X_{i,t-1}$ includes log firm age, and log size measured in assets.[34] Controlling for heterogeneity in age and size allows us to abstract from key differences amongst firms found in the literature and not explicitly-accounted for in our model predictions. We include either industry and year, $\zeta_{t,k} = \zeta_t^1 + \zeta_k^2$, or interacted industry year, $\zeta_{t,k} = \zeta_t^1 \times \zeta_k^2$, fixed effects to control for different industry-wide trends.

INSERT TABLE 2

[31] Observe that using Theorem 2, and taking the ratio of the early (E) and full sample (F) persistence parameters, $\frac{\underline{\sigma}(\tau;\lambda_z^E)}{\underline{\sigma}(\tau;\lambda_z^F)}$ we have $\frac{\rho+\frac{1}{\lambda_z^E}}{\rho+\frac{1}{\lambda_z^F}} = \frac{0.04}{0.07}$. Assuming the effective discount rate ρ is constant across time, we solve for the ratio of sample specific λ_z's implying persistence has declined. A formal structural estimation of the private information persistence λ_z is offered in Section V.

[32] This later argument is exemplified by famous value investors like Warren Buffett who abstained from investing in tech firms like Apple until the 2010s. For instance, in a Forbes article in 1999 `https://money.cnn.com/magazines/fortune/fortune_archive/1999/11/22/269071/`, he argued that he didn't invest in "innovation" due to the lack of a 'moat' (built by longevity and defensibility of competitive advantages) and difficulty in picking the winners in advance. In contrast, at the 2018 annual shareholder meeting he said, "I didn't go into Apple because it was a tech stock in the least. I went into Apple because ... of the value of their ecosystem and how permanent that ecosystem could be." `https://money.com/value-investing-embraces-tech/`.

[33] $Listed_{i,t}$ is an indicator value taking the value one if firm is listed in that year in a top 3 stock exchange and zero otherwise.

[34] Due to a negative autoregressive coefficient for about a quarter of the firms in the data for earnings, we do not use the log for the earnings persistence but rather its level. Despite the large difference in usable sample size, the estimated qualitative and quantitative differences are small.

Our results of firm intangibility and cash-flow volatility on listing choice are consistent with the theoretical predictions in Theorem 2 across all six specifications, and are robust to the inclusion of industry $\times$ year fixed effects and the use of a linear or logistic link function. A 10% increase in firm tangibility corresponds to a 1 percentage point increase in the probability of being listed. Similarly, a doubling in the past three year earnings volatility corresponds to a 2-2.2 percentage point decrease in the probability a firm will be listed today. These results are all statistically significant at the 1% level clustered by firms, quantitatively similar across specifications and substantive in the sense they (weakly) dominate the effects of either age or size (which themselves have the expected effect that older and larger firms are more likely to be public and smaller / younger are private).

To the extent that persistence in earnings or markups capture persistence in private information the positive association of the persistence in earnings and markups on listing status runs counter to our sorting predictions. The magnitude of the effects of persistence are however relatively small compared to the volatility and tangibility. A 10 percentage point increase in earnings persistence corresponds to a 0.03 p.p. increase in firm listing probability, while a 10% increase in markup persistence corresponds to a 0.25 percentage point increase in the probability of a firm being publicly listed.

B. Testing Cross-Sectional CEO Pay Predictions

We present empirical tests of our theory predictions from Theorem 1 for the relation of the level of CEO compensation with firm characteristics in Table 3. The regression specification is the same as the listing regression specified in (23) but replacing the logarithm of total CEO compensation as the dependent variable and including indicators of listed status as covariates. We obtain estimates for both private information process proxies earnings and markups.

The results are again remarkably consistent across the different specifications, sub-samples and proxies with the exception of the persistence measure. A 10% increase in lagged firm intangibility implies a roughly 3% increase in CEO total pay. Similarly, a 10% percent increase in lagged firm volatility implies a 1% increase in CEO total compensation based on earnings and a smaller 0.4% increase for markups. Persistence has a similar positive effect on total CEO pay across both proxies with the markups proxy, although the markup proxy is not found to be significant. As has been found previously in the literature, listed firms pay higher total compensation, and pay more the older and larger the firm is.

INSERT TABLE 3

In Table 4 we test the compensation predictions of Theorem 1 on various components of CEO pay: salary, bonus, long-term incentive plans (LTIP), restricted stock and option grants. Higher persistent information frictions within the firm should lead to a higher share of a CEO's compensation being performance-based, and backloaded. We regress the log CEO compensation components against lagged firm private information proxies, age size and firm listing status as well as firm year interaction fixed effects.[35]

For our sample, we find that the share of pay which is explicitly fixed as measured by salary is increasing in firm tangibility and decreasing in firm volatility. A ten percent increase in firm tangibility will on average increase the contracted CEOs salary by roughly 1%, while a 10% increase in volatility results in an average 1% (0.2%) decrease in salary share based on earnings (markups). Although bonus pay is typically tied to specific earnings and other accounting metrics, in practice the targets which are set seems to lead to bonus pay not being very sensitive to the long-run performance of the firm (Frydman and Jenter (2010)). Viewed in this way, persistent firm information frictions on bonus pay broadly acts as a muted version of salary with a ten percent increase in tangibility increases the bonus share by 0.3% across both proxies, while an increase in volatility reduces the bonus share for earnings (although the effect is insignificant for earnings).

Non-cash based (variable) compensation in the form of long-term incentive plans, restricted stock grants and options, which are more backloaded and tied to the future value of the firm, have the opposite relationship to firm tangibility than the fixed components above. A 10% increase in firm intangibility corresponding to an average increase of between 0.3% and .9% depending on the proxy and stock or option share. The effect of volatility for stock grants is qualitatively the same across our two proxies although the markup proxy is not statistically significant. In contrast, the effect of volatility differs across our two proxies with earnings (markup) volatility increasing (decreasing) the option pay share, with the negative association for markups and order of magnitude smaller than the earnings effect. All told it seems that the positive association of total CEO pay to volatility found in Table 4 is driven by restricted stock grants and options, not by an increase in the fixed portion of pay.

Persistence of earnings has no significant impact on the individual pay components. In contrast, persistence in markups has a significant and substantial positive association with stock grants (as well as a positive but not statistically significant association with options). The fact that persistence in earnings has no effect on incentive provision while markup persistence does suggests different information content between the two proxies. It also may suggest a difficulty with our proxy of persistence of private information through earnings persistence, since higher persistence of earnings can be associated with stable market conditions and low marginal effect of various shocks to the firm like managerial changes. On the other hand, more persistence in markups suggests an accumulation of market power where the nature of the competitive edge of the firm and the CEOs ability to influence it is likely more difficult to disentangle.

Our estimated effects for firm tangibility and volatility are economically mean-

[35] The number of observations for each component varies substantially due to Capital IQ reporting missing values as zeros, as such we treat all zero components as missing in this analysis.

ingful and are of the same magnitude as firm age and size. We find that older firms offer higher percentage shares of cash-based (fixed) pay while larger firms offer lower salary but higher compensation across the other three (non-other) categories. Average level effects of public and private are in line with the relative shares given in Table 1. Our model fit is quite similar across the different pay components, ranging between 0.63 and 0.77. Our results are broadly in line with the examination by Cheng et al. (2015) of stock market volatility and firm CAPM beta. One exception being that restricted stock grants were found in their paper to not have significant relationship while we found a strongly positive association for our earnings volatility proxy.[36]

INSERT TABLE 4

In the analysis above, the regressions examined the intensity of a given component of pay provided it was non-zero. However, only 33.8% of observations with CEO compensation data have disclosed restricted stock grants, and 38.3% of observations with option grants. Further, 54.8% have at least one of the two and the correlation between an indicator of the two is 19.1% suggesting substantial variation in firms choice of whether or not to provide these more backloaded and performance-based components. As our final test in this section, we therefore examine the extensive margin of firms electing to offer compensation in the form of option and restricted stock grants. The results from linear regressions for the two private information proxies are provided in Table 5.[37] For brevity, we use industry-year interacted fixed effects for all specifications.

The results for the extensive margin of firms electing to use restricted stock grants and options follow the same patterns as the intensive margin for tangibility and volatility. Unlike the extensive margin, earning persistence increases the probability of a firm offering equity grant compensation. Persistence in markups does not have a statistically significant effect on firms' choice to use either equity grants.

INSERT TABLE 5

C. Evaluating Time-Series Trends

In this section, we study some of the longer-term historical trends in CEO compensation and listing decisions and how they relate to different policy interventions and other structural changes discussed in Section II.F. In particular, we are interested in evaluating the effects of various implemented policies like NIMSA in 1996, SOX in 2001, JOBS act in 2012 - 2014. Since our primary data source, Capital IQ, has CEO compensation data extending back to 2000 and firm data to 1993, we use a combination of Compustat, Execucomp and Frydman and Saks

[36]We did find very little relationship for our markups proxy, suggesting stock returns and markup volatility are more closely tied than earnings volatility.

[37]In unreported results, we estimate logistic regressions as well and find the same overall patterns.

(2010) data to evaluate the longer historical trends (extending back to the 1950s). In addition to using the measure of firm tangibility from Peters and Taylor (2017), we focus on primarily large, public firms in Compustat allows us to introduce a second measure of private information cash-flows (e.g. firm intangibility) based on Kogan et al. (2017) estimation of the market value of a firm's patents.[38] Details on variable definitions and construction are provided in Appendix A.

Figure 3 depicts (solid line) the average share of annual CEO compensation paid in terms of equity grants (common or restricted stock and options) from 1955 - 2010 as well as the (dashed line) the average intangibility of the firm implied from the ratio of the accumulated market value of a firms patents to the sum of this market value and their gross property plant and equipment. We can see that from 1955 to 1980 the average equity grant share, and tangibility remain fairly flat and have a slight negative trend, while between 1980 and 2000 the two moved fairly consistently in lock-step upwards. After the burst of the dot-com bubble and imposition of SOX, both have decreased to levels seen in the mid 90s but the patent share showed more sensitivity to the market boom in 2007. Further, with a Dickey-Fuller test-statistic of -4.4138 (p-value less than 1%) there is significant evidence of a co-integrated relationship between the two series. Finally, as average annual CEO pay has a 0.891 correlation with the equity share over the sample, and a Dickey-Fuller statistic of -3.7366 (p-value $<$ 1%) we the level of CEO pay and equity share move in virtual lockstep.[39] Thus, the broad compensation trends for average CEO compensation from 1950 to 2010 are in line with our theory outlined in Corollary 1 that the information-sensitive component of pay (and through risk-compensation, the level) is driven up by the intangibility of the firm.

INSERT FIGURE 3

We test how our theory of the influence of firm intangibility on CEO pay holds over the longer historical time-series and cross-section. A leading alternative explanation of the rise in CEO pay seen since the 1970s are based on size as in Gabaix and Landier (2008) and so we examine the relative contributions of size and intangibility over the historical time-series. To do so, we run the same regression exercises as in the earlier subsection on this extended time-sample and alternative tangibility for each year separately and plot the estimated coefficients for our measure of intangibility $1 - \hat{\tau}$ and size in Figure 4. This allows us to examine how the relative importance of key predictors in CEO compensation

[38]We are not the first to examine some associations between innovation and CEO pay given by these two historical datasets. Frydman and Papanikolaou (2018) examine how the market value of a firms patents estimated as in Kogan et al. (2017) correlate with the divergence in CEO pay from the average worker, but do not examine how it affects the individual components of pay (like options) or examine how the influence has evolved over the time-series. They also use a slightly different measure by simply scaling with PPEGT rather than the sum of the patents and PPEGT.

[39]Further, we obtain a 0.219 correlation in our historical panel of firms and CEOs (that is we compute the correlation of total CEO pay and equity grant share across firm $\times$ year observations).

have varied over time and contribute to the observed historical evolution in CEO pay.

INSERT FIGURE 4

Here we see that for the early sample the estimated elasticity of CEO pay to intangibility is on average not statistically different from zero, while by the end of the 70s into the early 80s intangibility spikes to over 2.5% increase in pay for a 1% increase in intangibility. The implied information asymmetry stemming from patented innovations broadly declines to the end of the sample at 2010, converging to the same estimated magnitude as the firm size elasticity. This suggests that our channel of asymmetric information through firm intangibility plays a larger role than other leading theories for the rise of the level of CEO pay attached to firm size like Gabaix and Landier (2008). Intriguingly, the weakening effect in the 2000s of intangibility on the level of CEO pay corresponds to the relative flattening of CEO pay over this time window. Furthermore, the lack of movement of CEO pay in the 50s-70s is rationalized by our theory with a statistically flat effect of intangibility in this period, while a significant positive effect for the latter sample, while with a size story, average CEO pay should have counterfactually risen over this post WWII period.

Last, we examine the dynamics of CEO pay, PE premia and listing trends around NSMIA and SOX to evaluate through the lens of our model, Section II, the effects of these policies. In Figure 5, we depict the time-varying coefficients of intangibility and size on firm listing, while in Figure 6(a) we plot the time-varying intercept for firm listing regression, in Figure 6(b) we plot the time-varying intercept for the CEO pay regression and in Panel Figure 6(c) we plot the evolution of PE premia from Harris et al. (2014) using the weighted average public market equivalent (PME) and the average amongst the top quartile of the vintage-year funds for buyout and venture capital separately.

From Figure 6a, we see little potential residual effect of NSMIA on CEO pay outside of what is accounted for by our other covariates, however from Figure 4 we see that the effect of intangibility on CEO pay decreased substantially immediately after NSMIA's passage (in 1997 and 1998) but then partially rebounded upwards for the end of the dot-com bubble. This is consistent with attrition of the relatively higher information sensitive firms which were on the margin of being public and private prior to NSMIA moving private. This can be seen in Figure 5 where the selection of intangible firms private increased markedly over the end of the dot-com bubble. Moving to the private equity premia in panel C we see that the spike in PE premia for VC spiked in the year of NSMIA's passage and declined but remained high and positive until 1999 suggesting that the high quality VC firms benefitted initially from the relaxation of funds and scooped up firms on the edge of being public and private.

INSERT FIGURE 5

Moving to SOX which became effective in April 2002, we see a small reduction in the compositional shift of public firms away from intangibility based on Figure 5 while the time-varying intercept increases slightly between 2002 and 2005, before a steady decline to 2010. This suggests that SOX did not increase the costs of being public sufficiently to cause an exodus, and in fact may have reduced the marginal information premium slightly (i.e. the sorting line $\underline{\sigma}$). From Figure 4 we see that the elasticity of intangibility on CEO pay remained essentially flat around the passage of SOX which is consistent with the countervailing forces discussed in Corollary 3.2. The performance of buyout funds supports a consolidation story through the early 2000s, but only the top end saw much of a performance boost following the passage of SOX (Figure 6c). Finally, looking at the remainder of the 2000s, we see that the marginal effect of intangibility on both listing and public CEO pay has somewhat decayed, while the PE performance has converged roughly to that of the public markets suggesting the degree of informational asymmetry has relatively declined to the end of our sample.

Altogether these dynamics suggest that NSMIA substantially affected the sorting and CEO pay in a manner consistent with our model predictions, while based on the local response SOX itself seems to have had a small reduction on the information frictions associated with intangibility.

INSERT FIGURE 6

V. Structural Estimation

We estimate the model using the generalized method of moments (GMM) (Hansen and Singleton (1982)). As our model implies a common underlying information premium governing both the firm listing decision and CEO compensation packages we would seek to estimate the underlying parameters governing the size and distribution of this premium $\pi(\theta)$ and the private monitoring cost ν. We assume all heterogeneity in the information premium is due to dispersion in the loading on intangible cash-flows $1 - \tau$ and the instantaneous volatility of these private cash-flow innovations σ^2. We again treat the loading on observable cash-flows, τ, as given by our proxy of firm tangibility, and assume the distribution of σ^2 to be Gamma(a_0, a_1), which is the same parametric form as earnings volatility, and independent from τ.[40] All other parameters are assumed to be common across firms. To keep the estimation tractable and achieve identification of firm-side characteristics governing the compensation/listing decisions, we fix the CEO preference parameters governing risk-aversion $\psi = 2$, and their effective

[40] We assume independence to facilitate closed-form moment expressions. Testing for independence of a copula with marginal beta and gamma is non-trivial, however, the relatively low Kendall statistic (which is a sufficient statistic for the dependence when using the Clayton copula) of 0.08 conditional on public listing using the earnings volatility proxy and 0.019 using the markups volatility proxy suggests only a small distortion. Accounting for dependence in the structural estimation could be done at the cost of using simulated method of moments rather than GMM.

rate of time discounting to be $\rho = 0.04$ consistent with Ai et al. (2016), and take the CEO outside options q_0 conditional on listing status as constants.[41]

Let Θ denote the vector of parameters to estimate and $g(\Theta, x_i)$ the vector of moment conditions as a function of the parameters Θ and the firm-level characteristics data x_i.[42] We estimate the model parameters by minimizing the objective function,

$$\widehat{\Theta} = \arg\min_{\Theta} \; \bar{g}_n(\Theta)' W \bar{g}_n(\Theta) \tag{24}$$

where $\bar{g}_n(\Theta) = n^{-1} \sum_i g(\Theta, x_i)$ is the sample average of the vector of m moment conditions for a sample of n firm observations. We use iteratively updated feasible GMM to estimate the optimal weight matrix, $W = W^*$ (as in Hansen et al. (1996)).

A. *Estimation using Firm Listing Status*

Guided by our model results on firm listing in Section II.D, we use firm listing moments which are informative on the information premium. Our key listing moments consider our model implied listing choice, $L_i = \{\nu - \pi(\theta) \geq 0\}$. Since our model abstracts from many other considerations dictating firm listing choice, we assume that listing choice is given by $L_i^* = \{\nu - \pi(\theta) + \varepsilon \geq 0\}$ where the unobserved preference shocks ε are iid and have a logistic distribution and imply the the log odds ratio is given by:

$$\log\left[\frac{Pr(L_i = 1)}{1 - Pr(L_i = 1)}\right] = \nu - b^*\left(\sigma^2, \lambda_z\right)(1-\tau)^2 \tag{25}$$

where $b^* = \frac{-\sigma^2\psi}{2(\rho+\frac{1}{\lambda_z})^2}$. Since we take σ to be firm specific and latent in the structural estimation, we average over σ to make $b(\Theta) = E[b^*] = \frac{-\sigma^2\psi}{2(\rho+\frac{1}{\lambda_z})^2}$ independent of the firm i and yielding the logistic regression:

$$E[\log\left[\frac{Pr(L_i = 1)}{1 - Pr(L_i = 1)}|\tau\right] = \nu - b(\Theta)(1-\tau)^2. \tag{26}$$

Taking the appropriate GMM moment conditions for a logistic regression provides us with two moments that identify the monitoring cost ν from the constant in the logistic regression and $\frac{E[\sigma^2]}{\rho+\frac{1}{\lambda_z}}$ from the slope estimate on $(1-\tau_i)^2$.

To pin down the volatility of the private information we use a linear combination

[41] The moments utilized to estimate the key parameters of interest are independent of the level of q_0 and hence we do not estimate the outside options q_0.

[42] We collapse the panel data set structure into a single cross-section with listing status given by the median value (dropping observations which are exactly public half the time), taking the appropriate mean and variances of cash-flows for the other relevant firm characteristics. Details are given in Appendix A.

of the mean and variance of the earnings proxy of cash-flows y for our cash-flow moments and the variance and autocorrelation of our proxy for the tangible cash-flow innovation process based on firm's physical investment (CAPEX scaled by PPEGT).[43] The full list of moments is given in Appendix A.A3 . In total we have a just-identified system of 6 firm cash-flow and listing based moments to identify 6 parameters.

We conduct the estimation in two steps, first estimating the parameters from the logistic regression ν, b, then estimate the remaining parameters using the cash-flow and physical investment moments holding ν fixed and specifying $\lambda_z(\Theta_c) = \left(\sqrt{\left[-\frac{a_0 a_1 \psi}{2b}\right]} - \rho\right)$ for $\Theta_c = (a_0, a_1, \sigma_x, \lambda_x)$.[44] Standard errors are bootstrapped using 10,000 resampling draws.

The results of the estimation are given in the first column of Table 6. We find that the average size σ^2, (persistence, λ_z) of the private information component of cash-flows are estimated to be 3 (13) times larger than the tangible component of cash-flows as proxied by physical investment intensity volatility σ_x^2 (persistence λ_x). The estimated monitoring cost ν is positive and significant. Our estimated hyper-parameters for σ^2 suggest that the distribution for $\sigma^2, \Gamma(a_0, a_1)$ is log-concave since $a_0 > 1$ (see Bagnoli and Bergstrom (2005)). Furthermore, using maximum likelihood to fit the distribution of the square of firm intangibility to a beta distribution, and simulating the implied distribution of $\pi(\theta)$ as the scaled product of these two distributions, we find (as depicted in Figure 7) that the log CDF of $\pi(\theta)$ is log-concave. We use this result combined with our theoretical comparative static findings in Section II.F to infer the effects of various policies in Section V.C.

B. Estimation using CEO Compensation

In this subsection, we test our main theoretical result that the same information premium governs both the cross-sectional listing decisions of firms (Theorem 2) and the level, growth and performance sensitivity of public CEO compensation packages (Theorem 1). Since in our theory the information premium appears only in the compensation of the public CEOs, the selection of firms into being public makes it difficult to compare our estimates of the distribution of information premia from public CEO compensation data with the estimates obtained in Section V.A. Instead we seek to estimate the private information persistence parameter λ_z which is assumed common to all firms and examine how closely our estimate identified off of CEO compensation data coheres with our results using moments implied by the firm listing decision. To ensure consistency of the sample across

[43]We use physical investment intensity as our proxy for the process x_t following the arguments by Olley and Pakes (1996) estimation of TFP from a neoclassical production function which reasons that physical investment identifies innovations in productivity on tangible assets (capital/labour hours).

[44]While in principle we could estimate the full-system in a GMM estimation, due to numerical issues stemming from high levels of collinearity, we utilized a two-step approach similar to **?**. See Appendix A.A4.

estimations we use the Capital IQ compensation data rather than the richer Execucomp for this estimation, although we note that our compensation sample only begins in 2001.

To identify the private information persistence parameter λ_z we use a measure of the pay-performance sensitivity of public CEO contracts,

$$h_1^{CEO}(\Theta) = \frac{cov\left(c_t, \frac{dy_t}{dt}\right)}{V[\frac{dy_t}{dt}]}.$$

From our results in Section II.D and primitives on y_t, we have

$$cov\left(c_t, \frac{dy_t}{dt}\right) = E\left[\frac{\rho(1-\tau)^2\sigma^2}{\rho + \frac{1}{\lambda_z}}\right].$$

Further using the conditional variance decomposition, $V\left[\frac{dy_t}{dt}\right] = V[E[\frac{dy_t}{dt}|\theta]] + E[V[\frac{dy_t}{dt}|\theta]]$ which given that $E[\frac{dy_t}{dt}|\theta] = 0$ simplifies to

$$V[\frac{dy_t}{dt}] = E[\tau^2\sigma_x^2 + (1-\tau)^2\sigma^2],$$

we have the theoretical moment

$$h_1^{CEO}(\Theta) = \frac{E\left[(1-\tau)^2\sigma^2\right]}{E[\tau^2\sigma_x^2 + (1-\tau)^2\sigma^2]}\frac{\rho}{\rho + \frac{1}{\lambda_z}}.$$

As our focus in this subsection is on λ_z, $E[\sigma^2] = cd$ and σ_x^2 are nuisance parameters. In addition, from our theory CEO compensation packages are independent of the observable cash-flow process, we cannot identify σ_x from CEO compensation moments diluting the exercise. To avoid this issue, we make the simplifying assumption that $\sigma_x \approx 0$ which then further simplifies our target moment condition to

$$h_1^{CEO}(\Theta) = \frac{\rho}{\rho + \frac{1}{\lambda_z}}$$

which depends only on λ_z and the fixed parameter ρ.[45]

We take total CEO pay, c_t, as the total compensation awarded in year t. We descale each CEO $\times$ firm pay by the first period total compensation of a given CEO-firm pair. Similarly, we take the year over year change in earnings (EBITDA)

[45]This approximation is supported by our estimation results in Table 6 where we found $E[\sigma^2] = a_0 a_1 = 2.654 \cdot 0.625 >> \sigma_x = 0.122$.

scaled by the first period of the firm's earnings to be $\frac{dy_t}{dt}$. Our moment is thus

$$g^{CEO}(\lambda_z, x_i) = \frac{\text{total pay awards}_{it}\text{earnings change}_{it}}{\text{average cross-firm variance in earnings change}} - h_1^{CEO}(\Theta). \tag{27}$$

The results from estimating this moment estimation are given in Column 2 of Table 6. We find that using CEO compensation pay sensitivity our estimate for the persistence λ_z is 1.32 which falls slightly below the firm listing estimate of 1.47. In discrete time, this corresponds to a relatively high AR(1) coefficient of 0.506. Using bootstrapped standard errors on the difference between these two estimates, we find that there is no statistically significant difference between our persistence estimate from the firm listing or CEO compensation moments. Now to the extent that σ_x^2 is strictly positive, our estimate of λ_z is downward biased. However, using our estimates for $E[\tau^2]$, $E[(1-\tau)^2]$ and parameter estimates from column 1 of Table 6 the bias in the inverse of the persistence is simply given by $\frac{1}{\lambda_z} - \frac{1}{\lambda_{z,0}} = 1 - \frac{E[(1-\tau)^2]E[\sigma^2]}{E[\tau^2]\sigma_x^2 + E[(1-\tau)^2]E[\sigma^2]} = 0.15$ which implies that $\lambda_{z,0} = 1.64$ which with a p-value of 0.65 (using bootstrapped standard errors on the bias corrected difference across the estimations) is still not statistically different from the listing parameter.[46]

INSERT TABLE 6

C. *Evaluating Structural Changes to Persistent Private Information*

As our final set of exercises, we use our structural estimation procedure to examine the evolution of the information premium over time and how it relates to various polices discussed in Section II.F and the evolution of the private equity premium computed by Harris et al. (2014). As was noted in Section II.F, many of the comparative statics depend on the curvature of the distribution of the information premium $G_\pi(\pi)$ and the monitoring costs $F(\nu)$. Using our firm listing structural estimates we find that the information premium $G_\pi(\pi)$ is log concave while the survival function $\bar{G}_\pi(\pi)$ is log convex (see Figure 7). Consequently, if we assume that $F(\nu)$ shares the log convexity of $\bar{G}_\pi(\pi)$ then from Lemma 3 there will be a positive correlation between the amount of funds injected into PE and the average PE premium. Harris et al. (2014) however find a strongly negative correlation to the average PE PME in response to an increase in aggregate funds. This suggests from our Lemma 3 that $F(\nu)$ is in fact log concave and is generally much more elastic than $\bar{G}_\pi(\pi)$ (so that the effect on differences in the marginal to average PE costs $\nu^* - E[\nu|\nu \le \nu^*]$ dominates the average PE information premium above the marginal info premium). Given this inference and temporarily

[46]Denote $\bar{z}$ as the empirical moment, and $\frac{b_0}{b_0+b_1} = \frac{E[(1-\tau)^2]E[\sigma^2]}{E[\tau^2]\sigma_x^2+E[(1-\tau)^2]E[\sigma^2]}$, then re-arranging (27) we have $\frac{1}{\tilde{\lambda}_z} = \rho[\frac{1}{\bar{z}} - 1]$ while the true moment condition gives us $\frac{1}{\lambda_z} = \rho[\frac{b_0}{b_0+b_1}\frac{1}{\bar{z}} - 1]$. The bias correction follows immediately.

holding fixed λ_z, σ^2 hyperparameters, we have an ambiguous comparative static prediction for the evolution of the aggregate level of public CEO pay $\bar{c}$ (after controlling for the selection effect) and average PE premium as given by Corollary 3.1. This ambiguity depends on the horse race of whether the increase in the information premium for firms that stay in the same listing status over the change in intangibility dominates the selection effect of firms exiting out of public.

Examining the evolution of the PME estimated by Harris et al. (2014) (plotted in Figure 6c) we find that throughout our sample period there has overall been a positive PE premium but has broadly declined since 1997. The spike in the aftermath of the passage of NSMIA conforms with our short-run Corollary 3.2 predictions given our log convex $\bar{G}_\pi(\pi)$ and the decline after is consistent with the marginal to average PE costs change dominating the rise in rents in PE, suggesting the extent of the relaxation may have in the end diluted the returns of incumbent PE (especially VC) firms. The decrease in VC returns through the early 2000s and slightly declining average CEO pay in this period (given the log concavity in $G_\pi(\pi)$) conforms most closely with our results from Corollary 3.4 that is the increased disclosure may have reduced information costs, although our estimates of the time-varying λ_z suggest that this decline began before SOX was implemented.

The above discussion held fixed all 'deep' parameters besides the distribution of intangibility and monitoring costs. As our final exercise we examine how these parameters evolved over time by structurally estimating our model over a four-year rolling sample. In Figure 8 we plot the evolution of the estimated private information persistence λ_z and the private financier (relative) monitoring cost ν, where a given year includes the sample of the three preceding years plus itself. Intriguingly we find that the pattern of the time-varying private information persistence estimate closely aligns with the dynamics of the VC PE premium estimated from Harris et al. (2014) which is based on entirely different data. We see that the private information persistence peaks in 1997 (the same year that the listing decline begins) and fairly consistently declines through the rest of the sample. Contrast this, the estimated monitoring cost is highest in the first available year of our sample 1996 and precipitously drops the following year in the first full year following the relaxation of PE funding through the passage of NSMIA. Since then the monitoring cost remained relatively stable through the 2000s with a slight reduction in the two years following the passage of SOX. Intriguingly, since 2012, the monitoring cost appears to have rebounded to the level in 1997 with a small corresponding uptick in the private information persistence, possibly rationalized by the passage of the Leahy-Smith America Invents Act ('AIA') which reformed patent protections and has been argued to weaken patent protections and increase firms reliance on keeping innovations private through trade secrets.[47]

[47]See for instance discussion by an industry litigator, `https://www.stout.com/en/insights/article/trade-secrets-your-secret-weapon-under-patent-reform`.

VI. Discussion and Conclusion

We find evidence that intangible assets affects firm listing choice and CEO compensation in a manner consistent with a persistent information friction across all size, industries and ages of firms. A sectoral technological shift in firm's dependence on intangible assets can then rationalize (i) the observed decline in publicly listed firms, (ii) expansion of committed PE funds and (iii) rise in the use of equity grants and the level of public CEO compensation. We quantify the level of persistence of private information implied by both our sorting predictions and the intangibility dependent optimal public CEO compensation contract. We find that although intangibility has increased over time, the persistence of private information has broadly declined through the 2000s, consistent with a growing market-wide familiarity and understanding of the sources of value for many firms intangible assets.

Our model allows the identification of a common level of persistent private information separately from firm listing and public CEO pay sensitivity loadings. This separability allows us to test the joint determination of firm listing and public CEO compensation based on persistent info frictions by running two separate structural estimation procedures on firm listing and CEO compensation moments. Our parameter estimates from the two separate estimations are statistically indistinguishable from each-other despite the entirely different dependent variables utilized across the two. To our knowledge, this paper is the first to conduct such a test of the identification of a structural model, offering a potential new methodology for evaluating the empirical content of structural models.

The relative magnitude of our estimated private information cash-flows to the observable cash-flows is substantially larger than the corresponding quantity estimated by Ai et al. (2016). In their model, the principal must incentivize optimal investment policies by the CEO in the presence of idiosyncratic (and transient) unobservable shocks to physical capital. This leads to their relative magnitude of private information to be primarily identified based on the correlation of firm size with (i) firm growth rates and (ii) pay performance insensitivity, where a negative correlation occurs in their model for both when the relative moral hazard friction is low. In contrast, in our setting, the agency friction does not affect the firm's equilibrium level of output but rather (after scaling/controlling by size) the magnitude of the information friction is primarily identified off of the correlation of firm's intangible assets with firm listing or CEO pay performance sensitivity (where a negative correlation would falsify the model and the higher the positive correlation the stronger the implied information friction).

Many other recent papers have examined the effects of rising firm intangibility on the declining labour share and physical investment, or rising firm cash holdings and markups (Karabarbounis and Neiman (2013),Crouzet and Eberly (2018b), Ward (2019), Gutiérrez and Philippon (2017), Falato et al. (2020), Autor et al. (2020)). These studies have largely focused on US public firms and typically associate higher intangibility with greater markups, productivity and profitability. In our data encompassing both public and private firms we do not find this overall positive association for productivity or profits suggesting the selection of high intangibility firms to be public have some other characteristics that distinguish them from the private intangible firms. The quality and nature of the intangible assets are no doubt crucial in this regard, as a small start-up firm with its only asset of the entrepreneurs existing human capital has substantially different performance outcomes than a platform (e.g. Amazon, Apple, Alphabet) used by a large consumer and supplier base. For such firms, scale considerations may be important, giving motivation to get access to public funds. Large institutional shareholders may be able to reduce the size of the information frictions in these firms similar to private financiers through hiring the necessary expertise and gaining access to privileged information of the firm (e.g. board seats). Indeed such a sorting pattern of concentrated institutional owners amongst public firms has been found by Aghion et al. (2013) between patents or R&D intensity and institutional ownership.

For transparency in the model mechanism and identification in our structural estimation we made some simplifying assumptions that may limit the generalizability of our results. First, we abstracted from dynamic investment and financing opportunities for a given firm (akin to the static structural estimation of block pricing by Albuquerque and Schroth (2010)), taking the firm level of intangibility as an exogenous, permanent characteristic. Allowing an exogenous evolution of intangibility for a given firm should not affect the main thrust of our channel, simply adding variability in the growth and pay-performance sensitivity under the optimal contract. Endogenizing existing firms level of intangibility is likely important for capturing the evolution and distribution of firm size (Ward (2019)), and consequently capture lifecycle determinants in firms capital structure (e.g. Falato et al. (2020)) and timing of going-public or going private decisions (e.g. Ferreira et al. (2012)), but due to conflicting effects in firm size and age for listing likelihood it is unclear of the size or direction of the bias introduced by our static sorting mechanism. Second, in our contracting environment we restricted attention to CARA utility and precluded the CEO from over-reporting. Relaxation of either one or both of these restrictions will modify and complicate the equilibrium evolution of optimal compensation (see for instance Edmans et al. (2012) and Di Tella and Sannikov (2016)) but shouldn't change the the qualitative links between firm intangibility, performance sensitivity and the level of CEO pay. Third, we abstract from career concerns and heterogeneity in the outside options of potential CEOs which has been found to be important considerations in the cross-sectional variation in public executive pay. To the extent that these career concerns haven't changed substantially over time this abstraction is innocuous.

Our mechanism provides a micro-foundation to Glover and Levine (2017) who found that the size of agency issues implied by observed compensation contracts correlate strongly with firm intangibility. We find that the elasticity for intangible assets on the level of pay and level of restricted equity grants (stocks or options) is of the same or higher magnitude than that of firm size or age. The influence of firm intangibility on compensation has changed dramatically over time, being of little importance in the 1950s-early 1970s, spiking in the early 1980s with the explosion in patenting, and slowly decaying through to the end of the financial crisis. Shue and Townsend (2017) argue that the close tracking of firm market value of patents to physical assets and CEO option grant share of pay in the 90s/early 2000s can be explained alternatively by a money-illusion like rigidity in the annual number of options awarded and their nominal value tracking with the stock market. Our model with CARA agents implies a constant proportional pay sensitivity can be operationalized with a constant number of options awarded each period even with firm growth in size. This is distinct from other moral hazard compensation theories, even with multiplicative production functions like Edmans et al. (2008), which predict a decline in fractional ownership in firm-size.[48] Shue and Townsend (2017) explanation however does not apply to restricted stock grants which began substituting for options near the end of the dot-com bubble, leaving the equity share of CEO compensation unaccounted for. Our explanation complements the arguments of the rising pay inequality in the labour force (e.g. Garicano and Rossi-Hansberg (2006), Lustig et al. (2011) and Frydman and Papanikolaou (2018)) that the ICT revolution has increased the growth opportunities from heterogeneous labourer ability to leverage new information to expand the production set of the firm. Such explanations predict increased levels of pay and feature performance sensitivity as a by-product of increasing outside options which may be a less salient feature for CEOs who rarely are substituted across firms and tend to be promoted internally (Cziraki and Jenter (2020)).

The implied relative decline in the magnitude of persistent private information frictions seen in our estimated elasticities on CEO pay is also evidenced from the evolution of our estimated elasticities of listing propensities. We examine additional tests of our theory leveraging our general equilibrium predictions relating the information premium to PE premia and committed funds to PE, finding that the observed dynamics in the VC segment of private equity as estimated in Harris et al. (2014) track well our theory predictions and estimates (consistent with the role of specialist monitoring of VCs found by Bernstein et al. (2016)), while the buyout side demonstrates aggregate movements that appear less well correlated with our information premia.

Our estimates are based off of data on large US non-financial firms. We suspect the inference of the overall declining information premia is more pronounced in the large, established firms in our sample where although the new innovations of the big tech firms are still difficult to independently value, the market is still well-acquainted with the sources of their market power and profits. Data on smaller private firms linked to VC-funds would allow for more micro-level examination of our theory on the cross-section of private firms and the resulting VC performance.

[48] Having said that, some sub-optimality seems to exist in the data given their finding of the number of options awarded frequently not adjusting to stock splits.

Our theory suggests the decline of US public firms is the efficient market equilibrium response to rising informational asymmetry between firm insiders and the general public. In our static financing decision, differential returns between the private financiers and the public investors have no feedback effects on the future selection of firms. A simple dynamic extension of the model would imply that the highest ability private financiers obtain the highest net return and accumulate ever increasing shares of aggregate wealth over time, crowding out public investors from a widening segment of the economy and leading to a declining correlation between US stock market performance and domestic economic indicators (as found by Greenwald et al. (2019)). We leave such extensions and examinations of household wealth dynamics for future work.

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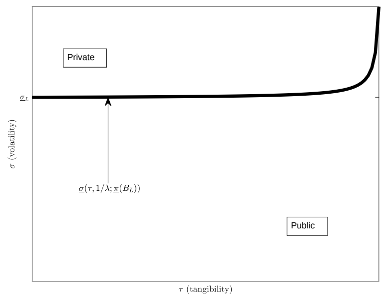
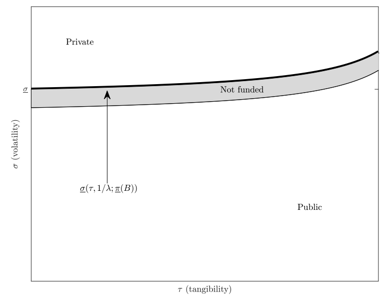
Appendix



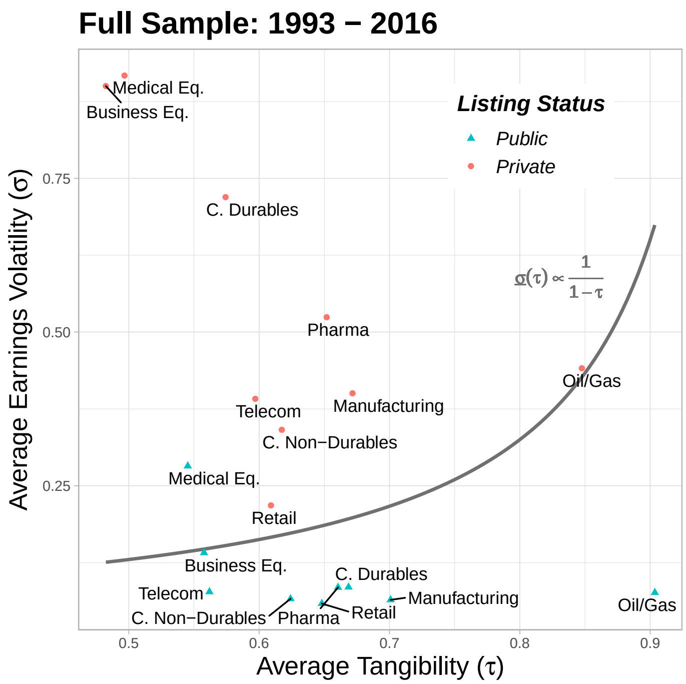
(a) Baseline sorting predictions



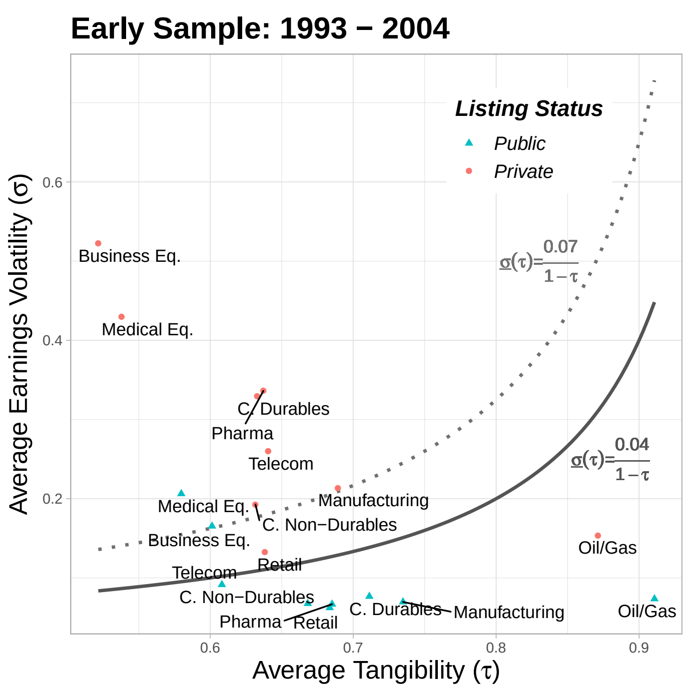
(b) Unproductive disclosure predictions

Figure 1. : Theoretical sorting predictions on firm tangibility and private information volatility

The left-hand graph depicts the model sorting predictions implied by Theorem 2 over tangibility τ and volatility σ of the intangible cash-flow process for a fixed level of private financier funding B and given level of persistence λ. All firms with (τ, σ) above the solid line are predicted by the model to be funded by the private financier, while all those below will be funded by the public financier. The right-hand graph depicts the effects of the sorting predictions implied by Corollary 3.3 where the set of firms publicly financed decreases and in the short-term there is a set of firms which are not-financed by either financier.



(a) Firm Sorting on Firm Tangibility and Earnings Volatility, 1993- 2015



(b) Firm sorting based on firm intangibility and cash-flow volatility,1993 - 2003

Figure 2. : Empirical firm sorting

Within-industry (Fama-French 12) average tangibility and 3-year earnings volatility conditional on listing status as Public or 'Private' (non-listed). Super-imposed is the theoretical sorting prediction line given in Figure 1a taking the form $\underline{\sigma}(\tau) = .07/(1-\tau)$. Data is from Capital IQ and excludes firms with less than 1 million in assets.

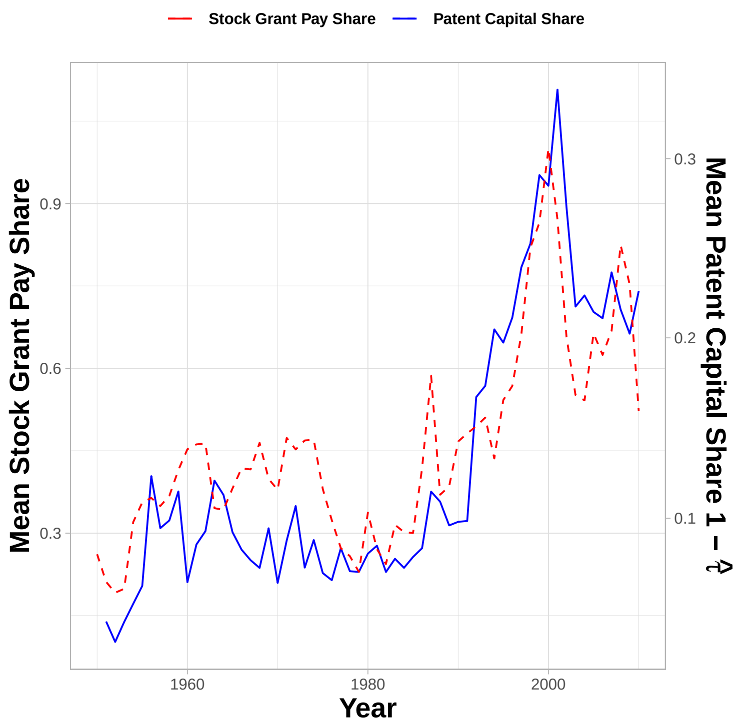


Figure 3. : Historical CEO Stock Grants and Firm Intangibility
This figure depicts the average stock grants as a share of total compensation (left-axis) and implied market value of patents θ_{sm} as a share of PPEGT + θ_{sm}. Market value of newly granted patents are from Kogan et al. (2017). CEO compensation data pre 1991 is taken from Frydman and Saks (2010), CEO compensation post 1991 is from Execucomp. Stock grants are equal to options award pre 1991, options awarded (Black Scholes value) + restricted stock grants in Execucomp pre 2006, options awarded (fair value) + stock awards (fair value) in Execucomp post-2006. The sample of firms consist of the largest 100 firms found in Frydman's data.

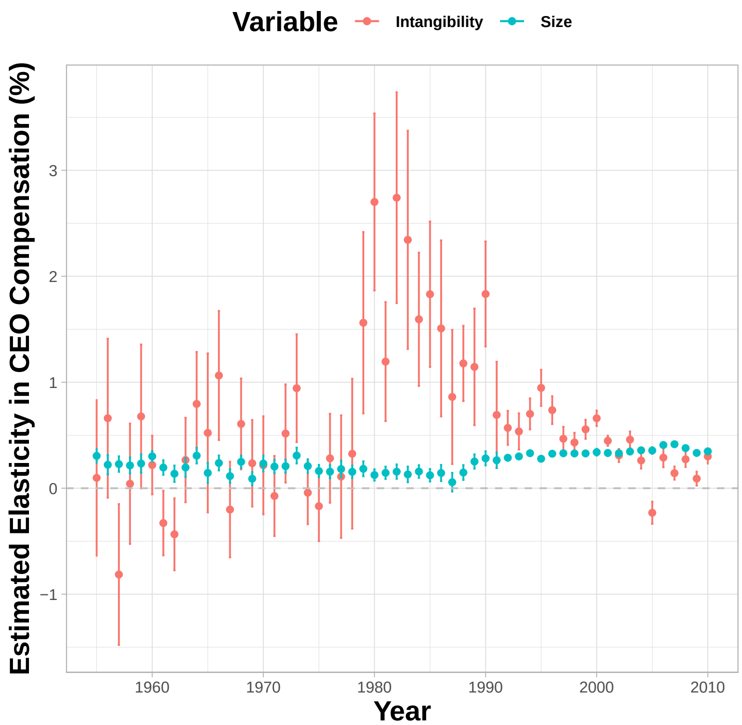


Figure 4. : Annual Estimated Elasticities of Intangibility and Size on Pay

This figure depicts the regression point estimates and standard errors for firm intangibility and size from the regression: $\log \text{Total CEO Pay}_{it} = \beta_t \log \text{Intangibility}_{it-1} + \xi_t \log \text{Volatility}_{it-1} + \gamma_t \log \text{Size}_{it-1} + \varepsilon_{it}$. Intangibility is measured by implied market value of patents θ_{sm} as a share of PPEGT + θ_{sm} using estimates from Kogan et al. (2017). CEO compensation data pre 1991 is taken from Frydman and Saks (2010), CEO compensation post 1991 is from Execucomp. Stock grants are equal to options award pre 1991, options awarded (Black Scholes value) + restricted stock grants in Execucomp pre 2006, options awarded (fair value) + stock awards (fair value) in Execucomp post-2006. The sample of firms consist of the largest 100 firms found in Frydman and Saks (2010) data.

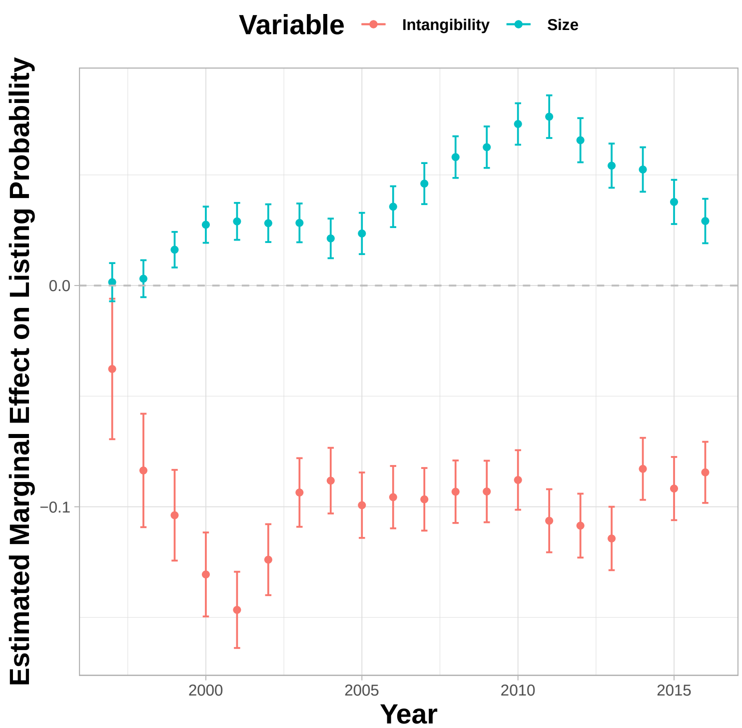
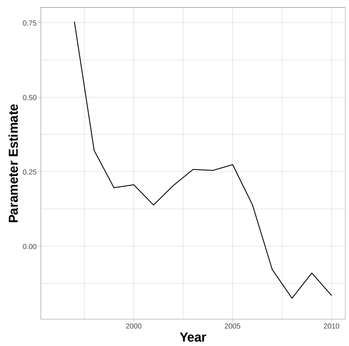
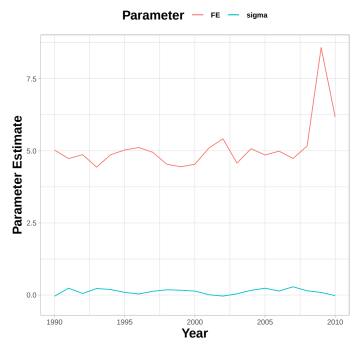


Figure 5. : Annual Estimated Marginal Effects of Intangibility and Size on Listing Probability

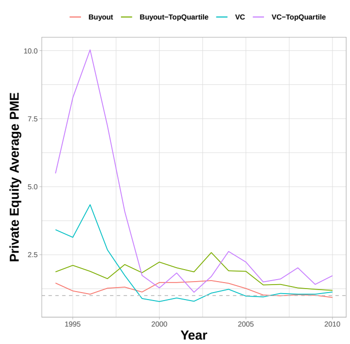
This figure depicts the regression point estimates and standard errors for firm intangibility and size from the regression: $\log \text{Listed on top } 3_{it} = \beta_t \log \text{Intangibility}_{it-1} + \xi_t \log \text{Volatility}_{it-1} + \gamma_t \log \text{Size}_{it-1} + Industry_{it} + \varepsilon_{it}$. Data is from Capital IQ. Intangibility is measured by the method of Peters and Taylor (2017). Listed takes the value 1 if a firm was listed on AMEX, Nasdaq or NYSE in that filing year.



(a) Firm Listing Time-Varying Intercept



(b) CEO Compensation Time-Varying Intercept



(c) Private Equity Public Market Equivalent (PME)

Figure 6. : Evolution of Firm Listing, CEO Pay Time Intercepts and PE Premia
We plot the intercept from the annual listing choice regressions and CEO compensation discussed in Section IV.C and contrast with the evolution of Private Equity Public Market Equivalent (PME) return premia estimated by Harris et al. (2014).

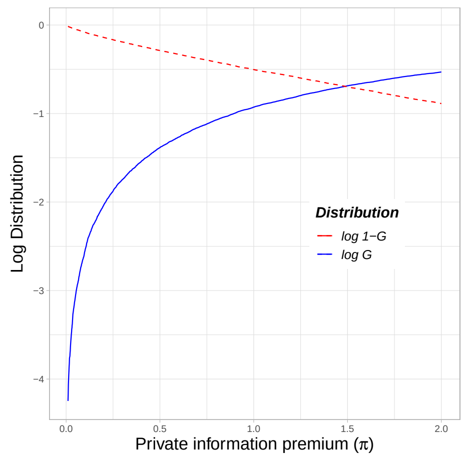


Figure 7. : Estimated Log Distributions of the Information Premium
We plot the log CDF $G_\pi(\pi)$ of the information premium $\pi(\theta)$ and the log survival distribution $\bar{G}_\pi(\pi) = 1-G_\pi(\pi)$ implied from our structural estimation. We use the estimated shape a_0 and scale a_1 parameters of σ^2 and private information persistence estimate λ_z from the Firm Listing Structural Estimation (Table 6) and the maximum likelihood estimates of the square of firm intangibility fitted to the beta distribution to generate the distribution of the information premium $\pi(\theta) \sim G_\pi(\pi)$. We make 10,000 draws from the fitted marginal distributions to obtain the empirical $\hat{G}_\pi(\pi)$ which after taking the log is plotted above.

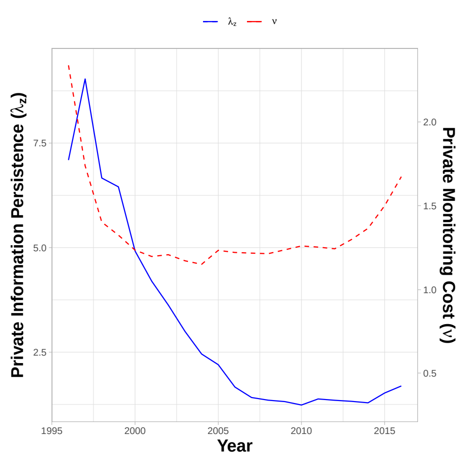


Figure 8. : Time-varying Estimates of Persistence and PE monitoring costs
We depict the estimates using the firm listing moments as in Section V.A estimated on 4-year rolling windows of the Capital IQ data from 1996 - 2016 with year t corresponding to the sample from $t-3$ to t.

Table 1—: Summary Statistics

This table reports summary statistics for measures of CEO compensation and firm characteristics for non-financial US firms in Capital IQ from 1993-2016. The sample is divided between firm-years publicly listed on NYSE, Nasdaq or AMEX and 'private firms', which are not listed on these three or any other minor US stock exchange. Unbounded variables are winsorized annually at the 1% and 99% levels. All other firm characteristic variables below the first panel are scaled by book assets. CEO pay components are scaled by total compensation. Dollar amounts are adjusted to 2016 dollars using the BEA GDP deflator.

	Public				Private			
Variables	**Mean**	**Median**	**Std**	**N**	**Mean**	**Median**	**Std**	**N**
Firm Size, Age and CEO Compensation								
Assets	3035.83	328.60	14687.95	78868	831.18	20.78	4943.67	53347
Employees	6157.44	705.00	25427.58	77281	1956.23	102.00	9958.43	47532
Firm Age	33.06	24.00	25.41	78868	18.84	11.00	20.71	53347
CEO Pay	3.81	1.63	6.06	47248	1.00	0.33	2.65	24326
Private Information Proxies								
Intangibility	0.36	0.36	0.21	78868	0.44	0.43	0.27	53347
Earnings Volatility*	-2.78	-2.93	0.81	62775	-1.92	-2.50	1.68	25318
Earnings Persistence	0.43	0.27	1.93	55158	0.32	0.18	1.85	19582
Markup Volatility*	-0.83	-2.43	4.58	58274	-3.08	-3.77	4.38	18900
Markup Persistence	0.24	0.25	0.10	71940	0.23	0.24	0.17	33527
Performance Metrics								
Earnings	0.13	0.10	0.14	78720	0.11	0.02	0.12	51826
Sales	0.88	0.90	0.89	74593	0.76	0.84	0.62	42042
TFP	0.59	0.62	0.51	74410	0.52	0.59	0.64	42862
Markups	28.30	0.44	118.37	74410	9.21	0.04	58.17	42862
Other Firm Characteristics								
Gross Property, Plant and Equipment	0.50	0.30	0.65	76850	0.56	0.30	0.66	48272
Research and Development Expenditures	0.04	0.04	0.04	30456	0.01	0.07	0.02	16509
Capital Expenditure	0.05	0.03	0.06	78370	0.06	0.04	0.06	47991
Cost of Goods Sold	0.61	0.57	0.64	77590	0.54	0.65	0.50	50358
SG&A Expenditures	0.14	0.17	0.13	77817	0.11	0.32	0.11	52546
Goodwill	0.23	0.18	0.21	43767	0.40	0.85	0.32	16498
CEO Pay Components								
Salary	0.42	0.34	0.31	47248	0.70	0.79	0.31	24326
Bonus	0.19	0.15	0.20	47248	0.11	0.00	0.19	24326
Restricted Stock Grants	0.37	0.34	0.25	21077	0.38	0.31	0.36	3100
Option Grants	0.39	0.32	0.31	22293	0.39	0.32	0.31	5154
Other Compensation	0.05	0.02	0.13	39491	0.11	0.04	0.19	11555

Notes: *- variable in logs

Table 2—: Listing Regressions
This table presents the regression results of an indicator of a firm being publicly listed on a top 3 US stock exchange on lagged firm characteristics and industry / year fixed effects. Panel A presents the results using earnings (EBITDA/Assets) as proxy for the private information process z. Panel B presents the results using firm markups as proxy for the private information process z. A linear probability model is used for columns (1) - (2) and (4) - (5) where standard errors are clustered at the firm level. A logistic link is used for columns (3) and (6). All covariates are in logs and are, when time-varying, lagged by a year.

	Publicly Listed on a Major US Stock Exchange					
	Panel A: Earnings As Private Information			**Panel B: Markups As Private Information**		
	OLS		**Logistic**	**OLS**		**Logistic**
	(1)	(2)	(3)	(4)	(5)	(6)
Tangibility ($\widehat{\tau}_{it-1}$), t-1	0.103***	0.103***	0.570***	0.126***	0.127***	0.675***
	(0.004)	(0.004)	(0.025)	(0.004)	(0.004)	(0.026)
Volatility ($\widehat{\sigma}_{it-1}$), t-1	−0.020***	−0.021***	−0.050***	−0.022***	−0.022***	−0.120***
	(0.002)	(0.002)	(0.012)	(0.001)	(0.001)	(0.008)
Persistence ($\widehat{\lambda}_i$), t-1	0.003***	0.003***	0.015***	0.024***	0.025***	0.105***
	(0.001)	(0.001)	(0.005)	(0.003)	(0.003)	(0.021)
Age, t-1	0.036***	0.035***	0.292***	0.039***	0.039***	0.293***
	(0.002)	(0.002)	(0.014)	(0.002)	(0.002)	(0.014)
Size, t-1	0.070***	0.070***	0.493***	0.091***	0.091***	0.594***
	(0.001)	(0.001)	(0.006)	(0.001)	(0.001)	(0.011)
Industry + year FE	Y	N	Y	Y	N	Y
Industry × year FE	N	Y	N	N	Y	N
N	73,900	73,900	73,900	73,301	73,301	73,301
R^2	0.808	0.809		0.817	0.819	
Adjusted R^2	0.807	0.807		0.817	0.816	
Log Likelihood			-32,028.360			-31,749.320
Akaike Inf. Crit.			64,188.720			63,632.640

Table 3—: Compensation Regressions

This table presents the regression results of a public CEO's total compensation on lagged firm characteristics and industry / year fixed effects. Panel A presents the results using earnings (EBITDA/Assets) as proxy for the private information process z. Panel B presents the results using firm markups as proxy for the private information process z. CEO compensation data from Capital IQ from 2001 - 2016. Standard errors are clustered at the firm level. All continuous variables besides persistence for earnings in Panel A are in logs and are lagged by a year.

	Total Public CEO Compensation				
	Panel A: Earnings As Private Information			**Panel B: Markups As Private Information**	
	(1)	(2)		(3)	(4)
Tangibility ($\widehat{\tau}_{it-1}$), t - 1	-0.340^{***} (0.012)	-0.337^{***} (0.012)		-0.330^{**} (0.010)	-0.329^{***} (0.010)
Volatility ($\widehat{\sigma}_{it-1}$), t - 1	0.130^{***} (0.006)	0.136^{***} (0.009)		0.036^{***} (0.003)	0.038^{***} (0.003)
Persistence ($\widehat{\lambda}_i$), t - 1	0.010^{***} (0.003)	0.011^{***} (0.007)		0.009^{***} (0.011)	0.009 (0.011)
Age, t - 1	0.104^{***} (0.007)	0.098^{***} (0.007)		0.059^{***} (0.007)	0.053^{***} (0.007)
Size, t - 1	0.458^{***} (0.003)	0.460^{***} (0.003)		0.398^{***} (0.005)	0.397^{***} (0.005)
Public , t - 1	0.298^{***} (0.014)	0.302^{***} (0.014)	0.254^{**} (0.011)	0.256^{***} (0.011)	
Industry + year FE	Y	N		Y	N
Industry × year FE	N	Y		N	Y
N	34,457	34,457		52,894	52,894
$\mathbf{R}^2$	0.619	0.629		0.602	0.609
Adjusted $\mathbf{R}^2$	0.618	0.622		0.605	0.604

Table 4—: Compensation Components

This table presents the regression results of a CEOs compensation components as a share of total compensation (in logs) on lagged firm characteristics and industry × year fixed effects. Panel A presents the results using earnings (EBITDA/Assets) as proxy for the private information process z. Panel B presents the results using firm markups as proxy for the private information process z. CEO compensation data from Capital IQ from 2001 - 2016. Standard errors are clustered at the firm level. All continuous variables besides persistence for earnings in Panel A is in logs and are lagged by a year.

	CEO Pay Component Shares of Total Compensation							
	Panel A: Earnings As Private Information				Panel B: Markups Private Information			
	Salary	**Bonus**	**Stock**	**Options**	**Salary**	**Bonus**	**Stock**	**Options**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Tangibility ($\widehat{\tau}_{it-1}$), t-1	0.110***	0.031**	−0.044**	−0.027*	0.111***	0.034**	−0.030*	−0.089***
	(0.010)	(0.013)	(0.017)	(0.016)	(0.011)	(0.013)	(0.018)	(0.017)
Volatility ($\widehat{\sigma}_{it-1}$), t-1	−0.120***	−0.016**	0.093***	0.177***	−0.021***	0.003	0.003	−0.025***
	(0.005)	(0.007)	(0.009)	(0.008)	(0.003)	(0.004)	(0.005)	(0.005)
Persistence ($\widehat{\lambda}_i$), t-1	−0.0002	−0.003	−0.001	0.002	0.008	−0.004	0.035**	0.019
	(0.002)	(0.003)	(0.003)	(0.003)	(0.010)	(0.012)	(0.017)	(0.015)
Age, t-1	0.051***	0.068***	−0.097***	−0.187***	0.084***	0.064***	−0.111***	−0.220***
	(0.006)	(0.007)	(0.010)	(0.010)	(0.006)	(0.007)	(0.010)	(0.010)
Size, t-1	−0.240***	0.058***	0.126***	0.128***	−0.202***	0.060***	0.118***	0.133***
	(0.002)	(0.003)	(0.004)	(0.004)	(0.004)	(0.005)	(0.007)	(0.007)
Public, t-1	−0.135***	−0.111***	0.046*	0.181***	−0.124***	−0.124***	0.091***	0.064***
	(0.012)	(0.015)	(0.027)	(0.022)	(0.012)	(0.014)	(0.026)	(0.021)
Industry + year FE	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*
Industry × year FE	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
N	55,272	37,532	21,395	23,060	52,894	37,073	20,764	22,162
R^2	0.631	0.776	0.710	0.704	0.632	0.775	0.709	0.699
Adjusted R^2	0.626	0.772	0.701	0.696	0.628	0.770	0.699	0.691

Table 5—: Discrete Choice of Offering Delayed Stock-Based Compensation
This table presents the regression results of an indicator of restricted stock grants, option grants or both, on lagged firm characteristics and industry / year fixed effects. Panel A presents the results using earnings (EBITDA/Assets) as proxy for the private information process z. Panel B presents the results using firm markups as proxy for the private information process z. CEO compensation data from Capital IQ from 2001 - 2016. Columns (1) and (4) pertain to Restricted Stock Grants, (2) and (5) pertain to Options, and (3) and (6) use a dependent variable indicating both are offered. Standard errors are clustered at the firm level. All continuous variables besides persistence for earnings in Panel A is in logs and are lagged by a year.

	Discrete Choice to Offer Delayed Stock-Based CEO Compensation					
	Panel A: Earnings As Private Information			**Panel B: Markups As Private Information**		
	Stock	**Options**	**Both**	**Stock**	**Options**	**Both**
	(1)	(2)	(3)	(4)	(5)	(6)
Tangibility ($\widehat{\tau}_{it-1}$), t-1	-0.063^{***} (0.004)	-0.054^{***} (0.005)	-0.053^{***} (0.004)	-0.058^{***} (0.005)	-0.070^{***} (0.005)	-0.052^{***} (0.004)
Volatility ($\widehat{\sigma}_{it-1}$), t-1	0.019^{***} (0.002)	0.030^{***} (0.002)	0.020^{***} (0.002)	0.008^{***} (0.001)	0.002 (0.001)	0.008^{***} (0.001)
Persistence ($\widehat{\lambda}_i$), t-1	0.0005 (0.001)	0.003^{***} (0.001)	0.002^{**} (0.001)	-0.001 (0.004)	-0.006 (0.005)	-0.006 (0.004)
Age, t-1	0.034^{***} (0.003)	0.011^{***} (0.003)	0.029^{***} (0.002)	0.026^{***} (0.003)	0.005^{*} (0.003)	0.023^{***} (0.002)
Size, t-1	0.067^{***} (0.001)	0.037^{***} (0.001)	0.052^{***} (0.001)	0.055^{***} (0.002)	0.028^{***} (0.002)	0.040^{***} (0.002)
Public , t-1	0.144^{***} (0.005)	0.170^{***} (0.006)	0.072^{***} (0.004)	0.153^{***} (0.005)	0.157^{***} (0.006)	0.077^{***} (0.004)
Industry + year FE	*N*	*N*	*N*	*N*	*N*	*N*
Industry × year FE	*Y*	*Y*	*Y*	*Y*	*Y*	*Y*
N	55,272	55,272	55,272	52,894	52,894	52,894
R^2	0.587	0.513	0.364	0.591	0.509	0.364
Adjusted R^2	0.582	0.507	0.356	0.586	0.502	0.356

Table 6—: Structural Estimates

This table reports the GMM estimation results for the Firm Listing and CEO compensation moments. Firm listing moments are given in Appendix A.A3. CEO pay sensitivity moment is given in (27). Firm estimation uses all firms in our dataset with non-missing moments, while the compensation estimation is based on the subset of these firms which are public firms and have non-missing CEO total compensation data. Listing status is the median status of the firm throughout the sample. Standard errors are in parentheses and computed from non-parametric bootstrap with $B = 10,000$ replications.

Parameter	**Firm Listing**	**Compensation**	**Difference**
Private - Persistence (λ_z)	1.47 (0.068)	1.315 (0.248)	0.152 (0.289)
Private - Monitoring (ν)	1.078 (0.036)		
Private - Volatility Shape (c)	2.654 (0.249)		
Private - Volatility Scale (d)	0.625 (0.007)		
Observable - Volatility (σ_x^2)	0.122 (0.007)		
Observable - Persistence (λ_x)	0.543 (0.010)		
N	10025	5878	

Data

A1. Primary Capital IQ data - Variable definitions

Main intangibility proxy, $1 - \hat{\tau}$

Our proxy for firm intangibility is computed using a perpetual inventory method consistent with most of the literature about innovation. That is we compute off-balance sheet stocks of knowledge and organizational capital using the reported flows of R&D and 30% of SG&A which we sum together with on balance-sheet goodwill and other intangible assets to yield our proxy. For knowledge capital, we use the industry R&D depreciation rates from Li and Hall (2020), and for uncovered industries we set the depreciation rate to 15%. For organizational capital, we apply a 20% depreciation rate as in Falato et al. (2020).

We assume that intangible capital is accumulated each year from their year of foundation provided by Capital IQ and supplemented by data from Loughran & Ritter (2004) when missing and when not provided by either source, we assume that the firm was founded 1 year before appearing in our sample. Following the convention of the latter paper, we cap the age of a firm at 80.

For firms which are not founded during our sample period, we follow Peters and Taylor (2017) and use the mean log change of expenses per each age pooled across our sample to give the level of intangibility. In the case of gap years for a firm in our panel, we interpolate assuming that in the gap year the intangible expense has an average of the year before and after the gap.

Earnings volatility proxy of $\hat{\sigma}$

Computed as the three year lagged volatility of Earnings = EBITDA/Total Assets.

Earnings persistence proxy, $\hat{\lambda}$

Use Han & Phillips (2010) method to estimate the persistence of earnings for each firm separately. We exclude gap years from the calculation.

Estimation of TFP and Markups

Details given in the main body. TFP is estimated from the production function estimation by Wooldridge (2009). See in-depth discussion on markup estimation by Flynn et al. (2019) and De Loecker et al. (2020).

Other firm variable definitions

Age = years from Capital IQ foundation year or year from Loughran & Ritter (2004) data. To be consistent with Loughran & Ritter (2004) age is truncated at 80 years (i.e a firm incorporate in 1867 will be taken to be the same age as a firm incorporated in 1776).

Physical investment = CAPEX scaled by PPEGT

Other CEO variable definitions and data details

Capital IQ provides CEO compensation data from 1999 however the coverage is sparse in the first two years and further as we use Capital IQ events data which begins in 2001 to help identify the CEO from the set of disclosed executives, we limit our CEO sample from Capital IQ to 2001.

Total annual compensation is computed according to Execucomp's TDC1 definition, following the adjustments by Coles et al. (2014) for the Financial Accounting Standards Board (FASB) reporting changes and expanded reporting requirements by the SEC which was mandated in 2006.

Total annual compensation = Salary + Bonus + Stock + Options + Other

where (A) for years prior to the reporting change in 2006:

Bonus = Bonus (bonus) + LTIP (ltip) Stock = Restricted Stock Grants (rstkgrnt) Option = Black-Scholes Value of Option Grants (option_awards_blk_value) Other Comp = Other Annual Compensation (othann) + All Other Compensation (allothtot)

and (B) for years after the reporting change in 2006:

Bonus = Bonus + Deferred Reported As Compensation (defer_rpt_as_comp_tot) + NonEquity Incentives (noneq_incentives) Stock = Fair Value of Stock Grants (stock_awards_fv) Option = Fair Value of Option Grants (option_awards_fv)

A2. Historical data

As stated in the main body, for our longer historical analysis we merge Compustat (which begins in 1950) and Execucomp (began in 1992) with historical executive compensation data provided by **?** (hereon FS) extending back to the 1936, and firm-level market value of patents estimated by Kogan et al. (2017). Execucomp contains data on compensation for firms which have appeared in the S&P 1500 while FS data were the 50 largest publicly traded corporations in 1940, 1960 and 1990 for a total of 101 distinct firms. Due to the substantially restricted sample from FS when possible we use Execucomp for our analysis.

Proxies of intangibility

We use two proxies: (1) the same measure of intangibility for our main analysis computed by Peters and Taylor (2017) and (2) compute our own innovation measure which takes the firm-level market value of patents estimated by Kogan et al. (2017) scaled by firms Gross property plant and equipment given by Compustat.

Equity grant share of compensation

We use the same definition of total compensation (T1DC) as for our Capital IQ sample. Frydman & Saks (2010) data provides the quantity of stock held each year, which to compute stock compensation we compute the stock awards as the difference in quantity of stock awarded times the stock price recorded in the end of year filing report of Compustat.

A3. Structural Estimation Moments

Firm moments

Define the residual cash-flow variance $\tilde{\sigma}_Y^2 = V[y_t|\theta] - \tau V[x_t|\theta] = \sigma_Y^2 - \frac{\sigma_x^2 \lambda_x}{2} = (1-\tau)\frac{\sigma^2 \lambda_z}{2}$ where in the data $\tilde{\sigma}_Y^2 = \sigma_{y,i}^2 - \tau \sigma_{x,i}^2$ where $\sigma_{y,i}$ is cash-flow volatility, $\sigma_{x,i}$ is the tangible cash-flow volatility. $\tilde{y} = y - \tau x_t$

$$
\begin{aligned}
E[g(\theta)] &= 0 \\
g_1(\Theta, x_i) &= [L_i - F_i(\Theta)] \\
g_2(\Theta, x_i) &= \left[L_i - \frac{1}{1+\exp(-(1-\tau_i)^2 b(\Theta) - \nu)}\right](1-\tau_i)^2 \\
g_3(\Theta, x_i) &= \tilde{\sigma}^2_{Y,i} - E[\tilde{\sigma}^2_Y] \\
g_4(\Theta, x_i) &= (\sigma^2_{y,i} - \bar{\sigma}_{y_i})^2/\bar{\sigma}_{y_i} - V[V[\tilde{y}|\theta]]/E[\tilde{\sigma}^2_Y] \\
g_5(\Theta, x_i) &= \sigma(\iota_i)^2 - \frac{\sigma_x^2\lambda_x}{2} \\
g_6(\Theta, x_i) &= HP(\iota_i) - \rho_X
\end{aligned}
$$

where the estimation of persistence follows Han & Phillips (2010), $HP(w) = \frac{\sum_t \Delta w_{it}(2\Delta w_{it-1} + \Delta w_{it})}{\sum_t \Delta w_{it}^2}$, $\rho_X = \frac{1}{\lambda_x}$, and $F_i(\Theta) = \frac{1}{1+\exp(-(1-\tau_i)^2 b(\Theta)+\nu)}$.

A4. Details on the firm listing side structural estimation procedure

We conduct the structural estimation in two-stages.[49] We first run a logistic regression of firm listing choice against firm intangibility and a constant. We then take the coefficient estimate for firm intangibility from this logistic regression and use it in conjunction with the definition of the information premium π to yield an expression for λ_z (as a function of the σ hyper-parameters a_0, a_1 and fixed CEO parameters ρ, ψ). We then estimate the implied split between a_0, a_1, λ in the listing intangibility coefficient b (which captures the information premium) through the remaining firm cash flow and investment moments. As mentioned in the main body, standard errors are bootstrapped by applying this exact same method on subsamples of the data 10,000 times.

[49]This sort of approach is discussed in Nelder & McFadden Chapter 4 and is akin to the two-step estimation approach in **?**. In theory the logistic regression could be converted into GMM moments as well for a simultaneous estimation, but .

Proofs

Change of measure from P_0 to P_Δ

We follow Williams (2011). For a given path for Δ, define

$$\Gamma_t(\Delta) = \exp\left(\int_0^t \left[\frac{\mu\left(\frac{\tilde{y}_t}{(1-\tau)f(k)} - m_t\right) + \Delta_s}{\sigma}\right] dW_s^0 - \frac{1}{2}\int_0^t \left[\frac{\mu\left(\frac{\tilde{y}_t}{(1-\tau)f(k)} - m_t\right) + \Delta_s}{\sigma}\right]^2 ds\right).$$

Using this definition of Γ, it is clear that $E_0[\Gamma_T(\Delta)] = 1$ and Γ_t is a martingale. Thus, an application of Girsanov's Theorem gives us the above result.

Notice that with this, the financier can construct a Wiener process under the diversion distribution P_Δ where

(B1)
$$W_t^\Delta = W_t^0 - \int_0^t \left[\frac{\mu\left(\frac{\tilde{y}_t}{(1-\tau)f(k)} - m_t\right) + \Delta_s}{\sigma}\right] ds.$$

Transformation of Entrepreneurs problem

This transformation follows the same approach as Williams (2011), except integrating as well over the sample paths of x_t. The transformed problem for the entrepreneur is:

Problem 1' - Entrepreneur's Transformed Reporting Problem

$$\max_{\Delta_s \le 0} V(\bar{x}, \bar{z}; c, \Delta) = E_0^0\left[\int_0^T \Gamma_t e^{-\rho t} u(c_t(\bar{x}, \bar{z}, m_t^y) - m_t^y) dt + \Gamma_T e^{-\rho T} U(c_T(\bar{x}, \bar{z}, m_T^y) - m_T^y)\right]$$

subject to

(B2)
$$d\Gamma_t = \frac{\Gamma_t}{\sigma}[\mu(z_t - m_t) + \Delta_t] dW_t^0$$

(B3)
$$db_t = \Gamma_t \Delta_t dt + \frac{b_t}{\sigma}[\mu(z_t - m_t) + \Delta_t] dW_t^0$$

$$b_t = \Gamma_t m_t$$
$$m_t^y = (1-\tau) f(k) m_t dt.$$

Proof of Lemma 1 / 2

Define

$$A_t = \begin{bmatrix} \Gamma_t \\ b_t \end{bmatrix}, \Omega_t = \begin{bmatrix} q_t \\ p_t \end{bmatrix}, \Lambda_t = \begin{bmatrix} \gamma_t \\ Q_t \end{bmatrix}.$$

From the evolutions of Γ_t, b_t given in (B2) and (**??**) we have

$$dA_t = \underbrace{\Gamma_t \left[\begin{array}{c} 0 \\ \Delta_t \end{array}\right]}_{M_t} dt + \underbrace{\frac{\Gamma_t}{\sigma}[\mu(z_t - \frac{b_t}{\Gamma_t}]\left[\begin{array}{c} 1 \\ m_t \end{array}\right]}_{N_t}.$$

Then the current value Hamiltonian of the Entrepreneur's transformed Problem (Problem 1') is

$$\mathcal{H}(\Gamma, b) = \Gamma H = \Gamma u(c - (1-\tau)f(k)[\frac{b}{\Gamma}]) + \Omega_t' M_t + \Lambda_t' N_t.$$

By the stochastic maximum principle of Bismut (1978):

$$(1) \qquad H_\Delta - \lambda^{LM} = 0$$

where λ^{LM} is the Lagrange multiplier on the non-positivity constraint of Δ, and

$$(2) \qquad d\Omega_t = \rho \left[\begin{array}{c} q_t \\ p_t \end{array}\right] - \frac{\partial \mathcal{H}}{\partial A} dt + \Lambda_t \sigma dW_t^0,$$[50]

with terminal condition given by

$$\Omega_T = \frac{\partial \Gamma_T U(c_T - m_T^y)}{\partial A_T}.$$

Direct calculation gives that $\frac{\partial \mathcal{H}}{\partial \Gamma} = H$,

$$\frac{\partial \mathcal{H}}{\partial b} = \frac{\partial \mu(z - \frac{b}{\Gamma})}{\partial b}[\gamma + Qm] + Q[\mu(z - \frac{b}{\Gamma}) + \Delta] - \Gamma \frac{\partial u}{\partial b}$$

where $\frac{\partial u(c - m^y)}{\partial b} = -u'(c - m^y)(1-\tau)\frac{1}{\Gamma}$.

Finally, using the change of measure from W_t^0 to W_t^*, given in (B1) we obtain the final form of (5), (6).

The local optimality condition from this maximum principle for the diversion under truth-telling is

$$\Gamma \Big[p + \gamma + Qm \Big] \geq 0.$$

Noting $\Gamma \geq 0$, imposing truth-telling in the past (so $m = 0$) leads the IC constraint.

C1. Verifying Incentive Compatibility

With the adjustment for $\tau > 0$, the proof of incentive compatibility follows those of Williams (2011).

More specifically, from the above, we have $Q_t = (-k_0)^2 q_t = -(1-\tau)^2 \psi^2 (\frac{\tilde{\rho}}{\tilde{\rho} + \frac{1}{\lambda}}) q_t$.

[50]Note here in an abuse of notation we replaced $f(k)\sigma$ with σ since we later normalize $f(k) = 1$.

Let Q_t^W denote the Q_t with $\tau = 0$ (which was studied in Williams (2011)), then $Q_t = (1-\tau)^2 Q_t^W$ and hence the verification of sufficient conditions in Theorem 4.1 of Williams (2011) follows immediately from A3.2 of his paper.

C2. Proof that stochastic job-destruction arrival simply scales the discount rate of both agents: $\tilde{\rho} = \rho + \eta$.

With stochastic death following a poisson arrival process, assuming the contracted relationship is destroyed at this point for both parties with outside consumption c^A obtained for each instant of time thereafter for the entrepreneur, the promised utility process follows

$$q_t = \begin{cases} \int_t^T u(c_s)\exp(-\rho s)ds, & N_s = 0 \\ q_t^A = \int_t^T u(c^A)\exp(-\rho t)ds, & N_s = 1. \end{cases}$$[51]

By the Martingale representation theorem,

$$dq = [\rho q - u(c - m_t) + \Delta_t]dt + \gamma\sigma dW - \phi^q(q_t, N_t)dM_t$$
$$M_t = \int_0^t [-\eta_s ds + dN_s]$$

with

$$\phi^q(q_t, N_t) = \begin{cases} 0 & N_t = 0 \\ -q_t + q_t^A A, N_t = 1 \end{cases}.$$

Thus, the entrepreneurs value function is then modified from $V(z, x; c)$ given in the main-body (taking $\eta = 0$ there) to

$$V(z, x, N; c) = V(z, x; c)E_s\big[\int_s^T \{N_{\tilde{s}} = 0\}d\tilde{s}|N_s = 0\big]$$
$$+ \int_0^T \big[\int_0^{\hat{t}} \exp(-\rho t)u(c_s - m_s)ds + q_{\hat{t}}^A\big]Pr(dN_{\hat{t}} = 1)d\hat{t}.$$

By direct calculation, $\mathbb{E}_0[\int_0^T \{N_s = 0\}ds] = [\eta(T-0)]^0\exp(-\eta T)$ and so

$$V(z, x, N; c) = E\bigg(\int_0^T \exp(-(\eta+\rho)t)u(c_t - m_t^y)dt + \int_0^T (1 - \exp(-\eta t))q_t^A dt$$
$$+ \exp(-(\eta+\rho)T)U(c_T - m_T^y)\exp(-\eta t) + (1 - \exp(-\eta T))\exp(-\rho T)U(c^A)\bigg).$$

C3. Proof for Theorem 1

HJB for public financier is (re-framing $\tilde{J} = -J$ (so that we are finding the minimum not maximum), where we use that the W_t^x is independent of W_t^*

$$\rho\tilde{J}(z,x,p,q;\theta) = \min_{c,Q,\gamma\geq -p} c - y + J_z\mu(z) + \tilde{J}_x\mu^x(x) + \frac{1}{2}\tilde{J}_{zz}\sigma^2 + \frac{1}{2}J_{xx}\sigma^2$$

$$+J_q[\tilde{\rho}q - u(s)] + \tilde{J}_p[\tilde{\rho}p - \gamma\lambda^{-1} + (1-\tau)u'(c)] + \frac{\sigma^2}{2}\big[\tilde{J}_{qq}\gamma^2 + 2\tilde{J}_{qp}\gamma Q + \tilde{J}_{pp}Q^2\big]$$
$$+\sigma^2\big[\tilde{J}_{zq}\gamma + \tilde{J}_{zp}Q\big].$$

Assuming that the IC constraint is binding everywhere $\gamma = -p$, taking FOCs wrt c, Q, and using the CARA functional form for the entrepreneur

$$1 = (\tilde{J}_q + \tilde{J}_p\psi(1-\tau))u'(c)$$

$$\sigma^2\big[\tilde{J}_{qp}\gamma + Q\tilde{J}_{pp}\big] + \sigma^2\tilde{J}_{zp} = 0$$

We guess that the cost function for the public financier is

$$\tilde{J} = j_0 + (1-\tau)j_1 z + j_1^x x - j_2 log(-q) + h(k)$$

where $k = \frac{p}{q}$.

With this guess, the optimal solutions for c and Q are given by

$$c = \frac{\log\psi}{\psi} + \log\big(j_2 + h'(k)(k - \psi(1-\tau))\big) - \frac{\log(-q)}{\psi}$$

$$Q = p\frac{\tilde{J}_{pq}}{\tilde{J}_{pp}} = -qk\big(\frac{h'(k)}{h''(k)} + k\big).$$

Taking derivatives of the guess, we have $\tilde{J}_z = j_1(1-\tau)$, $\tilde{J}_x = \tau j_1^x$, $\tilde{J}_q = -\frac{1}{q}[j_2 + h'(k)k]$, $\tilde{J}_p = \frac{h'(k)}{q}$, $\tilde{J}_{pp} = \frac{h''(k)}{q^2}$, $\tilde{J}_{qq} = \frac{1}{q^2}\big[j_2 + 2h'(k)k + h''(k)k^2\big]$, $J_{pq} = -\frac{1}{q^2}(h'(k) + kh''(k))$.

Combining this with the FOC/solution for Q we have

$$\frac{\sigma^2}{2}\big[\tilde{J}_{qq}\gamma^2 + 2\tilde{J}_{qp}\gamma Q + \tilde{J}_{pp}Q^2\big] = \frac{\sigma^2k^2}{2}\big[j_2 - \frac{(h'(k))^2}{h''(k)}\big].$$

Hence, substituting all of the above into the HJB and matching coefficients we get

$$\tilde{\rho}j_0 = \frac{\log\psi}{\psi} + j_1(1-\tau)\mu_0 + j_1^x\tau\mu_0^x \tag{C1}$$

$$\text{(C2)} \qquad \tilde{\rho} j_1 = -(1 + \frac{j_1}{\lambda})$$

$$\text{(C3)} \qquad \tilde{\rho} j_1^x = -(1 + \frac{j_1}{\lambda^x})$$

$$\text{(C4)} \qquad \tilde{\rho} j_2 = \frac{1}{\psi}$$

$$\text{(C5)} \quad \tilde{\rho} h(k) = \frac{h'(k)k}{\lambda} + \frac{1}{\psi} \log\big(j_2 + h'(k)(k - \psi(1-\tau))\big) + \frac{\sigma^2 k^2}{2}\big[j_2 - \frac{(h'(k))^2}{h''(k)}\big].$$

The last equation is a second order ODE, with p_0 fixed. The final solution for the public financier takes q_0 as fixed (as well as x_0, z_0 and solves for the optimal p_0. From the definition fo $k_t = \frac{p_t}{q_t}$ and the solved forms of p_t, q_t as promised marginal utility and promised utility processes given in (**??**), (**??**) respectively, that when $\lambda \to \infty$ (intangible TFP is permanent), $k_t = (1-\tau)\psi = k^*_{\lambda\to\infty}$ for all t. Referring to Williams (2011), who has the same ODE except with $\tau = 0$, and finds (via numerical methods) that for not perfectly persistent processes the optimal initial condition is $k_0 = \frac{\tilde{\rho}}{\tilde{\rho}+\frac{1}{\lambda}} k^*_{\lambda\to\infty}$. This k_0 is simply the ratio of the discount factors for the promised utility and marginal utility process (the wedge coming from the degree of persistence in the private information cash-flow component). In our case, with $\tau > 0$,

$$\text{(C6)} \qquad k_0 = \frac{\tilde{\rho}}{\tilde{\rho} + \frac{1}{\lambda}}(1-\tau)\psi.$$

Solving the above system of equations and plugging in the optimal k_0 in (C6) yields the solution for $J^P = -\tilde{J}^P$ given in Theorem **??**, (**??**), where we use the fact that $h'(k_0) = 0$ and so

$$\text{(C7)} \qquad \tilde{\rho} h(k_0) = \frac{1}{\psi} \log(\frac{1}{\tilde{\rho}\psi}) + \frac{\sigma^2}{2\tilde{\rho}\psi} k_0^2.$$

With the above, optimal compensation under the contract is given by

$$\text{(C8)} \quad c(z,x,q,p) = \frac{1}{\psi}\left(\log(\frac{1}{\tilde{\rho}} + \psi h'(k)(k - \psi(1-\tau)) - \log(-q) \right) \equiv -\frac{\log(-q\hat{c}(k))}{\psi}.$$

In other words, compensation is independent of the levels / history of x and z conditional on the level of promised utility q and the ratio of promised marginal utility to promised utility k.

Using these results, $u(c_t) = \hat{c}(k_t) q_t$ and so the dynamics of q_t and p_t can be written as

$$dq_t = [\tilde{\rho} - \hat{c}(k_t)]q_t dt - \sigma p_t dW_t$$
$$dp_t = [(\tilde{\rho} + \frac{1}{\lambda})p_t - \psi\hat{c}(k_t)q_t]dt - \sigma\hat{Q}(k_t)q_t dW_t$$

where $\hat{Q}(k) = k\left(\frac{h'(k)}{h''(k)} + k\right)$ and $W_t = W_t^*$.

At the optimal k_0, applying Ito's lemma, direct calculation gives the ratio $k_t = \frac{p_t}{q_t}$ remains constant.

At k_0, $\hat{c}(k_0) = \tilde{\rho}$ and since $p_t = k_0 q_t$, q_t is a martingale:

$$dq_t = -\sigma k_0 q_t dW_t^*. \tag{C9}$$

Solving this directly we obtain

$$q_t = q_0 \exp\left(-\frac{\sigma^2 k_0^2}{2}t - k_0 W_t\right) \tag{C10}$$

or, in terms of consumption,

$$c_t = \bar{c}(q_0) + \frac{\sigma^2 k_0^2}{2\psi} + \exp\left(-\frac{k_0^2}{2}t - k_0 W_t\right). \tag{C11}$$

Formal partial equilibrium definition

D1. Financing Equilibrium Definition

Given individual firm cash holdings M_0, price of initial capital p_0^k, financial resources of specialist financiers, B and monitoring cost ν, a public listing equilibrium consists of (i) contracts $(s, \gamma, Q, q_0, p_0)^f$, $f \in \{S, P\}$ yielding ex-ante promised utility q_0 to the entrepreneur with diversion process $\Delta = 0$, (ii) financiers bidding rules $q_0^P(\theta), q_0^S(\theta)$ and (iv) entrepreneur financier selection rules, $i^S(q_0^S, q_0^P; \theta, M_0)$, $i^P(q_0^P, q_0^S; \theta, M_0)$ indicating which (if any) of the principal's offered contracts to choose given project θ and internal financing M_0 such that:

1) Contracts $(c, \gamma, Q, p_0)^j$ offered induce truth-telling and are optimal principal-agent contracts given principal's information
   a) $(c, \gamma, Q, p_0)^P$ solves (8) yielding $J^P(q_0; \theta)$
   b) $(c, \gamma, Q, p_0)^S$ solves (9) yielding $J^S(q_0; \theta)$
2) Financing allocation is a sub-game perfect Nash equilibrium where given the type-contingent contracts above

a) Given beliefs about the specialist financier's bidding strategy $b^S(\theta) = q_0^S(\theta)$, and entrepreneur's financier choice rules $i^P(q_0^P, q_0^P; \theta,)$, Public financier value from contract $J^P(\cdot)$ and funding B_P, P chooses bidding strategy $b^P(\theta) = q_0^P(\theta)$ for each project that is a best-response, i.e. solving (10)

b) Given beliefs of $q_0^P(\theta)$, entrepreneurs' financier choice rules $i^S(q_0^G, q_0^S; \theta, M_0)$, value from contract $J^S(\cdot)$, financing demands $f(\theta) = 1$, monitoring cost ν and budget constraint B^S, financier S chooses the bid $q_0^S(\theta)$ that is a best-response, i.e. solving (10)

c) Entrepreneur's make financing choice $i^P(q_0^P, q_0^S; \theta), i^P(q_0^G, q_0^S; \theta, M_0) \in \{0, 1\}$, $i^P(q_0^P, q_0^S; \theta) + i^S(q_0^S, q_0^P; \theta) \leq 1$ maximizing promised utility $q_0(\theta)$ subject to their outside option $V^A(\theta)$

d) Financier's P, S and each entrepreneur θ's beliefs are consistent.

D2. Proof of Theorem 2

PROOF:

The proof follows the logic of Bertrand competition with heterogeneous costs across firms. As q_0 is a sufficient statistic for the entrepreneur in his utility under either financier's contract, the entrepreneur's best-response is to select the financing offer which offers the highest q_0.

Notice that the public financier faces no fixed cost of financing and has no financing constraint and so provided the projects under the individual rationality assumption for the public financier in funding all projects, the dominant strategy to bid $q_0 > 0$ for all θ. On the other hand, this is not the case for the private specialist given $\nu > 0$.

Fix a given θ and suppose $q_0^S = q_0^P \geq V^A(\theta)$. With equal levels of promised utility and cost of injecting capital, from the contracting results of the earlier section the specialist's surplus above that of the public financier is $\pi(\theta) - \nu$.

First case: $\pi(\theta) - \nu > 0$

First, if $J^P(q_0^P; \theta) - 1 > 0$. Assuming the entrepreneur puts some positive weight on accepting the specialist offer the public financier can deviate and offer $q_0^P + \varepsilon$ and win the bid with probability one. On the other hand, if all weight is put on the entrepreneur selecting the public financier's offer, then the specialist can offer $q_0 + \varepsilon$. Taking $\varepsilon \to 0$, by continuity of the specialist's contract, the net surplus of this deviation is $\pi(\theta) - \nu > 0, w[\pi - \nu]$ where $w \in (0, 1)$ is the entrepreneurs mixing strategy hence also not an equilibrium.

Now, if $J^P(q_0^P; \theta) - 1 < 0$ the public financier will always do at least weakly better by reducing q_0^P to the point $J^P(q_0^P; \theta) - 1 \geq 0$. Hence such a q_0^P cannot occur in equilibrium.

Finally if $J^P(q_0^P; \theta) - 1 = 0$, and the entrepreneur is mixing in their selection between the two financiers then the public financier cannot deviate to a higher promised utility to the entrepreneur without doing worse than autarky for themselves. On the other hand, the specialist can again make an arbitrarily small higher bid and earn $\pi(\theta) - \nu > w[\pi - \nu]$ where $w \in (0, 1)$ is the entrepreneurs mixing strategy. If instead the entrepreneur selects financing solely by the specialist given these bids, then the specialist will lose the bid if he bids any lower (with $q_0^S = q_0^P$) and win but with surplus less than $\pi(\theta) - \nu$ for any $q_0 > q_0^P$. Thus, $q_0^P = q_0^S$ s.t. $J^P(q_0^P) = 0$ with the entrepreneur being financed by the specialist is the unique, symmetric bid equilibrium for this case where the specialist has the comparative advantage.

<u>Second case:</u> $\pi(\theta) - \nu < 0$

If the entrepreneur is mixing with weight w then the specialist is better off reducing his bid $q_0^S < q_0^P$ and thus losing on θ. Now if $J^P(q_0^P) > 0$ and $q_0^P > V^A(\theta)$ then the public financier always has a positive deviation until $q_0^P = V^A(\theta)$. At this level, (with $q_0^S = q_0^P$), assuming the entrepreneur chooses the public financier in a tie, the payoff to the specialist is negative if he tries to weakly outbid the public financier and zero otherwise. The public financier cannot do any better while satisfying individual rationality for the entrepreneur and hence $q_0^P = V^A(\theta) = q_0^S$ with the entrepreneur financed by the public financier is the unique, symmetric bid equilibrium in this case.

<u>Asymmetric bid equilibria:</u>

Now we have shown that if bids are equal to each other what the equilibrium strategies must be (ie which levels of q_0 result in fixed points). It remains to pin down the asymmetric bid equilibria.

First if $\pi(\theta) - \nu > 0$ with $q_0^P = q_0^S$, suppose an equilibria exists with $q^P < q_0^P$. In this case, the specialist wins with certainty but earns $< \pi(\theta) - \nu$ (since from the contracting solution his payoff is strictly decreasing in q_0 and his payoff exactly equals $\pi(\theta) - \nu$ at $q^S = q^P$) and so can strictly increase his payoff by reducing his bid to $q^S \in (q^P, q_0^P)$.

Second, if $q^P > q_0^P = q_0^S$ then the Public financier wins the bid, resulting in zero for the specialist. But then the specialist could increase his bid to $q^S = q^P + \varepsilon$ and receive $\pi(\theta) - \nu > 0$. Thus no asymmetric bidding equilibrium exists when the specialist has a comparative advantage ($\pi(\theta) - \nu > 0$).

On the other hand, $\pi(\theta) - \nu \leq 0$ then we claim that any $q_0^S < V^A(\theta) = q_0^P$ with the entrepreneur selecting the Public financier is an equilibrium. As reasoned above, the entrepreneur will simply take his outside option for any downward deviation in q_0^P resulting in a payoff of zero for the public financier, while raising q_0^P increases the payment to the entrepreneur without increasing the winning probability. Finally the specialist strictly prefers to not bid than bid weakly higher than V^A (whereby he receives surplus $< \pi(\theta) - \nu < 0$).

To conclude the characterization of the equilibria set, it is sufficient to note that with a sufficiently low outside option for the entrepreneurs and insufficient internal funds to start the project and $\mu > 0, z_0 \geq 0$, an equilibrium where an entrepreneur receives no financing cannot occur.

To map to the specialists problem stated in the theorem, bidding on a firm is individually rational for the specialist only when $\pi(\theta) - \nu \geq 0$ and in the case he bids, the equilibrium must be as solved above. However, the set of $\theta : \pi(\theta) - \nu \geq 0$ may require more funding than the specialist is endowed with, thus the financing problem for the specialist must include the budget constraint.

The Public problem is even simpler. On the set of projects for which the specialist doesn't choose to bid above the entrepreneur's outside option, the public financier has monopoly power and so their optimal bid is to take the entrepreneur to her outside option, that is autarky. For the other projects, not bidding on the projects cannot be an equilibrium given the NPV of funding the project is positive.

D3. Proof of Lemma 3

PROOF:

Observe $\tilde{\Pi} \equiv E[\tilde{\pi}|\tilde{\pi} \geq \nu^*] - \nu^*$ is the mean residual life function and $\tilde{W} \equiv \nu^* - E[\nu|\nu \leq \nu^*]$ is the so-called mean-advantage over-inferiors function as defined in Bagnoli and Bergstrom (2005). Thus, from Bagnoli and Bergstrom (2005) Theorem 5 we have that the latter is monotone decreasing (increasing) if the CDF F is log convex (log concave), while from Bagnoli and Bergstrom (2005). Theorem 6 we have that $\tilde{\Pi}$ is monotone increasing (decreasing) if $\bar{G}$ is log convex (log concave).

Observing that $\Pi = \tilde{\Pi} + \tilde{W}$, the result follows directly from (i) and (ii).

D4. Proof of Corollary 3.1

PROOF:

$G'_\tau(\tau) = G_\tau(\tau) - \xi$ implies $G' \leq G$ (i.e G first-order stochastically dominates the new cdf G'). The short-run effect (ν^* fixed) is immediate.

For the long-run, since $F()$ and $\bar{G}$ are strictly monotonic (increasing / decreasing) and $HF()$ remains unchanged with ξ while $\bar{G}' \geq \bar{G}$ we have $\nu^*_{LR} > \nu^*$. The compensation result follows directly from the definition of $\bar{c}$, the direct effect from the increase in $E[\pi]$ and the second order effect of the increased ν^* increasing the right-side censoring of the expectation.

Now note $\Pi = \tilde{\Pi} + \tilde{W}$ where $\tilde{\Pi} \equiv E[\tilde{\pi}|\tilde{\pi} \geq \nu^*] - \nu^*$ is the mean residual life function and $\tilde{W} \equiv \nu^* - E[\nu|\nu \leq \nu^*]$ is the so-called mean-advantage over-inferiors function. From Bagnoli and Bergstrom (2005) Theorem 5 we have that the latter is monotone decreasing if the CDF F is log convex, while from Theorem 6 we have that $\tilde{\Pi}$ is monotone increasing if $\bar{G}$ is log convex, giving the result $\frac{\partial \Pi}{\partial \xi} > 0$ ignoring the transformation from G to G'.[52] Finally observing that the transformation of G' is linear, by Corollary 5, we have the result. Observe that we could apply

[52]To see this, note that (1) from Bagnoli and Bergstrom (2005) Theorem 1/2 left-side integrals of CDFs inherit the log concavity / log convexity of the other, (2) that $\tilde{\Pi} = \frac{\int_{\nu^*}^{\infty} \bar{G}(\pi) d\pi}{\bar{G}(\pi)}$ and $\tilde{W} = \int_0^{\nu^*} \frac{F(\nu) d\nu}{F(\nu^*)}$ and (3) we can define $H = \int_{\nu^*}^{\infty} \bar{G}(\pi) d\pi$ so $log'(H) = \tilde{\Pi}$.

symmetric arguments if both the relevant distributions were instead assumed to be log concave except the transformation ignoring the transformation. With the transformation, since the effects go in different directions the result does not go through.

Finally for CEO pay, $E[\pi|\pi \leq \nu^*] = \int_0^{\nu^*} \pi \frac{dG(\pi)}{G(\nu^*)}$, which if G is log convex, then $\frac{dG(x)}{G(x)}$ is monotone increasing (and again appealing to Corollary 5 of BB and that an increasing linear transformation will support this shift) of and so given ν^* increases in the long-run the result follows.

D5. *Proof of Corollary 3.2*

PROOF:

Proof is similar to above except noting that $\tilde{\Pi}$ now doesn't have the influence from the transformation to $G()$ allowing us to sign both the log concave and log convex cases.

D6. *Proof of Corollary 3.3*

PROOF:

(i) is direct implication of the project being negative NPV for the public financier. (iii) follows since cost c effectively reduces ν across all firms, thereby decreasing the promised utility q_0 in the financing bidding game.

(ii) If $G_\pi(\pi)$ log convex, using same arguments as earlier average public CEO pay decreases in the short-run due to the declining effective cutoff to be public $\nu_1 = \nu_0^* - c < \nu_0^*$.

For the long-run, as all projects are positive NPV for the private financier any cutoff $\nu_2^* < \nu^* - c$ will leave positive profits for a household with cost $\nu \in [\nu_2^*, \nu^* + c)$, contradiction. Public CEO pay in the long-run is unchanged since $\nu_1 = \nu_2^*$.

D7. *Proof of Corollary 3.4*

PROOF:

(i) follows from the direct effect of the information premium decreasing for all public firms

(ii) holding fixed the set of PE financiers / their funds from cutoff ν^*, the measure $\bar{G}(1+\nu^*)$ has decreased leading to some committed PE financiers having funds uncommitted.

(iii) With the set of financed funds decreased, the effective ν cutoff for PE has decreased implying (from same log concavity results) a higher (lower) average PE if $\bar{G}$ is log concave.

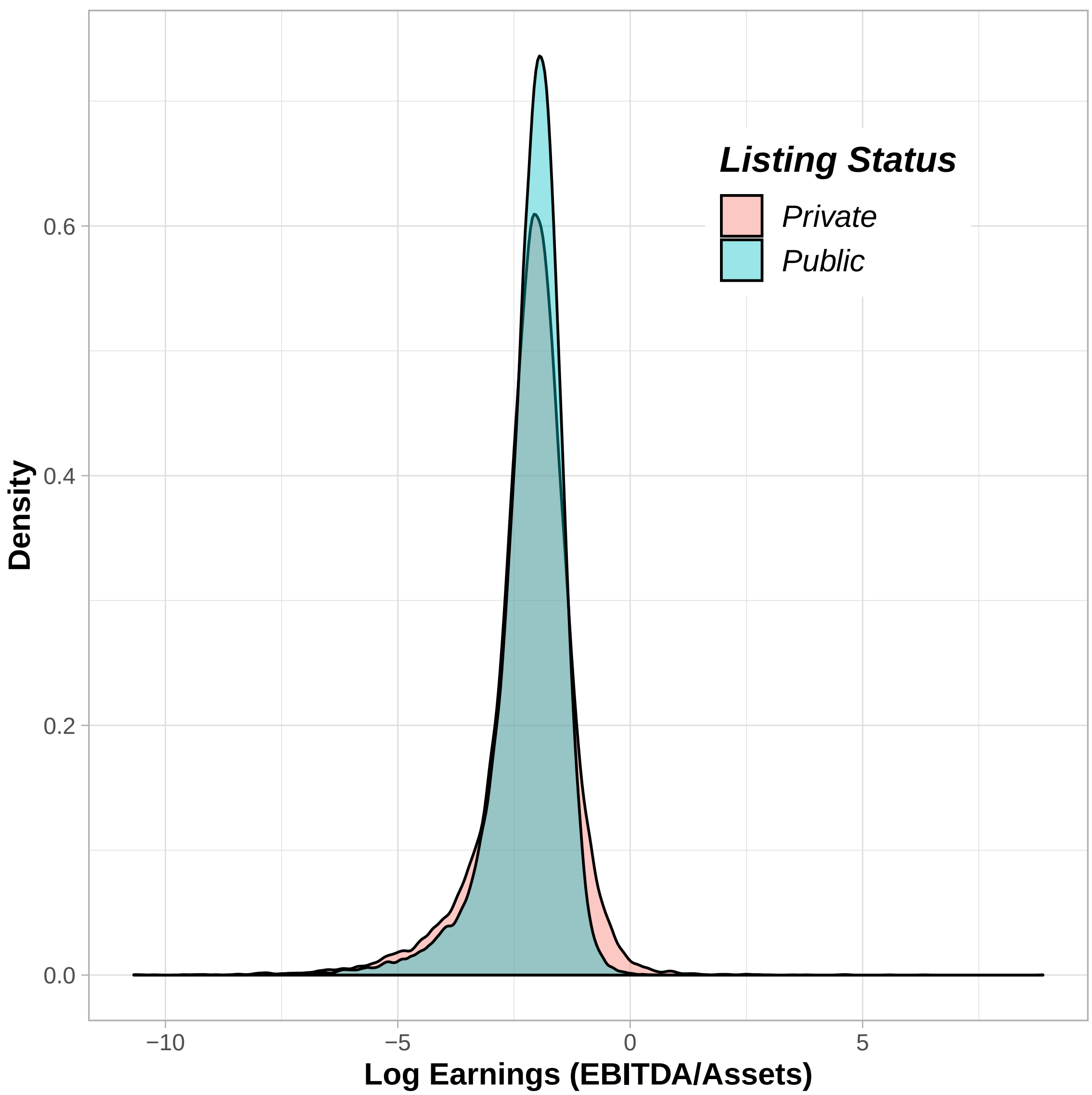


Figure A1. : Log earnings (EBITDA/Assets) distribution by listing status

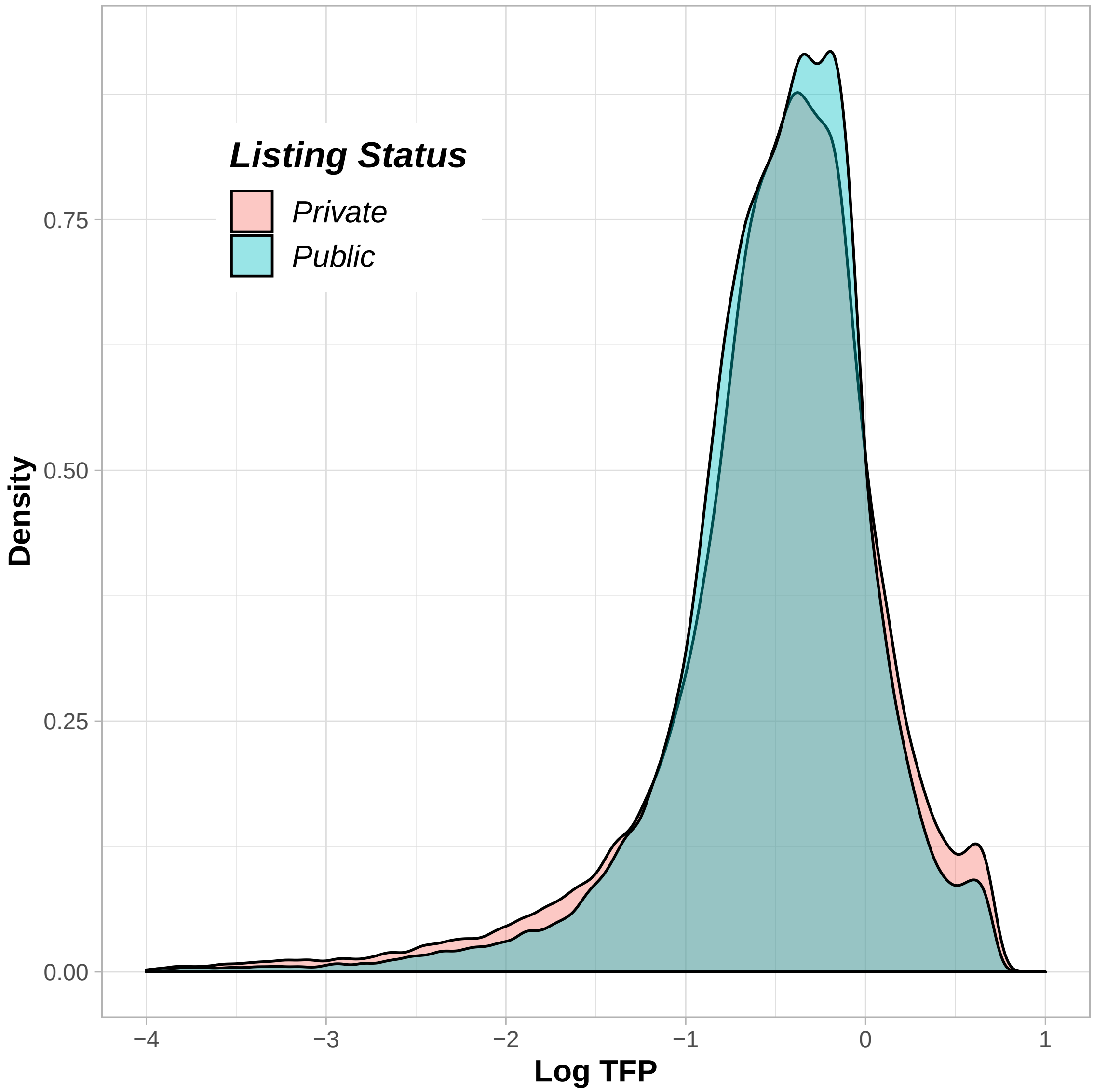


Figure A2. : Log TFP distribution by listing status

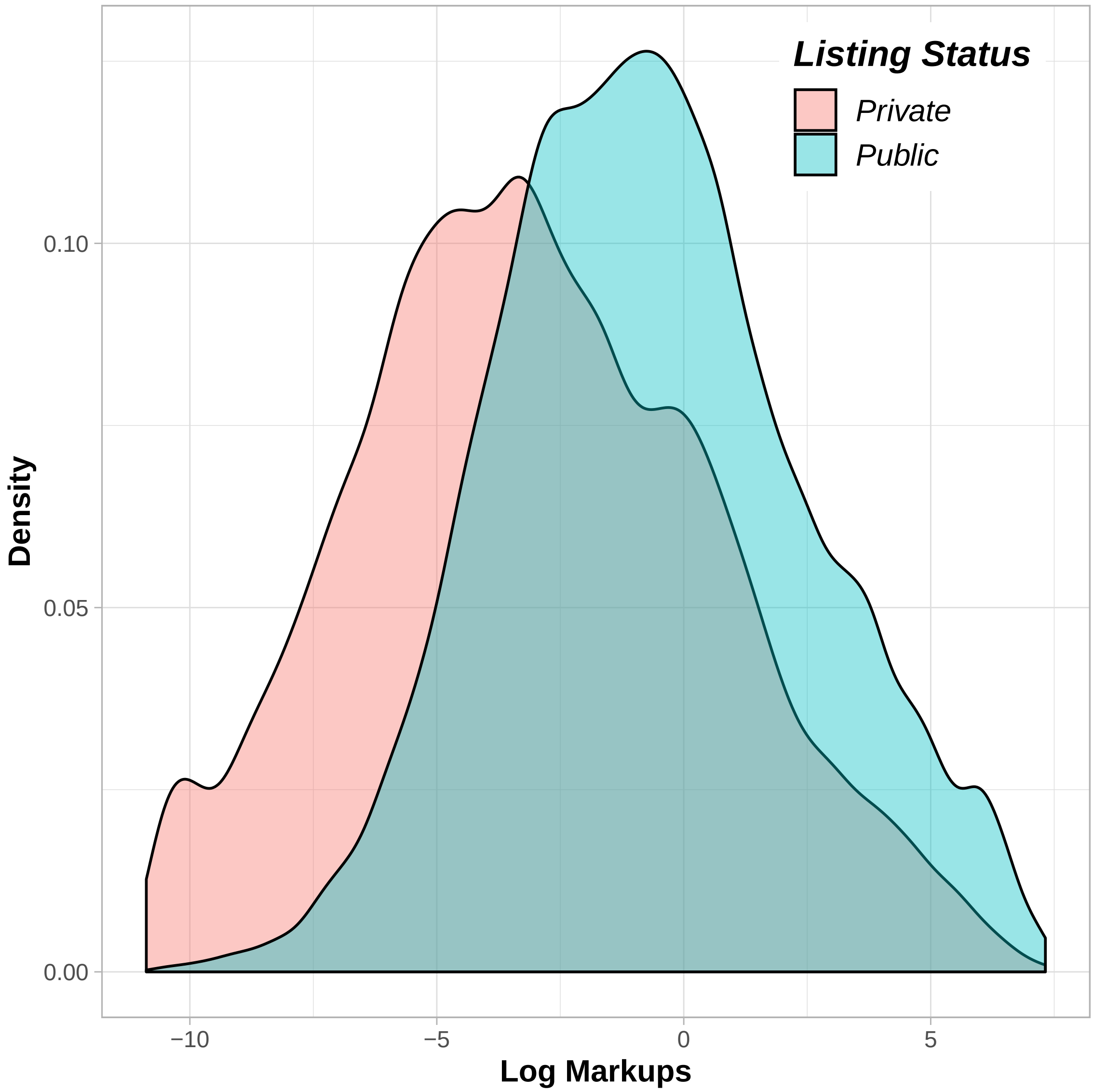


Figure A3. : Log markups distribution by listing status