Public Listing Choice with Persistent Hidden Information

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November 12, 2020

Abstract

How much does firm intangibility amplify CEOs' persistent private information and reduce firms' public listing propensity? We develop a model of competing public and private investors financing firms heterogeneously exposed to persistent private cashflows. Equilibrium financing is driven by information rent differentials in CEO compensation. We validate and structurally estimate the model using firm listing and CEO compensation data. We find private (intangible) cashflows exhibit 63% higher persistence than their tangible counterparts. Further, if firm intangibility levels returned to those of 1980, mean listing propensities would increase 8 percentage points while mean CEO variable pay growth would decrease by 43%.

Keywords: intangible capital, CEO compensation, private equity, dynamic optimal contracts, assignment model, structural estimation
JEL: C78, D86, E22, G32, M12, O33

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1 Introduction

"Our problem – which we can't solve by studying up – is that we have no insights into which participants in the tech field possess a truly durable competitive advantage...Predicting the long-term economics of companies that operate in fast-changing industries is simply far beyond our perimeter."

-Warren Buffett, 1999 Berkshire Hathaway shareholder letter

Many significant firm events, such as legal settlement agreements, new trade secrets, or proprietary consumer data, are associated with a firm's intangible assets. Such events have persistent effects on firm cashflows, yet are often not observed by outside investors. Furthermore, even for events with full public disclosure as in the case of newly granted patents, little consensus exists on how investors can appropriately value these individual developments. Firm insiders' persistent private information, not only magnifies the lifetime impact of a cashflow shock but also drastically alters the types of incentives needed for truthful reports. Due to the opacity of intangible assets, as well as the challenges in identifying their resulting cashflows, these assets may amplify persistent private information of insiders. Spurred by the information communication technology (ICT) revolution, firms' aggregate accumulation of intangible assets may have induced a rise in public CEO compensation. To the extent private investors can avoid these information frictions through their expertise and interaction with firm insiders, such increased compensation costs for public financiers may reduce the net benefit of public financing and cause a fall in public stock market listings.

In this paper, we quantify how much rising intangibility has amplified public CEOs' persistent private information and contributed to the fall in public listings. Identifying the substantive drivers of these trends is crucial to evaluate the efficiency of the market and potential policy interventions. However, the latent nature of private information precludes direct measurement. To tackle this problem, we build and estimate a market equilibrium model of firm financing and CEO compensation where CEOs have persistent private information over intangible cashflows.

Our model generates variations in public CEO compensation packages and firm listing decisions through heterogeneous firm-level exposure to private cashflows. We proxy the exposure to private cashflows using measures of firm intangibility and identify a common parameter governing the persistence of private information based on firm listing decisions and CEO compensation packages. To test our theory of a common information friction driving both CEO pay and firm listing decisions, we separately estimate this persistence parameter identified on non-overlapping moments (and disjoint data) of firm listing choice and CEO compensation and compare their estimated values. We then use our estimates to evaluate various candidate policies through the lens of our model. In particular, we quantify the amplification effect the ICT revolution had on persistent private information by evaluating the counterfactual where firm intangibility remained at the levels observed in 1980.

We find evidence of a common underlying information friction tied to firm intangibility which significantly shapes both CEO compensation packages and firm public listing decisions. Our estimates of private information persistence across the two structural estimations are statistically indistinguishable from each other. The estimation suggests a 63% higher persistence in private information cashflows than persistence in the tangible cashflows implied by physical investment. The inferred aggregate effects of a secular increase in firm intangibility is large. If US firm intangibility had remained at their 1980 levels, listing propensities would be 8 percentage points higher, while the annual growth in average CEO pay would be reduced by 43%.

In the model, public investors design optimal compensation contracts to dynamically induce truth-telling as in Williams (2011). Despite the manager having no influence over the actual cashflow process, optimal CEO pay is performance sensitive, with the level of sensitivity increasing in the lifetime size of the private information. The risk built into the contract to incentivize truthtelling is compensated with higher expected growth in pay over time. Private investors have access to a costly monitoring technology which allows them to design first-best efficient contracts. Competition in financing between public and private investors then generates a private equity (PE) premium as the foregone information rents net monitoring costs.[1] Capacity constraints for individual private investors together with competition against the public investors induces a selection effect where, ceteris paribus, highly intangible firms are privately financed and public CEO compensation is increasing in firm intangibility. Aggregate private investment is tied to the average

[1]This private equity premium is attached to the equity share of public CEO compensation, with higher persistence mapping to higher equity-based pay. While a positive private equity premium is generated with permanent shocks (i.e. brownian motion for cashflows), the gain in theoretical simplicity is diluted by empirical difficulties implied by non-stationary cashflow and compensation processes. Moreover, in our empirical work we find reported earnings and compensation dynamics are better captured by a persistent, but not permanent, cashflow process and more tightly squares up their relationships with firm intangibility.

PE premium and in equilibrium is an increasing function of average firm intangibility. Finally, while an increase in intangibility amongst public firms will lead to higher compensation, due to the selection effect with rising PE funds, an increase in intangibility can in fact lower average public CEO compensation

The model is informed and validated on a large dataset of public and private US firms and CEO compensation. We find variation in firm intangibility is an important source of cross-sectional variation in observed public CEO compensation packages and firm listing decisions. Using a supplemental dataset on historical CEO compensation, we find time-series variation in aggregate firm levels of intangibility helps rationalize the patterns of average public CEO compensation observed over the second half of the 20th century both in level and use of equity grants. This is important as according to the recent survey by Edmans et al. (2017), "[t]he reasons for this evolution is not well understood." Furthermore, the estimated magnitude of these elasticities of CEO pay sensitivity to firm intangibility are of equal or larger magnitude than firm size over this time period and thus complements the size-based explanations (such as Gabaix and Landier (2008)) in the literature.

Patterns of public CEO pay since 2001 have been less clear cut, with median public CEO pay inexorably rising, while average public CEO pay slightly falling or remaining relatively flat. Our model rationalizes these patterns through the changing selection of firms being publicly listed in this time period. The (endogenous) expansion of private equity funds in this time period reduces the threshold informational advantage private investors demand to profitably finance the firm. Consequently, even though the aggregate pool of firms is becoming increasingly intangible, the right tail of informationally sensitive public firms is shifting leftwards and pushing downwards average public CEO pay. These selection effects suggest that the increased disclosure requirements of Sarbanes-Oxley (SOX) Act may not have been effective in increasing transparency in these markets. Instead it may have acted more as a subsidy for private investors similar to the relaxation of PE funds by the National Securities Market Improvement Act (NSMIA).

The remainder of the paper is structured as follows. Section 2 reviews the literature. Section 3 outlines the model. Section 4 describes our dataset. Section 5 uses proxies on firm's private information cashflow characteristics to test the model's sorting and compensation prediction. Section 6 structurally estimates the model and conducts counterfactuals. We conclude in Section 7.

2 Related Literature

We provide and quantify a new technologically driven channel driving the precipitous decline in publicly listed US firms since 1997 documented by Doidge et al. (2017), and Gao et al. (2013b). Although this decline was initially seen to be a US phenomenon based on World Development Indicators (WDI) data, more detailed data on international listings suggest this phenomenon is more widespread across advanced economies if somewhat delayed relative to the US trends.[2] Ward (2019) studies the effect of an intangibility driven agency friction on public firm investment behavior and market valuation dynamics. The 'pure moral hazard' agency friction in his model is tied to hidden effort on intangible asset accumulation rather than the 'hybrid moral hazard' friction in our model.[3] As noted by Edmans et al. (2017) small differences in information frictions generally lead to substantively different economic implications. For instance, the former predicts a positive correlation between information frictions (e.g. intangibility) and productivity/profitability while the latter does not require any type of association with intangibility.[4] Our choice to study a hybrid moral hazard friction is also motivated by empirical work by Gayle and Miller (2015) who test the class of 'pure moral hazard' and 'hybrid moral hazard' models on data of CEO compensation, accounting and stock returns, and find evidence that the former is rejected in the data, while the latter cannot be.

Explanations for the decline have 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). Our paper endogenizes the supply of private equity funds tied to the distribution of

[2]From WDI data, public listings have markedly declined across many advanced economies since the mid-2000s including Germany, UK and France. In addition, while total listings in Canada have increased (as seen in the WDI data), the increase seems to be comprised largely in financial vehicles (so called "frankenstocks") and in fact corporate listings have dropped from 1,232 in 2008 to 861 in 2017 (see Globe and Mail article, May 5, 2017 (link)).

[3]Gayle and Miller (2015) define 'pure moral hazard models' to be those with hidden actions of the agent but with no private information on the realized output, as opposed to 'hybrid moral hazard' where the agent has private information on the output, but doesn't influence its actual level.

[4]Controlling for selection is important for understanding the fundamental information frictions at play in our dataset, as we find firm intangibility has a slightly negative correlation with productivity when pooling across public and private firms, as opposed to the positive correlation found in Ward (2019) based on public firms.

firm characteristics and captures the costs of being public through the net monitoring cost of private investors. However, our paper abstracts from size or productivity differences and so complements the selection mechanisms highlighted in these models. Caskurlu (2020) examines a non-pecuniary cost of going public stemming from a heightened risk of patent litigation with public disclosure. This channel reinforces the selection of intangible firms to be privately listed but should not influence public compensation, hence differences in our structural estimates of the private information across public CEO pay and firm listing should be exacerbated by this channel.

Classical theories on firm listing choice focus typically highlight the benefits of going public from a lower implied cost of capital stemming arising due to (i) a broader pool of financing (Merton (1987), Rajan (1992)), (ii) diversification of insider risks (Levine (1991), Pagano (1993)), (iii) improved performance monitoring through price signals (Holmström and Tirole (1993), Pagano and Röell (1998)), or (iv) better guidance from market experts (Maug (2001)). Some more recent theories focus on the type of investment needed for financing (Clementi (2002), Ferreira et al. (2014), Spiegel and Tookes (2013)). Standard costs of going public include fixed or on-going regulatory costs (Ritter (1987), Gupta and Rust (2017)), loss of confidentiality (Campbell (1979), Yosha (1995), Maksimovic and Pichler (2001), Spiegel and Tookes (2013)), loss of active management expertise from investors (Jensen (1989)) or static agency frictions (Jensen and Meckling (1976), Leland and Pyle (1977), Chemmanur and Fulghieri (1999)). These standard theories largely favor sorting in terms of older, more productive and larger firms, whereas Doidge et al. (2017) find that firm listing propensities have declined across all sizes and industries thereby suggesting that neither the amount of capital or the type of investment projects undertaken across industries are the core driver.[5] Our theory predicts firms with larger private cashflow risk should stay private regardless of firm productivity, size or age.[6]

Due to a historical dearth of data on private firms empirical testing of theories on listing decisions have been relatively scarce. A few notable exceptions examine the 'going public' angle, Lerner (1994) studies the timing

[5]Recent work by Clementi (2002), Ferreira et al. (2014) 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.

[6]While more mature firms may typically have less private cashflows due to better understood business models, examples like Bloomberg challenge this theory.

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, 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.

To our knowledge, our paper is the first to quantify economic effects of persistent private information arising from intangible assets, as well as provide a credible estimate for the level of persistent private information. Until recent work by Williams (2011), technical challenges impeded the study of dynamic optimal contracts with persistent hidden information in the levels of a cashflow process.[7] Empirical work examining agency frictions has largely focused on the class of 'pure moral hazard' models. Ai et al. (2016) structurally estimates a dynamic 'pure moral hazard' model and finds the estimated size of the private information shock to be relatively small in comparison to observed cashflow volatility and overall effects dwarfed by those of firm size. In contrast, our structural estimates of a 'hybrid moral hazard' model with persistence suggest relatively high volatility (persistence) in the private information cashflows compared to the volatility (persistence) implied by physical investment.

In contrast to much of the literature, our paper focuses on non-size based firm level determinants of CEO compensation and financing decisions. 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

[7]Continuous time contracting frameworks have become increasingly popular due to their tractability, beginning with DeMarzo and Sannikov (2006), Biais et al. (2007), Sannikov (2008) and He (2009). However, these works have largely focused on agency issues of the variant in Holmstrom and Milgrom (1987) with private effort and independent and identically distributed private information on the costs of producing a given amount of output. 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 might increase CEOs' risk exposure.

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)).[8] 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 persistent firm characteristics which we find to have similar levels of explanatory power in the cross-section. Moreover, the evolution of intangibility 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)) as well as the changing composition of CEO pay from around 1980.[9]

A number of other papers have examined different facets of exogenous technological change driving trends in compensation. One strand of the literature, beginning with Lustig et al. (2011) interprets intangibility as raising the importance of human capital within a firm, inducing firms to expend more compensation to retain 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.[10]

3 Model

The model adapts the reporting and optimal contracting problem characterized by Williams (2011) into a corporate finance setting modeling a cash-flow process as a mixture of privately and publicly observed cash-flows and embeds it into a market framework with competing principals (investors) which have heterogeneous access to a monitoring technology. We begin with a repre-

[8] 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.

[9] In particular, the rising utilization of equity grants that occurred in tandem to the pay growth.

[10] Of course, there are other suggested mechanisms in the literature for the overall rise in option-based compensation (for a survey, see Murphy (2013)).

sentative public (non-monitoring) and private (monitoring) investor, taking as given the amount of capital available to private investors, and in Section 3.7, endogenize the supply of funds and the set of public and private investors based on an individually rational cutoff which sorts low cost monitoring investors into private and high cost into private.

3.1 Environment

There is a unit mass of firms, each 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. A firm of unit scale requires a single unit of funds to get off the ground. For $t > 0$, a firm of size A produces (net) cash-flows $Y_t = y_t A$ where y_t is the (scale-free) unit profits of the firm. Since the channel we wish to highlight does not depend on size, we will for the remainder of this section abstract from size effects and set $A = 1$. The unit profits of the firm can be decomposed into tangible components x_t and intangible components z_t with share τ of tangible cash-flow dependence, so that,

$$y_t = (1-\tau)z_t + \tau x_t.$$

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,

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

and

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

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 investors, with common discount rate ρ, compete using compensation contracts to fund a pool of heterogeneous firms that differ in their cash-flow characteristics $\theta = (\{\mu_i, \lambda_i, \sigma_i\}_{i\in\{x,z\}})$. The representative 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 representative private investor is a specialist, S, and so is to use a monitoring technology to observe the intangible cash-flows and thereby avoid the information friction. However, the representative private investor is constrained by a budget $B < \infty$.

3.2 Truthful Revelation Compensation Contracts

In this sub-section and Sections 3.3-3.4, we draw from the work of Williams (2011) and characterize truth-telling contracts in our setting.[11] Details on the derivations and solution of the optimal contract for $\tau \in [0, 1]$ are given in Appendix B - C.

Denote q_t as the promised utility to the agent under the contract at time t and p_t to be the (negative of) promised marginal utility to the agent under the contract. 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:

$$dq_t = [\rho q_t - u(c_t)]dt + \gamma_t \sigma dW_t^z \tag{3}$$

$$dp_t = [\rho p_t + (1 - \tau)u'(c_t) - \lambda_z^{-1} \gamma_t]dt + Q_t \sigma dW_t^z \tag{4}$$

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

As an immediate consequence, any truthful revelation contract can be summarized by (q_0, p_0, γ, Q) where q_0, p_0 are the initial conditions for the promised utility and marginal utility processes, and γ, Q are stochastic processes which control the volatility of the promised utility and marginal utility processes in response to the evolution of cash-flow reports.

Notice that here the persistence of private information introduces an additional state variable, requiring a truthful revelation contract to control separately the evolution of both promised utility (standard) and promised marginal utility.[12] 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.

[11] Williams (2011) provides a general framework for solving persistent private information contracting problems and characterizes the case of CARA utility used here for $\tau \in \{0, 1\}$.

[12] 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.

3.3 Contracting with the Private Investor

Having obtained the necessary conditions on compensation consistent with truthful revelation, we now move to characterize the (first-best) optimal contract for the private investor endowed with costly monitoring technology (per project cost ν).[13] At the time of financing / contracting, the agent and investor are both fully informed as to the firm's cash-flow characteristics $\theta = (\{\mu_i, \lambda_i, \sigma_i\}_{i \in \{x,z\}})$. The private investor chooses the level of compensation c_t, the volatility in the level of utility γ_t and promised marginal utility Q_t

$$J^S(q_0;\theta) = \max_{p_0 \leq 0} \max_{\gamma_t, Q_t, c_t} E_0 \left[\int_0^\infty e^{-\rho t}(y_t - c_t)dt \right] - \nu \tag{5}$$

subject to (1) - (4) that is the evolution of cash-flows dy_t, dz_t, dx_t, promised utility and marginal utility dq, dp, the initial conditions of the cashflows z_0, x_0 and the transversality conditions $\lim_{T\to\infty} e^{-\rho T} q_T = \lim_{T\to\infty} e^{-\rho T} p_T = 0$.

Since the private investor faces no information frictions and is risk-neutral while the agent is risk-averse, the first-best solution will stabilize compensation to the agent over the life of the contract. That is, the optimal compensation contract is given by

$$c_t^S = c_f(q_0)$$

where $c_f(q_0) = -\frac{\log(-\rho q_0)}{\psi}$ is fixed compensation.[14]

3.4 Contracting with the Public Investor

The contracting problem for the public investor faces the same necessary conditions on the contract for truthtelling as the private investor above. In addition, to ensure truth-telling is incentive compatible, the public investor faces the following additional constraint

$$p_t + \gamma_t \geq 0. \tag{6}$$

That is, to induce truth-telling, the investor is restricted to have a positive correlation between cashflow reports and the compensation.

[13] 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.

[14] Recall $u(c) = -e^{-\psi c}$ so that $q_0 \leq 0$, and note that $c_f > 0$ for q_0 not too large (ie $q_0 < \frac{1}{\rho}$). Details of the solution are in the Appendix which generalize the result of $\tau \in \{0,1\}$ in Williams (2011).

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 marginal utility p_0 as follows:

$$J^P(q_0;\theta) = \max_{p_0 \leq 0} \max_{c_t, \gamma_t \geq -p_t, Q_t} E_0 \left[\int_0^\infty e^{-\rho t}(y_t - c_t)dt \right] \tag{7}$$

subject to the evolution of cash-flows (1) - (2), the necessary evolution for promised utility / marginal utility (3) - (4) and the IC constraint (6), as well as, the initial conditions of the cashflows z_0, x_0 and the transversality conditions $\lim_{T\to\infty} e^{-\rho T} q_T = \lim_{T\to\infty} e^{-\rho T} p_T = 0$.

The optimal public CEO compensation contract of type θ is then given by

$$c_t^P(\theta, q_0) = c_f(q_0) + c_g(\theta)t + c_p(\theta)W_t \tag{8}$$

where $c_f(q_0) = -\frac{log(-\rho q_0)}{\psi}$ is the same base compensation as the contract with the private investor, $c_g(\theta) = \rho^2\pi(\theta)$ is the average drift in pay and $c_p(\theta) = \rho\sqrt{\frac{2\pi(\theta)}{\psi}}$ is the performance component of pay. Both the growth and performance components of pay depend on what we hereon refer to as the information premium $\pi(\theta)$, which for CARA utility takes the form

$$\pi(\theta) \equiv \frac{(1-\tau)^2\sigma^2\psi}{2(\rho + \frac{1}{\lambda_z})^2}. \tag{9}$$

Here we see a substantial difference in the type of compensation awarded to an agent of type θ contracted with a private or public investor. In the private case, the agent obtains a fixed initial level of promised utility q_0 reflecting the risk-premium the risk-neutral private investor can extract from insuring the cashflow risks. In the public investor case, incentive constraints distort the contract to ensure the agent finds it in their best interest to report the full cash-flows in each instant. To do so, the public investor must introduce some performance pay component $c_p(\theta)$ which is sensitive to the reported performance of the firm W_t^z. Because of the risk-aversion of the agent, to compensate the agent for this additional risk in their compensation the public investor must raise and backload the expected compensation given by $c_g(\theta)$.[15]

[15]Note that here over a sufficiently long time horizon, the investor 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 $\tilde{\rho} = \rho + \eta$.

3.5 Market for Firm Financing

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 q^A. Further, we abstract from firm differences in initial conditions by assuming all projects cash-flows are initiated at their unconditional means.[16] 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

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

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

where in the case of the public financier $B^P \to \infty$ (reflecting deep pockets) while the specialist financier has $B = B^S < \infty$.

Finally, the firms' (agents') listing choice selection rules, (i^P, i^S), $i^P(q_0^P, q_0^S; \theta) + i^S(q_0^S, q_0^P; \theta) \leq 1$, are simply the highest of the promised initial lifetime payoffs under the contract q_0^P, q_0^S and their outside option q^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.[17]

[16]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.
[17]See Appendix D for a formal definition of the partial equilibrium setting.

3.6 Partial Equilibrium Outcomes

Having outlined the model primitives, we move to characterizing the market allocations and prices for each firm type θ in the unit measure of firms distributed according to CDF $G(\theta)$. Comparing the compensation contracts of the private and public investor, it is evident that for a fixed firm type θ the private investor will earn higher profits over the public investor. In particular, observe that the expected difference in annual compensation, $c_{[0,1]} = \int_0^1 dc_t$, paid to a given agent with firm type θ between the public and private investor is simply $E[c^P_{[0,1]}|\theta] - E[c^S_{[0,1]}|\theta] = c_g(\theta)$. By direct computation, this annual average variable compensation translates into the following premium a private investor values a firm of type θ above that of the public investor.

Theorem 3.1. *The firm type$-\theta$ private equity premium is*

$$J^S(q_0;\theta) - J^P(q_0;\theta) = \pi(\theta) - \nu \tag{13}$$

where $J^S(\theta, q_0)$ is the surplus of the private specialist investor and $J^P(q_0;\theta)$ the surplus of the public investor.

From this result, we see that for any θ such that $\pi(\theta) - \nu > 0$, the private investor has a comparative advantage in financing this firm and so can bid the public investor's total surplus on the firm and still earn a positive profit. This premium arises entirely from the information rents paid by the public investor due to the persistent private information of the agent, which the representative private investor is able to forgo due to their monitoring technology.

Since the private investor has limited funds B, the private investor cannot finance all projects. As a consequence, the private specialist will prioritize their investment to firms with higher information rents $\pi(\theta)$ and allow the public investor 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 ($\bar{\tau}$).

By inspection of $\pi(\theta)$ it is clear the only relevant heterogeneity in firm type θ in our mechanism involves λ_z, τ, σ. Consequently, without loss of generality, we will hereon abstract from heterogeneity in the expected returns μ_i, $i \in \{x, z\}$ and persistence of observed cashflows λ_x, so that $\theta = (\tau, \sigma, \lambda_z)$.

Theorem 3.2 (Equilibrium firm sorting)**.** *Let $\underline{\pi}$ denote the minimal information premium financed by the private investor in equilibrium. The optimal sorting of firms into being privately funded for a given λ_z is given by*

$$\underline{\sigma}(\tau;\underline{\pi}) \equiv \sqrt{\frac{2\underline{\pi}}{\psi}\frac{(\rho+\frac{1}{\lambda_z})}{1-\tau}}. \tag{14}$$

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 investor.

INSERT FIGURE 1

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 premium cutoff $\underline{\pi}$ is pinned down by the budget constraint B if there is sufficient mass of information premia above their net costs of private equity financing ν. Otherwise, the budget constraint is immaterial and the information premium cutoff is simply given by the monitoring cost 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 can be expressed as

$$\underline{\pi}(B,\nu) = \max\{\bar{G}_\pi^{-1}(B), \nu\}. \tag{15}$$

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

$$\underbrace{\mathbb{M}(B,\nu)}_{\text{Mass of specialist (private) financed firms}} \quad = \quad \bar{G}_\pi(\underline{\pi}(B,\nu)). \tag{16}$$

3.7 Endogenizing Private Equity Funds

Up until now we have taken the amount of funds allocated to the private investor 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 shares of the public investment fund at competitive price s to earn a unit of the expected lifetime proceeds of the investment with payoff,

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

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 competition drives the public value to their cost of financing, $J^P(q_0^P, \theta) = 1$ in equilibrium for any firm the private investor finances, so the private 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 investors.

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), Becker (1974) or Gabaix and Landier (2008)) 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.[18]

Funds to private equity are then pinned down by the marginal private equity investor 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 $\nu \leq \nu^*$, $H \cdot F(\nu^*)$.

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

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.[19] The marginal investor will therefore have monitoring cost ν^* so that $r(\nu^*) = 0$. Thus, an equilibrium in this context is pinned down by ν^* which solves

$$\nu^* = \bar{G}_\pi^{-1}(H \cdot F(\nu^*)) \tag{17}$$

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 (17) $\bar{G}_\pi^{-1}(HF(\nu^*)) \to \infty$ 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 3.3. *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*

$$B = H \cdot F(\nu^*) \tag{18}$$

and the marginal PE investor's monitoring cost implicitly given by $\nu^* = \bar{G}_\pi^{-1}(HF(\nu^*))$.

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:

$$\text{Average PE Return premium, } \Pi = \mathbb{E}[\pi(\theta)|\pi(\theta) \geq \nu^*] - \mathbb{E}[\nu|\nu \leq \nu^*] \tag{19}$$

and the average annual public CEO compensation is

$$\bar{C} \equiv E[c_t^P|\pi \leq \nu^*] = c_f + E[\pi(\theta)\rho^2|\pi \leq \nu^*] \tag{20}$$

[19] A positive expected return could easily be generated with imperfect diversification or aggregate risk, but would simply distract from our analysis without any substantive impact on the main results.

where $c_f = c_f(q^A)$.[20]

3.8 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 (e.g. NSMIA as studied by Ewens and Farre-Mensa (2020)) and (iii) the impact of costly public disclosure like the 2002 Sarbanes-Oxley (SOX) act (e.g. 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, $F(\nu)$. For simplicity in exposition, we will make the following two sets of restrictions on the distributions $G_\pi(\pi)$ and $F(\nu)$.

Assumption 3.1 (A1)**.** Assume that (1) the distribution of information premia $G_\pi(\pi)$ is log concave, and $\bar{G}_\pi(\pi) = 1 - G_\pi(\pi)$ log convex and (2) the distribution of monitoring costs $F(\nu)$ is log convex.

Assumption 3.2 (A2)**.** Assume that (τ, σ, λ) are independent, i.e. $G_\pi(\pi) = G_\tau(\tau) \cdot G_\sigma(\sigma) \cdot G_\lambda(\lambda)$.

As it will turn out from our empirical work in Section 6.3, the distribution of the information premium G_π will be consistent with A1. Unfortunately, $F(\nu)$ is a latent distribution which, lacking appropriate private equity data, we cannot feasibly assess. In this context, it is natural to define the partial equilibrium setting of Section 3.6 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. The following lemma establishes that aggregate funds to private investors, B (corresponding to an increase in ν^*), can unambiguously increase or decrease the average PE premium if the distributions fall within the class of log concave or log convex distributions respectively.[21]

[20] For simplicity, we set the average duration of a contract to be one year. Since tenure is exogenous in our setting (we have only stochastic contract breakdown), all our subsequent results hold regardless of the average tenure.

[21] 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

Lemma 3.4. *Suppose A1 (converse) holds, 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^*.*

Equipped with this lemma, we then examine three comparative statics. The first comparative static we consider is a proportional increase in all firms intangibility levels. The results are summarized in the next theorem.

Theorem 3.5. *Suppose firm intangibility is scaled up by $\xi > 1$ for all firms, i.e. $(1 - \tau') = \xi(1 - \tau)$, then in the short-run (i.e. no change in selection of public or private), the average PE premium Π and average public CEO compensation $\bar{c}$ increases. Further, if A1 holds, the change in the average PE premium remains positive in the long-run, while the long-run effect on the average public CEO compensation is ambiguous.*

Increasing firm intangibility in public firms while holding PE funds constant induces a higher information premium and thus requisite compensation for public CEOs. Similarly, this increase of intangibility increases the comparative advantage of the private investor for the private firms they were already financing, leading to a higher PE premium Π. In general equilibrium (in the long-run), more funds will flow into private financing and diminish the gains in the PE premium. The resulting attrition in public firms that have relatively high information premia in public markets similarly reduces the average public CEO compensation from the short-run effect. Whether the long-run effect leads to a on net higher or lower levels of PE premium or public CEO pay depends on the curvature of $G_\pi(\pi)$ and $F(\nu)$.

We now move to our second policy counterfactual inspired by the relaxation of funding restrictions to private equity provided by NSMIA 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.

Theorem 3.6. *Suppose funding restrictions on private investors are relaxed so that $\nu' = \frac{1}{\xi}\nu$ for some $\xi > 1$, and A1 holds then the average PE premium Π and average public CEO compensation $\bar{c}$ will decrease in the long-run.*

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log concavity properties, the sign is ambiguous and can depend on the level of aggregate funds B (or equivalently the cutoff ν^*).

In other words, with the relaxation of restrictions on private equity funds, more funds naturally flow to private equity markets. This will lower the average public CEO compensation due to the highest information rent firms switching to private financing. The effect on average private equity premia is ambiguous in general, but if $F(\nu)$ is log convex, the average PE premium will actually decrease in the long-run.

Finally, we move to our last comparative static, examining the imposition of additional disclosure requirements with the passage of SOX Act in 2002. There are broadly two possible interpretations of the outcomes of SOX: (i) that increased disclosure requirements did not ameliorate information frictions, but imposed additional costs to being public or (ii) that increased disclosure requirements did at least partially ameliorate information frictions between investors and firm insiders. The later (with disclosure costs set to zero) corresponds to the converse of Theorem 3.5, while the next theorem characterizes the pure costly and un-productive disclosure case.

Theorem 3.7. *Suppose publicly financed firms are subject to an additional cost $\iota > 0$ then in the short-run, (i) if ι sufficiently large so that $J^P(q^A, \theta) - \iota - 1 < 0$ for some θ with $\pi(\theta) < \nu^*$, a positive measure of firms ε will not be financed, and (ii) average public CEO pay decreases and PE premium increases. In the long-run, total private financing (i.e. ν^*) increases, and if A1 holds, then the PE premium Π will fall relative to the short-run, but the net long-run effect is ambiguous.*

This result predicts that in the extreme case that the imposition of extra disclosure requirements does not actually lead to any reduction in amount of hidden information cash-flows, a subset of firms which would otherwise be publicly funded are no longer financed whatsoever in the short-run. Further, these increased disclosure costs act as a transfer to the private investors, who now face less effective competition in financing a given firm. The selection of relatively intangible firms exiting the public markets, leads to a net reduction in the average pay of public CEOs. In the long-run, the higher profits the private investors earn per project leads to an expansion of funds directed to private markets, which diminishes the average private equity premium relative to the short-run.

4 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.[22] 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.[23] 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.[24] 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 5.3 we use Execucomp and Frydman and Saks (2010) historical data.

[22]S&P is the data provider for both Capital IQ and Compustat, where Capital IQ is a newer product 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.

[23]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

[24]Compustat Snapshot has historical listing information about the Compustat firms while the standard database only has header (contemporaneous) information. We use this database rather than CRSP due to it also providing coverage of minor stock exchanges (which we exclude from our analysis).

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 main 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.[25] 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

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

production function using the estimator by Wooldridge (2009).[26] 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 value of total assets.[27] 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).[28] 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.[29]

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

[26]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).

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

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

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

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.[30] 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.[31] 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 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

5 Empirical Results

Our theoretical results in Section 3.4 and Section 3.6 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.[32] We first examine the cross-sectional listing predictions of Theorem 3.2 in subsection 5.1. We then

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

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

[32] 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 6 where we estimate the parameters governing a firms information premium through the structure imposed by our model via a GMM structural estimation.

move on to assessing the cross-sectional public CEO compensation predictions given in Section 3.4 on the level and the performance-pay components in subsection 5.2. We conclude this section by considering some of the time-series and policy predictions from Section 3.8.

5.1 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).[33] We superimpose the sorting rule predicted by Theorem 3.2 (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 mis-classification 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 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.[34] This is consistent

[33]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.

[34]Observe that using Theorem 3.2, 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 6.

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.[35]

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.[36] The regression specification takes the following form for a firm i, in industry k and year t:

$$g(\text{Listed}_{i,t}) = \beta_0 + \beta_1 \log(\text{Tangibility}_{i,t-1}) + \beta_2 \log(\text{Volatility}_{i,t-1})$$

$$+\beta_3 \log(\text{Persistence}_i) + \Gamma X_{i,t-1} + \zeta_{t,k} + \varepsilon_{i,t}, \tag{21}$$

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.[37] 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

Our results of firm intangibility and cash-flow volatility on listing choice are consistent with the theoretical predictions in Theorem 3.2 across all six

[35]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/`.

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

[37]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.

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.

5.2 Testing Cross-Sectional CEO Pay Predictions

We present empirical tests of our theory predictions 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 (21) 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 our model's compensation predictions 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.[38]

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.

[38]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.

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 meaningful 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.[39]

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

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

provided in Table 5.[40] 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

5.3 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 3.8. In particular, we are interested in evaluating the effects of various implemented policies like NSMIA 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 (2010) data to evaluate the longer historical trends (extending back to the 1950s). As the data pertains to only large public firms in Compustat, we are able to improve the book measures of firm tangibility from Peters and Taylor (2017) with market prices of some intangible assets as computed by Ewens et al. (2020) and an alternative measure of intangibility based solely on the implied market value of a firm's patents provided by Kogan et al. (2017).[41] Details on variable definitions and construction are provided in Appendix A.[42]

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

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

[41]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.

[42]We thank Michael Ewens, Noah Stoffman and Carola Frydman for generously making their data publicly available.

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 find the level of CEO pay and equity share move in virtual lockstep.[43] 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 4a. This allows us to examine how the relative importance of key predictors in CEO compensation have varied over time and contribute to the observed historical evolution in CEO pay.

INSERT FIGURE 4a

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%

[43]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).

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 3, the effects of these policies. In Figure 4b, we depict the time-varying coefficients of intangibility and size on firm listing, while in Figure 5(a) we plot the time-varying intercept for firm listing regression, in Figure 5(b) we plot the time-varying intercept for the CEO pay regression and in Panel Figure 5(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 5a, we see little potential residual effect of NSMIA on CEO pay outside of what is accounted for by our other covariates, however from Figure 4a 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 4b 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 4b

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 4b 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 4a 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 3.6. 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 5c). 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 5

6 Structural Estimation

In this section we structurally estimate the model and quantitatively study some counterfactuals. In the remainder of this section we describe the estimation method. In Section 6.1 we apply our estimation method to firm listing data and evaluate the counterfactual where firm intangibility levels are returned to 1980. In Section 6.2, we estimate the model on public CEO compensation data and compare the persistence estimate across the two distinct methods. Finally, we examine and discuss time-variation in the estimates over our sample in Section 6.3.

We estimate the model using the generalized method of moments (GMM) developed by 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.[44] 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 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.[45]

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.[46] We estimate the model parameters by minimizing the objective function,

$$\widehat{\Theta} = \arg\min_{\Theta}\ \bar{g}_n(\Theta)' W \bar{g}_n(\Theta) \tag{22}$$

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)).

[44]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.

[45]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.

[46]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.

6.1 Estimation using Firm Listing Status

Guided by our model results on firm listing in Section 3.6, 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 of listed vs not listed is given by:

$$\log\left(\frac{Pr(L_i = 1)}{1 - Pr(L_i = 1)}\right) = \nu + b^*\left(\sigma^2, \lambda_z\right)(1 - \tau)^2 \tag{23}$$

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 $b(\Theta) = E[b^*] = \frac{-\mathbb{E}[\sigma^2]\psi}{2(\rho + \frac{1}{\lambda_z})^2}$ independent of the firm i and yielding the logistic regression:

$$E\left[\log\left(\frac{Pr(L_i = 1)}{1 - Pr(L_i = 1)}\right)\middle|\tau\right] = \nu + b(\Theta)(1 - \tau)^2. \tag{24}$$

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 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).[47] The full list of moments is given below. It consists of the two listing moments, the expected volatility in private cashflows, the dispersion in cashflow variance scaled by the expected variance in cashflows, the variance of physical investment and the autocorrelation of physical investment.[48]

[47] 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).

[48] The residual variance of cash-flows is $\tilde{\sigma}_Y^2 = V[y_t|\theta] - \tau V[x_t|\theta] = (1 - \tau)\frac{\sigma^2\lambda_z}{2}$ while 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.

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

where the autocorrelation of tangible cash-flows ρ_X is $\rho_X = \exp(-\frac{1}{\lambda_x})$, the estimation of persistence follows Han & Phillips (2010), $HP(w) = \frac{\sum_t \Delta w_{it}(2\Delta w_{it-1} + \Delta w_{it})}{\sum_t \Delta w^2_{it}}$, the residual variance of cash-flows is $\tilde{\sigma}^2_Y = V[y_t|\theta] - \tau V[x_t|\theta] = (1-\tau)\frac{\sigma^2 \lambda_z}{2}$, $\bar{\sigma}^2_{y_i}$ is average realized cashflow variance, $\sigma(\iota_i)^2$ is variance in physical investment and $F_i(\Theta) = \frac{1}{1+\exp(-(1-\tau_i)^2 b(\Theta) + \nu)}$.

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 estimating 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 $\Theta_c = (a_0, a_1, \sigma_x, \lambda_x)$.[49] 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^2_x (persistence λ_x). In other words, private information persistence is estimated to be 63% higher than the persistence implied by physical investment. 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

[49]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 Erickson and Whited (2002). See Appendix A.3 for more details.

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 6) that the log CDF of $\pi(\theta)$ is log-concave. We use this result combined with our theoretical comparative static findings in Section 3.8 to infer the effects of various policies in Section 6.3.

As our final exercise in this subsection, we consider the counterfactual that average firm intangibility levels were reduced to the levels observed in 1980 as measured by the universe of Compustat firms in 1980. We use the measure of firm intangibility computed by Ewens et al. (2020), which is an updated version of Peters and Taylor (2017) with market prices. However, due to the different sample coverage of our Capital IQ data to the Compustat we scale the implied squared intangibility to make the average of the two samples equal over our sample period of 1993 - 2016.[50]

We compute that average firm intangibility increased 47% from 1980 to our sample period from 18.2% to 26.8%. Using this change along with our structural estimates implies that returning intangibility levels to those in 1980 would increase the listing probability from 59.9% in our sample to 68.2%, that is an 8 percentage point increase. Further, using the implied information premium our public firms only, we find that substituting in the implied tangibility levels of the 1980s implies a 43% lower information premium, $E[\pi(\theta)_{1980}]$, whose percent reduction is equal to that of the average annual variable pay growth.

6.2 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 3.2) and the level, growth and performance sensitivity of public CEO compensation packages (given in Section 3.4).[51] 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 6.1. Instead, we seek to estimate the private information persistence parameter λ_z which is

[50] We use the median ratio of the squared intangibility as our adjustment factor of 0.59.

[51] We thank Mark Garmaise, our discussant at the 2019 USC PhD Finance conference, for the suggestion.

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 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 3.6 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, $V\left[\frac{dy_t}{dt}\right] = V\left[E[\frac{dy_t}{dt}|\theta]\right] + E\left[V\left[\frac{dy_t}{dt}|\theta\right]\right]$ which given that $E\left[\frac{dy_t}{dt}|\theta\right] = 0$ simplifies to

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

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.[52]

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

$$g^{CEO}(\lambda_z, x_i) = \frac{\text{total pay awards}_{it}\text{earnings change}_{it}}{\text{average cross-firm variance in earnings change}} - h_1^{CEO}(\Theta). \tag{25}$$

The results from 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 parameter identified on the listing moments.[53]

INSERT TABLE 6

6.3 Evaluating Structural Changes

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 3.8 and the evolution of the private equity premium computed by Harris et al. (2014). As was noted in Section 3.8, many of the comparative statics depend on the curvature of the distribution of the information premium $G_\pi(\pi)$ and the monitoring costs

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

[53]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 (25) we have $\frac{1}{\lambda_z} = \rho[\frac{1}{\bar{z}} - 1]$ 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.

$F(\nu)$. 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 6). We have thus verified from our estimation that the estimated distribution of information premia satisfies Assumption 3.1. Thus, provided $F(\nu)$ is log convex, we haver 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 3.4 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 $\nu^* - E[\nu|\nu \leq \nu^*]$ dominates the average PE information premium above the marginal info premium). Given this inference and temporarily 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 Theorem 3.5. 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.

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 5d 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. 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. 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. Contrasting 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. 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.[54]

7 Conclusion

Firm's reliance on intangible assets is a significant source of cross-sectional and time-series variation in firm public listing choice and public CEO compensation. Public CEOs in relatively intangible firms are paid more than CEOs of public firms with more tangible cash-flows, yet highly intangible firms are typically privately financed and have lower levels of CEO pay (even for the comparable levels of size, age and profitability). Public CEO pay began growing in the US at the same time that patents (an important intangible asset) and their contribution to firm value exploded around 1980. Since the dot com bubble collapse, public CEO pay growth has been less monotonic as a selection effect of high intangibility firms reduced their public listing propensities.

Our equilibrium framework generates these sorting and compensation patterns through a hidden information agency conflict and monitoring advantage of private investors. Our mechanism provides a micro-foundation to Glover and Levine (2017) who find that the size of agency issues implied by observed compensation contracts correlate strongly with firm intangibility. The hidden information friction is important to understand these patterns and account for findings by Gayle and Miller (2015) that CEOs are paid for luck in cash-flows whose risk profile they have no control over. Persistence in the hidden information, not only magnifies the agency friction, but generates a growing expected share of profits accruing to the CEO through the duration of the contract independent of the expected profitability evolution of the firm. Our estimates of private information from intangible sources are larger than those of Ai et al. (2016) identified from physical investment in a hidden action framework.

Our explanation for the rise in CEO compensation 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

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

production set of the firm. Such explanations predict increased levels of pay and feature performance sensitivity as a by-product of increasing outside options. Cziraki and Jenter (2020) provide evidence that only a small fraction of CEOs are substituted across firms and that the majority are promoted internally which motivates examination of complementary channels like ours of increasing private information.

A number of 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 (2018), 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 public and large private firms we do not find this overall positive association of intangibility and either 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. Alternatives to private financing like large institutional shareholders may be able to reduce the size of the information frictions for high intangibility public firms similar to private investors as suggested by Aghion et al. (2013) with the positive association between innovative activity 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 framework suggests the decline of US public firms is the efficient market equilibrium response to rising informational asymmetry between firm insiders and the general public. A richer model with welfare costs to wealth inequality and advantages to broader access to financial makers may (e.g. with highly concentrated wealth) entirely reverse the efficiency of private financing. In our static financing decision, differential returns between the private investors and the public investors have no dynamic effects on the future selection of firms. A simple dynamic extension of the model would imply that the highest ability private investors 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 for future work.

To increase public listings and reduce public CEO pay our model suggests improving accounting, general understanding and disclosure of intangible assets is key. However, transparency in intangible assets may be impossible without diluting their value or exposing them to increased litigation risk. Consequently, providing broader access to private investments through new investment vehicles for the broader public, or making alternative disclosure requirements may mitigate the diminishing value of public markets without unduly distorting market efficiencies.

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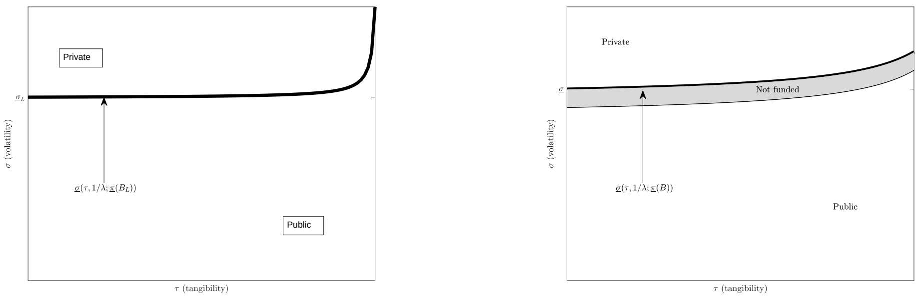
Appendix

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

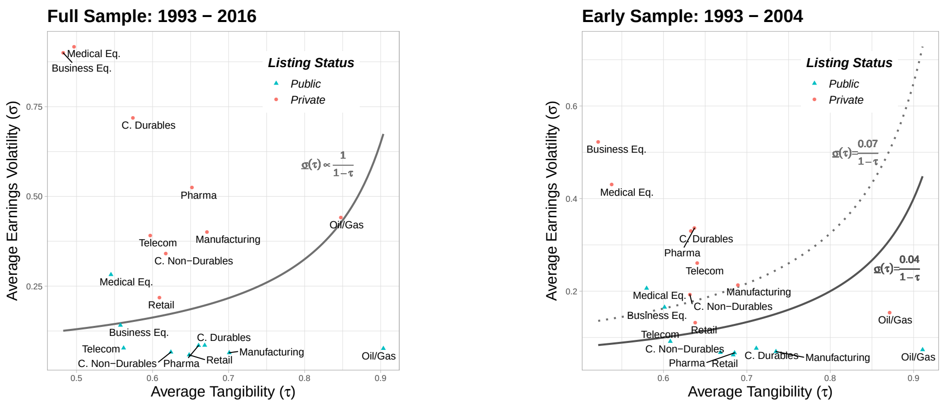
The left-hand graph depicts the model sorting predictions implied by Theorem 3.2 over tangibility τ and volatility σ of the intangible cash-flow process for a fixed level of private investor funding B and given level of persistence λ. All firms with (τ, σ) above the solid line are predicted by the model to be funded by the private investor, while all those below will be funded by the public investor. The right-hand graph depicts the effects of the sorting predictions implied by Theorem 3.7 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 investor.



(a) Baseline sorting predictions (b) Unproductive disclosure predictions

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.



(a) Firm Sorting on Firm Tangibility and Earnings Volatility, 1993- 2016

(b) Firm sorting based on firm intangibility and cash-flow volatility, 1993 - 2004

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.

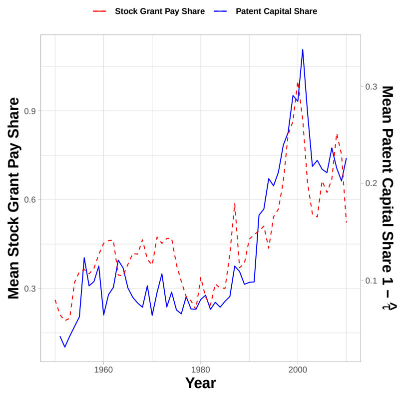
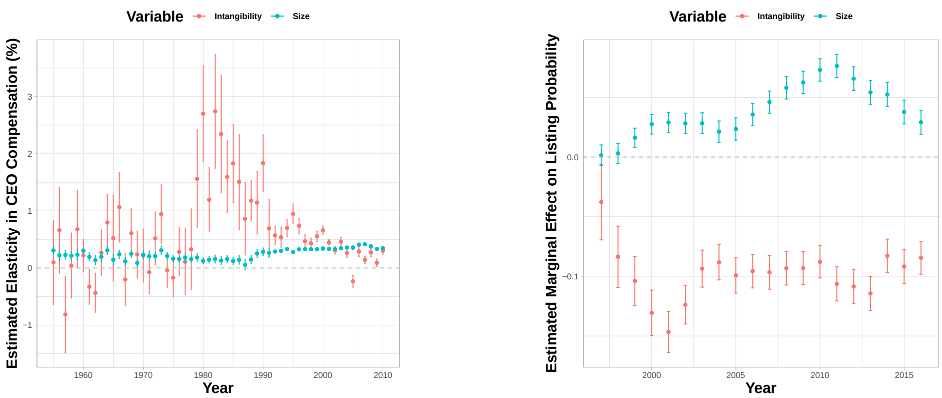


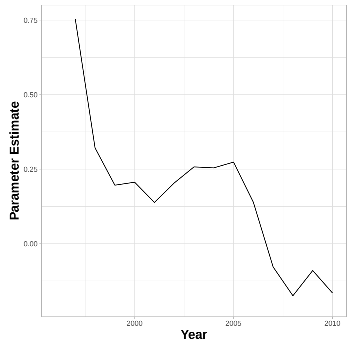
Figure 4: Annual Estimated Elasticities of Intangibility and Size on Pay and Listing Choice

The two figures depict the annual point estimates and standard errors of the elasticities of intangibility and size from regressions of the form $\log Y_{it} = \beta_t \log \text{Intangibility}_{it-1} + \xi_t \log \text{Volatility}_{it-1} + \gamma_t \log \text{Size}_{it-1} + \theta_t \text{Controls}_{it} + \varepsilon_{it}$ for Y_{it} as total public CEO pay or listing status on a top 3 US stock exchange. 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 for the CEO compensation regression consist of the largest 100 firms found in Frydman and Saks (2010) data. Due to the small number of firms, no additional controls are added for the CEO regressions. Listing status is obtained using CRSP / Compustat Snapshot and is applied to our full sample of firms in Capital IQ.

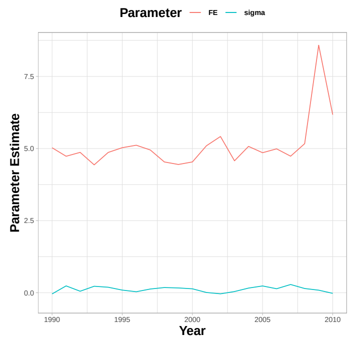


(a) Annual marginal effects on CEO pay (b) Annual marginal effects on listings

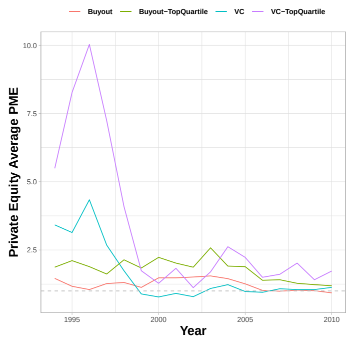
Figure 5: Evolution of Firm Listing, CEO Pay Time Intercepts and PE Premia
In panels (a) - (c), we plot the intercept from the annual listing choice regressions and CEO compensation discussed in Section 5.3 and contrast with the evolution of Private Equity Public Market Equivalent (PME) return premia estimated by Harris et al. (2014). In panel (d) we depict the structural estimates from the firm listing moments as in Section 6.1 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.



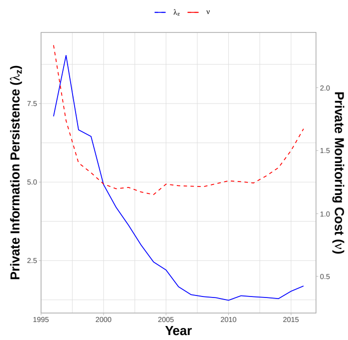
(a) Firm Listing Time-Varying Intercept



(b) CEO Pay Time-Varying Intercept



(c) Private Equity Public Market Equivalent (PME)



(d) Time-Varying Structural Estimates

Figure 6: 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.

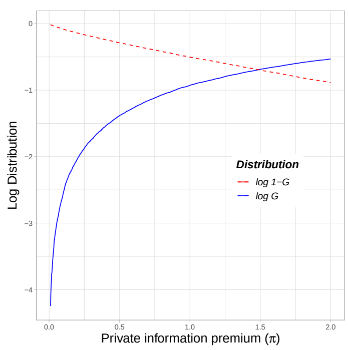


Table 1: Summary Statistics

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. Starred variable are in logs.

	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

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^{***}	-0.337^{***}	-0.330^{**}	-0.329^{***}
	(0.012)	(0.012)	(0.010)	(0.010)
Volatility ($\widehat{\sigma}_{it-1}$), t - 1	0.130^{***}	0.136^{***}	0.036^{***}	0.038^{***}
	(0.006)	(0.009)	(0.003)	(0.003)
Persistence ($\widehat{\lambda}_i$), t - 1	0.010^{***}	0.011^{***}	0.009^{***}	0.009
	(0.003)	(0.007)	(0.011)	(0.011)
Age, t - 1	0.104^{***}	0.098^{***}	0.059^{***}	0.053^{***}
	(0.007)	(0.007)	(0.007)	(0.007)
Size, t - 1	0.458^{***}	0.460^{***}	0.398^{***}	0.397^{***}
	(0.003)	(0.003)	(0.005)	(0.005)
Public , t - 1	0.298^{***}	0.302^{***}	0.254^{**}	0.256^{***}
	(0.014)	(0.014)	(0.011)	(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^{***}	-0.054^{***}	-0.053^{***}	-0.058^{***}	-0.070^{***}	-0.052^{***}
	(0.004)	(0.005)	(0.004)	(0.005)	(0.005)	(0.004)
Volatility ($\widehat{\sigma}_{it-1}$), t-1	0.019^{***}	0.030^{***}	0.020^{***}	0.008^{***}	0.002	0.008^{***}
	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)
Persistence ($\widehat{\lambda}_i$), t-1	0.0005	0.003^{***}	0.002^{**}	-0.001	-0.006	-0.006
	(0.001)	(0.001)	(0.001)	(0.004)	(0.005)	(0.004)
Age, t-1	0.034^{***}	0.011^{***}	0.029^{***}	0.026^{***}	0.005^{*}	0.023^{***}
	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.002)
Size, t-1	0.067^{***}	0.037^{***}	0.052^{***}	0.055^{***}	0.028^{***}	0.040^{***}
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)
Public , t-1	0.144^{***}	0.170^{***}	0.072^{***}	0.153^{***}	0.157^{***}	0.077^{***}
	(0.005)	(0.006)	(0.004)	(0.005)	(0.006)	(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 Section 6. CEO pay sensitivity moment is given in (25). 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	1.315	0.152
	(0.068)	(0.248)	(0.289)
Private - Monitoring (ν)	1.078		
	(0.036)		
Private - Volatility Shape (a_0)	2.654		
	(0.249)		
Private - Volatility Scale (a_1)	0.625		
	(0.007)		
Observable - Volatility (σ_x^2)	0.122		
	(0.007)		
Observable - Persistence (λ_x)	0.543		
	(0.010)		
N	10025	5878	

A Additional Data Details

A.1 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)

A.2 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 Frydman and Saks (2010) (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 analogous measure of intangibility for our main analysis computed by Ewens, Peters and Wang (2020) supplementing the method of Peters and Taylor (2017) with some market prices 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.[55]

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.

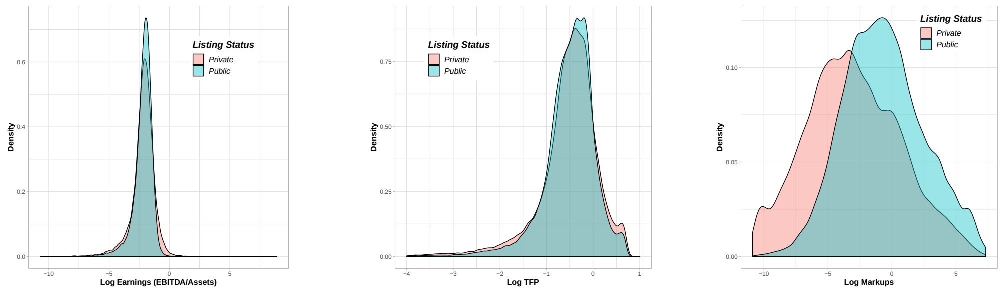
A.3 Details on the firm listing side structural estimation procedure

We conduct the structural estimation in two-stages.[56] 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.

[55]We thank Noah Stoffman for kindly publicly providing the data on firm's implied market value of patents and Michael Ewens for providing the data on firm intangibility.

[56]This sort of approach is discussed in Nelder & McFadden Chapter 4 and is akin to the two-step estimation approach in Erickson and Whited (2002). In theory the logistic regression could be converted into GMM moments as well for a simultaneous estimation, but .

Figure 7: Empirical distribution on full Capital IQ sample of public and private firms, 1993 - 2016.
Listed firms are on top 3 US stock exchange. Non-listed are not any US major or minor stock exchange.



(a) Log EBITDA/Assets (b) Log TFP (c) Log markups

B Details on contracting problem

B.1 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:

$$d\hat{y} = \tau dx_t + (1-\tau)dz_t - \frac{m_t}{\lambda_z}dt \tag{26}$$

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:

$$\max_{\Delta_s \geq 0} V(\Delta; c) = \max_{\Delta_s \geq 0} \mathbb{E}_0^{\Delta} \left[\int_0^{\infty} e^{-\rho t} u(c_t + m_t) dt \right] \tag{27}$$

subject to (1) - (2) 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.2 Financier's Contracting Problem

Lacking a monitoring technology, the public investor in designing an optimal compensation contract must take into account the agent's optimal reporting decision rules given by (27). 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 B.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:*

$$dq_t = [\rho q_t - u(c_t)]dt + \gamma_t \sigma dW_t^z \tag{28}$$

$$dp_t = [\rho p_t + (1-\tau)u'(c_t) - \lambda_z^{-1}\gamma_t]dt + Q_t \sigma dW_t^z \tag{29}$$

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.[57] 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 B.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*

$$p_t + \gamma_t \geq 0. \tag{30}$$

C Contracting proofs

The contracting results follow the same arguments as Williams (2011) but with $\tau \in (0, 1)$ and are given here for completeness.

Change of measure from P_0 to P_Δ

For a given path for Δ, define

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

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

$$W_t^\Delta = W_t^0 - \int_0^t \left[\frac{\mu\left(\frac{\tilde{y}_t}{(1-\tau)A} - m_t\right) + \Delta_s}{\sigma} \right] ds. \tag{31}$$

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

[57] 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.

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

subject to

$$d\Gamma_t = \frac{\Gamma_t}{\sigma}[\mu(z_t - m_t) + \Delta_t] dW_t^0 \tag{32}$$

$$db_t = \Gamma_t \Delta_t dt + \frac{b_t}{\sigma}[\mu(z_t - m_t) + \Delta_t] dW_t^0 \tag{33}$$

$$b_t = \Gamma_t m_t$$

$$m_t^y = (1 - \tau) A m_t dt.$$

Proof of Lemma B.1 and Lemma B.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 (32) and (33) we have

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

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

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

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

$$(2) \qquad d\Omega_t = \rho \begin{bmatrix} q_t \\ p_t \end{bmatrix} - \frac{\partial \mathcal{H}}{\partial A} dt + \Lambda_t \sigma dW_t^0,$$ [58]

[58]Note here in an abuse of notation we replaced $A\sigma$ with σ since we later normalize $A = 1$.

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 (31) we obtain the final form of (28), (29).

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.

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 $Q_t = (-k_0)^2 q_t = -(1 - \tau)^2 \psi^2 (\frac{\tilde{\rho}}{\tilde{\rho} + \frac{1}{\lambda}}) q_t$.

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.

Proof of extension with stochastic job-destruction

Here we establish that with Poisson arrival of an exogenous job destruction at rate η, the effective discount rate of both principal and agent becomes: $\tilde{\rho} = \rho + \eta$ with no other adaptations to the results.

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

$$q_t = \begin{cases} \int_t^T u(c_s) \exp(-\rho s) ds, & N_s = 0 \\ q_t^A = \int_t^T u(c^A) \exp(-\rho t) ds, & N_s = 1. \end{cases}$$ [59]

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

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

<u>Proofs for Section 3.4</u>

HJB for public financier is, reframing $\tilde{J} = -J$ (so that we are finding the min rather than max) and using the fact that W_t^x is independent of W_t^*:

$$\rho\tilde{J}(z, x, p, q; \theta) = \min_{c,Q,\gamma\geq -p} c - y + J_z\mu(z) + \tilde{J}_x\mu^x(x) + \frac{1}{2}\tilde{J}_{zz}\sigma^2 + \frac{1}{2}J_{xx}\sigma^2$$
$$+J_q[\tilde{\rho}q - u(c)] + \tilde{J}_p[\tilde{\rho}p - \gamma\lambda^{-1} + (1-\tau)u'(c)] + \frac{\sigma^2}{2}\big[\tilde{J}_{qq}\gamma^2 + 2\tilde{J}_{qp}\gamma Q + \tilde{J}_{pp}Q^2\big]$$
$$+\sigma^2\big[\tilde{J}_{zq}\gamma + \tilde{J}_{zp}Q\big].$$

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

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

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

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

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

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

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

Combining this with the FOC/solution for Q we have

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

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

$$\tilde{\rho} j_0 = \frac{\log\psi}{\psi} + j_1(1-\tau)\mu_0 + j_1^x\tau\mu_0^x \tag{34}$$

$$\tilde{\rho} j_1 = -(1 + \frac{j_1}{\lambda}) \tag{35}$$

$$\tilde{\rho} j_1^x = -(1 + \frac{j_1}{\lambda^x}) \tag{36}$$

$$\tilde{\rho} j_2 = \frac{1}{\psi} \tag{37}$$

$$\tilde{\rho} h(k) = \frac{h'(k)k}{\lambda} + \frac{1}{\psi}\log\left(j_2 + h'(k)(k - \psi(1-\tau))\right) + \frac{\sigma^2 k^2}{2}\left[j_2 - \frac{(h'(k))^2}{h''(k)}\right]. \tag{38}$$

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 (29), (28) 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).

Solving the above system of equations and plugging in k_0 yields the public principal value function ($J^P = -\tilde{J}^P$) where we use the fact that $h'(k_0) = 0$ and so

$$\tilde{\rho} h(k_0) = \frac{1}{\psi} \log(\frac{1}{\tilde{\rho}\psi}) + \frac{\sigma^2}{2\tilde{\rho}\psi} k_0^2. \tag{39}$$

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

$$c(z,x,q,p) = \frac{1}{\psi}\Bigg(\log(\frac{1}{\tilde{\rho}} + \psi h'(k)(k - \psi(1-\tau)) - \log(-q) \Bigg) \equiv -\frac{\log(-q\hat{c}(k))}{\psi}. \tag{40}$$

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:

$$dq_t = -\sigma k_0 q_t dW_t^*. \tag{41}$$

Solving this directly we obtain

$$q_t = q_0 \exp\left(-\frac{\sigma^2 k_0^2}{2} t - k_0 W_t \right) \tag{42}$$

or, in terms of consumption,

$$c_t = \bar{c}(q_0) + \frac{\sigma^2 k_0^2}{2\psi} + \exp\left(-\frac{k_0^2}{2}t - k_0 W_t \right). \tag{43}$$

D Partial equilibrium proofs

D.1 Financing Equilibrium Definition

Given agent's outside options q^A, 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 outside option q^A 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 (7) yielding $J^P(q_0; \theta)$
   (b) $(c, \gamma, Q, p_0)^S$ solves (5) 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 $i^S(q_0^P, q_0^S; \theta, q^A)$, value from contract $J^S(\cdot)$, financing demands $f(\theta) = 1$, monitoring cost ν and budget constraint B, financier S chooses the bid $q_0^S(\theta)$ that is a best-response, i.e. solving (10)
   (c) Entrepreneur's make financing choice $i^P(q_0^P, q_0^S; \theta), i^P(q_0^P, q_0^S; \theta, M_0) \in \{0, 1\}$, $i^P(q_0^P, q_0^S; \theta) + i^S(q_0^S, q_0^P; \theta) \leq 1$ maximizing promised utility $q_0(\theta)$ subject to their outside option $q^A(\theta)$
   (d) Financier's P, S and each entrepreneur θ's beliefs are consistent.

D.2 Proof of Theorem 3.2

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 $q_0^S = q_0^P \geq q^A(\theta)$. 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. $J^P(q_0^P) = 1$ with the entrepreneur being financed by the specialist is the unique, symmetric bid equilibrium for this case where the specialist has the comparative advantage.

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

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 $J^P(q_0^P) > 1$ and $q_0^P > q^A(\theta)$ then the public financier always has a positive deviation until $q_0^P = q^A(\theta)$. 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 $q_0^P = q^A(\theta) = q_0^S$ with the entrepreneur financed by the public financier is the unique, symmetric bid equilibrium in this case.

Asymmetric bid equilibria:

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 $q_0^S < q^A(\theta) = q_0^P$ 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 q^A (whereby he receives surplus $< \pi(\theta) - \nu \leq 0$).

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.

□

E Market equilibrium proofs

E.1 Proof of Lemma 3.4

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).

□

E.2 Proof of Theorem 3.5

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'.[60] With Assumption 3.1, these conditions are satisfied.

Finally observing that the transformation of G' is linear, by Corollary 5, we have the result.[61]

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.

□

E.3 Proof of Theorem 3.6

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

□

E.4 Proof of Theorem 3.7

Proof. (i): For $\theta : \pi(\theta) < \nu^*$, the private financier is rationed and cannot feasibly bid on these firms. Consequently the public financier prior to the implementation of the cost ι makes a take-it-or-leave it offer to the entrepreneurs in this set, yielding $J^P(V^A, \theta) - 1 \geq 0$. With ι sufficiently large, $J^P(V^A, \theta) - \iota - 1 < 0$ automatically implies it is no longer individually rational for the public financier to bid on this type θ.

The private financier in bidding against the public financier can now reduce their promised utility bid q_0^P from solving $J^P(q_0, \theta) - 1 = 0$ to $J^P(q_0, \theta) - \iota - 1 = 0$. Now as this does not change the amount of capital that needs to be injected into the firm, but simply changes the equity split, the private financier still funds the same set of firms as before but gains ι in additional profits from each firm due to the lower competition.

[60] 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 $log'(H) = \tilde{\Pi}$.

[61] Observe that we could apply 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.

Further, using same arguments as earlier average public CEO pay decreases in the short-run unambiguously due to the selection of the highest intangible public firms exiting (that is a higher cutoff $\nu_1 = \nu_0^* + \iota > \nu_0^*$).

(ii): In the long-run, additional funds will be supplied to the private financier to fund all the unfunded projects above. Suppose not, then for $\nu \in (\nu_0, \iota + \nu_0)$ the investor earns zero profits from keeping their funds invest publicly, while they could earn strictly positive profits by investing privately (given the assumption all projects are positive NPV for the private financier as assumed initially).

No change in the public CEO compensation occurs relative to the short-run.

□