Repeated Signaling and Firm Dynamics*

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Abstract

As an alternative to the pecking-order, we develop a dynamic calibratable model where the firm avoids mispricing via signaling. The model is rich, featuring endogenous investment, debt, default, dividends, equity flotations, and share repurchases. In equilibrium, firms with negative private information have negative leverage, issue equity, and overinvest. Firms signal positive information by substituting debt for equity. Default costs induce such firms to underinvest. Model simulations reveal that repeated signaling can account for: countercyclical leverage; leverage persistence; volatile procylical investment; and correlation between size and leverage. The

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model generates other novel predictions. Investment rates are the key predictor of abnormal announcement returns in simulated data, with leverage only predicting returns unconditionally. Firms facing asymmetric information actually exhibit higher mean Q ratios and investment rates.

1 Introduction

Three decades have passed since Ross (1977) and Leland and Pyle (1977) developed the signaling theory of corporate finance. Although their work has been extended, signaling models remain static and qualitative, making it impossible for empiricists to assess the theory's ability to match observed time-series moments. Further, most signaling models ignore investment. This further hinders empirical testing, and also makes it impossible to assess the impact of signaling on the real economy. The objective of this paper is to fill the existing void, and facilitate empirical testing, by developing a *dynamic signaling theory* of corporate financing and investment. The model is rich in that debt, default, equity flotations, dividends, share repurchases, and investment are all determined endogenously, as is the evolution of net worth.

A second objective is to demonstrate that dynamic signaling theory merits as much attention as the pecking-order of Myers (1984), which is currently the most commonly tested theory of corporate behavior under ex ante hidden information. We base this claim on four arguments. First, our model explains observed departures from the pecking-order such as equity-first financing by firms with ample debt capacity (see Leary and Roberts (2009)).[1] Second, the pecking-order cannot explain abnormal returns surrounding corporate policy announcements since it is based upon a pooling equilibrium. Third, our theory stands in contrast to the pecking-order in modeling investment and retentions endogenously. The failure to model these policies creates a bias in favor of the pecking-order in empirical horse-races, since these remaining variables effectively become free parameters. Finally, we show signaling theory explains a much broader set of stylized facts than previously recognized, especially those related to investment and leverage dynamics.

[1] See also Lemmon and Zender (2008) for tests of the debt capacity channel.

The model features only two financial frictions: superior information held by a controlling insider-shareholder and bankruptcy costs. The firm has a single scalable production technology, and the capital is fungible. The firm is hit with independent (public) macroeconomic shocks and a Markovian private shock affecting the future productivity of capital.[2] The private shock is observed by the insider at the start of each period, with outsiders observing the shock with a one-period lag. Using her temporary information advantage, the insider maximizes the value of her equity stake.

An insider-shareholder with positive private information benefits from credibly signaling the information, since this allows her to avoid debt underpricing and excessive equity dilution that would result if investors pooled her firm with the low type.[3] We show leverage is a credible signal, with the high type being more willing than the low type to assume higher debt in exchange for lower equity flotations (higher share repurchases). Bankruptcy costs make this signal costly.

The *baseline model* confines attention to *least-cost separating equilibria* (LCSE below). In LCSE, the high type chooses the financing and investment policies that maximize the value of her equity stake, subject to the constraint that the low type prefers not to mimic. If net worth is high, this no-mimic constraint is slack and the high type simply finances desired investment with internal equity. If net worth is low, the high type must raise a large amount of external funds to implement desired investment. Here the no-mimic constraint binds since issuance of a large block of securities creates a strong temptation for low types to mimic and gain from selling overvalued securities. In order to deter mimicry, the high type signals by financing with debt. The possibility of default on the debt, and concomitant bankruptcy costs, reduces the expected return on real capital, causing the high type to underinvest.

The low type only finances with equity, since there is no need for him to signal. A standard result in static signaling models is that low types implement first-best investment, issuing zero debt and holding zero cash. In contrast, our model predicts that low types overinvest and hoard cash. In order to motivate this result, we recall that type is Markovian

[2]The theoretical framework actually accommodates private information confined to assets-in-place. Due to space limitations, we do not simulate that model.

[3]We here emphasize that type is not permanent in the model. Instead, type is governed by a Markov process.

in our model. Regardless of their current type, firms realize they will incur signaling costs in subsequent periods if their future type is high and they require external funds. The desire to avoid signaling costs creates an endogenous precautionary motive to hoard cash and (fungible) capital. This precautionary motive biases low types away from static first-best policies. Conversely, this precautionary value of internal funds induces an indirect cost for high types signaling via leverage, as debt service depletes their valuable stock of internal funds.

The first set of novel predictions from the model concerns investment. Simulations of the calibrated model reveal that asymmetric information results in a lower average capital stock. This is consistent with the conventional wisdom that asymmetric information induces underinvestment. However, empiricists often focus on investment rates. In contrast to the conventional wisdom, an economy with asymmetric information actually exhibits a higher average investment rate than an equivalent economy with symmetric information. Although asymmetric information reduces average investment levels, it also reduces the capital stock, resulting in higher investment rates.

This decline in capital stock also leads to an interesting prediction regarding Q ratios. In simulated data, firms facing asymmetric information actually exhibit higher mean Q ratios than those operating under symmetric information. Although costly signaling reduces the numerator of Q, it also reduces the denominator. Consequently, Q is actually inversely related to transparency and allocative efficiency. This finding casts doubt on cross-country empirical studies using Q as a proxy for allocative efficiency.

The simulated model is consistent with the finding of Fama and French (2002) that there is a positive relation between leverage and firm size (which they proxy by capital). This stylized fact is commonly attributed to collateral value. In our model firms with positive information choose higher capital stocks and credibly signal this information by financing with debt, resulting in positive correlation between leverage and size.

Model simulations show that signaling results in volatile procyclical investment. In the simulated economy with asymmetric information, negative macroeconomic shocks reduce subsequent investment even though we rig the model with independent macroeconomic shocks. After a negative shock net worth is low. High types respond by increasing leverage as they go external for funds, with default costs inducing underinvestment. Signaling also increases investment volatility dramatically relative to the symmetric information benchmark. These quantitative results complement those of Carlstrom and Fuerst (1997), who show that such financial accelerator effects can be explained by ex post private information.

The other set of novel predictions concerns announcement effects.[4] The calibrated model represents an ideal laboratory since we can perfectly isolate announcement effects in simulated data and analyze their determinants. McConnell and Muscarella (1985) document equity returns of 1.2% surrounding increases in capital budgets and -1.5% for decreases. Consistent with this evidence, in simulated data investment rates predict abnormal returns unconditionally and conditionally.[5] This stems from the fact that our model assumes private information concerns the future productivity of capital.

Masulis (1983) documents a 14% primary announcement return in debt-for-equity exchanges and a -10% return in equity-for-debt exchanges. This finding is consistent with our model's single-crossing condition which predicts that marginal substitutions of debt-for-equity represent a positive signal. This finding is also consistent with static signaling models where private information concerns future productivity, e.g. Ross (1977), but not those where private information concerns net worth, e.g. Miller and Rock (1985).

Nandy, Kamstra and Shao (2008) document that the announcement return to leverage is particularly high for firms that begin floating debt after having been "equity types" in prior years. Our model is consistent with this finding. In simulated data, leverage has some power to predict abnormal returns unconditionally. However, the predictive power of leverage is much higher if we interact it with a dummy variable for a switch from no debt to positive debt. The intuition is simple. Persistence in type implies that there will be a particularly high abnormal return if a firm moves from issuing zero debt to positive debt, since the market will make a large revision in belief from its uninformed prior.

In the simulated data, leverage ratios only predict abnormal returns if the investment

[4]See Eckbo, Masulis and Norli (2007) for a comprehensive survey of event studies on announcement effects.

[5]In the model, markets are semi-strong efficient but not strong-form efficient. An agent who knew the policy announcement beforehand could make abnormal returns.

rate is not included as a conditioning variable. In the model, there is always a large gap between the investment of high and low types, regardless of net worth. However, the gap between leverage ratios is only high when net worth is low. Consequently, real investment is the best predictor of abnormal announcement returns in the simulated data.

Consistent with the findings of Korajczyk and Levy (2003), the model generates countercyclical leverage. Negative macroeconomic shocks reduce net worth in subsequent periods. This forces firms with positive information to substitute debt for equity as they go external for funding. The same mechanism explains the model's prediction that leverage ratios decrease with net worth, consistent with the findings of Fama and French (2002). Myers (1984) makes similar predictions.

An interesting prediction of the model is that firms with negative information will have negative leverage and finance with external equity. Thus, the model may help to explain the following finding of Leary and Roberts (2009): "Among larger, older, or more capital intensive firms, for which debt capacity is less likely to be a concern, we still find that the pecking order accurately classifies only a minority of financing decisions...debt capacity concerns do not appear to be the motivation for the majority of firms whose equity issuances violate the pecking order."[6]

Our model may also help to explain the leverage persistence puzzle documented by Lemmon, Roberts and Zender (2008). The simulated leverage ratio is highly persistent despite the fact that debt is chosen period-by-period, and despite the fact that there are no direct transactions costs. In our model, leverage persistence is due to two factors. First, leverage is a function of the firm's private type, and type is persistent. Second, leverage is a function of net worth, and net worth is also persistent.

We now discuss related theoretical models. Leland and Pyle (1977) were the first to show that managerial equity stakes are a positive signal, while Ross (1977) was the first to show the signaling value of debt. Our model features both results.

Myers and Majluf (1984) show that firms with positive private information regarding assets-in-place may forego a non-scalable investment if constrained to financing with equity. They then describe a *pooling* equilibrium in which both types finance with debt, since this

[6] An alternative explanation of this finding is an entrenched CEO averse to debt.

reduces the cross subsidy from the high to low type.[7] In contrast, our theory is based upon a *separating* equilibrium. Importantly, only a theory based upon separating equilibria predicts announcement effects, since no information is revealed if firms pool. Further, our model predicts that low types will finance with equity despite having ample debt capacity.

Constantinides and Grundy (1990) show that asymmetric information need not induce pooling nor underinvestment. In their model, with costless bankruptcy, first-best investment is achieved with the firm issuing debt in excess of the amount needed to fund investment, with excess funds used for share repurchases. Aside from introducing dynamics, we depart from Constantinides and Grundy by introducing default costs. It is this feature of our model that allows it to generate cyclicality of investment and a financial accelerator effect.

Our model differs from static models in five respects. First, we model the evolution of the capital stock. Second, we show that the equilibrium set of each periodic signaling game changes with net worth. Third, the utility of the insider depends on endogenous equity value functions that capitalize the payoffs in all future signaling games. Fourth, in static models, default occurs when debt exceeds internal funds. Finally, in a static setting, the firm necessarily distributes all cash.

Maskin and Tirole (1992) develop a general algorithm for computing the set of perfect Bayesian equilibria (PBE) in static signaling games. We develop a tractable recursive approach for numerically computing PBE for infinitely-lived public firms. Lucas and McDonald (1990) develop a dynamic model of investment under long-lived hidden information with only equity financing. Morellec and Schurhoff (2007) examine the effect of hidden information on the timing and financing of a single growth option.

The remainder of this paper is organized as follows. Section 2 describes the economic setting. Section 3 characterizes separating equilibria. Section 4 presents the model calibration and simulation. Section 5 discusses pooling equilibria. Section 6 concludes.

[7] See also Nachman and Noe (1994).

2 The Economic Environment

2.1 Technology

Time is discrete and the firm's horizon is infinite. There is a riskless asset paying interest rate $r > 0$. All parties are risk-neutral and share the discount factor $\beta \equiv (1+r)^{-1}$. Physical capital (k) decays exponentially at rate $\delta \in [0,1]$. We impose standard restrictions on the firm's profit function.

Assumption 1. *The operating profit function $\pi : \mathcal{K} \times \Theta \times \mathcal{E} \rightarrow \Re_+$ has the following properties: (i) weakly positive; (ii) strictly increasing; (iii) strictly concave in capital; (iv) twice continuously differentiable; and (iv) satisfies the Inada conditions.*

The price of capital is one. Following Cooley and Quadrini (2001), there are no costs to adjusting the capital stock.

Assumption 2. *The physical capital stock is perfectly reversible.*

Assumption 2 limits the number of state variables. Since capital is perfectly reversible, it may be added to cash to compute fungible net worth (w_t).

The driving processes are described next. For reasons made clear below, θ_t is labeled a private shock and ε_t a public shock.

Assumption 3. *The private shocks $\{\theta_t\}_{t=1}^{\infty}$ take values in $\Theta \equiv \{\theta_L, \theta_H\}$ and follow a first-order Markov process with no absorbing state. The public shocks $\{\varepsilon_t\}_{t=1}^{\infty}$ are independently and identically distributed with a continuously differentiable density function $f : [\underline{\varepsilon}, \infty) \rightarrow [0,1]$ satisfying $f(\varepsilon) > 0$ for all $\varepsilon \geq \underline{\varepsilon} > 0$.*

Let $p(\theta_i|\theta_j)$ denote the probability of θ_i conditional on lagged type θ_j.

The firm can finance its activities using internal resources, external equity, or debt. Funds may be distributed to shareholders using dividends or share repurchases. In distinguishing between alternative modes of distribution, the model is unique within the class of dynamic structural models. Dividends (d) cannot be negative.[8] The face value of debt is denoted b and the price of debt is denoted ρ. The borrowing technology is similar to that assumed by Cooley and Quadrini (2001). However, the method used to determine the default threshold is different. Cooley and Quadrini (2001) allow shareholders of a distressed firm to directly inject their own funds to meet an outstanding debt obligation. In our model, funds can only be raised from *bona fide* uninformed outside investors. The next assumption summarizes the set of available contracts.

Assumption 4. *The contract space consists of equity and single-period debt. Default occurs if the firm cannot raise sufficient funds in its next financing round to meet an outstanding debt obligation. Lenders are senior in default and incur proportional* ($\phi > 0$) *bankruptcy costs.*

Following Carlstrom and Fuerst (1997), Gomes, Yaron and Zhang (2003) and Cooley, Marimon and Quadrini (2004), the firm faces the risk of a catastrophic event (exponential death). As concrete examples, one may think of the catastrophic event as approximating mass tort claims for defective products or expropriation by a government.

Assumption 5. *Each period there is a probability* $1-\gamma$ *of a catastrophic event, where* $\gamma \in (0,1)$. *If a catastrophic event occurs, all marketable claims on the firm are worthless.*

As noted by Carlstrom and Fuerst (1997), an infinitely-lived firm facing an imperfect financial market will save all funds if it can earn the same rate of return as investors. In such a setting, the effect of financial frictions vanishes over time as the firm builds up its cash reserve and becomes self-financing. However, the possibility of a catastrophic event provides a countervailing cost to saving within the corporate shell.[9] Assumption 5 stands in contrast to existing models which commonly apply a higher effective discount rate in equity markets than in debt markets. Such models create an exogenous bias against equity as a source of

[8]A negative dividend corresponds to a rights-issue. A rights-issue would be the preferred source of external funding given asymmetric information. One can rationalize the dividend constraint by appealing to shareholder wealth constraints outside the model.

[9]Corporate income taxes also discourage saving within the firm. However, the introduction of a corporate income tax would greatly complicate the analysis and limit our ability to compare results with other models in this literature which uniformly assume exponential death.

external finance. Assumption 5 ensures debt and external equity face the same catastrophic risk and the same effective discount factor ($\beta\gamma$).

In terms of the real and financial technologies available to the firm, the model is a standard neoclassical investment framework. Our point of departure is the introduction of hidden information.

Assumption 6. *At the end of period t, realized profits are $\pi(k_t, \theta_t, \varepsilon_t)$. The shock θ_t is privately observed by a controlling insider-shareholder at the start of period t. At the end of period t, the realized values of ε_t and net worth are observed simultaneously by all agents.*

Assumption 6 implies the insider has a one-period information lead relative to outsiders each period. To see this, note that an outsider can infer θ_t after observing net worth and the public shock at the end of period t. Although the private information can be inferred with a one-period lag, we assume this information is not verifiable in a court. Intuitively, it would be difficult to prove to a court that a firm's poor performance stemmed from negative private information rather than negative macroeconomic shocks.

Since any information advantage is short-lived, truthful revelation is here easier to achieve than under fixed types. The second part of Assumption 6 (observability of w_t *and* ε_t), which allows outsiders to infer the lagged type is not essential. The model encompasses i.i.d. types as a special case. If types are i.i.d., one may assume outsiders can only observe net worth and the results stated below remain valid.

Insider objectives, stated as Assumption 7, are identical to those assumed by Constantinides and Grundy (1990).

Assumption 7. *The choice of contracts is made by a risk-neutral infinitely-lived insider who maximizes the expected discounted value of the future dividends coming from fixed stock holdings.*

The insider holds a fixed number of shares of stock, denoted $m > 0$. Total shares outstanding at the start of the period is c. Shares are issued and repurchased ex dividend. The number of new shares issued is n, with $n < 0$ indicating a share repurchase. Let $s \equiv n/(c+n)$ represent the percentage equity stake sold (with a negative s denoting share repurchases).

The insider receives a fraction m/c of total dividends and holds an equity stake of $m/(c+n)$ at the end of the period.

2.2 Issuance Games

Figure 1 provides a timeline. There is an infinite sequence of issuance games played between the insider and atomistic (competitive) outside investors. There are two state variables. The firm enters the period t financing round with net worth w_t and his lagged type, say θ_j. Both state variables are common knowledge given Assumption 6.

After privately observing his current type, say θ_i, the insider offers an *option contract* to outsiders. If accepted, the option contract gives the insider the right to choose between two allocations, say $(\mathbf{a}_{Lj}, \mathbf{a}_{Hj})$. Equivalently, one can think of the allocation being based on an announced type. An *allocation* is simply a vector determining financing and investment.[10] In particular, a generic allocation $\mathbf{a} = (b, d, k, s)$. We recall that b is the face value of debt, d the dividend, k the capital stock, and s the percentage equity stake sold to outside investors.

We define $\mathbf{a}_{ij}$ to be the allocation received by an insider reporting type i with known lagged type j. Without loss of generality, attention can be restricted to contracts inducing truthful reporting of the current type. Allowing allocations to be predicated upon the lagged type, which is common knowledge at the time of contracting, is important since the lagged type determines transition probabilities and investor priors. After receiving the option contract offer, outsiders update beliefs and accept or reject. If the offer is rejected, the insider cannot transact in the firm's securities that period. If the option contract is accepted, the insider is free to implement either $\mathbf{a}_{Lj}$ or $\mathbf{a}_{Hj}$.[11] Finally, the firm is exposed to the catastrophic risk.

At the start of period $t+1$, ε_t is commonly observed. Lenders then determine whether the firm will be able to deliver the debt obligation b_t coming due. In order to make this determination, lenders compute provisional net worth. The *provisional net worth* of a type-i

[10] Tirole (2006) uses a different definition of an allocation.

[11] Effectively, the parties to the option contract are entering into a direct revelation mechanism.

that took the type-j allocation is

$$\widetilde{w}(b_j, k_j, \theta_i, \varepsilon) \equiv (1-\delta)k_j + \pi(k_j, \theta_i, \varepsilon) - b_j. \tag{1}$$

There is a cutoff $w_i^d < 0$ such that a firm of type i can (and will) deliver the promised debt payment if and only if $\widetilde{w} \geq w_i^d$. As shown below, a firm with negative net worth may still have the ability to pay off its outstanding debt by issuing new securities against the going-concern value of the firm. This gives the firm additional risk-free debt capacity, over and above what is implied by a static model.

It is worth stressing that the default threshold w_i^d depends on the *actual current type*, which the lender is able to infer at the time of the default determination. Under the stated timing assumptions (Figure 1), the default threshold cannot possibly depend on the *next* realized type since that information is not yet available to any party at the time of the default determination.

This formulation allows the firm to pay the debt coming due (b_t) using a portion of the proceeds from the flotation of new securities in financing round $t+1$. To see this, note that for any $\widetilde{w} \in [w_i^d, 0)$, the firm has insufficient internal resources to deliver b_t and must therefore use new external financing to cover the debt.

If $\widetilde{w} < w_i^d$, lenders know the firm cannot possibly deliver the promised debt payment. In this case, lenders are forced to incur bankruptcy costs in order to reset the debt payment.[12] Recall, under Assumption 4 bankruptcy costs are a fraction ϕ of total asset value. After incurring bankruptcy costs, lenders reset the debt payment to the maximum amount consistent with shareholders' limited liability. This bankruptcy process leaves a defaulting firm to enter the upcoming financing round with net worth w_i^d. As verified below, resetting the debt payment in this manner leaves shareholders of a defaulting firm with a claim worth zero. The resulting law of motion for net worth is

$$w(b, k, \varepsilon, \theta_i) \equiv \max\{w_i^d, \widetilde{w}(b, k, \varepsilon, \theta_i)\}. \tag{2}$$

[12] In the U.S., bondholder unanimity is required to change any core provision of public debt outside formal bankruptcy. Most distressed firms enter the costly Chapter 11 bankruptcy forum in order to restructure public debt.

After the net worth w_{t+1} is determined, the insider privately observes θ_{t+1} and the next issuance game begins.

There are (only) two unknown value functions (V_L, V_H), with $V_j : [w_j^d, \infty) \to \Re_+$. Here $V_{\theta_t}(w_{t+1})$ denotes the total value of shareholders' equity for a firm that realized type θ_t in period t and entering the $t+1$ financing round with net worth w_{t+1}. It is important to stress that $V_{\theta_t}(w_{t+1})$ is computed after the lender makes the default determination, and thus does any resetting of the debt payment, but prior to the insider's observation of the next realized type (θ_{t+1}). In the special case where the type is i.i.d. there is no need to maintain the lagged type as a state variable and there is a single unknown value function V.

Since default occurs if $\widetilde{w} < w_i^d$, a firm of type-i taking the type-j allocation defaults for any $\varepsilon \leq \varepsilon_{ij}^d$ where ε_{ij}^d is defined implicitly by

$$\widetilde{w}(b_j, k_j, \varepsilon_{ij}^d, \theta_i) \equiv w_i^d. \tag{3}$$

Define Ω as the informed insider's expectation of the discounted value of total shareholders' equity given his true type θ_i, if he takes the type-j allocation:

$$\Omega(b_j, k_j, \theta_i) \equiv \beta\gamma \int_{\varepsilon_{ij}^d}^{\infty} V_i[(1-\delta)k_j + \pi(k_j, \theta_i, \varepsilon) - b_j] f(d\varepsilon). \tag{4}$$

The informed insider of type-i maximizes the cum-dividend value of his equity stake, which is equal to

$$\left(\frac{m}{c}\right) d + \left(\frac{m}{c+n}\right) \Omega(b, k, \theta_i). \tag{5}$$

Using the definition of s, the objective function for the type-i insider (5) simplifies to $(m/c)U_i(b, d, k, s)$ where

$$U_i(b_j, d_j, k_j, s_j) \equiv d_j + (1-s_j)\beta\gamma \int_{\varepsilon_{ij}^d}^{\infty} V_i[(1-\delta)k_j + \pi(k_j, \theta_i, \varepsilon) - b_j] f(d\varepsilon). \tag{6}$$

Conveniently, the multiplicative term m/c has no effect on incentive compatibility constraints. Appendix A shows the objective function in equation (6) is proportional to the insider's fractional claim on all future dividends accounting for dilution.

The function U_i in equation (6) is labeled the type-i *insider utility function* and is defined on the set of technologically feasible allocations[13]

$$\mathcal{A} \equiv \{\mathbf{a} : b \in \Re,\ d \geq 0,\ k \geq 0,\ s \leq 1\}.$$

Given a lagged type j, the option contract $(\mathbf{a}_{Lj}, \mathbf{a}_{Hj})$ is *incentive compatible* (IC) if

$$IC_L : U_L(\mathbf{a}_{Lj}) \geq U_L(\mathbf{a}_{Hj})$$
$$IC_H : U_H(\mathbf{a}_{Hj}) \geq U_H(\mathbf{a}_{Lj}).$$

In order to evaluate investors' response to an option contract, one must derive the fair value of debt. If provisional net worth $\widetilde{w} < w_i^d$ for a firm of type-i who took the type-j allocation, lenders demand a revised debt payment, call it $b_{ij}^r < b_j$, that leaves the firm with the minimum net worth w_i^d. Therefore, we compute b_{ij}^r using

$$(1-\delta)k_j + \pi(k_j, \theta_i, \varepsilon) - b_{ij}^r = w_i^d \Rightarrow b_{ij}^r = (1-\delta)k_j + \pi(k_j, \theta_i, \varepsilon) + \left|w_i^d\right|. \tag{7}$$

Equation (7) shows that in default, lenders seize the firm's capital, operating profits, and an amount $|w_i^d|$ which represents *going-concern value.*

Let χ be an indicator function equal to one if $b_j \geq 0$. The true value of debt issued by type-i under the type-j allocation is

$$\rho(b_j, k_j, \theta_i) \equiv \beta[\chi\gamma + (1-\chi)] \left[b_j \int_{\varepsilon_{ij}^d}^{\infty} f(d\varepsilon) + (1-\phi) \int_{-\infty}^{\varepsilon_{ij}^d} [(1-\delta)k_j + \pi(k_j, \theta_i, \varepsilon) + |w_i^d|] f(d\varepsilon) \right]. \tag{8}$$

An incentive compatible option contract is *profitable type-by-type* if it satisfies the budget constraints

$$BC_{i \in \{L,H\}}(w) : d_i + k_i - w \leq \rho(b_i, k_i, \theta_i) + s_i \Omega(b_i, k_i, \theta_i). \tag{9}$$

The left side of the budget constraint measures the amount of funding provided by investors and the right side measures the value of securities received in return.

[13]An additional constraint is that the firm cannot repurchase more than $c - m$ shares. That is, $s \geq -(c/m - 1)$. This constraint never binds for c/m sufficiently large.

An incentive compatible option contract is *profitable in expectation* (PIE) given lagged type j if it satisfies

$$PIE(w,\theta_j): \sum_{i\in\{L,H\}} p(\theta_i|\theta_j)[\rho(b_i,k_i,\theta_i)+s_i\Omega(b_i,k_i,\theta_i)-(d_i+k_i-w)]\geq 0. \tag{10}$$

Clearly, any contract that is profitable type-by-type is also PIE, but not conversely. Effectively, a PIE contract is one in which investors break even on average based upon their prior beliefs. Given the Markov structure of the model, priors are based upon the known lagged type. Importantly, a PIE contract allows firm types to pool at the same allocation, with cross-subsidies being provided from the high type to the low type, since the low type issues overvalued securities if he is pooled with the high type. The PIE contract will only become relevant in Section 5 where we consider the possibility for pooling equilibria.

Finally, an option contract is *interim efficient* if it is Pareto optimal (across firm types) within the set of option contracts that are IC and PIE. As shown below, the concept of interim efficiency plays an important role in determining the set of potential equilibria.

3 Least-Cost Separating Equilibria

Fix a point w on the net worth space and two equity value functions (V_L, V_H), which are conjectured to be increasing and concave. In a separating equilibrium, the current type is fully revealed by firms' choice of allocations, implying that separating allocations are independent of the lagged type.[14] Therefore, in a separating equilibrium the second index can be dropped, with

$$\mathbf{a}_{LL}=\mathbf{a}_{LH}\equiv\mathbf{a}_L^S$$
$$\mathbf{a}_{HL}=\mathbf{a}_{HH}\equiv\mathbf{a}_{H.}^S$$

[14]Section 5 shows that the lagged type is relevant if pooling occurs.

The (least-cost) *separating contract* $(\mathbf{a}_L^S(w), \mathbf{a}_H^S(w))$ relative to (V_L, V_H) is defined as follows:

$$\mathbf{a}_L^S(w) \in \arg\max_{\mathbf{a}\in\mathcal{A}} \quad U_L(\mathbf{a}) \quad s.t. \quad BC_L(w) \tag{11}$$
$$\mathbf{a}_H^S(w) \in \arg\max_{\mathbf{a}\in\mathcal{A}} \quad U_H(\mathbf{a}) \quad s.t. \quad BC_H(w),\ IC_L.$$

We define the payoffs corresponding to the separating contract as follows:

$$\Gamma_i^S(w) \equiv U_i[\mathbf{a}_i^S(w)]. \tag{12}$$

Maskin and Tirole (1992) show that separating allocations are always in the set of PBE.[15] Further, this will be the unique equilibrium if and only if it is interim efficient. Their theorem is modified here to account for the fact that the equilibrium set in our model varies with net worth. More importantly, their characterization of the equilibrium set is defined relative to exogenous utility functions. In our setting, the equilibrium set will ultimately be defined relative to two internally consistent equity value functions (V_L, V_H) which determine the insider utility function per equation (6).

Proposition 1 (Maskin-Tirole). *The set of perfect Bayesian equilibria at net worth w, relative to value functions (V_L, V_H), corresponds to all incentive compatible and profitable in expectation option contracts that weakly Pareto-dominate the separating contract.*

Since the incentive constraint (IC_L) plays an important role, it merits discussion. Rearranging the equation for IC_L, any high type allocation in the feasible set $(\mathbf{a}_H)$ must satisfy

$$[\rho(b_L^S, k_L^S, \theta_L) + \Omega(b_L^S, k_L^S, \theta_L) - k_L^S] - [\rho(b_H, k_H, \theta_L) + \Omega(b_H, k_H, \theta_L) - k_H] \tag{13}$$
$$\geq s_H[\Omega(b_H, k_H, \theta_H) - \Omega(b_H, k_H, \theta_L)] + [\rho(b_H, k_H, \theta_H) - \rho(b_H, k_H, \theta_L)].$$

The first line of equation (13) measures the efficiency gain to the low type from implementing policies that maximize his type-specific firm value, as opposed to mimicking

[15] Without loss of generality we may confine attention to $s_L \geq 0$. In such cases, Tirole's weak monotonic profit assumption is satisfied and the separating contract is equivalent to the low-information-intensity optimum or the Rothschild-Stiglitz-Wilson contract.

the high type. The second line measures the gain to the low type from masquerading as the high type and issuing mispriced securities. Equation (13) also illustrates the potency of share repurchases for achieving separation. Specifically, if $s_H < 0$ the low type is actually harmed by the mispricing of his securities since he is repurchasing shares at inflated prices and thus diluting his claim on future dividends.

3.1 Recursive Equilibrium

Proposition 1 characterizes the set of PBE in each period's signaling game taking the equity value functions as given. An intertemporal equilibrium requires the value functions to be internally consistent. Conveniently, the equity value functions can be defined recursively by taking expectations over future type-contingent payoffs. We say

$$\begin{aligned} w^d_{j\in\{L,H\}} &\in \Re_- \\ \widetilde{\mathbf{a}}_{ij\in\{L,H\}\times\{L,H\}} &: [w^d_j, \infty) \to \mathcal{A} \\ \widetilde{V}_{j\in\{L,H\}} &: [w^d_j, \infty) \to \Re_+ \end{aligned}$$

constitute a *recursive perfect Bayesian equilibrium* (RPBE) if: For each lagged type j and net worth $w \geq w^d_j$, $(\widetilde{\mathbf{a}}_{Lj}(w), \widetilde{\mathbf{a}}_{Hj}(w))$ is a PBE relative to $(\widetilde{V}_L, \widetilde{V}_H)$; (Endogenous Default) $\widetilde{V}_L(w^d_L) = \widetilde{V}_H(w^d_H) = 0$; and (Recursivity)

$$\widetilde{V}_j(w) \equiv \sum_{i\in\{L,H\}} p(\theta_i|\theta_j)\left[\widetilde{d}_i(w) + [1-\widetilde{s}_i(w)]\,\beta\gamma\int_{\varepsilon^d_{ii}}^{\infty} \widetilde{V}_i[(1-\delta)\widetilde{k}_i(w) + \pi(\widetilde{k}_i(w),\theta_i,\varepsilon) - \widetilde{b}_i(w)]f(d\varepsilon)\right]. \tag{14}$$

Proposition 2 constructs an RPBE using a continuum of separating contracts on the net worth space.

Proposition 2. *Let (a^S_L, a^S_H) be least-cost separating contracts with respect to (V^S_L, V^S_H)*

where

$$V_j^S(w) \equiv \sum_{i\in\{L,H\}} p(\theta_i|\theta_j)\Gamma_i^S(w)$$

and

$$\underline{w} \equiv -\max_{b,k} \quad \rho(b,k,\theta_L) + \Omega(b,k,\theta_L) - k.$$

Then $(\underline{w}, \underline{w}, a_L^S, a_H^S, V_L^S, V_H^S)$ *is a recursive perfect Bayesian equilibrium.*

Proof. Proposition 1 states that the separating contract is always in the set of PBE. By construction, each V_j^S satisfies recursivity. By construction, $\Gamma_L^S(\underline{w}) = 0$. At $\underline{w}$, the only allocations satisfying IC_L entail $d_H = 0$ and $s_H = 1$. Therefore

$$\Gamma_L^S(\underline{w}) = 0 \Rightarrow \Gamma_H^S(\underline{w}) = 0 \Rightarrow V_L^S(\underline{w}) = V_H^S(\underline{w}) = 0. \blacksquare$$

Some technical details of the construction are worth noting. First, when we construct an RPBE using separating contracts, the endogenous default threshold is the point at which the low type is just unable to satisfy BC_L. At that point, the high type cannot possibly separate from the low type and necessarily receives a payoff of zero. Hence, the default threshold is invariant to firm type in this particular RPBE. Second, Proposition 1 indicates that for arbitrary $w > \underline{w}$, the contract $(\mathbf{a}_L^S(w), \mathbf{a}_H^S(w))$ is the unique PBE if and only if it is interim efficient. We return to this point in Section 5, where an RPBE is constructed using pooling contracts in addition to separating contracts.

3.2 Low Type Policies

To set a baseline, it is useful to characterize policies if outsiders have the same information as the insider. The superscript FB denotes first-best policies in this case of symmetric information. Under symmetric information, optimal debt entails $b_L^{FB} = b_H^{FB} = 0$. With symmetric information, external equity dominates defaultable debt since default induces deadweight losses. Saving within the corporate shell is also dominated under symmetric information since the firm faces catastrophic event risk.

Under symmetric information, optimal investment equates the discounted marginal product of capital with its price:

$$1 = \beta\gamma[1 - \delta + E(\pi_k(k_i^{FB}, \theta_i, \varepsilon))]. \tag{15}$$

In order to interpret the first-order conditions for the separating contract, derived in Appendix B, it is useful to introduce constraint multipliers. Below $\{\mu, \lambda\}$ denote the (wealth-contingent) multipliers on the no-mimic and budget constraints for the high type program determining $\mathbf{a}_H^S$. Lemma 1 follows from the first-order conditions determining $\mathbf{a}_H^S$.

Lemma 1. *For the recursive perfect Bayesian equilibrium in Proposition 2, there exists a level of net worth, $\widehat{w}$, such that*[16]

$$\begin{aligned} V_i'(w) &= 1 + p(\theta_H|\theta_i)\mu(w)\left(1 - \frac{\Omega(b_H^S(w), k_H^S(w), \theta_L)}{\Omega(b_H^S(w), k_H^S(w), \theta_H)}\right) \text{ for } w \in (\underline{w}, \widehat{w}) \\ &= 1 \text{ for } w \geq \widehat{w}. \end{aligned} \tag{16}$$

Proof. See Appendix C.

Recalling that μ is the multiplier on the no-mimic constraint, Lemma 1 indicates that anticipation of this constraint binding next period creates a precautionary motive for accumulating internal resources. The intuition is as follows. As shown in the next subsection, the high type deters imitation by substituting debt for equity as its source of external funds. However, bankruptcy costs (Assumption 4) imply that use of this signal results in deadweight losses.[17] Thus, the multiplier μ is properly understood as measuring marginal signaling costs incurred by the high type as it attempts to raise another dollar, while deterring mimicry in the least costly manner. If the next realized type is low, there is no need to incur signaling costs, so a dollar is then just worth a dollar. If the next realized type is high, a dollar of internal funds is worth more than a dollar since this reduces marginal signaling costs associated with going external for another dollar. This explains why the shadow value of

[16] To make room for primes we suppress the superscript S from the value function.

[17] The absence of bankruptcy costs in the model of Constantinides and Grundy (1990) explains why firms only signal with debt in their model, with no distortions of real policies.

internal resources depends upon the probability of transitioning to the high type.

An important implication of Lemma 1 is that the equity value functions will exhibit concavity, since the shadow value of internal funds falls to unity once net worth is sufficiently high. Intuitively, marginal signaling costs fall to zero for a high net worth firm since investment can be funded internally. The concavity of the equity value functions carries over to the insider's objective function, as shown in equation (6). Therefore, the insider behaves as if he were risk averse, despite the fact that he is assumed to be risk neutral.

From the program defining the separating contract, equation (11), it follows that the low type's policies maximize the total value of marketable claims on the firm:

$$(b_L^S, k_L^S) \in \arg\max_{b,k} \quad \rho(b,k,\theta_L) + \Omega(b,k,\theta_L) - k.$$

Proposition 3 follows from the first-order conditions for this problem.

Proposition 3. *For all $w \in [\underline{w}, \infty)$, $k_L^S(w) = k_L^S > k_L^{FB}$ and $b_L^S(w) = b_L^S \le 0$ where*

$$\beta\gamma \int_{-\infty}^{\infty} V_L'[(1-\delta)k_L^S + \pi(k_L^S,\theta_L,\varepsilon) - b_L^S][1-\delta+\pi_k(k_L^S,\theta_L,\varepsilon)]f(d\varepsilon) = 1$$
$$b_L^S\left[\gamma \int_{-\infty}^{\infty} V_L'[(1-\delta)k_L^S + \pi(k_L^S,\theta_L,\varepsilon) - b_L^S]f(d\varepsilon) - 1\right] = 0.$$

Dividends and equity issuance for the low type depend on net worth with

$$w < k_L^S - \beta b_L^S \Rightarrow d_L^S = 0 \quad \text{and} \quad s_L^S > 0$$
$$w \ge k_L^S - \beta b_L^S \Rightarrow d_L^S = w - (k_L^S - \beta b_L^S) \quad \text{and} \quad s_L^S = 0.$$

The intuition for the low type policies is as follows. In order to discourage imitation by the low type, the separating contract makes the low type as well off as possible, subject to his budget constraint. In a static signaling model, the low type would receive the symmetric information allocation for his type. In a setting with repeated signaling and changing types, the low type is given a second-best allocation which accounts for the fact that the shadow value of internal funds exceeds one at some levels of net worth. Consequently, the low type overinvests relative to symmetric information and maintains costly financial slack. It is also worth nothing that b_L^S and k_L^S are invariant to net worth. Therefore, the low type satisfies BC_L by varying dividends and equity issuance only.

In our proposed theory, the low type sits on cash and floats equity should it need funds. That is, equity is the low type's first and only source of external funds. It is useful to contrast this prediction with the pecking-order. In the *pure* pecking-order theory articulated by Myers and Majluf (1984), debt is the only source of external financing, regardless of firm type. Myers (1984) articulated a *modified* pecking-order predicting that firms will only float equity after exhaustion of "debt capacity." Thus, Myers predicts that equity will be the last source of funds for all firms, whereas we predict that equity is the first source of funds for firms with low current capital productivity.

3.3 High Type Policies

The marginal effect of b on the discounted value of shareholders' equity for a type-i that has taken the type-j allocation is

$$\Omega_b(b_j, k_j, \theta_i) = -\beta\gamma \int_{\varepsilon_{ij}^d}^{\infty} V_i'[(1-\delta)k_j + \pi(k_j, \theta_i, \varepsilon) - b_j] f(d\varepsilon). \tag{17}$$

The marginal effect of k on the discounted value of shareholders' equity for a type-i that has taken the type-j allocation is

$$\Omega_k(b_j, k_j, \theta_i) = \beta\gamma \int_{\varepsilon_{ij}^d}^{\infty} V_i'[(1-\delta)k_j + \pi(k_j, \theta_i, \varepsilon) - b_j][1 - \delta + \pi_k(k_j, \theta_i, \varepsilon)] f(d\varepsilon). \tag{18}$$

In order to obtain indifference curves over alternative allocations, we compute the total differential of the insider's objective function U_i. Indifference curves are defined by

$$\Delta U_i(a_j) = \Delta d + (1 - s_j)\Omega_k(b_j, k_j, \theta_i)\Delta k + (1 - s_j)\Omega_b(b_j, k_j, \theta_i)\Delta b - \Omega(b_j, k_j, \theta_i)\Delta s = 0. \tag{19}$$

From (19), the insider's willingness to exchange equity for reductions in the face value of debt is

$$\frac{ds}{db}(a_j; \theta_i) \equiv \frac{(1 - s_j)\Omega_b(b_j, k_j, \theta_i)}{\Omega(b_j, k_j, \theta_i)}. \tag{20}$$

In general, the relative slope of indifference curves in (s, b) space is ambiguous. On one hand, the low type is more willing to give up equity since he knows his equity is less valuable. On the other hand, the high type views servicing debt as more costly since he is less likely to default.

From (19), the insider's willingness to exchange equity for capital is determined by

$$\frac{ds}{dk}(a_j;\theta_i) \equiv \frac{(1-s_j)\Omega_k(b_j,k_j,\theta_i)}{\Omega(b_j,k_j,\theta_i)}. \tag{21}$$

Again, there are potentially competing effects at work. On one hand, the low type is more willing to give up his equity, since his equity is less valuable. On the other hand, the high type has a weakly higher marginal product of capital. Therefore, the signal content of equity-financed investment is ambiguous absent some restrictions on primitives.

In Appendix B it is shown that the high type will not pay a dividend if IC_L binds. Intuitively, the high type pays no dividend if the incentive constraint binds in order to minimize the amount of external financing. The high type's debt under the separating contract (b_H^S) is determined by the following first-order condition:

$$\begin{aligned}
&\beta\gamma\left[\int_{\varepsilon_{HH}^d}^{\infty}[V_H'((1-\delta)k_H^S+\pi(k_H^S,\theta_H,\varepsilon)-b_H^S)-1]f(d\varepsilon)\right.\\
&\left.+\frac{\partial\varepsilon_{HH}^d}{\partial b_H}f(\varepsilon_{HH}^d)\phi[(1-\delta)k_H^S+\pi(k_H^S,\theta_H,\varepsilon_{HH}^d)+|\underline{w}|]\right]\\
&=\left[\frac{\mu\Omega(b_H^S,k_H^S,\theta_L)}{\lambda}\right]\left[\left|\frac{ds}{db}(a_H^S;\theta_L)\right|-\left|\frac{ds}{db}(a_H^S;\theta_H)\right|\right].
\end{aligned} \tag{22}$$

Equation (22) implies that high type debt trades efficiency against information revelation. The term $V_H'-1$ captures a novel deadweight cost of debt service in a dynamic setting with repeated hidden information. The bondholder values a dollar of debt service at one dollar. However, Lemma 1 indicates that anticipation of future signaling costs causes shareholders to view the cost of debt service as potentially greater than one. The next term on the left side of the equation measures marginal default costs. The right side measures the signal content of debt-for-equity substitutions as measured by the difference between indifference curve slopes.

The first-order condition determining k_H^S is

$$1 = \beta\gamma \left[\int_{\varepsilon_{HH}^d}^{\infty} [V_H'((1-\delta)k_H^S + \pi(k_H^S, \theta_H, \varepsilon) - b_H^S)][1 - \delta + \pi_k(k_H^S, \theta_H, \varepsilon)] f(d\varepsilon) \right] \tag{23}$$
$$+ \beta\gamma(1-\phi) \int_{-\infty}^{\varepsilon_{HH}^d} [1 - \delta + \pi_k(k_H^S, \theta_H, \varepsilon)] f(d\varepsilon)$$
$$- \beta\gamma \frac{\partial \varepsilon_{HH}^d}{\partial k_H} f(\varepsilon_{HH}^d)\phi[(1-\delta)k_H^S + \pi(k_H^S, \theta_H, \varepsilon_{HH}^d) + |\underline{w}|]$$
$$+ \left[\frac{\mu\Omega(b_H^S, k_H^S, \theta_L)}{\lambda} \right] \left[\frac{ds}{dk}(a_H^S; \theta_H) - \frac{ds}{dk}(a_H^S; \theta_L) \right].$$

Equation (23) states that high type investment equates marginal benefits with the unit price of capital. The first term on the right side of the equation measures the marginal benefit to shareholders from an additional unit of installed capital. Installed capital has a precautionary benefit since $V_H' \geq 1$. This effect encourages overinvestment relative to a setting with symmetric information. The second term measures the net marginal benefit of investment accruing to bondholders in the event of default. Note that bankruptcy costs discourage investment, since a portion of the return to capital is lost in the event of default. The next term measures the marginal benefit of capital accumulation in terms of reducing the region over which default costs are incurred. The final term measures the signal content of equity-financed investment as measured by the difference between indifference curve slopes. Again, we see that the separating contract trades efficiency against information revelation. In fact, the pair (k_H^S, b_H^S) equates the ratio of distortion to information content across real and financial signals.

Proposition 4 spells out some implications of the first-order conditions when the IC_L constraint is slack.

Proposition 4. *For all $w \geq \widehat{w}$, $k_H^S(w) = k_H^S > k_H^{FB}$ and $b_H^S(w) = b_H^S \leq 0$ where*

$$\beta\gamma \int_{-\infty}^{\infty} V_H'[(1-\delta)k_H^S + \pi(k_H^S, \theta_H, \varepsilon) - b_H^S][1 - \delta + \pi_k(k_H^S, \theta_H, \varepsilon)] f(d\varepsilon) = 1$$
$$b_H^S \left[\gamma \int_{-\infty}^{\infty} V_H'[(1-\delta)k_H^S + \pi(k_H^S, \theta_H, \varepsilon) - b_H^S] f(d\varepsilon) - 1 \right] = 0.$$

For all $w \geq \widehat{w}$, dividends and equity issuance for the high type are contingent upon net worth *with*

$$w < k_H^S - \beta b_H^S \Rightarrow d_H^S = 0 \quad and \;\; s_H^S > 0$$
$$w \geq k_H^S - \beta b_H^S \Rightarrow d_H^S = w - (k_H^S - \beta b_H^S) \quad and \;\; s_H^S = 0.$$

Consider next $w < \widehat{w}$. Characterization of high type policies on this region requires a characterization of relative indifference curve slopes. Determining the slopes of the indifference curves is complicated by the fact that unknown value functions, and their slopes, enter into the equations. To gain analytical tractability, one must place restrictions on the profit function π, beyond the rather general specification in Assumption 1.

Lemmas 2-4 present sufficient conditions for the relevant indifference curves to exhibit single-crossing. Consider first the slope of indifference curves in (b, s) space. On one hand, the low type knows his equity is less valuable, increasing his willingness to exchange equity for reductions in the face value of debt. On the other hand, the high type has higher costs of servicing a given debt obligation since he is less likely to default. Lemma 2 identifies conditions under which the first effect dominates.

Lemma 2. *If ε is exponentially distributed and the operating profit function satisfies $\pi_{\varepsilon\varepsilon} = 0$ and $\pi_{\varepsilon\theta} \geq 0$, then debt-for-equity substitutions are a positive signal with*

$$\left|\frac{ds}{db}(a;\theta_L)\right| > \left|\frac{ds}{db}(a;\theta_H)\right| \;\; \forall\; \mathbf{a} \in \mathcal{A} \;\; s.t. \;\; s < 1.$$

Proof. See Appendix C.

The numerical simulations presented in the next section assume $\pi = \theta\varepsilon k^{\alpha}$ and the conditions of Lemma 2 are satisfied. Under such a specification of the profit function, private information regarding θ affects the productivity of the firm's scalable capital. In this case, the positive signal content of debt-for-equity substitutions encourages the high type to take on debt when the incentive constraint binds (at low net worth levels). Formally, this is reflected in the fact that the right side of the debt optimality condition for the high type, given in equation (22) is positive when the assumptions of Lemma 2 are satisfied. Further, the greater the wedge in indifference curve slopes, the more willing is the high type to incur the signaling costs captured by the left side of equation (22).

Consider next the slope of indifference curves in (k, s) space, which enters into the capital optimality condition for the high type, as stated in equation (23). The signal content of capital also reflects competing forces. On one hand, the low type has a strong incentive to exchange equity for capital since he knows his equity is less valuable. On the other hand, the high type may be able to use a marginal unit of capital more productively, depending on the particular functional form of π. Lemma 3 presents sufficient conditions such that the first effect dominates.

Lemma 3. *If ε is exponentially distributed and the operating profit function satisfies $\pi_{\varepsilon\varepsilon} = 0$, $\pi_{k\varepsilon} = 0$ and*

$$\frac{\pi_{k\theta}}{1 - \delta + \pi_k} \leq \frac{\pi_{\varepsilon\theta}}{\pi_\varepsilon},$$

then equity financed investment is a negative signal with

$$\frac{ds}{dk}(a; \theta_L) > \frac{ds}{dk}(a; \theta_H) \ \forall \ \mathbf{a} \in \mathcal{A} \ s.t. \ s < 1.$$

Proof. See Appendix C.

For example, if asymmetric information were to concern only the value of assets in place, with $\pi = \theta\varepsilon + k^\alpha$, the conditions of Lemma 3 are satisfied. Effectively, this particular functional form ensures that the marginal product of new capital is independent of type, so signal content hinges upon relative equity valuations. Since the low type has less valuable equity, he is more willing to exchange equity for capital. Lemma 3 is consistent with the argument of Myers and Majluf (1984) that private information regarding assets in place will induce underinvestment by high types if they are constrained to finance with equity. The same effect would be present in our model if one assumes $\pi = \theta\varepsilon + k^\alpha$. However, our numerical simulations assume $\pi = \theta\varepsilon k^\alpha$, which ensures that debt-for-equity substitutions are a positive signal, but leaving ambiguity regarding the signal content of equity-financed investment. Thus, numerical simulations are required in order to determine whether the high underinvests or overinvests.

Consider finally the slope of indifference curves in (d, s) space. In our model, dividends are always a negative signal in the sense described by Lemma 4.

Lemma 4. *If Assumption 1 is satisfied, with* $\pi_\theta > 0$*, dividend payments are a negative signal with*

$$\frac{\partial s}{\partial d}(a;\theta_L) = \frac{1}{\Omega(b,k,\theta_L)} > \frac{1}{\Omega(b,k,\theta_H)} = \frac{\partial s}{\partial d}(a;\theta_H) \; \forall \; \mathbf{a} \in \mathcal{A}.$$

The intuition for Lemma 4 is simple. It is a negative signal to issue equity in order to pay a dividend, since this conveys negative information about insiders' valuation of equity. Further, it is a negative signal to pay a dividend instead of repurchasing equity, and increasing the insiders' equity stake. This explains why the high type never pays a dividend in our model unless the no-mimic constraint is slack. Note, Miller and Rock (1985) have a rather different prediction regarding the signal content of dividends. However, this is not surprising that their model features private information regarding net worth, while our model features symmetric information regarding net worth.

4 Model Calibration and Simulation

In this section we present results from numerical simulation of the model. Numerical simulations are necessary given that a full analytical solution for the equity value functions (V_L, V_H) is not feasible. Further, there are cases in which competing forces are at work, making it impossible to determine which effect dominates. For example, a high type may want to invest a high amount to signal positive information, but default costs on debt discourage capital accumulation. Finally, and most importantly, developing a simulated panel of firms allows us to determine precisely what type of regression coefficients are implied by the underlying theory.

A unique feature of the model is that it endogenizes a broad range of policies: debt and equity issuance, investment, dividends, repurchases, and default. This allows one to map it directly to real-world data and facilitates policy experiments. We conduct two policy experiments. We begin by assessing how asymmetric information alters firm behavior relative to technologically identical firms operating under symmetric information. Second, we analyze the effect of changes in bankruptcy costs. This policy experiment sheds light on the benefits of a streamlined bankruptcy process. Finally, we discuss the model's ability to replicate stylized facts.

4.1 Calibration

Each time period is one year. Following Carlstrom and Fuerst (1997), we set the real interest rate $r = 0.04$ and the probability of a catastrophic shock $1 - \gamma = 0.05$. The catastrophic risk is consistent with evidence presented by Evans (1987), who documents a 5% exit probability. Following Hall (2001), we set the depreciation rate $\delta = 0.10$. The operating profit function is $\pi = \theta\varepsilon k^{\alpha}$, where ε is an i.i.d. exponential random variable with mean $\bar{\varepsilon}$. This functional form implies that asymmetric information affects the future productivity of the firm's scalable capital stock. This concave functional form is standard in the calibration literature. The production technology satisfies the conditions of Lemma 2, implying that debt-for-equity substitutions are a positive signal.

To reduce the number of unknown parameters, the transition matrix for θ is symmetric with $p(\theta_i|\theta_i) \equiv p$. The model is initialized with one-half the firms of each type. There are five remaining unknown parameters relevant to the firm's production technology: $(\alpha, p, \bar{\varepsilon}, \theta_L, \theta_H)$. We choose these parameters to match moments from a symmetric information economy with five empirical moments reported by Gomes (2001): Mean capital stock; mean investment rate; variance of investment rate; mean of Tobin's Q; and mean profit rate.[18] This approach serves a practical purpose since we are able to derive closed-form solutions for each of these moments under symmetric information.[19] Appendix D contains the moment derivations for the symmetric information economy. Appendix E details the numerical algorithm used to solve for the least-cost separating equilibria and value functions under asymmetric information. Essentially, the numerical algorithm solves for the fixed point described in Proposition 2.

Table 1 provides details on the parameters. The elasticity of profit with respect to capital is in line with the estimate of $\alpha = 0.63$ obtained by Hennessy and Whited (2007) and the

[18]Specifically, we minimize the average squared percentage error over the five moments.

[19]In principle, one could apply simulated method of moments to the signaling model. However, this is not practical given model run-time.

estimate of $\alpha = 0.69$ obtained by Cooper and Ejarque (2001). Other parameter values cannot be compared across the studies since they utilize different driving processes.

The first five rows of the first column of Table 2 contain the data moments reported by Gomes (2001), which relate to the real driving process. The last two rows of the first column of Table 2 report two financial ratios reported by Hennessy and Whited (2007): market leverage and the dividend payout ratio. The second column reports the moments generated by the symmetric information model. Given the close matching of the first five real moments, it appears that the parameter vector captures production technologies reasonably well. However, it is clear that the symmetric information model is lacking when it comes to describing firm financial behavior. Under symmetric information, the dividend payout ratio is one, since the firm has no incentive to retain funds. Further, the market leverage ratio is zero under symmetric information since the firm strictly prefers equity finance given that bankruptcy involves deadweight costs.

Simulating the economy with asymmetric information requires assumptions regarding bankruptcy costs ϕ. Weiss (1990) estimates that direct costs of bankruptcy amount to 2.8% of the book value of assets. Andrade and Kaplan (1998) estimate that total costs of financial distress, including indirect costs, range from 10% to 20% of firm value. Based on the empirical evidence, we conduct two sets of simulations of the signaling model using $\phi = 0.05$ and $\phi = 0.15$. The simulated panel consists of 3000 independent firms observed over 10 periods. To capture the lifecycle behavior of firms, each firm enters the model with total market capitalization equal to zero.

The third column of Table 2 provides evidence on the effect of hidden information on firm behavior. An interesting quantitative finding is that asymmetric information dramatically increases the variance of the investment rate relative to the symmetric information benchmark. This is consistent with the well-known financial accelerator hypothesis that financial market imperfections amplify real cycles. In fact, the introduction of hidden information causes the model to overshoot the variance of the investment rate. An obvious remedy would be to introduce adjustment costs into the model. While the introduction of adjustment costs would increase realism, it would also complicate the analysis greatly since it would create the need to keep separate tabs on cash and real capital. This is an obvious avenue for future research.

Relative to the symmetric information economy, the average capital stock is lower for firms operating under asymmetric information. However, contrary to conventional wisdom, asymmetric information actually increases the average investment rate. This is because asymmetric information causes firms to operate below efficient scale. Firms then invest at a higher rate as they try to work their way up to the efficient scale despite the signaling costs associated with external funds. This result on investment rates is particularly important in light of the fact that empirical studies typically focus on investment rates as opposed to capital stocks.

Surprisingly, asymmetric information also induces higher values of Tobin's Q and profit rates. The intuition is simple. Although asymmetric information necessarily results in lower firm value and discounted profits, it also induces the firm to employ less capital. Apparently, this commonly-ignored denominator effect dominates. Taken together, these findings cast doubt on the common practice of using investment rates, Q ratios, and profitability to gauge firm efficiency or the allocative efficiency of capital markets.[20]

The last two rows of the third column report the average market leverage and dividend payout ratios generated by the simulated model under asymmetric information. At a bankruptcy cost of $\phi = .05$, the model generates an average market leverage ratio of 0.1430, while Hennessy and Whited (2007) report a market leverage ratio of 0.1204 in their real-world sample. So the model does a good job matching observed leverage ratios without the need to resort to unreasonable bankruptcy cost parameters. However, the model overshoots the dividend payout ratio, generating an average payout ratio of 0.3121 versus an observed payout ratio of 0.2226 in the real-world data.

The last column considers the effect of higher bankruptcy costs, where $\phi = 0.15$. Relative to the symmetric information case, a similar pattern emerges, with firms operating below their optimal scale, investing at a higher rate, and exhibiting higher variance in investment rates. If one compares columns three and four some interesting patterns emerge. First, although firms are clearly made worse off by higher bankruptcy costs, this does not imply that

[20] Maksimovic and Phillips (2002) also argue that the endogeneity of capital makes profitability a poor proxy for allocative efficiency.

capital stocks are lower. High bankruptcy costs induce firms to use less debt finance. Lower debt leads to higher net worth going into future periods. In turn, higher net worth leads to higher capital stocks. Consistent with this interpretation, we see that higher bankruptcy costs lead to lower Q ratios and profit rates. Turning next to financial ratios, the increase in bankruptcy costs results in an average market leverage ratio of 0.1196, which is very close to that observed in the real-world data. However, the model continues to overshoot the dividend payout ratio.

In all, the simulated model with asymmetric information does a reasonable job in matching all but two moments: the variance of the investment rate and the dividend payout ratio. Fixing the first weakness is simple in concept: one needs to introduce real adjustment costs. However, it is not obvious how to adjust the model to bring it into line with observed dividend payout behavior.

4.2 Behavior of Simulated Firms

This subsection discusses the behavior of the simulated firms. To illustrate concavity of the equity value function, and the precautionary value of internal funds, we follow Gamba and Triantis (2008) by plotting an *enterprise value function* (e_i) for each lagged type. To this end, return to Figure 1 and suppose it is the start of period t. The firm has paid off its prior debt obligation and finds itself with net worth w_t. Since capital is fungible in the model, this net worth can be treated as cash. Evaluated before the next type is observed, there is no outstanding debt and enterprise value is then just the difference between equity value at this point in time and internal "cash":

$$e_i(w_t) \equiv V_i(w_t) - w_t. \tag{24}$$

The slope of the enterprise value function is a direct measure of the precautionary value of internal funds, since $e_i' = V_i' - 1$. Alternatively, one can think of e_i' as measuring the gain that shareholders would capture if they could directly inject cash into the firm just before the next realized type is observed. Recalling that η denotes the multiplier on the dividend nonnegativity constraint in the high type program, one may express enterprise value as

$$e_i(w) = |\underline{w}| + \int_{\underline{w}}^{w} [V_i'(\omega) - 1] d\omega \tag{25}$$
$$= |\underline{w}| + p(\theta_H|\theta_i) \int_{\underline{w}}^{w} \eta(\omega) d\omega \qquad \forall \quad w > \underline{w}.$$

Thus, enterprise value is equal to going-concern value plus the cumulative precautionary value of internal resources. Figure 2 plots the two enterprise value functions. Consistent with concavity of both equity value functions (V_L, V_H), the slopes of both enterprise value functions are positive and decreasing in net worth. The enterprise value has a slope of zero for high levels of net worth where the incentive constraint is slack. Consistent with equation (25), the enterprise value function is particularly steep for a firm with a high lagged type. Intuitively, internal funds have high precautionary value when there is a high probability of transitioning to a high type and incurring signaling costs.

Figure 3 plots the capital allocations of each type relative to first-best. The low type invests a bit above first-best regardless of realized net worth. The overinvestment of the low type reflects the fact that informational asymmetries create a precautionary motive for capital accumulation. The high type generally underinvests relative to first-best, with investment increasing in net worth. It follows that a positive macroeconomic shock would increase subsequent investment through the net worth channel. This is noteworthy since the model is rigged with independent macroeconomic shocks. Similarly, the model is consistent with the findings of Blanchard, Lopez-de-Silanes and Shleifer (1994) and Rauh (2006) who document that *exogenous* increases in internal resources induce increases in capital expenditures.

It is worth noting that Fazzari, Hubbard and Petersen(1988) also predict that exogenous cash windfalls will induce increases in capital expenditures. Their graphical model assumes a cost of capital schedule that is increasing in external funds, but invariant to investment. In that setting, a cash windfall moves the firm to a lower cost of capital and boosts investment. The causation in our model differs fundamentally. In our model, a cash windfall allows the high type to substitute internal funds for debt. This reduces the probability of default and increases the expected return to capital.

Figure 4 (Panel B) plots the wealth-contingent financing policies of the low type. Consistent with Proposition 3, the low type uses dividends and equity issuance as the sole means of achieving budget-balance, while retaining a wealth-invariant level of savings. When net worth is low, the low type sets the dividend to zero and issues a large amount of equity. Equity issuance for the low type declines monotonically with net worth, while the dividend increases with net worth. Thus, the model is consistent with the positive relationship between corporate distributions and internal resources documented by DeAngelo, DeAngelo and Stulz (2006). The signaling model of Miller and Rock (1985) generates a similar prediction. In their theory, the firm has private information regarding net worth and signals positive information by paying out higher dividends. In contrast to our theory, their model predicts that debt flotations are a negative signal.

Figure 4 (Panel A) plots the wealth-contingent financing policies of the high type. If net worth is sufficiently high, the high type initiates payouts. The high type only issues small amounts of equity, and generally combines its equity flotations with high amounts of debt. In contrast, the low type issues equity without any debt. This is consistent with existing empirical studies. Asquith and Mullins (1986) document negative abnormal returns in a sample of pure common stock offerings. Masulis and Korwar (1986) find that seasoned equity offerings are associated with negative price changes on average. However, the announcement return is positively related to leverage changes.

The debt level of the high type is a nonmonotone function of net worth. When net worth is low, marginal increases in net worth induce increases in debt. As discussed above, when net worth is low, marginal increases in net worth also induce more investment. Since this reduces default costs, marginal increases in debt are optimal. Returning to Figure 3, we see that when net worth is sufficiently high, the high type no longer increases investment in response to cash windfalls. Rather, cash windfalls are used as a substitute for debt finance. Figure 5 shows that both the book and market leverage ratios of the high type are decreasing in net worth.

Table 3 reports results from regressing various variables on lagged net worth. Consistent with the findings of Fama and French (2002), book and market leverage ratios decline with lagged net worth. Since leverage declines with net worth it follows that the model also predicts countercyclical leverage ratios. Effectively, positive shocks to net worth allow the high type to substitute internal funds for external funds. Thus, the high type need not burn as much money on signaling via debt.

Continuing to examine Table 3, the model also generates a positive relationship between dividends and internal resources, consistent with the findings of DeAngelo, DeAngelo and Stulz (2006). This is to be expected given the firm policies depicted in Figure 4. Low types initiate dividends as soon as net worth is sufficient to cover desired investment and saving. High types initiate dividends as soon as the no-mimic constraint becomes slack.

The last row of Table 3 follows Cooley and Quadrini (2001) and regresses the growth rate of the firm, as measured by the percentage change in V, on lagged net worth. Consistent with the evidence presented by Evans (1987), the growth rate of the firm is decreasing in net worth. Intuitively, the firm grows faster at low levels of net worth since each dollar of net worth tends to crowd-in more investment when the firm is small. Cooley and Quadrini explain this tendency via direct flotation costs. Our model offers a micro-foundation for this relationship, based upon asymmetric information.

In untabulated regressions, we also perform the leverage-on-size regression specification employed by Fama and French (2002), where size is measured by the natural log of capital. When the bankruptcy cost parameter (ϕ) is set to 5%, the size coefficient (standard error) is 0.2399 (.0573). When the bankruptcy cost parameter is set to 15%, the size coefficient (standard error) is 0.1908 (.0564). The typical arguments advanced for the positive relation between size and leverage is that real capital provides collateral for loans. An alternative argument is that large firms have smoother taxable income, allowing them to exploit debt tax shields with lower cost. The causal mechanism in our model is as follows: Firms with positive information regarding the productivity of capital invest more, and signal their private information via leverage.

In a recent paper Lemmon, Roberts and Zender (2008) document that leverage is highly persistent. Transactions costs (e.g. underwriting fees) are commonly invoked to help explain their finding. Our model suggests that signaling may also contribute to leverage persistence. Recall, our model features no transactions costs. Further, each debt obligation has maturity of one year. So, this would seem to imply low persistence in leverage. However, in simulated data the correlation coefficient of both book and market leverage is roughly 0.5 across parameterizations. In our model, leverage persistence is due to two factors. First, leverage is a function of the firm's private type, and type is persistent. Second, leverage is a function of net worth, and net worth is also persistent.

The simulated model also provides a laboratory for analyzing the cross-sectional determinants of abnormal returns associated with investment and financing policy announcements.[21] In the simulated model data, one can perfectly isolate the policy announcement effect. The stock price just prior to the policy announcement at time t is equal to $V_{\theta_{t-1}}(w_t)/c$. The stock price immediately following the policy announcement is $\Gamma_{\theta_t}(w_t)/c$. The pure abnormal return (AR) associated with the announced policy is the ex post price less the ex ante price normalized by the ex ante price

$$AR_t \equiv \frac{\Gamma_{\theta_t}(w_t) - V_{\theta_{t-1}}(w_t)}{V_{\theta_{t-1}}(w_t)}. \tag{26}$$

Table 4 analyzes the determinants of model-implied abnormal returns, treating the simulated AR_t as a dependent variable. In order to get enough type switches per firm in our simulated sample each firm is observed over 50 periods in this case. Such regressions are common to the event study literature. A common theme running through the regressions is the prediction that high investment induces positive abnormal returns. This is consistent with the empirical evidence presented by McConnell and Muscarella (1985) who document raw equity returns of 1.2% following announced increases in capital budgets and -1.5% for decreases.

In the first regression reported in Table 4, we see that the investment rate has strong predictive power. In the second regression, we see that a high leverage ratio is also a positive signal, unconditionally. However, its statistical significance is low. Thus, the model may be interpreted as consistent with the finding of Eckbo (1986) that leverage, per se, does not predict abnormal returns. To explore this question further, the third reported regression includes leverage interacted with a dummy for a switch from no debt to positive debt. This specification is motivated by the empirical study of Nandy, Kamstra and Shao (2008) who

[21] The model can also be used to analyze the determinants of earnings announcement effects.

document that the announcement return to leverage is particularly high for firms that begin floating debt after having been "equity types" in prior years. Our model is consistent with this finding since the leverage interaction variable is highly significant in the third row.

Thus, in simulated data leverage has power to predict abnormal returns unconditionally. However, the last two regressions in Table 4 show that leverage and the leverage interaction variable become statistically insignificant once investment is included as a conditioning variable. Thus, investment rates are the best predictor of abnormal announcement returns in a purely statistical sense. The intuition for this finding is straightforward: The high type always invests much more than the low type, while leverage may or may not differ greatly, depending on net worth.

5 Pooling Equilibria

Prior sections confined attention to separating allocations, which are always in the set of PBE relative to fixed equity value functions. From a continuum of such separating contracts, a recursive PBE can always be constructed. This section identifies points on the net worth space at which it is possible to sustain pooling. Conveniently, the theorem of Maskin and Tirole (1992) indicates a PIE pooling contract is a PBE only if it weakly Pareto-dominates the separating allocations. Using this Pareto criterion to identify pooling PBE, we can update the equity value functions to reflect changes in PBE, and vice versa.

When attention is confined to separating equilibria, the default threshold is given by $w_L^d = w_H^d = \underline{w}$, as defined in Proposition 2. Anticipating, the selection of Pareto-dominant pooling allocations increases the firm's continuation region. The intuition is simple. At the net worth level $\underline{w}$, both types receive zero under the separating contracts because a low type, revealed as such, cannot satisfy his budget constraint. At this level of net worth, both types would be better off pooling at some PIE allocation. Intuitively, when net worth is extremely low, the high type must take on extremely high levels of debt in order to achieve separation. At such low levels of net worth, the high type is better off pooling at some allocation with zero debt, despite the fact that his equity is underpriced.

We consider PIE pooling allocations that maximize the expected payoff to the insider just prior to his private observation of the current type. As shown below, such allocations can also be viewed as "focal" since they also maximize the firm's ability to meet outstanding debt obligations. Recall that separating allocations depend on the current type but not the lagged type. By way of contrast, the pooling allocation depends on the lagged type but not the current type. Let $\mathbf{a}_j^P(w)$ denote the pooling allocation at net worth w, given the *lagged* type is j. That is, for the pooling contract we may write

$$\mathbf{a}_{LL} = \mathbf{a}_{HL} \equiv \mathbf{a}_L^P$$
$$\mathbf{a}_{LH} = \mathbf{a}_{HH} \equiv \mathbf{a}_{H.}^P$$

The pooling allocation solves

$$\mathbf{a}_j^P(w) \in \arg\max_{\mathbf{a}\in\mathcal{A}} \quad d + (1-s)\sum_{i\in\{L,H\}} p(\theta_i|\theta_j)\Omega(b,k,\theta_i) \quad s.t. \;\; PIE(w,\theta_j). \tag{27}$$

Substituting the PIE constraint into the maximand, it follows that the pooling allocation maximizes the total expected value of marketable claims on the firm:

$$(b_j^P, k_j^P) \in \arg\max_{b,k} \quad \sum_{i\in\{L,H\}} p(\theta_i|\theta_j)[\rho(b,k,\theta_i) + \Omega(b,k,\theta_i)] - k. \tag{28}$$

It follows that (b_j^P, k_j^P) do not depend on w. Rather, as w increases, the PIE constraint is satisfied by reducing equity flotations or increasing dividends. However, it is interesting to note that the *lagged* type does affect (b_j^P, k_j^P) since the lagged type determines transition probabilities.

In the conjectured recursive PBE, the pooling allocations are implemented on some right neighborhood of the default threshold. Default occurs when the firm is just unable to satisfy the PIE constraint. The resulting default threshold for a firm with lagged type j is

$$\underline{\underline{w}}_j \equiv -\arg\max_{b,k} \quad \sum_{i\in\{L,H\}} p(\theta_i|\theta_j)[\rho(b,k,\theta_i) + \Omega(b,k,\theta_i)] - k. \tag{29}$$

The equation for the endogenous default threshold (29) has two interesting features. First, the default threshold now depends on the firm's *lagged* type. This is to be expected. Here default occurs when the PIE constraint cannot be satisfied. The lagged type affects the PIE constraint since the lagged type determines transition probabilities. For example, with serial correlation in types, $\underline{\underline{w}}_H < \underline{\underline{w}}_L$. Second, comparison of equation (29) with the endogenous default threshold $\underline{w}$ given in Proposition 2 indicates that for either lagged type j, $\underline{\underline{w}}_j < \underline{w}$. This reflects the better terms offered by the PIE constraint relative to the constraint BC_L.[22]

The first-order conditions for the pooling contract given lagged type j are:

$$\sum_{i\in\{L,H\}} p(\theta_i|\theta_j)\beta\gamma \int_{-\infty}^{\infty} V_i'[(1-\delta)k_j^P + \pi(k_j^P, \theta_i, \varepsilon) - b_j^P][1-\delta+\pi_k(k_j^P, \theta_i, \varepsilon)]f(d\varepsilon) = 1 \quad (30)$$

$$b_j^P \left[\gamma \sum_i p(\theta_i|\theta_j) \int_{-\infty}^{\infty} V_i'[(1-\delta)k_j^P + \pi(k_j^P, \theta_i, \varepsilon) - b_j^P]f(d\varepsilon) - 1\right] = 0$$

$$b_j^P \leq 0.$$

Note that no debt is issued under the pooling contract. This is because debt carries with it default and deadweight costs stemming from the fact that the shadow value of internal funds potentially exceeds one. In a pooling equilibrium there is no point to incurring such costs since financial structure does not signal private information. The capital stock in the pooling allocation essentially splits the difference between the optimal type-specific capital stocks. Once capital and debt have been computed, dividends and equity flotations are pinned down by the PIE constraint.

The next step in the construction is to choose the pooling allocation and payoffs only if they Pareto-dominate the separating allocations. For this purpose, let Γ_{ij}^P denote the payoff to the insider of type-i under the pooling contract given the lagged type was j:

$$\Gamma_{ij}^P(w) \equiv U_i(\mathbf{a}_j^P(w)).$$

Next, let $\Gamma_{ij}^*(w)$ denote the PBE payoff to the insider of type-i given lagged type-j and let $\mathbf{a}_{ij}^*(w)$ denote the corresponding allocation. Since pooling can only be supported as a PBE

[22]Since Pareto-dominant pooling equilibria are selected, the value functions also increase endogenously. Thus, the inequality holds *a fortiori*.

if it Pareto-dominates the payoffs to the separating contract we have

$$\Gamma^P_{ij}(w) \geq \Gamma^S_i(w) \quad \forall i \Rightarrow \Gamma^*_{ij}(w) = \Gamma^P_{ij}(w) \text{ and } \mathbf{a}^*_{ij}(w) = \mathbf{a}^P_j(w) \quad \forall i \tag{31}$$

else

$$\Gamma^*_{ij}(w) = \Gamma^S_i(w) \text{ and } \mathbf{a}^*_{ij}(w) = \mathbf{a}^S_i(w) \quad \forall i.$$

The final step in the construction is to define the equity value functions recursively:

$$V^*_j(w) \equiv \sum_{i \in \{L,H\}} p(\theta_i|\theta_j)\Gamma^*_{ij}(w). \tag{32}$$

It follows that V^*_j inherits the properties of the Γ^* functions. For example, on the pooling region the Γ^* functions are in fact linear in net worth. On the region where separation occurs, $\Gamma^*_{Hj} = \Gamma^S_{Hj}$ and the value function has a slope exceeding one if the incentive constraint binds.

Proposition 5 provides a formal characterization of an RPBE that features regions of pooling and separation.

Proposition 5. *For each lagged type i there exists an interval $[\underline{\underline{w}}_i, w^P_i]$ such that the pooling allocation is in the set of PBE if and only if $w \in [\underline{\underline{w}}_i, w^P_i]$.*

Proof. Choose ϵ arbitrarily small and let $w \equiv \underline{\underline{w}}_i + \epsilon$. The separating payoffs at this point are zero since the feasible set is empty. However, if the types pool, they achieve strictly positive payoffs at some $s < 1$. From Proposition 1 it follows that pooling is here in the set of PBE. Further $\exists\ \widehat{w}$ s.t. IC_L is slack $\forall w \geq \widehat{w}$. Thus, for either lagged type j, $\Gamma^S_H(w) > \Gamma^P_{Hj}(w)\ \forall w \geq \widehat{w}$. From Proposition 1 it follows that the pooling allocation is not a PBE on this region.■

The intuition for Proposition 5 is simple. If and only if net worth is sufficiently low, the costs of signaling swamp the value to the high type of separating and receiving fair value for his securities. In such cases, the pooling allocation Pareto-dominates the separating allocation.

6 Conclusions

This paper takes a first step in constructing dynamic structural models of corporate financing when insiders have private information ex ante. We show that anticipation of future signaling costs converts a risk-neutral insider into a pseudo-risk-averse insider. The implied precautionary value of internal funds discourages debt and encourages capital accumulation relative to what one obtains in a static setting. In the least-cost separating equilibrium, firms signal positive information with high leverage. Default costs on debt cause such firms to underinvest relative to first-best. Firms with negative information use only equity finance and overinvest relative for first-best. We show that the nature of equilibrium may be contingent upon net worth. In particular, if net worth is sufficiently low, costs of separation are extremely high and firms may find their way to a Pareto dominating pooling equilibrium.

The model is consistent with a wide range of existing stylized facts regarding the dynamics of firm investment and financing. Further, the model provides a convenient laboratory for analyzing the determinants of abnormal returns surrounding policy announcements, in addition to the effect of asymmetric information on key macroeconomic variables such as the rate and volatility of investment. Finally, the model provides a rigorous diagnostic check for the economic content of variables commonly used in the empirical literature as proxies for allocative efficiency.

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Appendix A: The Insider's Objective Function

In an arbitrary period t, the privately informed insider has been assumed to maximize his payoff as if he were to hold for a single period

$$U \equiv d_t + (1 - s_t)\beta\gamma E_t[V_{t+1}] = d_t + \beta\gamma \frac{c_t}{c_{t+1}} E_t[V_{t+1}].$$

Using the law of iterated expectations

$$\begin{aligned} E_t[V_{t+1}] &= E_t\left[d_{t+1} + \beta\gamma \frac{c_{t+1}}{c_{t+2}} E_{t+1}[V_{t+2}]\right] \\ &= E_t\left[d_{t+1} + \beta\gamma \frac{c_{t+1}}{c_{t+2}} V_{t+2}\right]. \\ E_t[V_{t+2}] &= E_t\left[d_{t+2} + \beta\gamma \frac{c_{t+2}}{c_{t+3}} V_{t+3}\right]. \end{aligned}$$

Substitution of these terms into the function U yields

$$U = d_t + c_t E_t\left[(\beta\gamma)\left(\frac{d_{t+1}}{c_{t+1}}\right) + (\beta\gamma)^2\left(\frac{d_{t+2}}{c_{t+2}}\right) + (\beta\gamma)^3\left(\frac{V_{t+3}}{c_{t+3}}\right)\right].$$

Iterating in this fashion, one obtains

$$\frac{U}{c_t} = E_t\left[\sum_{\tau=0}^{\infty} (\beta\gamma)^\tau \left(\frac{d_{t+\tau}}{c_{t+\tau}}\right)\right].$$

Thus, maximizing U is equivalent to maximizing the expected discounted value of the future dividend stream coming from one share of stock.

Appendix B: First-Order Conditions for Separating Contracts

The first-order conditions for interior (b_L^S, k_L^S) are

$$\begin{aligned} \rho_b(b_L^S, k_L^S, \theta_L) + \Omega_b(b_L^S, k_L^S, \theta_L) &= 0 \\ \rho_k(b_L^S, k_L^S, \theta_L) + \Omega_k(b_L^S, k_L^S, \theta_L) &= 1. \end{aligned}$$

There is a kink in the debt value function at $b = 0$, and thus it is possible to have $b_L^S = 0$.

We know $b_L^S > 0$ cannot be optimal since the right derivative $\rho_b + \Omega_b < 0$ for all $b_L \geq 0$.

The Lagrangian for a_H^S is

$$L_H(w) \equiv d + (1-s)\Omega(b,k,\theta_H) + \lambda[\rho(b,k,\theta_H) + s\Omega(b,k,\theta_H) + w - k - d] \\ + \mu[\Gamma_L^S(w) - d - (1-s)\Omega(b,k,\theta_L)] + \eta d + \psi(1-s).$$

The first-order conditions for d_H^S and s_H^S are

$$1 - \lambda - \mu + \eta = 0$$

$$(\lambda - 1)\Omega(b_H^S, k_H^S, \theta_H) + \mu\Omega(b_H^S, k_H^S, \theta_L) = \psi.$$

Rearranging these equations one obtains

$$\eta\Omega(b_H^S, k_H^S, \theta_H) - \mu[\Omega(b_H^S, k_H^S, \theta_H) - \Omega(b_H^S, k_H^S, \theta_L)] = \psi.$$

It is straightforward to establish $\psi = 0$ on the continuation region. Suppose to the contrary $\psi > 0 \Rightarrow \eta > 0$. Thus, the high type gets a payoff of zero, which contradicts being on the continuation region. Since $\psi = 0$ we obtain

$$\eta = \mu\left[\frac{\Omega(b_H^S, k_H^S, \theta_H) - \Omega(b_H^S, k_H^S, \theta_L)}{\Omega(b_H^S, k_H^S, \theta_H)}\right].$$

Thus $\mu > 0 \Rightarrow d_H^S = 0$.

The first-order condition for b_H^S is

$$(1 - s_H^S)\Omega_b(b_H^S, k_H^S, \theta_H) + \lambda[\rho_b(b_H^S, k_H^S, \theta_H) + s\Omega_b(b_H^S, k_H^S, \theta_H)] = \mu(1 - s_H^S)\Omega_b(b_H^S, k_H^S, \theta_L).$$

Rearranging terms one obtains

$$\rho_b(b_H^S, k_H^S, \theta_H) + \Omega_b(b_H^S, k_H^S, \theta_H) = \left[\frac{\mu(1 - s_H^S)\Omega(b_H^S, k_H^S, \theta_L)}{\lambda}\right]\left[\frac{\Omega_b(b_H^S, k_H^S, \theta_L)}{\Omega(b_H^S, k_H^S, \theta_L)} - \frac{\Omega_b(b_H^S, k_H^S, \theta_H)}{\Omega(b_H^S, k_H^S, \theta_H)}\right].$$

The first-order condition for k_H^S is

$$(1 - s_H^S)\Omega_k(b_H^S, k_H^S, \theta_H) + \lambda[\rho_k(b_H^S, k_H^S, \theta_H) + s\Omega_k(b_H^S, k_H^S, \theta_H) - 1] = \mu(1 - s_H^S)\Omega_k(b_H^S, k_H^S, \theta_L).$$

Rearranging terms one obtains

$$\rho_k(b_H^S, k_H^S, \theta_H)+\Omega_k(b_H^S, k_H^S, \theta_H)-1 = \left[\frac{\mu(1 - s_H^S)\Omega(b_H^S, k_H^S, \theta_L)}{\lambda}\right]\left[\frac{\Omega_k(b_H^S, k_H^S, \theta_L)}{\Omega(b_H^S, k_H^S, \theta_L)} - \frac{\Omega_k(b_H^S, k_H^S, \theta_H)}{\Omega(b_H^S, k_H^S, \theta_H)}\right].$$

Appendix C: Proofs of Lemmas

Lemma 1. *For the recursive perfect Bayesian equilibrium in Proposition 2, there exists a level of net worth, $\widehat{w}$, such that*

$$V_i'(w) = 1 + p(\theta_H|\theta_i)\mu(w)\left[1 - \frac{\Omega(b_H^S(w), k_H^S(w), \theta_L)}{\Omega(b_H^S(w), k_H^S(w), \theta_H)}\right] \text{ for } w \in (\underline{w}, \widehat{w}) \qquad (33)$$

$$= 1 \text{ for } w \geq \widehat{w}.$$

Proof. First note IC_L must bind at $\underline{w}$ since the high type gets a zero payoff here but would achieve a strictly positive payoff if he needed to satisfy only BC_H. Thus, IC_L binds for sufficiently low net worth. Next consider high levels of net worth and maximize the utility of the high type subject only to BC_H. For w sufficiently high the solution to this relaxed program entails $s_H = 0$ and $b_H \leq 0$. Thus, the high type is not floating any securities and the low type cannot gain from mimicry since there is no gain from securities mispricing.

Next, we derive V_i' for net worth levels such that IC_L binds. We know

$$
\begin{aligned}
V_i'(w) &= p(\theta_H|\theta_i)\Gamma'_H(w) + p(\theta_L|\theta_i)\Gamma'_L(w) \\
&= p(\theta_H|\theta_i)\Gamma'_H(w) + p(\theta_L|\theta_i) \\
&= 1 + p(\theta_H|\theta_i)\left[\Gamma'_H(w) - 1\right] \\
&= 1 + p(\theta_H|\theta_i)[L'_H(w) - 1] \\
&= 1 + p(\theta_H|\theta_i)[\lambda(w) + \mu(w) - 1] \\
&= 1 + p(\theta_H|\theta_i)\eta(w).
\end{aligned}
$$

The second line follows from the linearity of Γ_L^S. The fourth line follows from the Envelope Theorem. The rest follows from the first-order conditions pinning down η.■

Lemma 2. *If ε is exponentially distributed and the operating profit function satisfies $\pi_{\varepsilon\varepsilon} = 0$ and $\pi_{\varepsilon\theta} \geq 0$, then debt-for-equity substitutions are a positive signal with*

$$
\left|\frac{ds}{db}(a;\theta_L)\right| > \left|\frac{ds}{db}(a;\theta_H)\right| \;\; \forall\ a \in \mathcal{A}\ s.t.\ s < 1.
$$

Proof. Note that

$$
\frac{dV_i}{d\varepsilon} = V_i'(w)\pi_\varepsilon.
$$

Using this equation and the hypothesis $\pi_{\varepsilon\varepsilon} = 0$ we obtain

$$
\begin{aligned}
\left|\frac{ds}{db}(a_j;\theta_i)\right| &= \frac{(1-s_j)\int_{\varepsilon_{ij}^d}^{\infty}(dV_i/d\varepsilon)f(d\varepsilon)}{\pi_\varepsilon \int_{\varepsilon_{ij}^d}^{\infty}(V_i)f(d\varepsilon)} \\
&= \frac{(1-s_j)E(\varepsilon)}{\pi_\varepsilon}.
\end{aligned}
$$

The second line uses integration-by-parts and the hypothesis of ε having the exponential distribution.■

Lemma 3. *If ε is exponentially distributed and the operating profit function satisfies $\pi_{\varepsilon\varepsilon} = 0$, $\pi_{k\varepsilon} = 0$ and*

$$
\frac{\pi_{k\theta}}{1-\delta+\pi_k} \leq \frac{\pi_{\varepsilon\theta}}{\pi_\varepsilon},
$$

then equity financed investment is a negative signal with

$$\frac{ds}{dk}(a;\theta_L) > \frac{ds}{dk}(a;\theta_H)\ \forall\ a \in \mathcal{A}\ s.t.\ s < 1.$$

Proof. Following the same steps as in Lemma 2 we obtain

$$\frac{ds}{dk}(a_j;\theta_i) = \left[\frac{(1-\delta+\pi_k)}{\pi_\varepsilon}\right](1-s_j)E(\varepsilon).$$

The stated hypothesis ensures the term in squared brackets is strictly decreasing in θ.■

Appendix D: Moments from the Model with Symmetric Information

Taking into account that the operating profit function is $\pi = \theta\varepsilon k^\alpha$, under symmetric information the firm optimally sets capital equal to

$$k_i^{FB} \in \arg\max_k \quad -k + \beta\gamma[(1-\delta)\,k + \pi(k,\theta_i,\bar{\varepsilon})]. \tag{34}$$

it follows that

$$k_i^{FB} = \left[\frac{\alpha\bar{\varepsilon}\theta_i}{(\beta\gamma)^{-1} - 1 + \delta}\right]^{\frac{1}{1-\alpha}}. \tag{35}$$

The investment rate is defined as

$$IR_t = \frac{k_{t+1}}{k_t} + \delta - 1. \tag{36}$$

To compute the expected investment rate we assume equal likelihood of either type. That is, at any point in time half the firms are high types. Therefore, the average capital stock is equal to

$$\mathrm{E}\,[k_t] = \frac{1}{2}\left(k_L^{FB} + k_H^{FB}\right). \tag{37}$$

For each of these firms investors use p to form priors about the next period's type. The expected investment rate is equal

$$\begin{aligned}
\mathrm{E}\left[IR_t\right] &= \underbrace{\frac{1}{2}\left\{p\delta + (1-p)\left[\left(\frac{\theta_H}{\theta_L}\right)^{\frac{1}{1-\alpha}} + \delta - 1\right]\right\}}_{\theta_t=\theta_L} \\
&+ \underbrace{\frac{1}{2}\left\{p\delta + (1-p)\left[\left(\frac{\theta_L}{\theta H}\right)^{\frac{1}{1-\alpha}} + \delta - 1\right]\right\}}_{\theta_t=\theta_H} \\
&= \delta + \frac{1}{2}(1-p)\left[\left(\frac{\theta_H}{\theta_L}\right)^{\frac{1}{1-\alpha}} + \left(\frac{\theta_L}{\theta_H}\right)^{\frac{1}{1-\alpha}} - 2\right]. \qquad (38)
\end{aligned}$$

The variance of the investment rate is equal to

$$\begin{aligned}
\mathrm{Var}(IR_t) &= \mathrm{E}\left[IR_t^2\right] - \left(\mathrm{E}\left[IR_t\right]\right)^2 \qquad (39) \\
&= p\delta^2 + \frac{1}{2}(1-p)\left\{\left[\left(\frac{\theta_H}{\theta_L}\right)^{\frac{1}{1-\alpha}} + \delta - 1\right]^2 + \left[\left(\frac{\theta_L}{\theta_H}\right)^{\frac{1}{1-\alpha}} + \delta - 1\right]^2\right\}.
\end{aligned}$$

Analogously, the average profit rate is equal to

$$\mathrm{E}\left[\frac{\pi(k_t,\theta_t,\varepsilon_t)}{k_t}\right] = \frac{\bar{\varepsilon}}{2}\left[\theta_H\left(k_H^{FB}\right)^{\alpha-1} + \theta_L\left(k_L^{FB}\right)^{\alpha-1}\right] = \frac{(\beta\gamma)^{-1} - 1 + \delta}{\alpha}. \qquad (40)$$

The ex-dividend value of the firm of each type is denoted X_i^{FB}. The expected Q ratio is given by

$$\mathrm{E}\left[Q\right] = \frac{1}{2}\left[\frac{X_L^{FB}}{k_L^{FB}} + \frac{X_H^{FB}}{k_H^{FB}}\right]. \qquad (41)$$

To estimate first-best firm value, we begin by computing the expected cash flow for each firm type. This is given by:

$$A_i \equiv -k_i^{FB} + \beta\gamma[(1-\delta)\,k_i^{FB} + \pi(k_i^{FB},\theta_i,\bar{\varepsilon})]. \qquad (42)$$

Thus the pair $\left(X_L^{FB}, X_H^{FB}\right)$ must solve the following system of equations

$$\begin{aligned} X_L^{FB} &= A_L + \beta\gamma \left[pX_L^{FB} + (1-p)X_H^{FB}\right], \\ X_H^{FB} &= A_H + \beta\gamma \left[pX_H^{FB} + (1-p)X_L^{FB}\right] \end{aligned} \tag{43}$$

to yield

$$\begin{aligned} X_L^{FB} &= \frac{(1-\beta\gamma p)A_L + \beta\gamma(1-p)A_H}{(1-\beta\gamma p)^2 - (\beta\gamma)^2(1-p)^2}, \\ X_H^{FB} &= \frac{(1-\beta\gamma p)A_H + \beta\gamma(1-p)A_L}{(1-\beta\gamma p)^2 - (\beta\gamma)^2(1-p)^2}. \end{aligned} \tag{44}$$

Appendix E: Numerical Algorithm

The solution procedure is based on value function iteration. The individual steps are as follows. The idiosyncratic shock ε is implemented by discretizing its domain using N possible values. Each maximization is implemented by discretizing the domain of the decision variables.

1. Guess default threshold $\underline{w}$.

2. Guess the end-of-period equity value functions (V_L, V_H) which are vectors on the net worth space.

3. For each point in the net worth grid, find the allocation a_L that maximizes the objective function of the low type subject to its budget constraint. Since the dividend is not unique, pick the allocation in the optimal set that minimizes the dividend.

4. For each point in the net worth grid, find the allocation a_H that maximizes the high type's objective subject to the budget and nonmimicry constraints.

5. Using the solutions from steps 3 and 4, compute new value functions $V_j^{'}$ using the recursive equation

$$V_j^{'} = p(\theta_H|\theta_j)\left[d_H + \beta\gamma(1-s_H)\sum_{n=1}^{N} f(\varepsilon_n)V_H[(1-\delta)k_H + \theta_H\varepsilon_n k_H^{\alpha} - b_H]\right]$$
$$+ p(\theta_L|\theta_j)\left[d_L + \beta\gamma(1-s_L)\sum_{n=1}^{N} f(\varepsilon_n)V_L[(1-\delta)k_L + \theta_L\varepsilon_n k_L^{\alpha} - b_L]\right].$$

6. The functions $V_j^{'}$ from the previous step are the new guesses for V_j. The procedure is then restarted from step 2 until convergence.

7. Check the endogenous default condition $V_j(\underline{w}) = 0$. If the condition is not satisfied, update the initial guess $\underline{w}$ and restart the procedure from step 1 until convergence.

Figure 1: **Timeline**

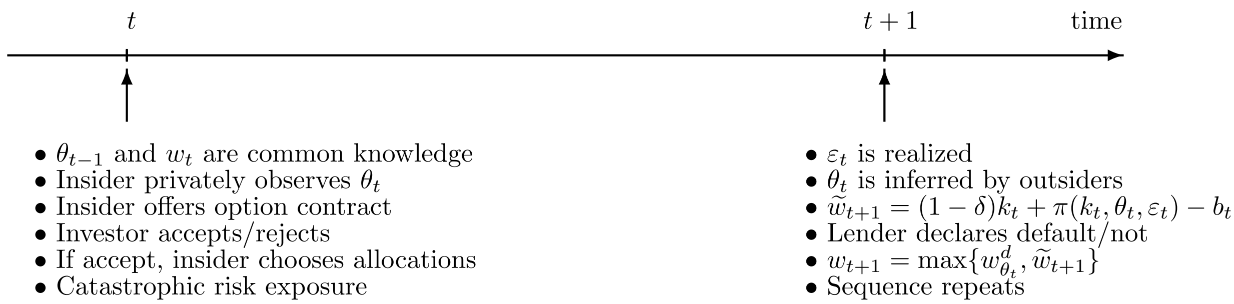


Figure 2: **Enterprise value of the firm**

The enterprise value of the firm $V_i - w$ is plotted as a function of the realized net worth, w. The productivity shock ε is i.i.d. exponentially distributed and we use parameters reported in Table 1 in calculations.

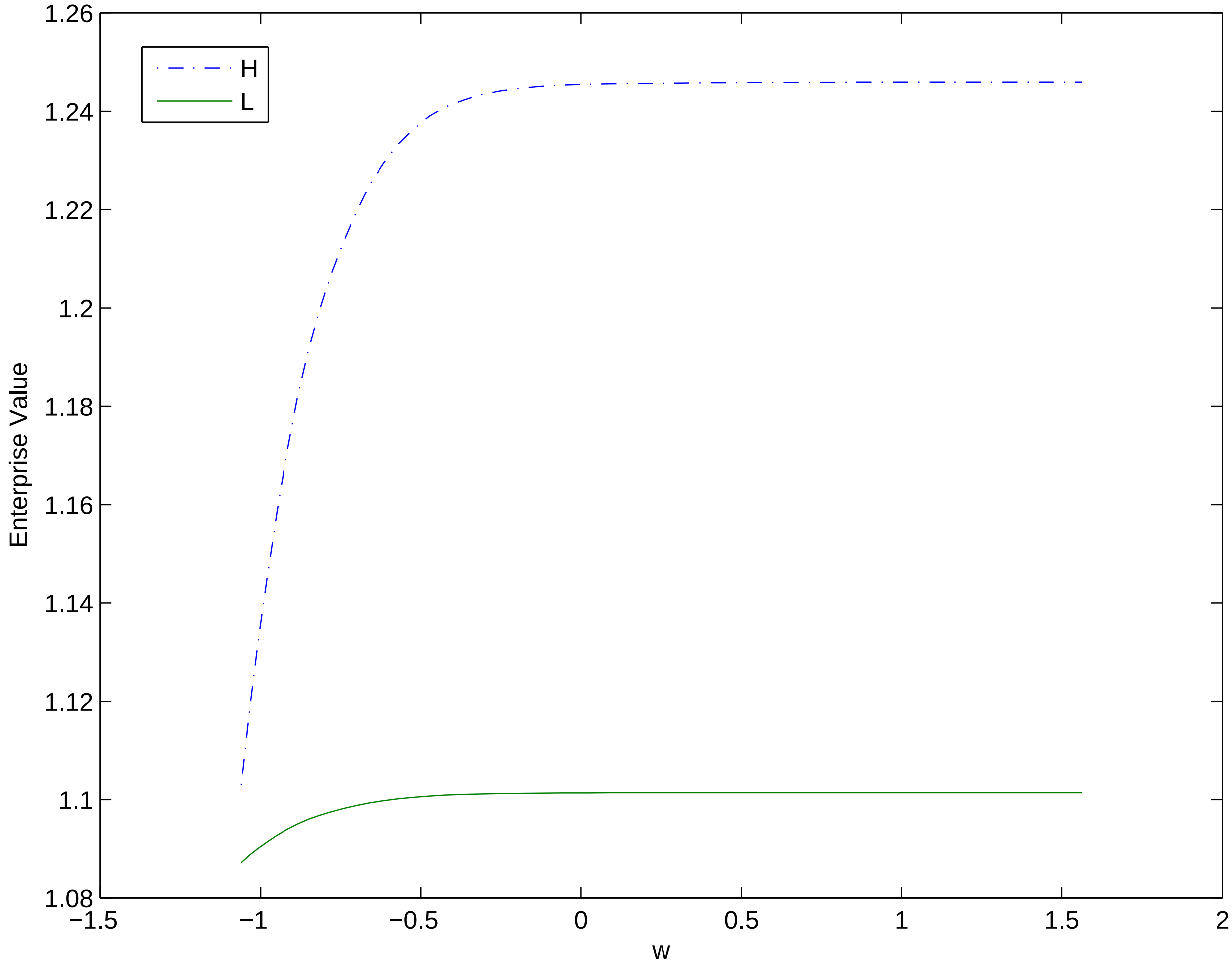


Figure 3: **Equilibrium capital allocations**

Equilibrium capital allocations, k_i^S, scaled by the first-best allocations, k_i^{FB}, are plotted as a function of the realized net worth, w, for both high and low values of θ. The productivity shock ε is i.i.d. exponentially distributed and we use parameters reported in Table 1 in calculations.

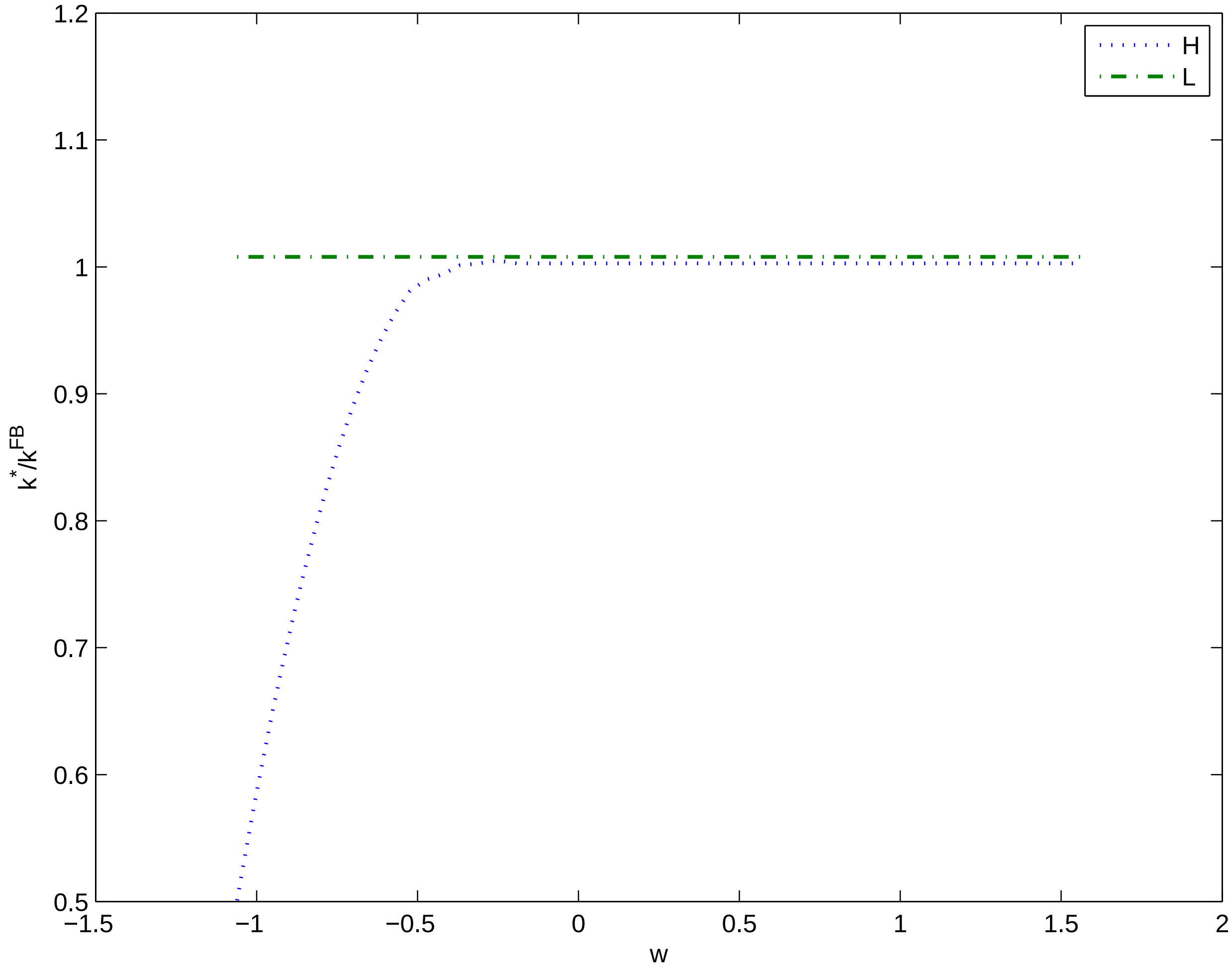
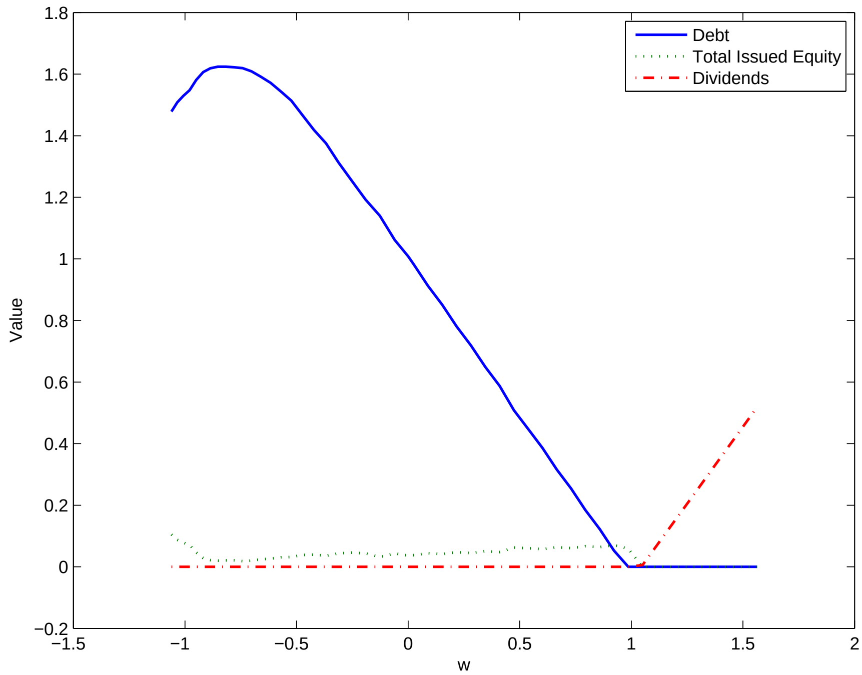


Figure 4: **Equilibrium financing policies**

Equilibrium financing policies: debt, ρ_i, and equity, $s_i^S\Omega$, as well as equilibrium dividend policy, d_i^S, are plotted as functions of the realized net worth, w. Panel A presents the case of high value of θ, while Panel B presents the case of low value of θ. The productivity shock ε is i.i.d. exponentially distributed and we use parameters reported in Table 1 in calculations.

Panel A: High value of θ



Panel B: Low value of θ

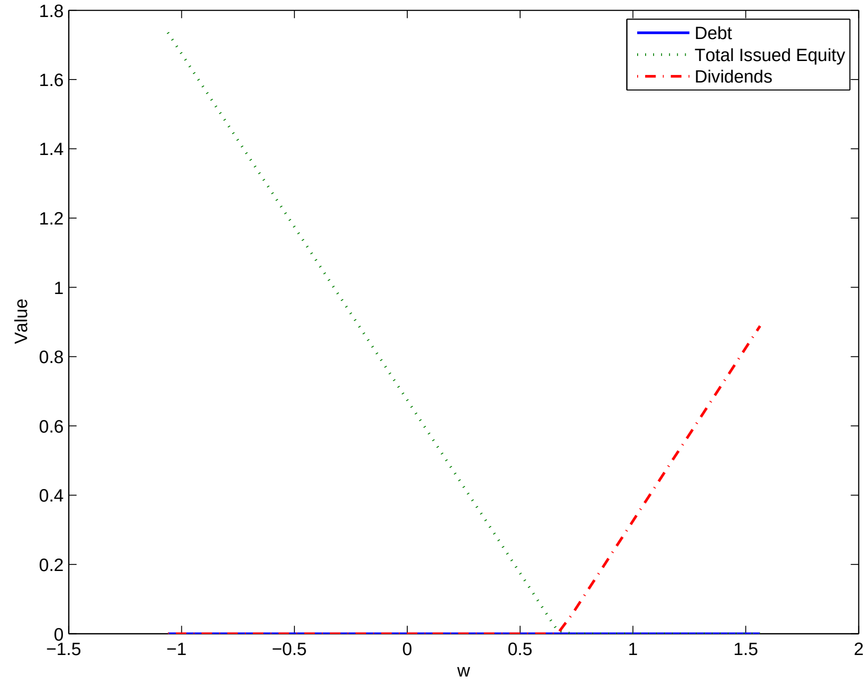


Figure 5: **Book and market leverage**

High type's book leverage, $\frac{\rho}{k_i^S}$, and market leverage, $\frac{\rho}{\rho+\Omega}$ are plotted as functions of the realized net worth, w. The public shock ε is i.i.d. exponentially distributed and we use parameters reported in Table 1 in calculations.

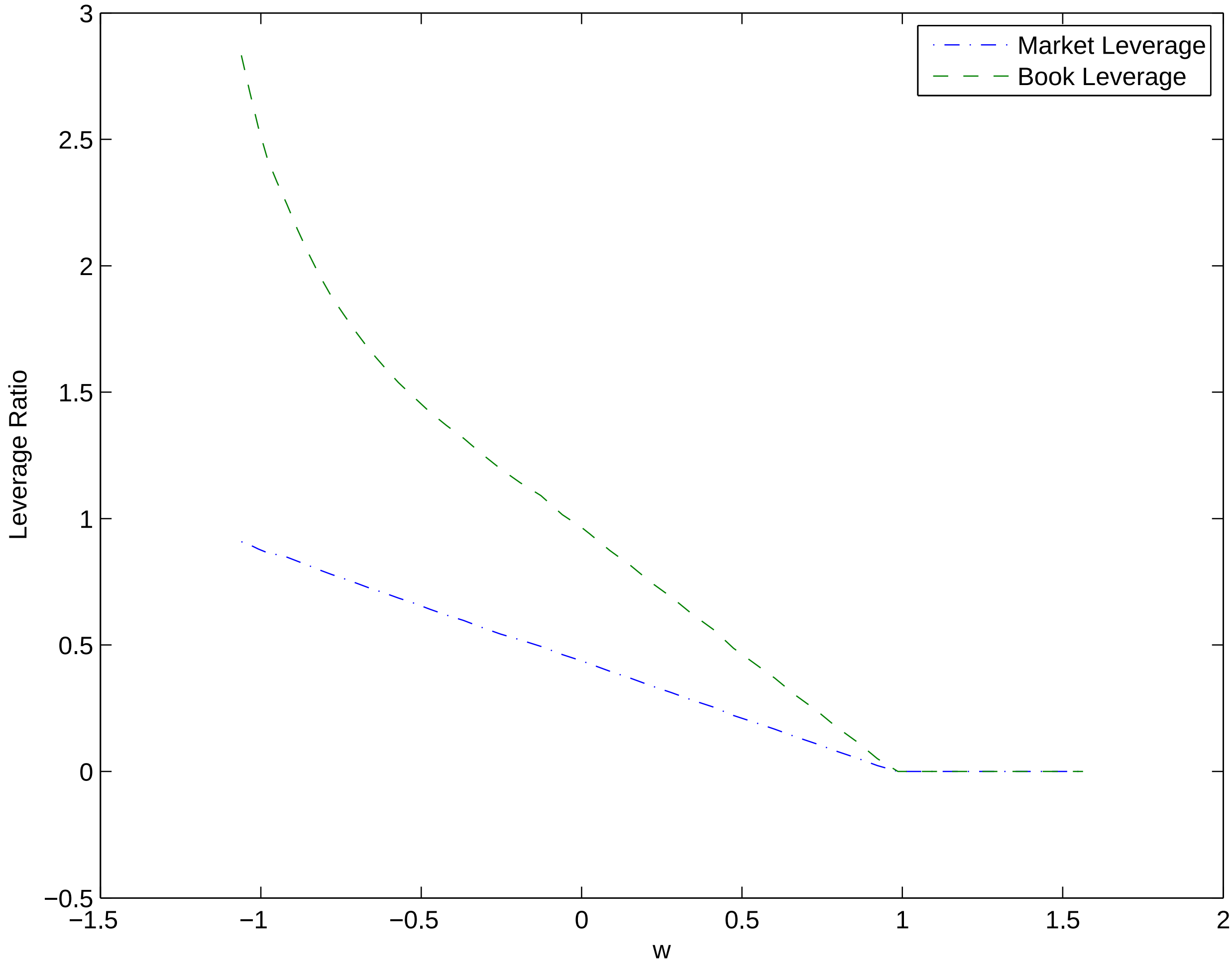


Table 1: **Parameter Values**

This table reports parameter values used to solve and simulate the model.

Notation	Parameter Value	Definition
r	0.0400	Risk-Free Rate
$1-\gamma$	0.0500	Catastrophic Event Probability
δ	0.1000	Capital Depreciation Rate
$\overline{\varepsilon}$	0.8568	Mean of Public Shock
θ_L	0.3226	Low Type Productivity
θ_H	0.3851	High Type Productivity
$p(\theta_i \vert \theta_i)$	0.9100	Type Persistence
α	0.6000	Capital Elasticity of Profits
ϕ	0.05 or 0.15	Proportional Bankruptcy Costs

Table 2: **Model and Data Moments**

This table reports moments implied by the model. The moments from the symmetric information version are calculated analytically under the assumption that the unconditional probability of each type is equal to 0.5. In the signaling case we use a simulated panel of 3000 firms. Half of the firms in the simulated panel start with positive information ($\theta = \theta_H$) while the other half starts with negative information ($\theta = \theta_L$). Both types start with the lowest net worth and are simulated for 10 time periods all of which are kept. In both cases we use i.i.d. exponentially distributed public shocks.

	Data	Symmetric Information Model	Signaling Model ($\phi = 0.05$)	Signaling Model ($\phi = 0.15$)
Average size (k_t)	0.8089	0.8556	0.7698	0.8125
Average investment rate $\left(\frac{i_{t+1}}{k_t}\right)$	0.1450	0.1091	0.1573	0.1588
Variance of investment rate	0.0193	0.0198	0.0516	0.0392
Mean Tobin's q $\left(\frac{v_{t+1}+b_t}{k_t}\right)$	1.5600	1.4153	1.8825	1.7763
Average profit rate $\left(\frac{\pi_t}{k_t}\right)$	0.2920	0.3246	0.3457	0.3354
Average market leverage $\left(\frac{\rho_t}{\rho_t+\Omega_t}\right)$	0.1204	0.0000	0.1430	0.1196
Average payout ratio $\left(\frac{d_t}{\pi_t-\rho_t+b_t}\right)$	0.2226	1.0000	0.3121	0.3170

Table 3: **Wealth Sensitivity Regressions**

This table reports results of several regressions on the simulated data with the parameter reported in the first column as the dependent variable and net worth as the explanatory variable. The simulated panel of firms contains 3,000 firms over 10 time periods. The public shock ε is i.i.d. exponentially distributed and we use parameters reported in Table 1 in simulations.

Parameter	Wealth Sensitivity	Std.	Wealth Sensitivity	Std.
	$\phi = 0.05$		$\phi = 0.15$	
Market leverage $\left(\frac{\rho_t}{\rho_t+\Omega_t}\right)$	-0.2219	0.0872	-0.2821	0.0947
Book leverage $\left(\frac{\rho_t}{k_t}\right)$	-0.2642	0.0806	-0.3096	0.1096
Dividends (d_t)	0.4182	0.0687	0.4147	0.0672
Growth rate $\left(\frac{v_{t+1}-v_t}{v_t}\right)$	-0.6277	0.2663	-0.7147	0.2957

Table 4: **Announcement Effect Regressions**

This table reports results of several regressions on the simulated data with the abnormal return on the announcement day, $AR_t = (\Gamma_{\theta_t}(w_t) - V_{\theta_{t-1}}(w_t))/V_{\theta_{t-1}}(w_t)$, as the dependent variable. The investment rate is defined as $k_{t+1}/k_t - (1-\delta)$. The simulated panel of firms contains 3,000 firms over 50 time periods. The public shock ε is i.i.d. exponentially distributed and we use parameters reported in Table 1 in simulations. $1_{\{\cdot\}}$ is the indicator function that takes the value of one if the event described in $\{\cdot\}$ occurs.

$\phi = 0.05$			$\phi = 0.15$		
Investment Rate	$\frac{\rho_t}{k_t}$	$1_{\{\rho_{t-1}=0,\rho_t>0\}}\frac{\rho_t}{k_t}$	Investment Rate	$\frac{\rho_t}{k_t}$	$1_{\{\rho_{t-1}=0,\rho_t>0\}}\frac{\rho_t}{k_t}$
0.1477	-	-	0.1511		-
(0.0245)	-	-	(0.0178)		-
-	0.0620	-	-	0.1616	-
-	(0.0400)	-	-	(0.1238)	-
-	0.0597	0.2822	-	0.0687	0.2891
-	(0.0449)	(0.0721)	-	(0.0775)	(0.0738)
0.1495	0.0039	-	0.1475	0.0211	-
(0.0487)	(0.0724)	-	(0.0227)	(0.0413)	-
0.1411	0.0329	0.0127	0.1411	0.0329	0.0127
(0.0405)	(0.0914)	(0.1296)	(0.0405)	(0.0914)	(0.1296)