Firm Payouts and Innovation Under Asymmetric Information

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This Draft: July 16, 2026

Abstract

Innovative US public companies distribute nearly 90% of their payouts through share repurchases. In the data, repurchasing firms subsequently raise leverage, R&D, and innovation, a pattern consistent with repurchases signaling favorable R&D project quality. To quantify the aggregate implications of this channel, we develop and structurally estimate an endogenous growth model with heterogeneous firms in which asymmetric information about project quality distorts financing decisions and costly repurchases credibly reveal quality. Repurchases reallocate credit toward firms with high-quality projects, raises R&D investment and social welfare by about 3%. Overall, stock repurchasing has contributed roughly 3.6 percentage points to cumulative output growth over the last two decades.

JEL Codes: E20, G30
Keywords: R&D, Growth, Repurchase, Heterogeneous Firms.

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We benefited from discussions with many including Stephen Terry. The views expressed here do not necessarily reflect those of the Banco de España or the Euro-System, the IMF or its Executive Board.

1 Introduction

Managers of public companies in the US economy can return cash to shareholders by distributing dividends or by repurchasing their own shares. Over the past few decades, repurchases have overtaken dividends as the dominant form of corporate payout, and nowhere is this shift more pronounced than among innovative firms. In 2025, S&P 500 companies returned a record $1.7 trillion to shareholders, with repurchases exceeding $1 trillion, and the largest technology firms alone accounted for more than half of repurchase activity (S&P Dow Jones Indices, 2025).[1] The rise of repurchases has fueled a contentious debate about their consequences for innovation and long-term growth. Proponents view repurchases as an efficient mechanism for reallocating capital to its most productive uses; critics argue that they come at the expense of long-term investment and growth.[2] In this paper, we quantitatively study the impact of share repurchases on firms' innovation and the economy.

In frictionless capital markets, payout policy is irrelevant for firm value (Miller and Modigliani, 1961). When managers hold private information about their firms' investment opportunities, however, the Modigliani-Miller irrelevance argument breaks down. A stock price below fundamental value makes repurchases attractive, and payout policy becomes a channel through which managers credibly convey private information to investors.[3] Information asymmetries are especially severe at innovative firms. The value of an R&D portfolio is inherently difficult for outsiders to assess for two reasons. First, managers rarely disclose their R&D projects in order to withhold information from competitors (Bhattacharya and Ritter, 1983; Hall and Lerner, 2010). Second, accounting standards prevent R&D investments from being precisely and promptly reflected in quarterly financial statements (Aboody and Lev, 2000).[4] It follows that, as investors value innovative firms under imperfect information, repurchases provide managers with a tool to signal the quality of their R&D opportunities, as in classic adverse-selection models (Akerlof, 1970; Myers and Majluf, 1984a).

We begin by documenting how firms adjust their financing and innovation following share repurchases, using Compustat data matched to the patent database of Kogan et al. (2017).

[1] Section 2 Figure 1 shows that repurchases account for nearly 90% of total payout at the typical R&D-intensive US firm in recent years.

[2] For different views see Lazonick (2014); Fried and Wang (2019); Grullon and Michaely (2004); Kahle and Stulz (2021); Almeida et al. (2016a), and Farre-Mensa et al. (2014) for a survey on the related literature.

[3] Bhattacharya (1979) and Miller and Rock (1985) develop the theory of payout policy as a signal under asymmetric information; Vermaelen (1981), Ikenberry et al. (1995a), and Dittmar (2000) provide evidence that repurchases respond to undervaluation.

[4] R&D projects could in principle be communicated through quarterly earnings calls; however, we find little evidence that company executives engage in detailed discussion of their R&D projects on these calls.

Within firms, repurchase quarters are followed by a persistent decline in cash holdings and a sizable increase in leverage relative to non-repurchase quarters, with debt rising by over 5 percent of assets in the subsequent three years. Cash buffers are drawn down as firms execute repurchase programs, while debt remains elevated, pointing to a lasting adjustment in the financing mix rather than a temporary liquidity response. At the same time, firms increase R&D expenditure and subsequently generate more patents, including patents with higher estimated economic value and more forward citations. Innovation inputs and outputs therefore rise even as firms return substantial resources to shareholders and rely more heavily on external finance.

To rationalize the empirical findings, we build a simple two-period signaling model with R&D investment and endogenous repurchasing. Two types of firms with no internal funds differ in the quality of their R&D projects, which is privately observed by their managers. Higher project quality raises both the probability that R&D yields a patent tomorrow and the revenues the patent generates; failed projects generate no revenue. After observing quality, managers can commit to a costly share repurchase. Outside investors observe the repurchase, update their beliefs about the firm's quality, and price debt and equity accordingly. Firms then issue one-period debt to finance R&D, repaying investors only if the project succeeds. When beliefs pool the two types, securities are priced at belief-weighted averages, so high-quality firms borrow at rates that overstate their risk while low-quality firms are cross-subsidized.

Repurchases act as a costly signal through which high-quality firms credibly reveal the quality of their R&D projects. Absent repurchases, lenders pool firms and price debt at the average probability of R&D success, so high-quality firms underinvest in R&D and low-quality firms overinvest relative to the full-information benchmark. Mimicking is unattractive for low-quality firms, since being perceived as high quality requires buying back their own shares above true value, a loss that can outweigh the gain from cheaper debt. A separating equilibrium can therefore be sustained in which only high-quality firms repurchase and investors correctly infer types. The resulting belief revision lowers high-quality firms' borrowing costs, and both types invest in R&D as under full information. However, because high-quality firms must also finance the repurchases, they issue more debt than in the full-information benchmark.

The simple model lacks the features needed to confront microdata and deliver quantitative macro insights, so we embed the signaling mechanism in an endogenous growth model in the spirit of Romer (1990)[5]. Time is discrete, and the economy grows through an expanding variety of intermediate goods produced by monopolistically competitive firms that invest in one-period R&D projects. We add three ingredients. First, firms face a persistent idiosyncratic productivity shock, publicly observed in the economy. Second, the private R&D project quality is a continuous draw that influences both the scale of a successful innovation and, together with R&D effort, the probability that R&D succeeds. Third, repurchasing is costly, with a fixed and a quadratic component; the fixed cost implies that only sufficiently high-quality firms repurchase, leaving the rest pooled at zero. We characterize the unique separating equilibrium in the model: only firms with sufficiently good projects repurchase, repurchases increase with quality, and the fund infers quality from the repurchase choice and prices securities accordingly. In general equilibrium, a stationary distribution of firms generates balanced growth equal to the success-weighted sum of firm innovation, which determines the representative household's welfare.

We structurally estimate the model by the simulated method of moments (SMM). The estimated parameters govern the elasticity of innovation to R&D, the persistence and volatility of demand, the dispersion of project quality, and the fixed and convex costs of repurchasing. Moments on the volatility of R&D growth, the average probability of patenting, and the sensitivity of patenting to R&D discipline the innovation technology, while the frequency and volatility of repurchases and their correlation with R&D pin down the cost of signaling. The estimates imply substantial dispersion in project quality, an R&D elasticity in line with conventional values, and repurchase costs small enough that high-quality firms find it worthwhile to separate.

Counterfactuals comparing the estimated economy to one without repurchasing reveal impacts at both the micro and macro levels. At the firm level, the ability to repurchase moves R&D closer to what firms would choose under full information. Mean R&D rises by 12.5%, and because investment shifts from low- toward high-quality projects, the typical project is more likely to succeed. At the aggregate level, the higher level and better allocation of R&D feed into innovation spillovers that individual firms do not capture. Output grows about 13 basis points faster per year, and welfare is 3.2% higher in consumption-equivalent terms. Over the last two decades, this implies that repurchases have contributed roughly 3.6

[5]The quantitative framework also relates to endogenous-growth models in which innovation and resource allocation determine aggregate growth, including Kogan et al. (2017) and Acemoglu et al. (2018), and to work showing that financial, informational, and managerial frictions distort innovative investment and affect aggregate outcomes, including Caggese (2019), Malamud and Zucchi (2019), Terry (2023), Terry et al. (2023a), and Celik and Tian (2023).

percentage points to cumulative output growth.

The model delivers two policy implications. First, banning repurchases—as several European countries did until the late 1990s and as proposed by U.S. legislators—would forgo the gains from signaling, and the cost would fall disproportionately on R&D-intensive sectors, where the information friction that repurchases resolve is most severe. Second, taxing repurchases is a milder intervention with a perhaps surprising effect. A linear excise tax, like the 1% levy introduced in 2022, raises the cost of mimicry along with the cost of the signal, so high-quality firms separate with smaller repurchases. The tax trims resources dissipated in signaling, modestly raising R&D and innovation, at a cost borne by shareholders and with little effect on long-run growth.

Literature. Our paper relates to three strands of literature. First, it contributes to work on payout signaling and asymmetric information. A macro-finance literature studies how adverse selection affects external finance and aggregate activity (Eisfeldt, 2004; Kurlat, 2013; Bigio, 2015; Guo et al., 2025). Our mechanism builds on classic models in which informed agents take costly actions to reveal private information (Spence, 1973; Leland and Pyle, 1977; Myers and Majluf, 1984b) and on theories of payout as a signal (Bhattacharya, 1979; Miller and Rock, 1985; Vermaelen, 1981).[6] Relative to this work, the private information in our model concerns the quality of an R&D project rather than assets in place, and the repurchase changes the terms at which both debt and equity investors finance innovation, complementing the issuance-side revelation in Guo et al. (2025) and linking the signal to leverage, R&D, and long-run growth.

Second, the paper relates to work on financial frictions and the financing of innovation, including structural models of costly external finance (Gomes, 2001; Hennessy and Whited, 2007), heterogeneous-firm models of borrowing constraints and allocation (Khan and Thomas, 2013; Midrigan and Xu, 2014; Moll, 2014), and, closest to us, earnings-based borrowing constraints (Lian and Ma, 2021; Drechsel, 2023).[7] Within this literature, evidence on the real effects of repurchases is mixed, with some studies finding cuts to investment around EPS targets and others finding improved innovation quality (Wang et al., 2021; Almeida et al., 2025). Our framework reconciles these findings by making the cost of external

[6] Empirically, returns are positive following repurchase announcements (Comment and Jarrell, 1991; Ikenberry et al., 1995b; Stephens and Weisbach, 1998), and repurchases serve as a flexible payout instrument (Jagannathan et al., 2000; Skinner, 2008; Brav et al., 2005).

[7] An empirical literature shows that innovative investment depends on access to external finance (Bernstein, 2015; Acharya and Xu, 2017) and that patents support debt capacity by making innovative assets pledgeable (Mann, 2018).

finance endogenous to the repurchase decision, so that separation lowers R&D at low-quality firms and raises it at high-quality ones, with higher leverage as the equilibrium cost of the improved allocation.

Finally, the paper contributes to the literature on endogenous growth. We build on expanding-variety and creative-destruction models (Romer, 1990; Grossman and Helpman, 1991; Aghion and Howitt, 1992; Klette and Kortum, 2004), on quantitative work linking firm heterogeneity to aggregate innovation (Kogan et al., 2017; Acemoglu et al., 2018), and on models in which managerial and informational frictions distort firm-level R&D with aggregate consequences (Terry, 2023; Celik and Tian, 2023). Our contribution is a payout decision that reveals privately observed project quality before firms invest, changing both the level and the composition of R&D. Embedding the mechanism in general equilibrium lets us quantify the gains from better-targeted R&D for growth and welfare, and provides a framework for evaluating taxes or restrictions on repurchases when payout policy itself carries information.

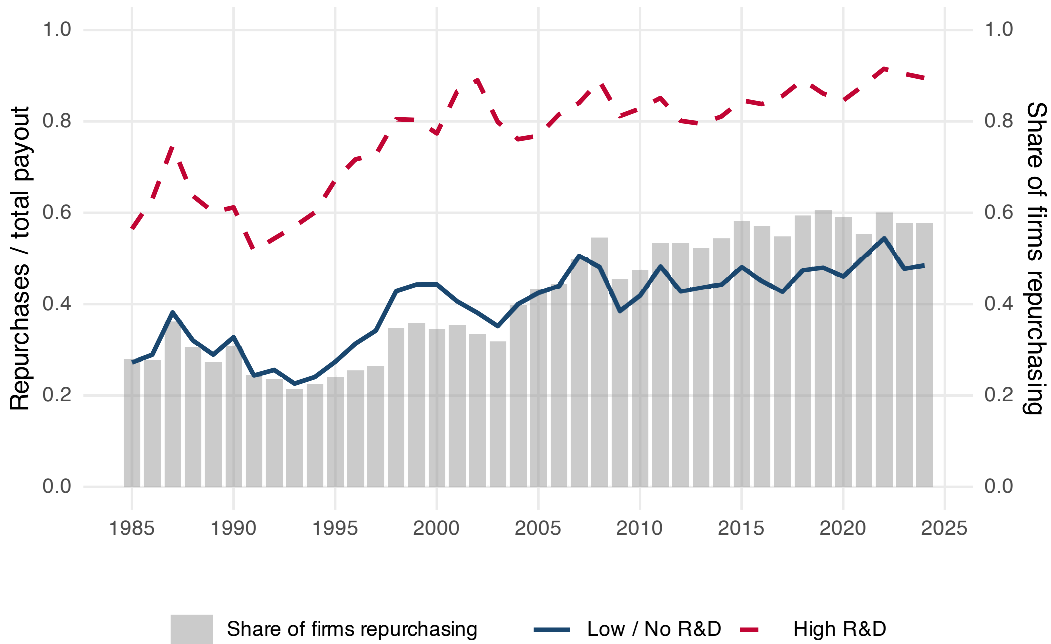
The rest of the paper is organized as follows. Section 2 presents the empirical evidence. Section 3 introduces the signaling model with asymmetric information and links their implications to the data. Section 4 embeds the signaling mechanism into a structural endogenous growth model to quantify the implications of repurchases on firms and long-run growth. Section 6 concludes.

2 Empirics

Our main data source is quarterly Compustat's North America, which contains financial statement information on US-incorporated public firms. We exclude firms in finance, utilities, and public administration. We apply standard cleaning, and retain firms with at least 40 consecutive quarters of investment data. The resulting panel covers 7,000 firms from 1985 to 2024. Our sample primarily consists of larger firms, which together account for more than 50% of R&D expenditures and the vast majority of share repurchases in the US economy. We merge the data to the USPTO patenting outcomes from Kogan et al. (2017) which allow us to observe innovation output alongside firms' real and financial decisions. Appendix A provides further details of the variable definitions and sample construction, with descriptive statistics in Table A.3.

Figure 1 shows the evolution of stock repurchases among US public firms from 1985 to 2024. Two patterns emerge. First, repurchases have become a common feature of corporate payout policy. The share of firms conducting repurchases rises sharply over the sample

Figure 1: Repurchasing activity in the US, 1985-2024



Notes: The figure plots, by year, the share of Compustat firms engaging in stock repurchases (gray bars) and the average share of payout distributed through repurchases (lines). Firms are split by R&D intensity (R&D expenditure over sales): the red dashed line shows firms with R&D intensity above the median among R&D-active firms, computed over 15-year windows; the blue solid line shows firms with low or no R&D. Repurchases and dividends are from annual Compustat data.

period, with the increase especially pronounced after the late 1990s. This pattern reflects both the growing use of buyback programs and changes in the regulatory environment, including the 2003 amendments to Rule 10b-18.[8] Second, the share of repurchases in total payout has increased substantially, with a marked difference between firms that engage in R&D and those that do not. Among firms with significant R&D activity, over the last five years repurchases accounted for almost all payout, while for firms with little R&D activity the repurchase share was slightly above 60%.

We next examine how firms' financial and innovation outcomes evolve following repurchase activity. We construct an indicator variable $\text{Repurchase}_{i,t}$, equal to one if firm i repurchases stock in quarter t, as measured from cash-flow statements. Then, for each outcome

[8]The SEC's 2003 amendments to Rule 10b–18 updated the safe-harbor conditions governing the timing, price, volume, and manner of open-market repurchases and introduced periodic disclosure requirements for issuer repurchase activity. Before 2004, we therefore impute repurchases from cash-flow statements as purchases of common and preferred stock net of preferred redemptions; from 2004 onward, we use the disclosure-based measures when available.

$Y_{i,t}$, we estimate

$$Y_{i,t+h} - Y_{i,t-1} = \gamma_h \cdot \text{Repurchase}_{i,t} + \boldsymbol{\beta}'_h \mathbf{X}_{i,t} + \alpha_i + \mu_{s(i),t+h} + \epsilon_{i,t+h}. \tag{1}$$

The dependent variable is the change in the outcome from $t-1$ to $t+h$, scaled by lagged total assets. The vector $\mathbf{X}_{i,t}$ includes lagged assets and lagged sales growth, and α_i and $\mu_{s(i),t+h}$ are firm and sector-by-quarter (two-digit SIC $\times$ quarter) fixed effects, respectively. The coefficient γ_h therefore measures how a firm's outcomes evolve after its repurchase quarters relative to its non-repurchase quarters, net of sector-by-quarter shocks. Identification comes from within-firm variation in repurchase activity over time, not from comparisons across repurchasing and non-repurchasing firms. Table 1 reports estimates of equation (1) at a three-year (twelve-quarter) horizon.

Panel A examines capital structure. Column (1) shows that cash holdings decline by 2.4% of assets over the three years following a repurchase, a reduction of 28% relative to the median firm. Column (2) shows that debt increases by 5.4% of assets, or 26% at the median. Book equity falls by 3.6% of assets in column (3). An accounting note is useful here. Book equity equals assets minus liabilities, so paying out cash and accumulating debt mechanically shrink equity. Repurchases reduce cash and book equity, while the accompanying increase in debt allows firms to finance a larger payout without an equivalent reduction in investment. Taken together, the estimates point to a persistent shift in the financing mix, away from internal liquidity and equity and toward debt.

Are repurchasing firms cutting back on investment and innovation? Our estimates suggest they do not. Panel B shows that repurchases are not followed by a contraction in investment expenditure. Column (1) reports that R&D expenditure rises by 0.2% of assets following a repurchase. Relative to the median R&D-to-assets ratio, this corresponds to an increase of approximately 14%. For a firm with the median level of assets, about \$194 million, the estimate implies roughly \$0.4 million in additional R&D expenditure. Columns (2) and (3) show that SG&A expenditure and capital expenditure also rise, by 0.3% and 0.2% of assets, respectively. Because reported R&D may reflect accounting discretion, and it is notoriously noisy in the financial statements, Panel C turns to external measures of innovation based on patenting. Column (1) reveals that patent counts rise by 27% relative to the median firm. Patent counts, though transparent, do not incorporate quality information. Columns (2) and (3) report that value-weighted and citation-weighted patenting rise by 49% and 57% at the median. To summarize, these results suggest that repurchasing firms are able to return

Table 1: Impact of Repurchase on Firms' Outcomes

Panel A: Capital Structure	(1) Cash	(2) Debt	(3) Equity
Repurchase	-0.0240***	0.0541***	-0.0364***
	(0.0050)	(0.0056)	(0.0092)
Effect at Median (%)	-27.9	25.9	-7.4
Firm & Sector × Quarter FE	Yes	Yes	Yes
Observations	284,392	267,944	284,287
Panel B: Investment Growth	**R&D**	**SG&A**	**CapEx**
Repurchase	0.0021***	0.0028***	0.0018**
	(0.0007)	(0.0010)	(0.0009)
Effect at Median (%)	14.2	4.0	21.6
Firm & Sector × Quarter FE	Yes	Yes	Yes
Observations	110,088	255,956	277,329
Panel C: Innovation Output	**Patent Count-Weight**	**Patent Value-Weight**	**Patent Cite-Weight**
Repurchase	0.0010***	0.0008***	0.0026***
	(0.0002)	(0.0002)	(0.0007)
Effect at Median (%)	26.5	48.7	57.1
Firm & Sector × Quarter FE	Yes	Yes	Yes
Observations	284,392	284,392	284,392

Notes: This table presents coefficient estimates from fixed-effects regressions examining the relationship between share repurchases and multiple firm outcomes. The dependent variable in each specification is constructed as the change in the outcome from quarter $t-1$ to quarter $t+12$ normalized by lagged total assets. Panel A reports effects on capital structure decisions: cash, debt and equity. Panel B presents effects on investment outcomes: R&D expenditures, selling general and administrative expenses, and capital expenditure. Panel C reports effects on subsequent patenting innovation. The patent variables are inverse-hyperbolic-sine transformations of patent counts, patent values, and forward citations. All models include firm and sector-by-quarter fixed effects. Standard errors are two-way clustered by firm and date. Standard errors, clustered at the firm-quarter level, are in parentheses. $*$ = 10% level, $**$ = 5% level, and $***$ = 1% level. See Appendix A for further details.

cash to shareholders while continuing to expand R&D investment and innovation output, in part by substituting external debt financing for internal funds.

Appendix A presents additional results and robustness checks. Table A.4 verifies that our estimates are qualitatively similar when R&D is replaced with capital expenditures or overhead costs measured by SG&A. Figure A.8 traces dynamic responses from one to twenty quarters after a repurchase and shows that the main patterns are stable across horizons. Figure A.9 shows that balance-sheet adjustments scale with repurchase size, while innovation responses vary little with it. Figure A.7 shows that larger repurchases earn stronger announcement returns, consistent with the market assigning greater informational content to larger transactions. Finally, Figures A.10 and A.11 show that the results hold in both the pre- and post-2004 samples, before and after the SEC began requiring disclosure of actual repurchases. Although exact magnitudes vary across these exercises, all checks deliver the same qualitative conclusions.

One caveat applies to our empirical estimates. Repurchase decisions are endogenous choices, so the estimates are descriptive and cannot be interpreted as causal. Rather, the resulting dynamics are empirical patterns that a model of repurchase behavior should rationalize. We now turn to a simple model that rationalizes the sign of our estimates.

3 A Simple Model of Stock Repurchase

A simple model illustrates how stock repurchases can be used by firms to signal the quality of their R&D projects in an economy with asymmetric information.

Timing. Consider two types of firms operating for two periods, t (today) and $t+1$ (tomorrow). At the beginning of t, Nature draws the quality of each firm's R&D project, $\theta \in \{\theta_L, \theta_H\}$ with $\theta_L < \theta_H$ and prior $\Pr(\theta = \theta_H) = \pi \in (0,1)$. The manager privately observes θ and commits to spending $e_t \geq 0$ dollars on share repurchases. Outsiders observe e_t and form posterior beliefs $\mu_t(\theta \mid e_t)$, which determine the equity price—and hence the fraction s_t of shares retired—and the price of debt. The manager then chooses R&D investment w_t and debt issuance b_{t+1}. At $t+1$, the R&D outcome is realized, debt is repaid upon success, and the firm sells its products.

Firm. Firms invest w_t dollars in R&D. The R&D project succeeds and yields a patent with probability increasing in project quality,

$$p(\theta) = 1 - e^{-\theta}. \tag{2}$$

Upon success, the patent generates a mass of products

$$m_{t+1}(w_t, \theta) = \frac{1}{\alpha}\,\theta\, w_t^{\alpha}, \qquad 0 < \alpha < 1, \tag{3}$$

which the firm sells tomorrow at unit price; upon failure, output is zero. Firms finance w_t by issuing one-period debt with face value b_{t+1} at discount price q_t. Debt must be fully repaid out of revenue whenever R&D succeeds, which caps issuance at the firm's future cash flow,[9]

$$b_{t+1} \leq m_{t+1}(w_t, \theta); \tag{4}$$

upon failure, lenders recover nothing. The manager chooses e_t, w_t, and b_{t+1} to maximize the post-repurchase value per share of equity,[10]

$$v_t^0(\theta) = \max_{e_t \geq 0}\; v_t^0(e_t \mid \theta) \equiv \max_{e_t \geq 0}\; \frac{1}{1 - s_t(e_t)}\, v_t(e_t \mid \theta, q_t), \tag{5}$$

where $(1 - s_t)^{-1}$ captures the accretion effect from retiring a fraction s_t of outstanding shares (normalized to unit mass), and $v_t(e_t \mid \theta, q_t)$ is the firm's continuation value,

$$v_t(e_t \mid \theta, q_t) = \max_{w_t,\, b_{t+1}}\; d_t + \frac{1}{R}\left[m_{t+1}(w_t, \theta) - b_{t+1}\right] p(\theta), \tag{6}$$

where R is the gross risk-free rate, subject to (3), (4), and non-negative dividends,

$$d_t = -w_t + q_t\, b_{t+1} - g(e_t) \geq 0. \tag{7}$$

Repurchasing e_t dollars of shares requires total resources $g(e_t) = e_t + \phi_1 e_t^2$, with $\phi_1 > 0$. The amount e_t is paid to tendering shareholders, while $\phi_1 e_t^2$ is the convex cost of executing the program.

[9] Since m_{t+1} measures the firm's future revenue, Equation (4) is a cash-flow-based borrowing constraint in the spirit of the corporate lending practices documented by Lian and Ma (2021) for innovative firms.

[10] With fairly priced debt and no taxes, the debt level is indeterminate beyond financing needs; we select the minimum level consistent with (7). When debt is mispriced, the choice is instead pinned down by the resource or borrowing constraints.

Debt. Lenders are risk neutral and competitive, observe e_t, and lend anonymously, without conditioning on the firm's R&D and debt choices. Let $b_{t+1}(\theta)$ denote the debt-issuance policies solving (6) for each type. The equilibrium debt price satisfies the lenders' break-even condition across the pool of firms choosing e_t:

$$q_t(e_t) = \frac{1}{R}\left[\sum_{\theta} p(\theta) \cdot b_{t+1}(\theta) \cdot \mu_t(\theta \mid e_t)\right]\left[\sum_{\theta} b_{t+1}(\theta) \cdot \mu_t(\theta \mid e_t)\right]^{-1}. \tag{8}$$

The debt price is a debt-weighted average of success probabilities across types: firms that borrow more contribute more to lenders' exposure and therefore receive greater weight.

Equity. Equity investors determine the share price and hence the fraction s_t of shares that each firm repurchases given e_t dollars spent. Under risk-neutral investors and perfect competition, the equity market satisfies a zero-profit condition:

$$e_t = \frac{s_t(e_t)}{1 - s_t(e_t)} \sum_{\theta} v_t(e_t \mid \theta, q_t)\, \mu_t(\theta \mid e_t), \tag{9}$$

which equates the cash paid out through repurchases to the market value of the tendered shares. Investors' beliefs μ_t influence the price of debt and the stock market value of firms.

3.1 Characterization of the Equilibrium

We show that, under incomplete information, a separating strategy profile where each type of firm repurchases a different amount of shares can be sustained as a Perfect Bayesian Equilibrium (PBE). Formal proofs of the existence and characterization of the PBE in the simple model are in Appendix B.

Separating PBE. In a separating strategy profile, high-quality firms choose a repurchase level $e_H > 0$ while low-quality firms choose $e_L \neq e_H$, with $e_L \geq 0$. Upon observing e_H, outside investors update their beliefs using Bayes' rule and assign probability one to the firm being of high quality, $\mu_t(\theta_H \mid e_H) = 1$; upon observing e_L, they assign probability zero, $\mu_t(\theta_H \mid e_L) = 0$. Given these beliefs, the debt and equity markets price securities at high-type values following e_H — the debt price is $q_t(e_H) = p(\theta_H)/R$ and the repurchased fraction $s_t(e_H)$ solves the equity zero-profit condition at $\mu_t = 1$ — and at low-type values following e_L. For any off-equilibrium repurchase level $e \notin \{e_L, e_H\}$, Bayes' rule does not apply. We sustain a separating equilibrium assuming off-path beliefs $\mu_t(\theta_H \mid e) = 0$ for all $e \notin \{e_L, e_H\}$. It follows that any off-path deviation is priced at low-type values and additionally incurs the execution cost, so it is dominated by choosing $e = 0$. Incentive compatibility therefore reduces to conditions (IC-low) and (IC-high) below.

Consider first the low-type firm's optimal choice. In any separating equilibrium, choosing $e_L \neq e_H$ reveals the firm as low quality, so investors set $\mu_t(\theta_H \mid e_L) = 0$ and price securities at low-type values. Since beliefs do not respond to e_L, repurchases convey no information. A Modigliani-Miller logic then applies and the e_L dollars paid out to tendering shareholders are exactly offset by the accretion gain to remaining shareholders, who retain a larger fraction of the firm. The only economic cost is the deadweight component $\phi_1 e_L^2$, which is strictly increasing in e_L. Hence, absent an informational benefit, the low-type firm avoids the deadweight cost of repurchasing, so that $e_L = 0$ in any separating equilibrium.

A high-type firm chooses the repurchase level prescribed by the separating strategy profile, e_H, rather than deviating to the low-type level $e_L = 0$, if the benefit of separating from the low type exceeds the cost of repurchasing; and the profile is an equilibrium only if the low type has no incentive to mimic. These two requirements yield a range of repurchase levels, $e_H \in [e_H^{\min}, e_H^{\max}]$, that sustain a separating PBE.

The lower bound on e_H is determined by the low-type firm's incentive to mimic. If the low type chooses e_H instead of $e_L = 0$, investors perceive it as high quality and price securities accordingly. The low type has no incentive to mimic if and only if [11]

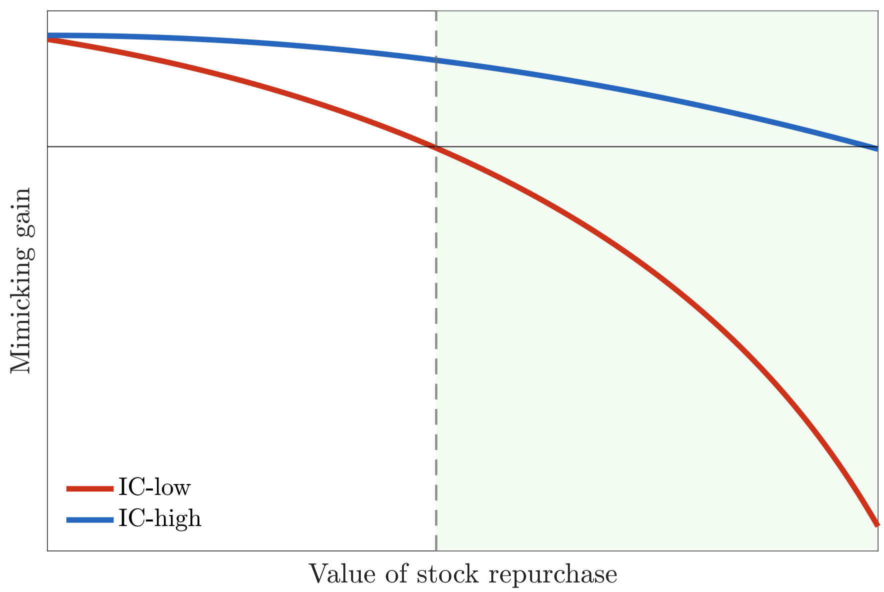
$$v_t^0(e_L = 0 \mid \theta_L,\, \mu_t = 0) \;\geq\; v_t^0(e_H \mid \theta_L,\, \mu_t = 1). \tag{IC-low}$$

The left side is the low type's value from revealing itself, where it is correctly identified and earns the low-type debt price; the right side is its payoff from mimicking, where it pays the repurchase cost $g(e_H)$ and buys back shares at a price that reflects high-type value—overpaying relative to its true continuation value—but is rewarded with the high-type debt price. Define $e_H^{\min}$ as the value of e_H at which (IC-low) binds. For $e_H \geq e_H^{\min}$, the low type weakly prefers not to mimic and separation is sustained. The least-costly separating PBE corresponds to $e_H = e_H^{\min}$: it is the smallest repurchase that credibly distinguishes the high type, since at any lower level the low type would strictly prefer to mimic.

The upper bound on e_H is determined by the high-type firm's incentive to signal. If the

[11] With slight abuse of notation, we write $v_t^0(e \mid \theta, \mu_t)$ for the payoff $v_t^0(e \mid \theta)$ in (5) when the schedules $q_t(e)$ and $s_t(e)$ are computed from the zero-profit conditions (8) and (9) at belief μ_t. On the equilibrium path, $v_t^0(e_t \mid \theta) = v_t^0(e_t \mid \theta, \mu_t(e_t))$.

Figure 2: Gains from Mimicking in the Separating Equilibrium



Notes: The figure reports the two incentive-compatibility objects as functions of the value of stock repurchases. The red curve (legend: IC-low) is the low-type mimicking gain, $v_L^{\text{mimic}} - v_L^{\text{truth}}$, and the blue curve (legend: IC-high) is the high-type separating gain, $v_H^{\text{truth}} - v_H^{\text{mimic}}$. The vertical dashed line marks the least-cost separating threshold and the shaded region denotes values consistent with separation. Parameter values used are $\theta_L = 0.95$, $\theta_H = 1.10$, $\alpha = 0.65$, $R = 1.04$, and $\phi_1 = 3.00$.

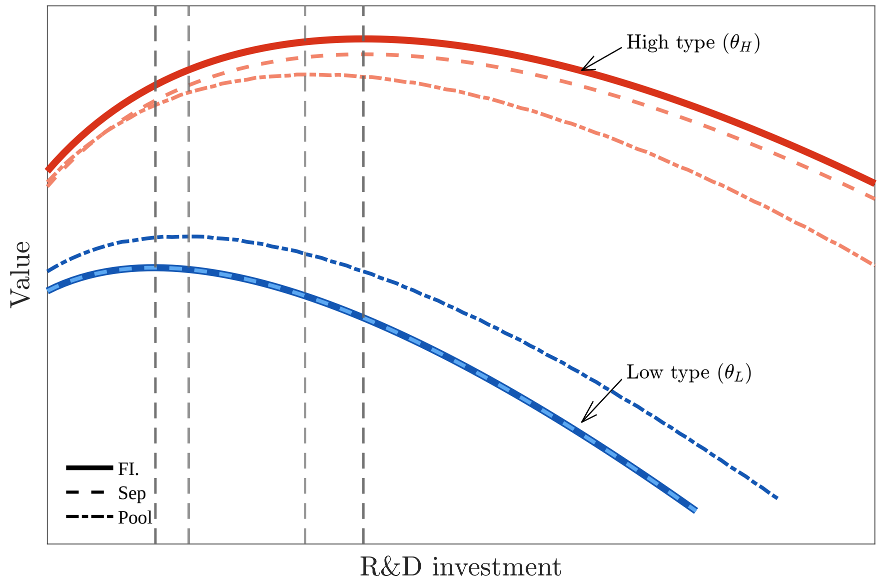
high type deviates to $e_L = 0$, its avoids the repurchase cost but is perceived as low quality. It therefore prefers the equilibrium strategy e_H over deviation if and only if

$$v_t^0(e_H \mid \theta_H,\, \mu_t = 1) \;\geq\; v_t^0(e_L = 0 \mid \theta_H,\, \mu_t = 0). \tag{IC-high}$$

The left side is the high type's equilibrium value at the signaling level e_H; the right side is its payoff from abandoning the signal and being mispriced as low quality. Define $e_H^{\max}$ as the value of e_H that makes (IC-high) bind. For $e_H \leq e_H^{\max}$, the high type prefers to signal rather than deviate. The least-costly separating PBE corresponds to $e_H = e_H^{\max}$, that is the largest repurchase the high type is willing to undertake to separate itself from the low type.

Among separating PBEs, the least-costly repurchase level is the unique one that survives the Cho and Kreps (1987) Intuitive Criterion. The criterion restricts off-equilibrium beliefs by requiring that, when a deviation could be profitable only for one type of sender, the receiver assigns probability one to that type. Consider any separating PBE with $e_H > e_H^{\min}$ and a deviation to some $e' \in (e_H^{\min}, e_H)$. By construction of $e_H^{\min}$, the low type cannot gain

Figure 3: Value Functions as Functions of R&D Investment



Notes: The figure plots firm value as a function of R&D investment with debt evaluated at the optimum for each case. The red lines are the value for the high-type firm (θ_H), blue lines are the value for the low-type firm (θ_L). Solid lines denote full information, dashed lines separating, and dash-dot lines pooling. Gray vertical dashed markers indicate the R&D values at which each curve attains its maximum.

from choosing e' even under the most favorable belief $\mu_t = 1$, whereas the high type gains whenever it is believed to be of high quality, since e' credibly deters mimicry at a lower execution cost. The criterion therefore forces $\mu_t(\theta_H \mid e') = 1$, the high type deviates, and the equilibrium unravels. The unique surviving strategy profile is the Riley outcome: the high-quality firm signals its type by undertaking the smallest repurchase that credibly deters mimicry by the low-quality firm, $e_H = e_H^{\min}$. In a pooling equilibrium, repurchases convey no information on path, so any common level $e > 0$ only burns resources through the execution cost; the natural pooling candidate therefore features $e = 0$ for both types. Appendix B shows that this no-repurchase pooling equilibrium also fails the Intuitive Criterion.

Figure 2 illustrates the two incentive-compatibility constraints when stock repurchases are used as a signal of project quality. The point at which the IC-low curve crosses zero identifies the least-costly separating equilibrium, $e_H^{\min}$. The shaded region shows the range of repurchase levels that can sustain a separating equilibrium.

Impact on R&D Investment. Figure 3 plots, for each type, value under full information, separating, and pooling as a function of R&D investment. Three results emerge. First, for the low-quality firm the separating allocation coincides with full information; firm does not repurchase in equilibrium ($e_L = 0$), so signaling leaves its continuation problem unchanged. Second, for high-quality firms, separation restores the full-information investment level but not the full-information value. In the separating equilibrium debt is fairly priced, so the repurchase program is financed by borrowing more without distorting the marginal return to R&D, and the cost of separation is the pure deadweight loss of the repurchase.[12] Third, pooling distorts investment in opposite directions across types through the debt price: low-quality firms borrow at a price that overstates their success probability and overinvest, while high-quality firms face the reverse and underinvest. In summary, separation restores type-specific pricing and investment relative to pooling, at the cost of higher leverage and the signaling expense borne by the high type.

How much do stock repurchases contribute to innovation and growth? Because they correct an informational friction, repurchases should contribute positively to both. The simple model, however, cannot address this question, for two reasons. First, in standard endogenous growth models, R&D generates spillovers that drive the creation of future ideas, a channel absent from the simple model. Second, the simple model lacks the dynamics and the idiosyncratic firm heterogeneity that are necessary to match salient features of the micro data quantitatively. We now extend the simple model into a general equilibrium endogenous growth framework.

4 Quantitative Model

We develop a quantitative model to study the impact of share repurchases on innovation and long-run growth. Time is discrete and there is no aggregate uncertainty. The economy grows through an expanding variety of products, as in the endogenous growth models of Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1992).[13] The model extends the simple model in section 3 along three dimensions. First, a unit mass of heterogeneous firms draws the quality of the project from a continuous distribution. Second, firms finance innovation with internal funds in addition to one-period debt. Third, the probability that

[12]This requires the borrowing constraint (4) to remain slack at the higher debt level, which holds in our parameterization.

[13]See Terry (2023); Terry et al. (2023b) for other recent applications with the same baseline quantitative framework.

R&D yields a patent increases in both project quality and R&D spending, as in the data (Appendix Figure A.12). The within-period timing is otherwise identical to the simple model. At the beginning of each period, managers privately observe project quality, commit to a repurchase, and then issue debt and choose R&D after investors update beliefs and price securities. R&D outcomes and revenues are realized at the start of the next period. We denote posterior beliefs over project quality by μ_t.

4.1 Households

A representative household owns final-good firms, intermediate-good firms, and a representative investment fund. It supplies one unit of land inelastically and solves the consumption-savings problem

$$\max_{\{C_t, B_{t+1}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \frac{C_t^{1-\eta}}{1-\eta} \quad \text{s.t.} \tag{10}$$

$$C_t + B_{t+1} = P_t^L L_t + R_t B_t + D_t^{Fin} + D_t^{Int} + D_t^{Fund}, \tag{11}$$

with initial condition B_0 given. Here, $\beta \in (0,1)$ denotes the subjective discount factor, $\eta > 0$ the coefficient of relative risk aversion, P_t^L the price of land, B_t the stock of risk-free debt securities, R_t the gross risk-free interest rate, and D_t^{Fin}, D_t^{Int} and D_t^{Fund} the payouts from the final-good sector, the intermediate-good sector and the investment fund. The Euler equation is:

$$\frac{1}{C_t^{\eta}} = \beta R_{t+1} \frac{1}{C_{t+1}^{\eta}}. \tag{12}$$

Because the household holds a diversified portfolio, idiosyncratic risk is fully insured.

4.2 Final Goods

A perfectly competitive final-good sector rents land L_t and aggregates a continuum of differentiated intermediate inputs x_{jt} produced by monopolistically competitive firms indexed by $j \in [0, Q_t]$, where Q_t denotes the measure of available varieties at time t. The final output Y_t is homogeneous and produced using a constant-returns technology:

$$Y_t = L_t^{1-\alpha} \int_0^{Q_t} z_{jt}^{1-\alpha} x_{jt}^{\alpha}\, dj, \tag{13}$$

where z_{jt} is an idiosyncratic demand shifter for variety j, and $0 < \alpha < 1$ governs the elasticity of substitution across intermediate goods.

The final-good producer takes input prices p_{jt} and the price of land P_t^L as given and chooses x_{jt} and L_t to maximize static profits:

$$\max_{\{x_{jt}, L_t\}} \; L_t^{1-\alpha} \int_0^{Q_t} z_{jt}^{1-\alpha} x_{jt}^{\alpha} \, dj - P_t^L L_t - \int_0^{Q_t} p_{jt} \, x_{jt} \, dj. \tag{14}$$

Given that the representative household supplies one unit of land inelastically ($L_t = 1$), the first-order condition for x_{jt} yields the demand for intermediate variety j:

$$x_{jt}\left(p_{jt}, z_{jt}\right) = z_{jt} \left(\frac{\alpha}{p_{jt}}\right)^{\frac{1}{1-\alpha}}. \tag{15}$$

The final-good producer earns zero profits in equilibrium and determines the aggregate demand faced by each intermediate producer.

4.3 Intermediate Goods

A unit mass of intermediate-good firms indexed by k invests in R&D, issues one-period debt and repurchases shares. Each firm is managed by a risk-neutral manager who maximizes the post-repurchase value to the shareholders.

Firms enter in t with a portfolio of measure M_{kt} of patented goods, whose patents expire after one period, outstanding debt B_{kt}, and a randomly assigned R&D project quality $\theta_{kt} \sim_{iid} \log N(-\frac{1}{2}\sigma_\theta^2, \sigma_\theta^2)$. All patented goods j in firm k's portfolio are subject to the same firm-level persistent demand shock z, following

$$\log z_{kt+1} = \rho_z \log z_{kt} + \nu_{kt+1}, \qquad \nu_{kt+1} \sim \mathcal{N}(0, \sigma_z^2). \tag{16}$$

where $0 < \rho_z < 1$ and $\sigma_z > 0$. Each intermediate good j in the portfolio is produced using a technology with constant marginal cost ψ and sold to the final-good sector at price p_{jt}. The profit of a single variety j in firm k's portfolio sold at the optimal price is:

$$\pi_{jt}^k(z_{jt}) = \max_{p_{jt}} \; \left(p_{jt} - \psi\right) \, x_{jt}\left(p_{jt}, z_{jt}\right) = (1-\alpha)\, \alpha^{\frac{1+\alpha}{1-\alpha}} \, \psi^{-\frac{\alpha}{1-\alpha}} \, z_{jt}. \tag{17}$$

The first-order condition yields a constant markup rule $p_{jt}^M = \frac{\psi}{\alpha}$, implying that each variety earns the same per-variety profit, proportional to the firm's demand shock. A competitive fringe with common demand shock $z = 1$ produces all off-patent varieties with pricing at marginal cost resulting in zero profits for such goods.

Innovation. At the beginning of t, managers privately observe the realization of their R&D project quality θ_{kt}, which determines the scale and likelihood of a firm's successful innovation. If R&D is successful, firm k's portfolio of new patented varieties produced tomorrow is

$$M_{kt+1} = \bar{\xi}\,\theta_{kt}\,W_{kt}^{\gamma}\,Q_t^{1-\gamma}, \qquad 0 < \gamma < 1. \tag{18}$$

The probability of successful innovation increases in both project quality θ_{kt} and R&D spending W_{kt}, the latter scaled by the aggregate stock of varieties Q_t:

$$p_{kt} = 1 - \exp\left[-\theta_{kt}\left(\frac{W_{kt}}{Q_t}\right)^{\chi}\right], \qquad 0 < \chi < 1. \tag{19}$$

Unsuccessful R&D yields zero patented varieties. The parameter χ governs the sensitivity of the innovation probability to R&D spending.

The aggregate stock of patented varieties Q_t generates positive knowledge-spillover effects, making it easier for firms to expand their variety portfolios.[14] At the aggregate level, the stock of available varieties evolves according to

$$Q_{t+1} = Q_t + M_{t+1}, \tag{20}$$

where $M_{t+1} = \int_0^1 p_{kt}\,M_{kt+1}\,dk$ is the total mass of newly patented varieties at $t+1$, with each firm's potential mass M_{kt+1} realized with probability p_{kt}.

Repurchasing. Upon observing θ_{kt}, the manager commits to a repurchase expenditure of E_{kt} dollars; the fraction s_{kt} of outstanding shares retired is determined by the equity market. Executing the repurchase requires the firm to pay E_{kt} to tendering shareholders plus a transaction cost

$$G_{kt} = \left[\phi_0 + \phi_1\left(\frac{E_{kt}}{Q_t}\right)^2\right] Q_t\,\mathbb{1}_{\{E_{kt}>0\}}, \tag{21}$$

where $\phi_0 \geq 0$ is a fixed cost and $\phi_1 > 0$ governs the variable component; the scaling by Q_t ensures stationarity along the balanced growth path. The fixed cost introduces inaction:

[14] This captures the notion that a larger pool of existing inventions facilitates innovation through learning, recombination, and shared technological components.

firms with sufficiently low repurchase gains do not repurchase at all. Outside investors observe E_{kt} and update their beliefs μ_t about the firm's project quality accordingly.

Financing. Firms finance R&D investment and share repurchases through internal and external funds. External funds add value to the firm because of tax advantage. After corporate taxes at rate τ and repayment of maturing debt B_{kt}, the firm's internal funds available at the beginning of period t are

$$N_{kt} = (1-\tau)\pi^k_{jt}(z_{jt})M_{kt} - B_{kt}. \tag{22}$$

Firms are subject to a non-negative dividend constraint. If internal funds are not sufficient to cover current expenses, firms issue one-period zero-coupon bonds B_{kt+1} at the market price q_{kt}.[15] Debt is riskless conditional on success. To ensure debt is repaid in every state when R&D is successful, the amount of debt issued cannot exceed the firm's after-tax profits under the lowest demand realization $\underline{z}$:

$$B_{kt+1} \leq (1-\tau)\pi^k(\underline{z})M_{kt+1}. \tag{23}$$

Firm Value. After security prices are formed, managers choose R&D investment and debt to maximize value. Along the balanced growth path (BGP), firm value grows at a constant rate g, and the homogeneity of the value function implies the stationary representation

$$V^0_t(N_{kt}, z_{kt}, \theta_{kt}, Q_t) = Q_t\, v^0_t(n_{kt}, z_{kt}, \theta_{kt}) \qquad n_{kt} = N_{kt}/Q_t,$$

where lowercase are detrended variables. The post-repurchase value of equity is

$$v^0_t(n_{kt}, z_{kt}, \theta_{kt}) = \max_{e_{kt}\geq 0} \frac{1}{1-s_{kt}(e_{kt})}\, v_t(e_{kt} \mid n_{kt}, z_{kt}, \theta_{kt}), \tag{24}$$

where v_t is the discounted continuation value of future cash flows,[16]

$$v_t(e_{kt} \mid n_{kt}, z_{kt}, \theta_{kt}) = \max_{w_{kt}, b_{kt+1}} d_{kt} + \frac{1}{R_{t+1}}\,\mathbb{E}_t\left[\sum_{s\in\{0,1\}} p_{kt}(s)\, v^0_{t+1}(n_{k,t+1}(s), z_{k,t+1}, \theta_{k,t+1})\right] \tag{25}$$

[15] The non-negativity constraint on dividends captures the fact that firms face significant costs of issuing equity and do so infrequently among established public firms Ottonello and Winberry (2020).

[16] The expectation in Equation (25) is over $(z_{k,t+1}, \theta_{k,t+1})$.

subject to

$$d_{kt} = n_{kt} - (1-\tau)w_{kt} + (1+g)[q_{kt} + \tau(1-q_{kt})]\, b_{kt+1} - e_{kt} - (\phi_0 + \phi_1 e_{kt}^2)\mathbb{1}_{\{e_{kt}>0\}}, \quad (26)$$

$$b_{kt+1} \leq (1-\tau)\pi(\underline{z})\; m_{kt+1}, \quad (27)$$

$$d_{kt} \geq 0, \quad (28)$$

where $s = 1$ denotes the successful R&D state (probability $p_{kt}(1) = p_{kt}$) and $s = 0$ denotes the failure state (probability $p_{kt}(0) = 1 - p_{kt}$). The term $\tau(1 - q_{kt})$ in the budget constraint captures the tax deductibility of the debt issue discount, the tax advantage of external funds. Detrended internal funds in the next period are zero in the failure state, $n_{k,t+1}(0) = 0$, since the firm does not repay its debt; in the success state,

$$n_{k,t+1}(1) = (1-\tau)\,\pi(z_{k,t+1})\,m_{kt+1} - b_{kt+1}. \quad (29)$$

The manager takes as given the pricing schedules $q_{kt}(\cdot)$ and $s_{kt}(\cdot)$, which depend on the repurchase choice through investors' beliefs.

4.4 Investment Fund

A risk-neutral investment fund holds the debt and equity of intermediate-good firms on behalf of the representative household. The fund observes each firm's idiosyncratic states but not its project quality θ_{kt}. After observing e_{kt}, the fund forms posterior beliefs $\mu_t = \mu_t(\theta_{kt} \mid n_{kt}, z_{kt}, e_{kt})$ by Bayes' rule given firms' equilibrium repurchase strategies, and prices equity and debt under risk-neutral, competitive pricing.

Equity. Conditional on available information, the fund is indifferent between holding and tendering shares, regardless of the firm's unobserved project quality. The fraction of shares s_{kt} repurchased per e_{kt} dollars paid satisfies

$$e_{kt} = \frac{s_{kt}(e_{kt} \mid n_{kt}, z_{kt})}{1 - s_{kt}(e_{kt} \mid n_{kt}, z_{kt})} \int v_t(\theta_{kt} \mid e_{kt}, n_{kt}, z_{kt})\, d\mu_t(\theta) \quad (30)$$

The left-hand side is the cash paid out to tendering shareholders; the right-hand side is the expected market value of the surrendered equity given posterior beliefs. Incentives to signal project quality mirror those in the simple model. Under asymmetric information, a high-quality firm is undervalued, so repurchasing—buying back shares below their true worth—raises the value of incumbent shareholders. A low-quality firm is overvalued, so repurchasing would buy shares above their true worth and reduce incumbent value.

Debt. Similarly, the fund prices one-period debt under a zero-profit condition. Given the borrowing limit, repayment is certain conditional on success. For each unit of face value, a debt investor pays the discount price q_{kt} today and recovers the face value next period only if firm k's project succeeds, which occurs with probability p_{kt}. Because the fund does not observe project quality, it prices a portfolio of bonds issued by firms that share the same observable states (n_{kt}, z_{kt}, e_{kt}) but differ in θ. Its expected profit on this portfolio is

$$\Pi_t^d(n_{kt}, z_{kt}) \; = \frac{1}{R_{t+1}} \int p_{kt}(\theta)\, B_{kt+1}(\theta)\, d\mu_t(\theta) \; - \; q_{kt}(e_{kt} \mid n_{kt}, z_{kt}) \int B_{kt+1}(\theta)\, d\mu_t(\theta), \tag{31}$$

the expected discounted repayment on the portfolio minus the funds lent. Competitive pricing drives expected profits to zero, which pins down the price of debt,

$$q_{kt}(e_{kt} \mid n_{kt}, z_{kt}) = \frac{1}{R_{t+1}} \frac{\displaystyle\int p_{kt}(\theta)\, B_{kt+1}(\theta)\, d\mu_t(\theta)}{\displaystyle\int B_{kt+1}(\theta)\, d\mu_t(\theta)}. \tag{32}$$

The price of debt therefore reflects firm quality only through the perceived success probability. A firm perceived as high quality borrows at a higher price (a lower yield), mirroring the equity undervaluation that motivates repurchases.

4.5 Equilibrium

Appendix C provides a definition of a Perfect Bayesian Equilibrium consistent with balanced growth in this model. An equilibrium consists of a growth rate, aggregate quantities, prices, firms' value functions and policies, the investment fund's dilution and debt prices, and posterior beliefs over project quality such that (i) managers solve (24)–(25), (ii) debt prices satisfy (32), (iii) the equity repurchase schedule solves (30), (iv) beliefs are consistent with firm policies through Bayes' rule on the equilibrium path and satisfy the D1 criterion of Banks and Sobel (1987) off the equilibrium path, (v) consumption and savings satisfy (12), (vi) the stationary distribution is consistent with manager policies and exogenous shocks, and (vii) markets clear, while aggregate quantities, growing at a common rate, satisfy a resource constraint. Appendix C verifies that balanced growth is compatible with the model, yielding a growth rate for all macro quantities equal to the growth rate g of varieties Q_t.

The model embeds a signaling game between firms, which privately observe θ_{kt}, and the investment fund, which updates beliefs after observing the repurchase decision e_{kt}. Appendix C characterizes the separating equilibrium of the quantitative model. A separating equilibrium in the model has two features. First, due to the fixed repurchase cost, there exists a cutoff $\underline{\theta}_t(n_{kt}, z_{kt})$ such that firms with $\theta_{kt} < \underline{\theta}_t$ choose $e_{kt} = 0$, while firms with $\theta_{kt} \geq \underline{\theta}_t$ choose $e_{kt} > 0$. Second, above the cutoff the repurchase function $e_t(\theta_{kt} \mid n_{kt}, z_{kt})$ is strictly increasing in θ_{kt}: each type repurchases just enough to deter mimicry by marginally lower types. We solve the model numerically by value function iteration. Further details on the algorithm used are in Appendix C.

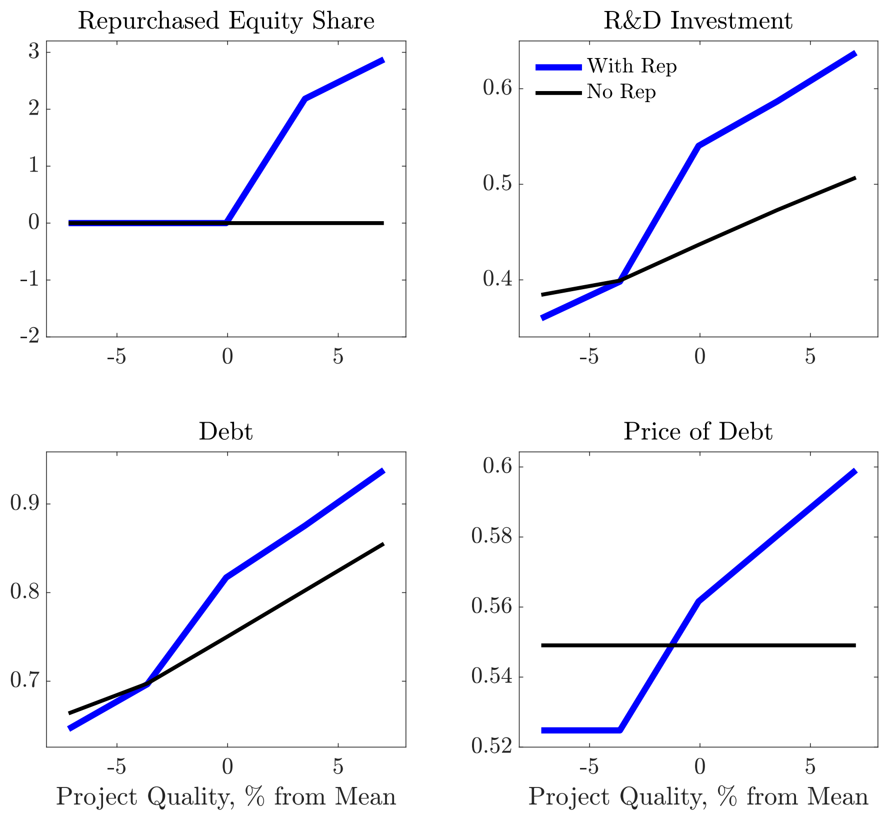
4.6 Manager Policies

Figure 4 plots the average managerial policy functions for the repurchased fraction of shares (top left), R&D investment (top right), debt issuance (bottom left), and the price of debt (bottom right) across different levels of project quality θ. To highlight the implications of stock repurchases for firms' decisions, we compare the average policies in our benchmark model with optimal repurchases (thick blue lines) to those in a counterfactual model in which managers are not allowed to repurchase shares (thin black lines).

Stock repurchasing allows the economy to attain a second-best R&D allocation. Without repurchases, managers cannot credibly signal the quality of their projects; investors price every firm at the pooled average based on their prior beliefs, so high-quality firms are underpriced and low-quality firms overpriced. Because of this informational friction, high-quality firms face a higher cost of external finance than their fundamentals warrant, and respond by investing less in R&D and issuing less debt than they would under full information. Low-quality firms, by contrast, have the strongest incentive to issue debt and invest in R&D, since they benefit most from being pooled with high-quality firms.[17] Repurchasing allows managers to credibly convey project quality and thereby eliminate the undervaluation of their firms' securities. Because of the fixed repurchase cost, only firms with sufficiently good projects find it optimal to buy back shares, and the incentive strengthens with θ, making repurchase activity increasing in project quality. In equilibrium, firms that choose not to repurchase are pooled together, while for firms that do repurchase, investors fully infer θ

[17] Adverse selection tilts the set of issuers toward low quality, and the zero-profit pooling price of debt is lower than the price implied by the prior distribution over θ, which does not condition on the decision to issue.

Figure 4: Manager Policies



Notes: In all panels, the blue line is the manager's policy in the separating equilibrium with optimal repurchasing; the black line is the policy in the pooling equilibrium without repurchasing. The top row plots the repurchased fraction of shares and R&D investment, and the bottom row plots debt issuance and the price of debt. Each panel reports average managerial policies as a function of project quality θ, weighting by the stationary marginal density of internal funds, with the demand shock held at its stationary mean. The repurchased fraction of shares outstanding is in percent; R&D and debt are in stationary dollar units; the price of debt is a one-period bond price reflecting the probability of R&D success. Policies are computed at the baseline parameter estimates in Panel A of Table 2.

from the repurchase choice. The cost of capital adjusts accordingly—the price of debt becomes increasing in θ, high-quality firms no longer subsidize low-quality ones, and each firm is fairly priced. The resulting decline in the cost of external finance raises both R&D and debt issuance for high-quality firms, since their projects are now correctly valued and they can credibly pledge more.

Repurchases affect aggregate growth through both the level and the composition of R&D. Since growth is the success-weighted sum of firms' innovation, it rises when R&D is reallocated toward more productive firms and when the average success probability increases.

Signaling operates on both margins. First, separation allows high-quality firms to be priced on their own fundamentals, easing the financing of the firms with the highest marginal value of R&D. These firms invest more and, being the most productive, contribute disproportionately to growth. Second, the average success probability rises, since the high-quality firms previously concealed under pooling expand their R&D relative to the rest. Both effects are partially offset by low-quality firms, which lose their cross-subsidy and invest less than they would absent signaling. The magnitude of the net effect is a quantitative matter.

5 Quantitative Results

This section structurally estimates the model and computes the quantitative impact of repurchasing at the micro and macro levels.

5.1 Estimating the Model

We solve the model annually, externally calibrating a set of parameters in line with the literature. The household's coefficient of relative risk aversion is $\eta = 2$. The growth rate along the balanced growth rate is $g = 2\%$ per year, consistent with long-term US TFP growth. The discount factor is $\beta = 0.98$ implies a risk-free rate of 6%. The intermediate-goods elasticity parameter $\alpha = 1/1.2$, corresponding to a markup of 20%. Finally, the corporate tax rate is $\tau = 0.20$, which is the effective rate on U.S. corporations according to CBO (2017), and the aggregate supply of land is normalized to 1.

Simulated Method of Moments. We structurally estimate the remaining 7 parameters listed in Panel A of Table 2 using the Simulated Method of Moments (SMM). These parameters govern the innovation and profitability processes and managers' incentives to repurchase shares. Panel B of Table 2 lists the 9 targeted moments, computed in annual Compustat data from 1990 to 2024 matched to the patent data of Kogan et al. (2017). We target the standard deviations of R&D growth and of repurchase expenditure, the frequency of repurchasing, and the correlations of repurchases with R&D and of R&D growth with the price of debt and with market value growth.[18] The repurchase moments jointly identify the fixed cost and the curvature of the repurchase cost function. The remaining moments

[18]We compute the price of debt from the implied probability of default, estimated from the distance to default following Merton (1974).

Table 2: Baseline model results

Panel A. Estimated Parameters	Symbol	Estimate	(Std. Error)
R&D elasticity of innovation	γ	0.4065	0.0022
Persistence idiosyncratic demand	ρ_z	0.9319	0.0153
Volatility idiosyncratic demand	σ_z	0.0644	0.0026
Volatility project quality	σ_θ	0.0356	0.0015
Probability of R&D success	χ	0.2101	0.0108
Fix repurchasing cost	ϕ_0	0.0113	0.0002
Quadratic repurchasing cost	ϕ_1	0.0174	0.0018
Panel B. Targeted Moments	**Data**	**(Std. Error)**	**Model**
Std. deviation of R&D growth	0.3085	0.0051	0.3061
Std. deviation of repurchases	0.0154	0.0002	0.0126
Correlation of R&D growth, price of debt	0.1351	0.0072	0.4837
Correlation of repurchases, R&D	0.1729	0.0126	0.3645
Average probability of patenting	0.5748	0.0100	0.5786
Share of firms repurchasing	0.4645	0.0082	0.4016
Slope of patenting on lagged R&D	0.1189	0.0038	0.0854
Correlation of R&D growth, firm value growth	0.1058	0.0092	0.4856
Correlation of patent value gain, R&D	0.4259	0.0121	0.4089
Panel C. Quantitative Impacts			
Mean increase in R&D costs from repurchasing			12.50 %
Mean gain (loss) in firm value from repurchasing			(3.53 %)
Deadweight loss of repurchase execution			4.14 b.p.
Welfare gain from repurchasing			3.16 %
Growth gain from repurchasing			12.50 b.p.

Notes: Panel A's SMM parameter estimates use efficient moment weighting. Panel B's data moments are from a panel using Compustat/CRSP-SDC Platinum data from 1990 to 2024. Model moments use a 50 periods simulated panel of 3,000 firms. Moment units are proportional (0.01 = 1%). Standard errors are firm-clustered. Panel C reports the quantitative effects of repurchases. The deadweight loss is the execution cost of repurchases as a share of firm value. The mean increase in R&D costs is the estimated percentage rise in R&D investment due to repurchasing. The mean value loss is the change in firm value when repurchasing is eliminated. The welfare gain is the consumption-equivalent gain relative to the no-repurchase counterfactual, and the growth gain is the increase in aggregate growth relative to the baseline rate of 2%. Units are percent (0.1 = 0.1%) or basis points (1 b.p. = 0.0001).

discipline the innovation technology. The average probability of patenting and the slope of patenting on lagged R&D identify the level and elasticity of the success probability, while the correlation between patent values and R&D informs the dispersion of project quality σ_θ.

We choose the parameter vector Θ such that the simulated model moments match the data moments as closely as possible. The estimated parameter vector $\hat{\Theta}_{\text{SMM}}$ solves

$$\hat{\Theta}_{\text{SMM}} = \Theta : \min_{\Theta} \quad \Big(m(\tilde{x} \mid \Theta) - m(\tilde{x})\Big) W \Big(m(\tilde{x} \mid \Theta) - m(\tilde{x})\Big)', \tag{33}$$

where $m(\tilde{x})$ is the vector of data moments and $m(\tilde{x} \mid \Theta)$ is the vector of simulated model moments. We use the asymptotically efficient weighting matrix W and cluster standard errors by firm following the asymptotic formulas in Hansen and Lee (2019). For each candidate parameter vector, we simulate 3,000 firms for 100 periods with a burn-in period of 50 periods, compute the model-implied moments from the simulated panel, and compare them to the empirical moments. We solve the minimization problem in Equation (33) using the particle swarm stochastic search algorithm.

We do not include the aggregate growth rate among the targeted moments. Because the estimation is overidentified, the fitted model need not reproduce every target exactly, so instead we impose the growth rate directly. For any candidate parameter vector Θ, we solve for the average R&D productivity level $\bar{\xi}$ that generates the chosen balanced growth rate in general equilibrium, repeating this step within each evaluation of the SMM objective in (33). Our baseline sets this rate to 2%, in line with long-run US growth. This restriction binds only on the estimated economy; in the counterfactual experiments below, growth is determined endogenously and is free to move while $\bar{\xi}$ is fixed at the estimated parameter. Appendix C.4 provides further detail on the model solution and estimation.

Baseline Estimates. Panel A of Table 2 reports the SMM parameter estimates with their standard errors. The estimates are broadly in line with previous studies. The R&D elasticity of innovation, $\gamma \approx 0.406$, is close to the values in Terry (2023) and Gourio and Rudanko (2014). Idiosyncratic demand is highly persistent, with $\rho_z \approx 0.931$, in line with Ottonello and Winberry (2020), and moderately volatile, with $\sigma_z \approx 6.4\%$, comparable to the estimates in Terry et al. (2023b) and Terry (2023). The estimated innovation technology implies an average R&D success probability of approximately 56%, in line with success rates for new-product development reported in management surveys (Barczak et al., 2009), and an R&D elasticity of the success probability of $\chi \approx 0.21$. The dispersion of R&D project quality, which governs the severity of asymmetric information, is estimated at $\sigma_\theta \approx 3.5\%$. Finally, the repurchase cost parameters are a fixed cost $\phi_0 = 0.010$ and a curvature parameter $\phi_1 = 0.017$, both in stationary dollar units, implying a deadweight cost of executing repurchases of roughly 0.04% of firm value per period for the average firm.

Model Fit. Table 2, Panel B, reports the data moments, their standard errors, and the corresponding simulated moments. Despite the overidentifying restrictions, the estimation achieves a reasonably good overall fit. The model reproduces the signs of all covariances and closely matches the volatility of R&D growth, the frequency of repurchasing, the average probability of patenting, and the correlation between patent values and R&D. A few moments are more challenging to replicate. The model overstates the correlation between R&D growth and market value growth conditional on success, and the correlation between R&D growth and the price of debt. Both correlations link R&D growth to equilibrium variables that, in the model, depend on the same small set of state variables that drive the R&D choice itself; absent additional sources of idiosyncratic variation in valuations and debt prices—or measurement error in their empirical counterparts—the model naturally overstates the strength of these comovements.

5.2 The Impact of Repurchasing

Panel C of Table 2 reports the quantitative impact of repurchasing at the micro (first three rows) and macro (last two rows) levels. We compare outcomes in our baseline estimated economy, in which managers can repurchase shares to signal the quality of their R&D projects to imperfectly informed investors, to a counterfactual economy in which repurchasing is not allowed. Importantly, asymmetric information about project quality is present in both economies; the counterfactual removes only firms' ability to signal through repurchases. The comparison therefore isolates the effect of repurchasing while holding the underlying information friction fixed. At the micro level, repurchasing pushes R&D investment toward the full-information solution, creating a benefit for high-quality firms and a loss for low-quality firms. Repurchasing raises aggregate innovation and R&D, so its social return is positive. But the average effect on firm value can be negative, since the gains accrue to high-quality firms while low-quality firms bear a loss.

The first quantity is the change in mean R&D investment induced by repurchasing which increases by 12.5%. Repurchasing moves the allocation toward the frictionless benchmark along two margins: low-quality firms scale back R&D and return cash to shareholders, while high-quality firms expand R&D toward its first-best level; under the estimated parameters, the second margin dominates. The magnitude is economically meaningful, implying about $70 billion in additional annual R&D when applied to the R&D performed by U.S. public firms in 2023 (NCSES, 2025). It is also in line with structural estimates of other frictions distorting R&D, such as short-termist pressure, which raises managers' effective marginal cost of R&D by about 2.4% (Terry, 2023), and reporting incentives, which distort profits partly through real R&D adjustments (Terry et al., 2023a).

The average firm value in the baseline economy is 3.53% lower than in the no-repurchase counterfactual. The decline reflects a partial and general equilibrium effect. First, separation removes the cross-subsidy embedded in pooled debt pricing: low-quality firms face higher borrowing costs, reducing their debt and R&D investment, while the resulting loss in value exceeds the gain from fair pricing enjoyed by high-quality firms.[19] Second, a general equilibrium effect through discounting: the separating economy grows faster, raising the equilibrium interest rate and lowering the discounted value of all firms. The magnitude is sizable in dollar terms: given an average market capitalization of $1.56 billion in our sample, average firm value is roughly $55 million lower with repurchasing. Our estimate is larger than structural estimates of the value impact of related governance and reporting frictions. Terry (2023) finds that short-termist discipline raises mean firm value by about 1.25%, Celik and Tian (2023) attribute roughly 1.5% of value to short-termism, and Terry et al. (2023a) find that eliminating earnings misreporting lowers average firm value by about 1%. Our estimate is closer in magnitude to the costs attributed to deeper agency frictions, such as the roughly 3% of value lost to CEO entrenchment (Taylor, 2010) or the 6% lost to agency conflicts over cash holdings (Nikolov and Whited, 2014).

The final two quantities are macroeconomic. Relative to a no-repurchase economy, the baseline economy grows roughly 12.6 basis points faster each year, and consumption-equivalent welfare is 3.16% higher. This means that over the last two decades, the effects of repurchasing compound to raise output by about 2.5%, accounting for 3.6 percentage points—roughly 7.5%—of cumulative output growth. The effect operates through a higher aggregate level of R&D together with an improvement in its allocation across firms, which raises the average success probability of R&D projects. These magnitudes place repurchasing between narrower and broader frictions studied in quantitative endogenous-growth settings. Our estimates are two to three times the costs attributed to short-termism—about 5 basis points of growth and 1.1% of welfare in Terry (2023)—and roughly half the gains from removing managerial agency frictions altogether—51 basis points and 7.3% in Celik and Tian (2023). This ordering is consistent with repurchases resolving a friction broader than misreporting but narrower than the full set of agency conflicts. For broader context, recent

[19] The deadweight cost of executing repurchases (third row of Panel C) is an order of magnitude too small to account for the decline.

estimates place the welfare costs of business cycles at 0.1–1.8% (Krusell et al., 2009), of moderate inflation near 1% (Lucas, 2000), and of near-rational investment around 5% (Hassan and Mertens, 2017).

5.3 The Role of the R&D Success Elasticity

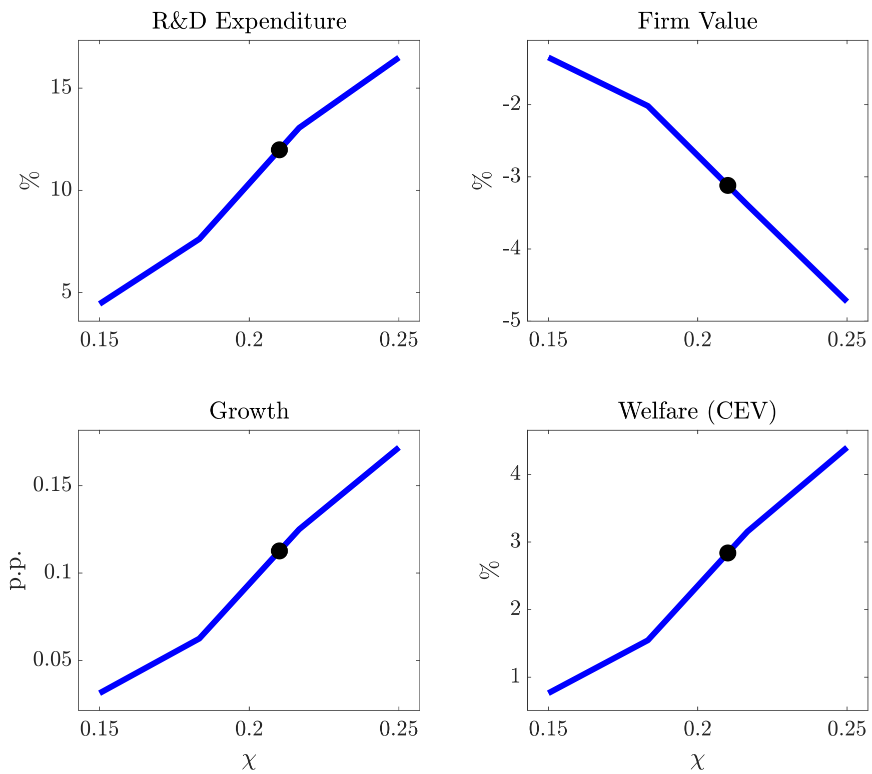
The elasticity of the probability of R&D success with respect to R&D spending, χ, governs the severity of the informational friction. The larger χ, the more tightly the success probability reflects quality and spending, and the more valuable the signal that undoes pooling. Studying how the gains vary with χ serves three purposes. It provides a sensitivity analysis for our headline estimates around the benchmark value; it delivers the model's interpretation of the cross-sectional concentration of repurchases among R&D-intensive firms documented in Section 2; and it characterizes the incidence of policies that prohibit repurchases. We solve the model on a grid of χ around the benchmark estimate, holding all remaining parameters at their SMM values (Table 2, Panel A), and compare each economy against its counterfactual in which the repurchase signal is unavailable.[20] Figure 5 plots the results.

The aggregate effect of repurchasing is increasing in χ. As χ rises from 0.15 to 0.25, the annual growth gain from repurchasing increases from about 3 to 17 basis points—a nearly sixfold rise—while the consumption-equivalent welfare gain rises from about 0.8% to 4.4%, the mean increase in R&D across firms from about 4.4% to 16.5%, and the average firm-value loss—the decline in firm value between the separating and pooling economies, weighted by the ergodic distribution—from 1.4% to 4.7%. The amplified response of growth reflects the compounding of the correction at the aggregate level. Since growth is the success-weighted sum of firm innovation, repurchases raise it both by increasing R&D at high-quality firms and by reallocating R&D toward them, while a larger χ amplifies both effects. Each unit of better-allocated R&D generates more successful innovation and, through the variety spillover, fosters future innovation.

Through the lens of the model, the comparative static rationalizes the empirical concentration of repurchases. R&D-intensive sectors are high-χ environments, where the signaling value of repurchases—and hence their use—is greatest. The same logic characterizes the incidence of restrictions on repurchasing. Our counterfactual corresponds to an outright ban,

[20] At each grid point we recalibrate R&D productivity $\bar{\xi}$ so the baseline economy grows at the target 2%, as in estimation; this fixes the level of baseline growth across the grid, so that what varies is the gain from repurchasing rather than the starting growth rate. We then remove the signal and solve the counterfactual with the growth rate determined endogenously.

Figure 5: Aggregate impact of repurchasing as a function of χ

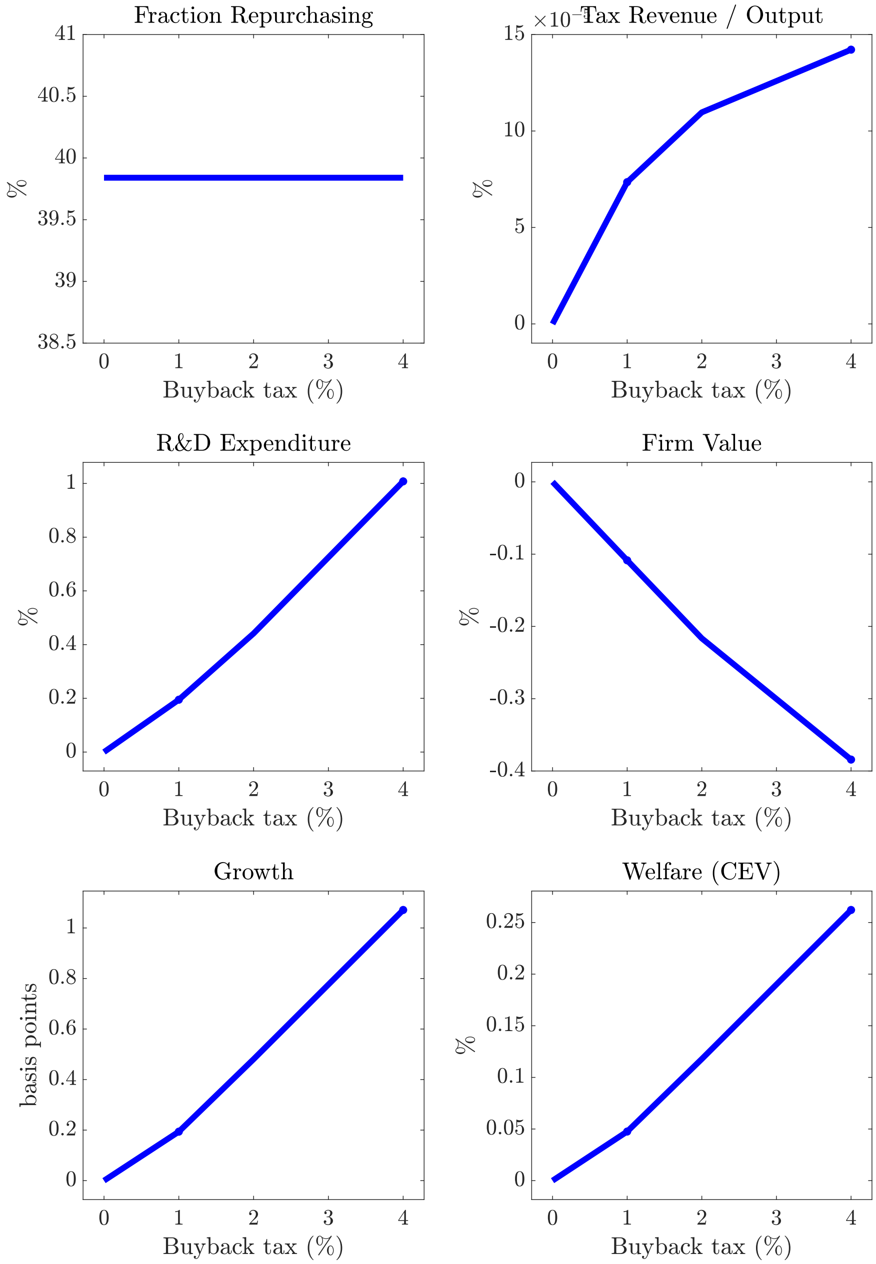


Notes: The figure plots the aggregate impact of repurchasing—the difference between the separating equilibrium (costly signaling via repurchases) and the pooling equilibrium (no signaling)—as a function of the success-probability elasticity χ. The circles mark the baseline estimates. Both equilibria are solved in general equilibrium. At each grid point, R&D productivity $\bar{\xi}$ is recalibrated so that the separating economy grows at the calibrated 2%; the pooling counterfactual is then solved at that $\bar{\xi}$ with the growth rate g clearing endogenously.

as prevailed in several European countries until the late 1990s and as recently proposed by U.S. legislators.[21] The model implies that the cost of a ban rises steeply with χ and therefore falls disproportionately on the sectors where R&D spending translates most strongly into successful innovation—precisely where repurchases are most valuable as a signal. Where restrictions are nonetheless imposed, improved disclosure of R&D quality is a natural complement. By shrinking the information gap that repurchases bridge, disclosure reduces the need for costly signaling exactly where χ is high.

[21]Germany and Sweden legalized open-market share repurchases in 1998 and 2000, respectively. In the United States, the Reward Work Act, introduced in the Senate in 2018, sought to effectively ban open-market buybacks by repealing SEC Rule 10b-18.

Figure 6: Impact of tax on share repurchasing



Notes: The figure plots the effect of a linear excise tax on repurchases, imposed on the estimated economy. We calibrate the R&D productivity $\bar{\xi}$ so the untaxed benchmark grows at 2%, then—holding $\bar{\xi}$ fixed—add $\tau_{rep}\, e$ to the cost of a repurchase and re-solve the separating equilibrium at each tax rate, letting g adjust endogenously. Tax revenue is rebated lump-sum to the household. Panels show changes relative to the no-tax benchmark.

5.4 Does Taxing Repurchases Promote Growth?

A tax on share repurchases has been widely invoked by politicians and commentators as a way to redirect resources toward productive investment. The discussion culminated in the United States with the Inflation Reduction Act of 2022, which imposed a 1% excise tax on share repurchases. We use the model to estimate the impact of the excise tax on firm value and long-run growth. Figure 6 shows the results.

An excise tax on repurchases raises the cost of signaling project quality to investors. The effect is a contraction in the dollar value of repurchases, but not in the fraction of firms repurchasing. A linear tax has a beneficial effect on innovation. Because the tax also raises low-quality firms' cost of mimicry, high-quality firms can separate with a smaller repurchase. As the signal shrinks, resources previously dissipated in signaling are freed, and aggregate R&D rises modestly. In this sense the tax operates as a Pigouvian correction on a signal that is privately optimal but socially excessive. At the same time, because the levy is borne directly by shareholders, average firm value declines. The effects on long-run growth and tax revenue are positive but small. The additional R&D is concentrated among smaller, more constrained firms that had been diverting resources to signaling, whereas large, well-capitalized firms can still afford the signal and continue to invest close to the first-best level. In summary, an excise tax reduces the size of repurchases and modestly improves the allocation of R&D, but at a cost to the average shareholder and with little effect on growth.

6 Conclusion

We study how share repurchases shape firms' financing, innovation, and long-run growth when investors cannot observe the quality of R&D projects. Empirically, repurchase activity is followed by persistent declines in cash, sizable increases in leverage, and sustained gains in R&D and patenting—patterns difficult to reconcile with the view that repurchases mechanically crowd out productive investment.

To interpret these facts, we build a signaling model in which managers privately observe project quality and use costly repurchases to reveal it. Absent signaling, pooling distorts investment. High-quality firms face financing terms that overstate their risk and invest too little, while low-quality firms invest too much. Separation moves R&D toward the full-information allocation, at the cost of the resources spent on signaling and of higher leverage, since firms must finance both the repurchase and the additional investment.

Embedding this mechanism in an endogenous growth model with earnings-based borrowing constraints, we quantify its implications. Relative to an economy in which firms cannot repurchase, signaling raises R&D and reallocates investment toward projects with a higher probability and scale of success. Long-run growth rises by about 13 basis points per year and consumption-equivalent welfare by 3.2%. The gains are unevenly distributed, and the faster-growing economy carries a higher interest rate that compresses discounted firm values, so average firm value is 3.5% lower even though growth and welfare are higher.

Our results offer a more nuanced view of share repurchases than the crowding-out narrative. When information about R&D quality is limited, repurchases serve an allocative role, and policies that restrict or tax them affect not only payouts but also the information available to investors. In the model, an excise tax reduces the size of the signal and releases resources for R&D, but lowers shareholder value and has little effect on growth, while improving the observability of R&D quality would reduce the need for costly signaling altogether. Extending the framework to aggregate uncertainty and richer non-repayment dynamics is a natural next step.

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Appendix

A Empirics

This section provides additional details on the data, variable construction, and supplementary empirical results.

A.1 Data sources

The analysis combines data from Compustat, CRSP, SDC Platinum, and the patent dataset of Kogan et al. (2017).

Compustat and CRSP. The main panel is constructed from Compustat North America Quarterly over the period 1985–2024. The sample includes U.S.-incorporated firms (FIC="USA") with consolidated and standardized financial statements. We exclude financial firms (SIC 6000–6999), utilities (SIC 4900–4999), and public administration firms (SIC 9900–9999). Following Ottonello and Winberry (2020), we retain only observations with positive total assets and non-negative capital stocks. We further exclude quarters in which acquisitions exceed 5 percent of assets and require firms to have at least 40 consecutive quarters of investment data to ensure sufficient within-firm time-series variation.

We impose additional filters to limit the influence of extreme observations and measurement error. Net current assets are restricted to the interval $[-10, 10]$ times total assets, debt-to-assets ratios are restricted to the interval $[0, 10]$, and quarterly real sales growth is restricted to the interval $[-1, 1]$. We also exclude observations in the top and bottom 0.5 percent of the investment-rate distribution, which typically correspond to major restructurings or reporting errors. To preserve continuity in firm histories, we remove observations whose preceding quarter fails the sample filters.

The panel contains information on firms' balance sheets, investment, and operating outcomes. Debt is measured as the sum of long-term debt and the current portion of long-term debt (DLTTQ + DLCQ). Equity is defined as total assets minus total liabilities (ATQ − LTQ), and cash corresponds to cash and cash equivalents (CHE). Capital stocks are constructed using the perpetual-inventory approach in Ottonello and Winberry (2020), cumulating changes in PPENT over time. Operating variables include capital expenditures, R&D expenditures, SG&A expenses, and cost of goods sold, all measured at the quarterly frequency. Unless otherwise noted, all outcome variables and continuous controls are winsorized at the 0.5 and 99.5 percent levels.

The Compustat panel is linked to CRSP using the standard CRSP–Compustat merge table, restricting attention to primary and valid links over active link periods. CRSP data are used to construct stock returns and announcement-window event studies.

The baseline specification includes two lagged firm-level controls. Firm size is measured as the logarithm of real total assets at quarter $t-1$, and sales growth is measured as the log difference in quarterly real sales between $t-1$ and $t-2$. Both variables are standardized to have mean zero and unit variance.

SDC Platinum. We use SDC Platinum data on U.S. share repurchases to study announcement effects and repurchase characteristics. The sample is restricted to transactions explicitly classified as repurchases. We exclude withdrawn deals, reorganizations, and transactions whose value exceeds 95 percent of lagged market capitalization, as these observations are typically associated with extraordinary corporate events rather than standard repurchases. Repurchase values are converted to 2024 dollars using the GDP implicit price deflator from FRED. Announcement dates are linked to CRSP through PERMNO-date identifiers.

Patent data. Innovation outcomes are measured using the public-firm patent dataset of Kogan et al. (2017). The dataset provides information on patent counts, value-weighted patent measures, and forward citations. Patent counts capture the quantity of innovation output, while citation-based measures proxy for the economic importance and quality of patented inventions.

Patent flows are linked to the Compustat panel through PERMNO identifiers using the CRSP–Compustat merge table. Following Kogan et al. (2017), we construct patent stocks by accumulating patent flows over time. To accommodate zero-valued observations and reduce the influence of extreme values, all patent variables are transformed using the inverse hyperbolic sine transformation,

$$\mathrm{IHS}(x) = \ln\left(x + \sqrt{x^2 + 1}\right).$$

Relative to the logarithm, the IHS transformation preserves observations with zero patents while retaining a similar interpretation for large values.

A.2 Variables construction

The main explanatory variable is a quarterly indicator for stock repurchase activity. In Compustat, repurchases are measured using the cash-flow statement item "Purchase of Common and Preferred Stock" (PRSTKCY). To isolate common-equity repurchases, we net out changes in preferred stock whenever applicable. Before 2004, Compustat reports repurchases only indirectly through cash-flow statements. Beginning in 2004, firms started reporting quarterly repurchase activity directly in SEC filings. Whenever disclosure-based measures are available, we replace the imputed Compustat series with the direct SEC measure, constructed as the number of shares repurchased multiplied by the average repurchase price. The repurchase indicator equals one if the firm repurchases shares in a given quarter and zero otherwise.

Table A.3: Summary Statistics

Variable	N	Mean	SD	P25	Median	P75
Treatment and controls						
Repurchase dummy	432,282	0.282	0.450	0.000	0.000	1.000
Repurchases / assets	403,102	0.004	0.013	0.000	0.000	0.000
Firm size (std)	403,131	0.000	1.000	-0.723	-0.014	0.700
Sales growth (std)	378,066	-0.000	1.000	-0.335	0.051	0.425
Outcomes (share of lagged assets)						
Equity / assets	403,041	0.452	0.561	0.316	0.495	0.690
Capital / assets	403,131	0.542	0.622	0.196	0.412	0.738
Debt / assets	388,435	0.269	0.339	0.046	0.209	0.379
Cash / assets	403,131	0.175	0.261	0.024	0.086	0.240
CapEx / assets	396,903	0.015	0.030	0.003	0.008	0.018
R&D / assets	180,381	0.028	0.052	0.002	0.015	0.034
SG&A / assets	366,343	0.092	0.104	0.035	0.069	0.119
COGS / assets	401,055	0.222	0.223	0.087	0.170	0.287
Innovation stocks (levels)						
Patent stock (count)	432,317	291.512	2,528.846	0.000	1.000	20.000
Patent stock (value)	432,317	8,256.805	83,870.903	0.000	0.207	56.175
Citation stock	432,317	5,427.979	48,411.505	0.000	3.000	432.000

Notes: This table reports summary statistics for the firm-quarter sample. The repurchase dummy equals one when a firm repurchases shares during the quarter. Repurchase expenditure and accounting outcomes are normalized by lagged total assets. Firm size and sales growth are standardized to have mean zero and standard deviation one. Patent count, patent value, and citation stocks are reported in levels. The number of observations varies across variables because of differences in data availability.

A.3 Market response to repurchase announcements

We conduct an event study using SDC repurchase announcements matched to CRSP returns. For each announcement, we compute cumulative abnormal returns over the three-day window $[t-1, t+1]$, where t denotes the announcement date. Abnormal returns are defined as firm returns net of the CRSP value-weighted market return.

We then group announcements by repurchase size, measured as deal value relative to lagged market capitalization. Figure A.7 reports average cumulative abnormal returns by size bin. Announcement returns are positive across all bins and increase with repurchase size. Repurchases equal to 0–3 percent of market capitalization are associated with abnormal returns of about 2 percent, while larger repurchases generate progressively larger announcement effects. This pattern indicates that investors respond favorably to repurchase announcements, particularly when the announced repurchase is large relative to firm value. The evidence is consistent with the firm-level results in Table 1: repurchases are not followed by weaker operating or investment outcomes, and the market reaction suggests that investors do not interpret buybacks as a signal of declining productive capacity.

Taken together, the results show that repurchases are not followed by a contraction in productive investment. Over the three-year horizon, repurchasing firms increase investment in both tangible and intangible capital: capital expenditures, R&D spending, and patenting activity all rise after repurchase activity. At the same time, these firms adjust their capital structure toward higher leverage. These patterns suggest that repurchases and productive investment need not represent competing uses of cash. Instead, repurchasing firms appear to combine shareholder payouts with continued investment. The positive announcement returns documented above are consistent with this interpretation: investors respond favorably to buyback announcements and do not appear to treat them as signals of weaker future investment capacity.

A.4 Additional results

Table A.4: Impact of Repurchase on Firms' Outcomes

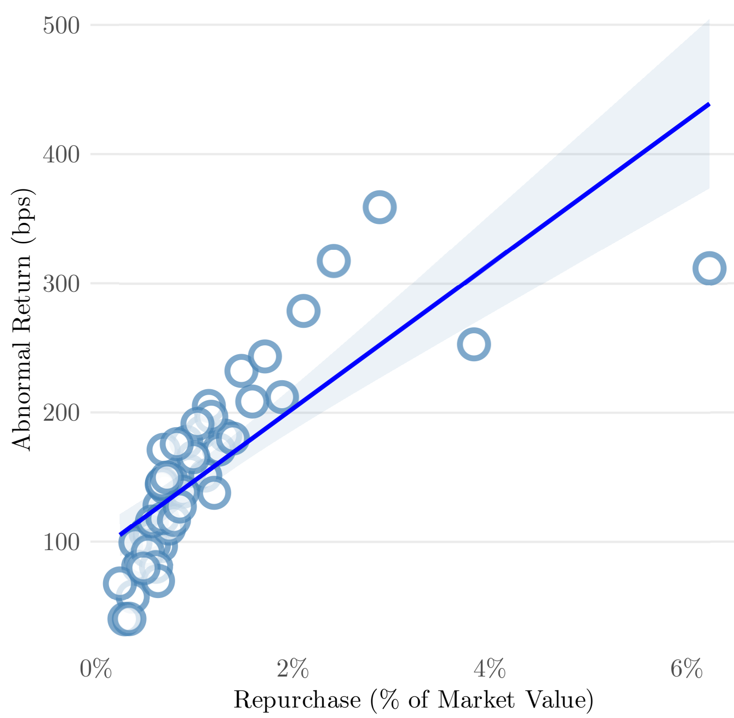
Panel A: Capital Structure				
	Equity (1)	Capital (2)	Debt (3)	Cash (4)
Repurchase	-0.0364***	0.0234***	0.0541***	-0.0240***
	(0.0092)	(0.0055)	(0.0056)	(0.0050)
% Effect at Median	-7.4%	5.7%	25.9%	-27.9%
Firm & Sector × Quarter FE	Yes	Yes	Yes	Yes
R^2	0.25357	0.33799	0.39498	0.16495
Observations	284,287	284,392	267,944	284,392

Panel B: Operating Outcomes				
	CapEx (1)	R&D (2)	SG&A (3)	COGS (4)
Repurchase	0.0018**	0.0021***	0.0028***	0.0072**
	(0.0009)	(0.0007)	(0.0010)	(0.0028)
% Effect at Median	21.6%	14.2%	4.0%	4.3%
Firm & Sector × Quarter FE	Yes	Yes	Yes	Yes
R^2	0.11941	0.25993	0.33255	0.30640
Observations	277,329	110,088	255,956	281,741

Panel C: Innovation Output			
	Patent Count (1)	Patent Value (2)	Patent Citations (3)
Repurchase	0.0010***	0.0008***	0.0026***
	(0.0002)	(0.0002)	(0.0007)
% Effect at Median	26.5%	48.7%	57.1%
Firm & Sector × Quarter FE	Yes	Yes	Yes
R^2	0.32735	0.31913	0.24327
Observations	284,392	284,392	284,392

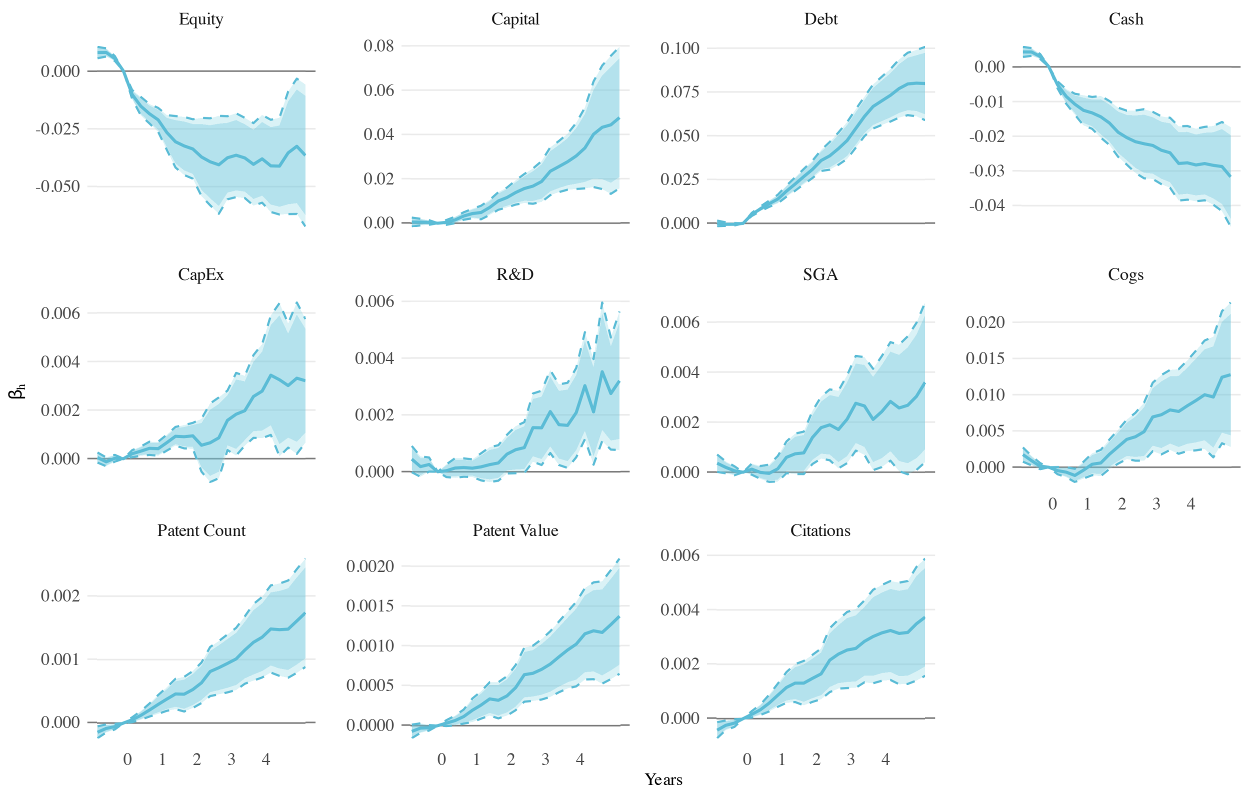
Notes: The Table presents coefficient estimates from fixed-effects regressions examining the relationship between share repurchases and multiple firm outcomes. The dependent variable in each specification is constructed as the year-over-year change in the outcome (measured from $t-1$ to $t+12$) and normalized by lagged total assets. Panel A reports effects on capital structure decisions: cash, debt, and equity. Panel C presents effects on investment outcomes: Capex, R&D expenditures, selling general and administrative expenses, and cost of goods sold. Panel C presents effects on patenting innovation. Patenting variables are the inverse hyperbolic sine of the count, market value, and forward citations. All models include fixed effects for firm (gvkey) and sector-by-quarter interactions to account for time-invariant firm heterogeneity and common time-sector shocks. Standard errors are two-way clustered by firm and date. Standard errors, clustered at the firm-quarter level, are in parentheses. $*$ = 10% level, $**$ = 5% level, and $***$ = 1% level. See Appendix A for further details.

Figure A.7: Cumulative Abnormal Returns on Announcement by Repurchase Size



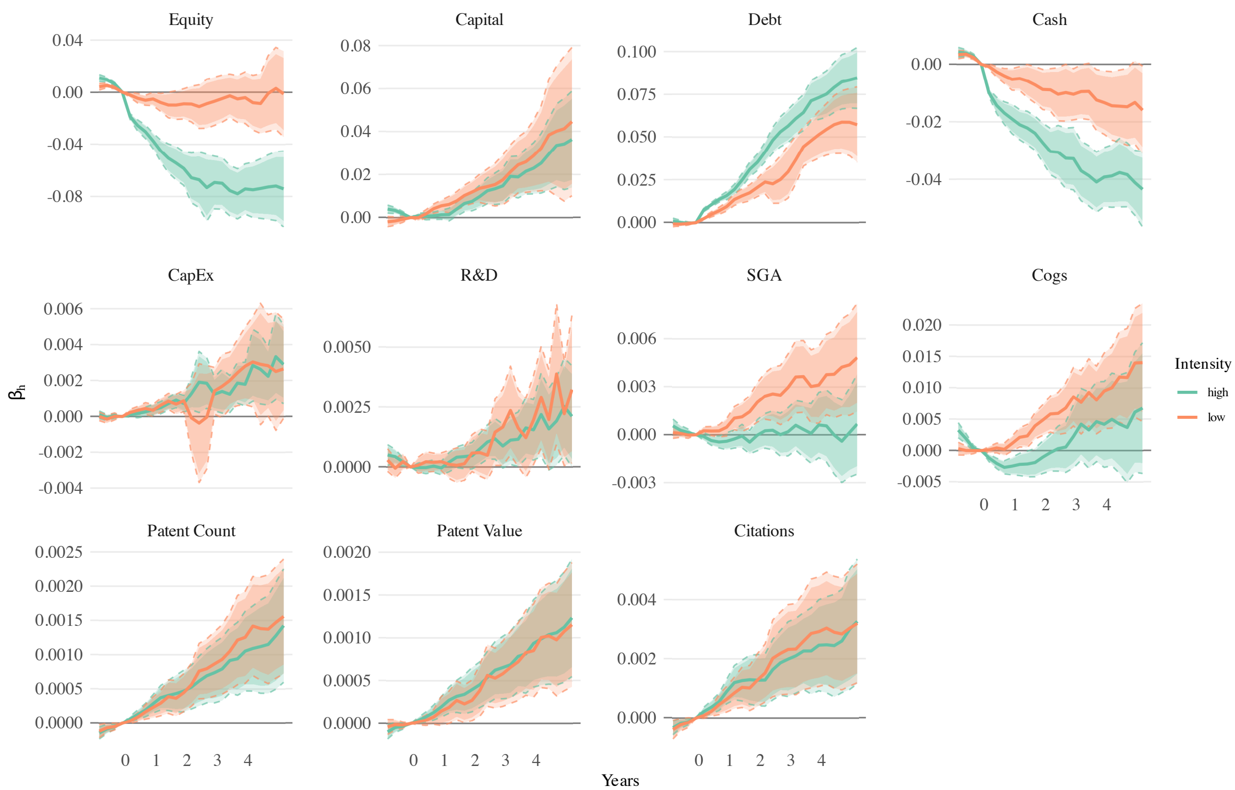
Notes: This figure presents average cumulative abnormal returns (CAR) for a 3-day window $[t-1, t+1]$ centered on repurchase announcement, binned by repurchase size as a fraction of lagged market capitalization. Abnormal returns are computed as actual returns minus CRSP value-weighted market returns. Sample includes U.S. share repurchases from SDC Platinum linked to CRSP, 1985–2024.

Figure A.8: Dynamic Impact of Stock Repurchase



Notes: R&D is research and development. SG&A is selling, general, and administrative expenses. Capital expenditure is spending on plants, property, and equipment. Standard error are two-way clustering by firm and calendar quarter. *,**,*** denote 10, 5, 1% significance.

Figure A.9: Dynamic Impact of Stock Repurchase (High vs Low Repurchases)

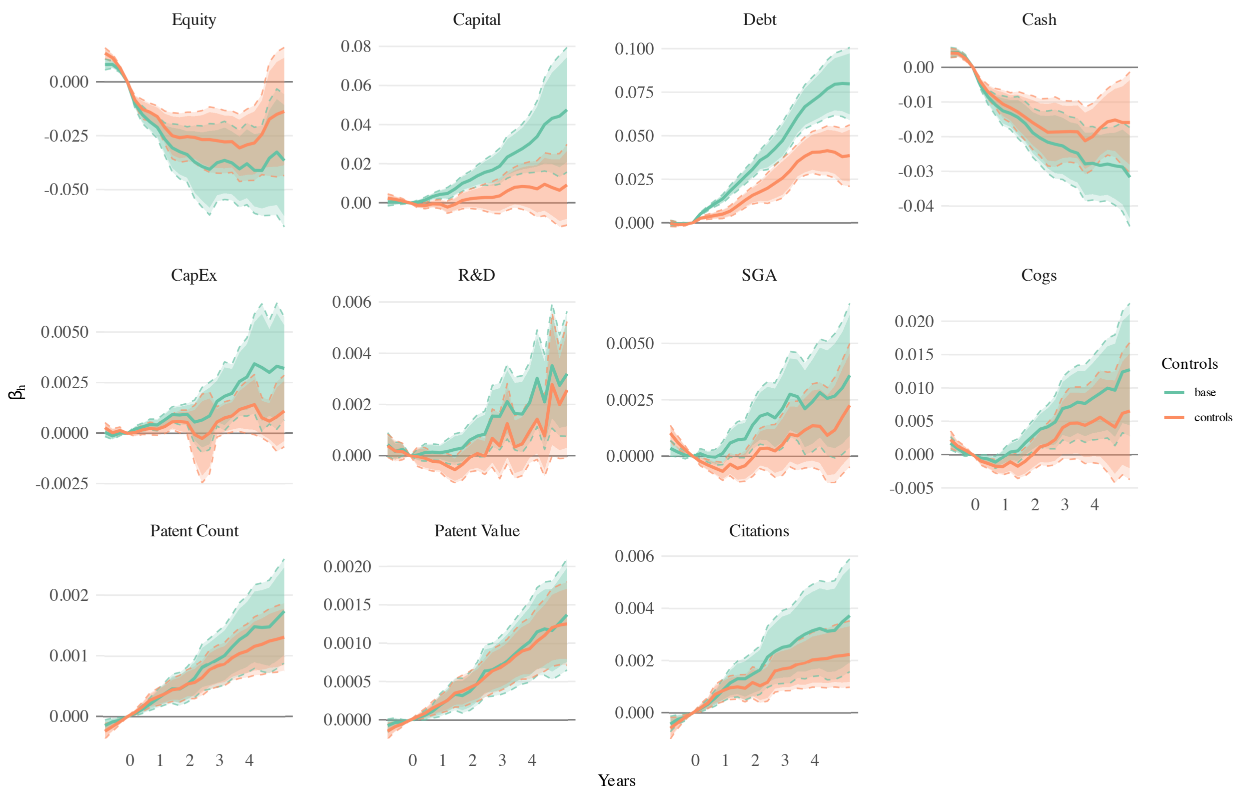


Notes: R&D is research and development. SG&A is selling, general, and administrative expenses. Capital expenditure is spending on plants, property, and equipment. Standard error are two-way clustering by firm and calendar quarter. *,**,*** denote 10, 5, 1% significance.

Figure A.10: Dynamic Impact of Stock Repurchase (Pre-2003)

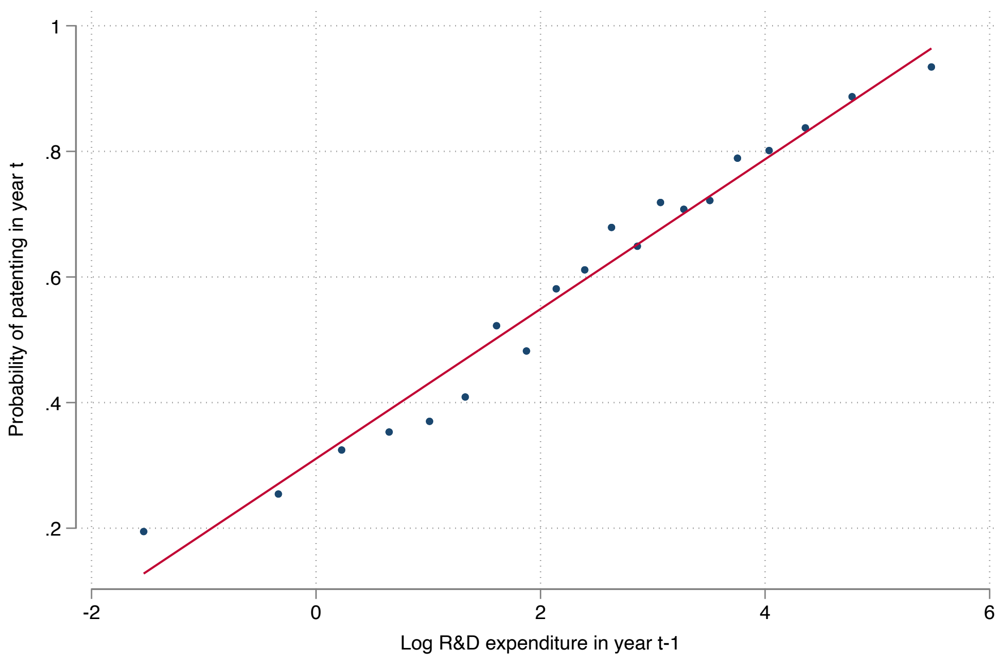
Notes: R&D is research and development. SG&A is selling, general, and administrative expenses. Capital expenditure is spending on plants, property, and equipment. Standard error are two-way clustering by firm and calendar quarter. *,**,*** denote 10, 5, 1% significance.

Figure A.11: Dynamic Impact of Stock Repurchase (Post-2003)



Notes: R&D is research and development. SG&A is selling, general, and administrative expenses. Capital expenditure is spending on plants, property, and equipment. Standard error are two-way clustering by firm and calendar quarter. *,**,*** denote 10, 5, 1% significance.

Figure A.12: Patenting Probability and R&D Expenditure



Notes: The figure plots the probability that a firm is granted a patent in year t against its log R&D expenditure in year $t-1$, residualized on year effects. Each point is a ventile of the lagged R&D distribution, and the red line is a linear fit. The sample is the estimation panel of Section 4: U.S. public firms in Compustat linked to the patent data of Kogan et al. (2017), restricted to non-censored firm-years. Patent grants are measured from KPSS; R&D expenditure is from Compustat.

B Characterization of the PBE in the Simple Model

We formalize the separating strategy profile in the simple model.

B.1 Preliminaries

Two preliminary results simplify the analysis. Lemma 1 characterizes the firm's investment and debt choice at an arbitrary debt price: the borrowing constraint binds when debt is overpriced relative to the true success probability, and a minimum-debt policy applies otherwise. Lemma 2 shows that the low type repurchases zero in any separating PBE.

Lemma 1. *Consider the inner problem*

$$v_t(e_t \mid \theta, q_t) = \max_{w_t,\, b_{t+1}} \; -w_t + q_t\, b_{t+1} - g(e_t) + \frac{1}{R}\big[m_{t+1}(w_t,\theta) - b_{t+1}\big]\, p(\theta), \tag{B.1}$$

subject to $d_t \geq 0$ and $b_{t+1} \leq m_{t+1}(w_t,\theta)$, where the firm is of true type θ and faces debt price $q_t > 0$. Assume

$$g(e_t) \;<\; \mathcal{V}(\theta, q_t) \;\equiv\; \max_{w_t \geq 0} \big\{q_t\, m_{t+1}(w_t,\theta) - w_t\big\}, \tag{B.2}$$

so that the constraint set is non-empty. Then optimal R&D is $w_t^* = (q_t\theta)^{1/(1-\alpha)}$ and:

(i) if $q_t > p(\theta)/R$ (overpriced debt), the borrowing constraint binds, $b_{t+1}^* = m_{t+1}(w_t^*,\theta)$, and $v_t(e_t \mid \theta, q_t) = \mathcal{V}(\theta, q_t) - g(e_t)$;

(ii) if $q_t \leq p(\theta)/R$ (fairly priced or underpriced debt), the firm issues the minimum debt consistent with $d_t \geq 0$, $b_{t+1}^* = \big(w_t^* + g(e_t)\big)/q_t$, the borrowing constraint is slack, and $v_t(e_t \mid \theta, q_t) = \frac{p(\theta)}{R\, q_t}\big[\mathcal{V}(\theta, q_t) - g(e_t)\big]$.

Proof. The constraints $d_t \geq 0$ and $b_{t+1} \leq m_{t+1}(w_t,\theta)$ jointly require

$$w_t + g(e_t) \;\leq\; q_t\, b_{t+1} \;\leq\; q_t\, m_{t+1}(w_t,\theta),$$

so an investment level w_t is feasible if and only if it lies in $W \equiv \{w \geq 0 :\; q_t\, m_{t+1}(w,\theta) - w \geq g(e_t)\}$. With $m_{t+1}(w,\theta) = \frac{1}{\alpha}\theta w^{\alpha}$, the map $w \mapsto q_t\, m_{t+1}(w,\theta) - w$ is strictly concave, with unconstrained maximizer and maximum

$$w_t^* = (q_t\theta)^{\frac{1}{1-\alpha}}, \qquad \mathcal{V}(\theta, q_t) = q_t\, m_{t+1}(w_t^*,\theta) - w_t^* = \frac{1-\alpha}{\alpha}\,(q_t\theta)^{\frac{1}{1-\alpha}}. \tag{B.3}$$

By (B.2), W is non-empty and contains w_t^* in its interior.

Optimal Debt. The objective (B.1) is linear in b_{t+1}, with slope

$$\frac{\partial}{\partial b_{t+1}}\Big\{q_t\, b_{t+1} + \tfrac{1}{R}\big[m_{t+1}(w_t,\theta) - b_{t+1}\big]\, p(\theta)\Big\} = q_t - \frac{p(\theta)}{R},$$

the debt price net of its actuarially fair value. Therefore, its sign governs the debt choice at every $w_t \in W$.

Case (i): $q_t > p(\theta)/R$. The slope is strictly positive, so for every $w_t \in W$ the optimal debt is the corner $b_{t+1} = m_{t+1}(w_t,\theta)$, at which the continuation term vanishes and the objective reduces to $q_t\, m_{t+1}(w_t,\theta) - w_t - g(e_t)$. Its unconstrained maximizer w_t^* lies in W and is therefore optimal, so $b_{t+1}^* = m_{t+1}(w_t^*,\theta)$ and

$$v_t(e_t \mid \theta, q_t) = \mathcal{V}(\theta, q_t) - g(e_t), \tag{B.4}$$

with dividend $d_t = \mathcal{V}(\theta, q_t) - g(e_t) > 0$ by (B.2).

Case (ii): $q_t \leq p(\theta)/R$. The slope is non-positive, so for every $w_t \in W$ the firm issues the least debt consistent with $d_t \geq 0$, namely $b_{t+1}(w_t) = \big(w_t + g(e_t)\big)/q_t$, at which $d_t = 0$; the borrowing constraint $b_{t+1}(w_t) \leq m_{t+1}(w_t,\theta)$ holds, with slack, precisely for w_t in the interior of W. Substituting $d_t = 0$ into (B.1) leaves the continuation term,

$$v_t(e_t \mid \theta, q_t) = \max_{w_t \in W} \frac{p(\theta)}{R\, q_t}\big[\, q_t\, m_{t+1}(w_t,\theta) - w_t - g(e_t)\,\big], \tag{B.5}$$

a positive multiple of the same strictly concave map as in Case (i). Its maximizer is again w_t^*, interior to W, so $b_{t+1}^* = \big(w_t^* + g(e_t)\big)/q_t$ and

$$v_t(e_t \mid \theta, q_t) = \frac{p(\theta)}{R\, q_t}\big[\mathcal{V}(\theta, q_t) - g(e_t)\big], \tag{B.6}$$

which at the fair price $q_t = p(\theta)/R$ reduces to $\mathcal{V}(\theta, q_t) - g(e_t)$. In the strict case $q_t < p(\theta)/R$, minimum debt is uniquely optimal; at the fair price the objective is independent of b_{t+1}, the firm is indifferent across all feasible debt levels, and the level is selected by the minimum debt policy. $\square$

Lemma 2. *In any separating perfect Bayesian equilibrium of the model, the low-type firm chooses $e_L = 0$.*

Proof. Fix a separating PBE with $e_L \neq e_H$ and suppose, toward a contradiction, that $e_L > 0$. By Bayes' rule $\mu_t(\theta_H \mid e_L) = 0$, so the low type is correctly identified: her debt trades at the fair price $q_t(e_L) = q_L$ and equity is priced at her own value, so the zero-profit condition (9)

$$e_L = \frac{s_t(e_L)}{1 - s_t(e_L)}\, v_t(e_L \mid \theta_L, q_L). \tag{B.7}$$

Hence $1/(1 - s_t(e_L)) = 1 + e_L/v_t(e_L \mid \theta_L, q_L)$, and

$$v_t^0(e_L \mid \theta_L, 0) = \frac{v_t(e_L \mid \theta_L, q_L)}{1 - s_t(e_L)} = v_t(e_L \mid \theta_L, q_L) + e_L. \tag{B.8}$$

By Lemma 1(ii) at the fair price q_L, debt is value-neutral and

$$v_t(e_L \mid \theta_L, q_L) = \mathcal{V}(\theta_L, q_L) - g(e_L) = v_t(0 \mid \theta_L, q_L) - g(e_L). \tag{B.9}$$

Substituting (B.9) into (B.8) and using $g(e_L) = e_L + \phi_1 e_L^2$,

$$v_t^0(e_L \mid \theta_L, 0) = v_t(0 \mid \theta_L, q_L) - \phi_1 e_L^2 \;<\; v_t(0 \mid \theta_L, q_L) : \tag{B.10}$$

the cash paid to tendering shareholders is returned in full through accretion, and the only cost of a positive repurchase is its deadweight component. Now consider the deviation to $e = 0$. No shares trade at $e = 0$, so the deviator's payoff is $v_t(0 \mid \theta_L, q_t(0))$ regardless of the equity-market belief; and since a higher belief only raises the debt price, this payoff is bounded below by $v_t(0 \mid \theta_L, q_L)$, its value under the least favorable belief. The deviation therefore strictly exceeds (B.10) under any off-path belief specification, contradicting optimality of $e_L > 0$. Hence $e_L = 0$. □

B.2 Single-Crossing Property

The next lemma shows that, at a common debt price and repurchase schedule, the high type is uniformly more willing than the low type to undertake a larger repurchase. This single-crossing property is the central tool for refining the equilibrium set.

Lemma 3 (Single Crossing in Repurchases)**.** *Fix a debt price $q_t > 0$ and a repurchase* *schedule $s_t : \mathbb{R}_+ \to [0,1)$, common to both types, and let*

$$U(e \mid \theta) \equiv \frac{v_t(e \mid \theta, q_t)}{1 - s_t(e)}$$

denote the type-θ payoff, where $v_t(e \mid \theta, q_t)$ is the inner value of Lemma 1. Consider two repurchase levels $e_t > e_t' \geq 0$ with $g(e_t) < \mathcal{V}(\theta_L, q_t)$. Then

$$U(e_t \mid \theta_L) \;\geq\; U(e_t' \mid \theta_L) \quad \Longrightarrow \quad U(e_t \mid \theta_H) \;>\; U(e_t' \mid \theta_H).$$

Proof. By Lemma 1, $v_t(e \mid \theta, q_t) = C(\theta, q_t)[\mathcal{V}(\theta, q_t) - g(e)]$, where $C(\theta, q_t) = 1$ if $q_t > p(\theta)/R$ and $C(\theta, q_t) = p(\theta)/(Rq_t)$ otherwise. Since $C(\theta, q_t) > 0$ does not depend on e, it scales each type's payoff by a positive constant and leaves preferences over repurchase levels unchanged; we may work with $\tilde{U}(e \mid \theta) = [\mathcal{V}(\theta, q_t) - g(e)]/(1 - s_t(e))$. Moreover, $g(e_t) < \mathcal{V}(\theta_L, q_t)$, g increasing, and $\mathcal{V}$ strictly increasing in θ imply $\mathcal{V}(\theta, q_t) - g(e) > 0$ at both levels for both types. Define

$$f(\theta) \equiv \frac{\mathcal{V}(\theta, q_t) - g(e_t)}{\mathcal{V}(\theta, q_t) - g(e_t')}, \qquad f'(\theta) = \frac{\mathcal{V}_\theta(\theta, q_t)\,[g(e_t) - g(e_t')]}{[\mathcal{V}(\theta, q_t) - g(e_t')]^2} > 0,$$

where the sign follows from $g(e_t) > g(e_t')$ and $\mathcal{V}_\theta > 0$. The low type's weak preference for e_t reads $f(\theta_L) \geq (1 - s_t(e_t))/(1 - s_t(e_t'))$, so $f(\theta_H) > f(\theta_L)$ delivers the high type's strict preference.[22] □

B.3 Existence and Uniqueness of the Separating PBE

We now construct the separating PBE. Lemma 4 characterizes the least-cost separating signal $e_H^{\min}$ as the smallest repurchase that deters mimicking by the low type; Lemma 5 establishes that this level is unique; Lemma 6 gives a condition under which the high type is willing to undertake it.

Lemma 4. *Let $\bar{e} > 0$ solve $g(\bar{e}) = \mathcal{V}(\theta_L, q_H)$, the largest repurchase the mimicking low type can finance, and define the mimicking payoff $M_L(e) \equiv v_t^0(e \mid \theta_L, 1)$ for $e \in [0, \bar{e}]$. Then:*

(i) $M_L(0) > v_t^0(0 \mid \theta_L, 0)$: costless separation is impossible;

[22] Equivalently, in (e_t, s_t) space the type-θ indifference curves of $\tilde{U}$ have slope $g'(e_t)(1-s_t)/[\mathcal{V}(\theta, q_t) - g(e_t)]$, strictly decreasing in θ: the model satisfies the standard Spence–Mirrlees single-crossing condition.

(ii) the smallest solution $e_H^{\min} \in (0, \bar{e})$ to the binding low-type incentive constraint exists and satisfies

$$\mathcal{V}(\theta_L, q_L) = v_t(e_H^{\min} \mid \theta_L, q_H) + e_H^{\min} \cdot \frac{v_t(e_H^{\min} \mid \theta_L, q_H)}{v_t(e_H^{\min} \mid \theta_H, q_H)}; \tag{B.11}$$

(iii) (IC-low) fails for every $e_H < e_H^{\min}$.

Proof. Step 1: payoffs. By Lemma 2 and Lemma 1(ii), truth-telling ($e = 0$, $\mu_t = 0$) at the fair price q_L yields

$$v_t^0(e = 0 \mid \theta_L, \mu_t = 0) = v_t(0 \mid \theta_L, q_L) = \mathcal{V}(\theta_L, q_L). \tag{B.12}$$

Under mimicking, the low type is perceived as high and faces $q_H > p(\theta_L)/R$: her debt is strictly overpriced relative to her true success probability, so Lemma 1(i) applies, the borrowing constraint binds, and $v_t(e \mid \theta_L, q_H) = \mathcal{V}(\theta_L, q_H) - g(e)$ for $e \in [0, \bar{e})$; note $g(e) < \mathcal{V}(\theta_L, q_H)$ on this domain by definition of $\bar{e}$, and beyond $\bar{e}$ mimicking is infeasible. The tendered shares are priced at high-type value, so the zero-profit condition

$$e = \frac{s_t(e)}{1 - s_t(e)} \, v_t(e \mid \theta_H, q_H). \tag{B.13}$$

Solving (B.13) for $1/(1 - s_t(e))$ and substituting,

$$M_L(e) = v_t(e \mid \theta_L, q_H) + e \, \frac{v_t(e \mid \theta_L, q_H)}{v_t(e \mid \theta_H, q_H)}, \tag{B.14}$$

where the denominator $v_t(e \mid \theta_H, q_H) = \mathcal{V}(\theta_H, q_H) - g(e) \geq \mathcal{V}(\theta_H, q_H) - \mathcal{V}(\theta_L, q_H) > 0$ on $[0, \bar{e}]$, so M_L is continuous there (at $e = \bar{e}$, by continuous extension).

Step 2: claim (i). At $e = 0$ no shares trade, $s_t(0) = 0$, and (B.14) gives $M_L(0) = \mathcal{V}(\theta_L, q_H)$: the low type collects the debt-overpricing rent at no repurchase cost. Since $\mathcal{V}(\theta_L, q) = \frac{1-\alpha}{\alpha}(q\theta_L)^{1/(1-\alpha)}$ is strictly increasing in q by (B.3) and $q_H > q_L$,

$$M_L(0) = \mathcal{V}(\theta_L, q_H) > \mathcal{V}(\theta_L, q_L) = v_t^0(e = 0 \mid \theta_L, \mu_t = 0).$$

Step 3: claims (ii) and (iii). At $e = \bar{e}$, $v_t(\bar{e} \mid \theta_L, q_H) = 0$ factors both terms of (B.14), so $M_L(\bar{e}) = 0 < \mathcal{V}(\theta_L, q_L)$. By continuity and Step 2, the solution set $S \equiv \{e \in [0, \bar{e}] : M_L(e) =$

$\mathcal{V}(\theta_L, q_L)\}$ is non-empty and closed, and $0 \notin S$; hence $e_H^{\min} \equiv \min S$ exists and lies in $(0, \bar{e})$, and it satisfies (B.11) by (B.12) and (B.14). Finally, if $M_L(e) \le \mathcal{V}(\theta_L, q_L)$ for some $e < e_H^{\min}$, then by Step 2 and the intermediate value theorem there would exist a solution in $(0, e]$, contradicting minimality of $e_H^{\min}$. Hence $M_L(e) > \mathcal{V}(\theta_L, q_L)$ for all $e < e_H^{\min}$.

□

Lemma 5 (Uniqueness and Monotonicity)**.** *The mimicking payoff M_L of Lemma 4 is strictly decreasing on $[0, \bar{e})$. Consequently, $e_H^{\min}$ is the unique solution to (B.11), and (IC-low) holds strictly for every $e_H > e_H^{\min}$ (trivially so for $e_H \ge \bar{e}$, where mimicking is infeasible).*

Proof. Write $M_\theta(e_H) \equiv v_t^0(e_H \mid \theta, 1) = v_t(e_H \mid \theta, q_H)/(1 - s_t(e_H))$, where $s_t(e_H)$ solves the equity zero-profit condition (B.13) at $\mu_t = 1$. The high type faces its fair price, so Lemma 1(ii) gives $v_t(e_H \mid \theta_H, q_H) = \mathcal{V}(\theta_H, q_H) - g(e_H)$; solving (B.13) for $1/(1 - s_t(e_H))$ and substituting,

$$M_H(e_H) = v_t(e_H \mid \theta_H, q_H) + e_H = \mathcal{V}(\theta_H, q_H) - \phi_1\, e_H^2, \tag{B.15}$$

which is strictly decreasing on $e_H > 0$. Both types evaluate any pair of repurchase levels at the common price q_H and the common schedule $s_t(\cdot)$, so Lemma 3 applies on $[0, \bar{e})$, where $g(e_H) < \mathcal{V}(\theta_L, q_H)$. For any $\bar{e} > e_H > e'_H \ge 0$, (B.15) gives $M_H(e_H) < M_H(e'_H)$, so the high type does not strictly prefer the larger level; by the contrapositive of Lemma 3, the low type cannot weakly prefer it either: $M_L(e_H) < M_L(e'_H)$. Hence M_L is strictly decreasing on $[0, \bar{e})$. A strictly decreasing function meets the constant $\mathcal{V}(\theta_L, q_L)$ at most once, so the binding (IC-low) has at most one solution; one exists by Lemma 4, hence it is unique, and $M_L(e_H) < \mathcal{V}(\theta_L, q_L)$ for all $e_H \in (e_H^{\min}, \bar{e})$.

□

Lemma 6 (IC-high at $e_H^{\min}$ and Non-Emptiness)**.** *Let $\Gamma_\theta(e_H) \equiv v_t^0(e_H \mid \theta, 1) - v_t^0(0 \mid \theta, 0)$ denote type θ's gain from separating with repurchase e_H rather than being perceived as low, and let $t \equiv q_L/q_H = p(\theta_L)/p(\theta_H) \in (0, 1)$. If*

$$\left(\frac{\theta_H}{\theta_L}\right)^{1/(1-\alpha)} \ \ge\ \frac{1 - t^{1/(1-\alpha)}}{1 - t^{\alpha/(1-\alpha)}}, \tag{C}$$

then (IC-high) holds strictly at $e_H^{\min}$, for every $\phi_1 > 0$; hence $e_H^{\min} < e_H^{\max}$, where $e_H^{\max} = \sqrt{\Gamma_H(0)/\phi_1}$ is the unique solution to the binding (IC-high), and the set of separating repurchase levels $[e_H^{\min}, e_H^{\max}]$ is non-empty.

Proof. Step 1: Condition (C) is equivalent to $\Gamma_H(0) \ge \Gamma_L(0)$. By Lemma 1(ii), a high type perceived as low borrows the minimum and its payoff carries the relief factor $p(\theta_H)/(Rq_L) =$

q_H/q_L, so $v_t^0(0 \mid \theta_H, 0) = \frac{q_H}{q_L}\,\mathcal{V}(\theta_H, q_L)$, while $v_t^0(0 \mid \theta_L, 0) = \mathcal{V}(\theta_L, q_L)$ by (B.12). With $M_\theta(0) = \mathcal{V}(\theta, q_H)$, the separation gains at $e_H = 0$ are

$$\Gamma_H(0) = \mathcal{V}(\theta_H, q_H) - \frac{q_H}{q_L}\,\mathcal{V}(\theta_H, q_L), \qquad \Gamma_L(0) = \mathcal{V}(\theta_L, q_H) - \mathcal{V}(\theta_L, q_L).$$

Since $\mathcal{V}(\theta, q) = \frac{1-\alpha}{\alpha}(q\theta)^{1/(1-\alpha)}$ by (B.3), a given type's value at two prices differs by the price ratio raised to $1/(1-\alpha)$; using $\frac{1}{1-\alpha} - 1 = \frac{\alpha}{1-\alpha}$, $\frac{q_H}{q_L}\,\mathcal{V}(\theta_H, q_L) = \mathcal{V}(\theta_H, q_H)\, t^{\alpha/(1-\alpha)}$, so the gains factor as

$$\Gamma_H(0) = \mathcal{V}(\theta_H, q_H)\big[1 - t^{\alpha/(1-\alpha)}\big], \qquad \Gamma_L(0) = \mathcal{V}(\theta_L, q_H)\big[1 - t^{1/(1-\alpha)}\big]. \tag{B.16}$$

With $\mathcal{V}(\theta_H, q_H)/\mathcal{V}(\theta_L, q_H) = (\theta_H/\theta_L)^{1/(1-\alpha)}$,

$$\frac{\Gamma_H(0)}{\Gamma_L(0)} = \Big(\frac{\theta_H}{\theta_L}\Big)^{1/(1-\alpha)} \cdot \frac{1 - t^{\alpha/(1-\alpha)}}{1 - t^{1/(1-\alpha)}},$$

so $\Gamma_H(0) \geq \Gamma_L(0)$ if and only if (C) holds.

Step 2: the high-type gain is a parabola. By (B.15) and the constancy of the deviation payoff,

$$\Gamma_H(e_H) = \Gamma_H(0) - \phi_1\, e_H^2, \tag{B.17}$$

strictly decreasing on $e_H > 0$, with unique zero $e_H^{\max} = \sqrt{\Gamma_H(0)/\phi_1}$.

Step 3: $\Gamma_H(e_H^{\min}) > 0$. Let $g^* \equiv g(e_H^{\min})$, $A \equiv \mathcal{V}(\theta_L, q_H) - g^*$, and $B \equiv \mathcal{V}(\theta_H, q_H) - g^*$; since $e_H^{\min} < \bar{e}$, $g^* < \mathcal{V}(\theta_L, q_H) < \mathcal{V}(\theta_H, q_H)$, so $A, B > 0$. Through (B.14), the binding (IC-low) reads $A(1 + e_H^{\min}/B) = \mathcal{V}(\theta_L, q_L)$, which solves to $g^* = \Gamma_L(0) + e_H^{\min} A/B$. Using $\phi_1 (e_H^{\min})^2 = g^* - e_H^{\min}$ and $D \equiv B - A = \mathcal{V}(\theta_H, q_H) - \mathcal{V}(\theta_L, q_H) > 0$,

$$\phi_1\, (e_H^{\min})^2 = \Gamma_L(0) - e_H^{\min}\,\frac{D}{B}. \tag{B.18}$$

Substituting into (B.17) at $e_H^{\min}$,

$$\Gamma_H(e_H^{\min}) = \big[\Gamma_H(0) - \Gamma_L(0)\big] + e_H^{\min}\,\frac{D}{B} > 0,$$

since $e_H^{\min} > 0$ and $D, B > 0$; the inequality uses Step 1. The identities hold for every $\phi_1 > 0$, hence so does the conclusion.[23] □

B.4 Equilibrium Refinement

Without restrictions on off-equilibrium beliefs the model admits a continuum of pooling and separating PBE. The Cho–Kreps Intuitive Criterion refines this set: Proposition 1 rules out pooling and Proposition 2 selects the least-cost separating PBE at $e_H = e_H^{\min}$, leaving it as the unique survivor.

Proposition 1 (No Pooling PBE Survives the Intuitive Criterion)**.** *No pooling PBE at* $e^{\text{pool}} = 0$ *is supported by off-equilibrium beliefs satisfying the Cho–Kreps Intuitive Criterion.*

Proof. Payoffs in the pool. At $e^{\text{pool}} = 0$ no shares are repurchased, so there is no dilution and each type earns its value at the common pooling price $q_\pi \in (q_L, q_H)$. For the low type q_π exceeds her fair price q_L, so her debt is overpriced, the borrowing constraint binds, and she earns $v_t(\theta_L, q_\pi)$ (Lemma 1(i)). For the high type q_π lies below her fair price q_H, so her debt is underpriced; she borrows the minimum and earns $(q_H/q_\pi)\, v_t(\theta_H, q_\pi)$ (Lemma 1(ii)).

Gains from separating. A type that deviates to some $\hat{e} > 0$ and is believed to be high ($\mu_t = 1$) is priced at q_H. Its gain over remaining in the pool is

$$G_L = v_t(\theta_L, q_H) - v_t(\theta_L, q_\pi) \quad \text{(low type)}, \qquad G_H = v_t(\theta_H, q_H) - \frac{q_H}{q_\pi}\, v_t(\theta_H, q_\pi) \quad \text{(high type)},$$

both strictly positive since $q_\pi < q_H$.

A pool-breaking deviation. Write $M_L(\hat{e})$ and $M_H(\hat{e}) = v_t(\theta_H, q_H) - \phi_1 \hat{e}^2$ for the two types' payoffs from deviating to $\hat{e}$ at $\mu_t = 1$ (Lemma 5); both are strictly decreasing in $\hat{e}$. Define two thresholds:

- $\hat{e}^*$, where the *low* type is indifferent between the deviation and the pool, $M_L(\hat{e}^*) = v_t(\theta_L, q_\pi)$. For $\hat{e} > \hat{e}^*$ the low type would lose by deviating even if believed high, so the deviation is equilibrium-dominated for her and the Intuitive Criterion assigns $\mu_t(\theta_H \mid \hat{e}) = 1$.

- $\hat{e}^{**}$, where the *high* type is indifferent, $M_H(\hat{e}^{**}) = (q_H/q_\pi)\, v_t(\theta_H, q_\pi)$, i.e. $\phi_1 (\hat{e}^{**})^2 = G_H$. For $\hat{e} < \hat{e}^{**}$ the high type strictly gains by deviating.

[23] At the parameterization of Figure 2, condition (C) holds.

Hence any $\hat{e} \in (\hat{e}^*, \hat{e}^{**})$ is believed high and taken by the high type, breaking the pool. It remains to show this interval is non-empty.

Non-emptiness: $\hat{e}^* < \hat{e}^{**}$. The identity behind (B.18), with the pooling payoff $v_t(\theta_L, q_\pi)$ in place of $v_t(\theta_L, q_L)$, gives

$$\phi_1(\hat{e}^*)^2 < G_L,$$

so the deadweight cost of the signal that deters the low type is below her own gain. Using Lemma 6 (with q_π in place of q_L) gives,

$$\frac{G_H}{G_L} \;\geq\; \alpha\Big(\frac{\theta_H}{\theta_L}\Big)^{1/(1-\alpha)} \;\geq\; 1, \qquad \text{so} \quad G_H \geq G_L.$$

Combining the two with $\phi_1(\hat{e}^{**})^2 = G_H$,

$$\phi_1(\hat{e}^*)^2 \;<\; G_L \;\leq\; G_H \;=\; \phi_1(\hat{e}^{**})^2,$$

so $\hat{e}^* < \hat{e}^{**}$. A pool-breaking deviation therefore exists, and the argument extends to $e^{\text{pool}} > 0$ in a neighborhood of zero by continuity.

□

Proposition 2 (Intuitive Criterion Selects the Least-Cost Separating PBE)**.** *Among separating PBE of the simple model with $e_L = 0$ and $e_H \in [e_H^{\min}, e_H^{\max}]$, only the equilibrium with $e_H = e_H^{\min}$ survives the Cho–Kreps Intuitive Criterion. Combined with Proposition 1, the unique PBE surviving the Intuitive Criterion is the separating equilibrium with $e_L = 0$ and $e_H = e_H^{\min}$.*

Proof. Fix a candidate separating PBE with $e_L = 0$ and $e_H > e_H^{\min}$. In it the low type plays $e = 0$, is priced as low, and earns $v_t(\theta_L, q_L)$, while the high type plays e_H, is priced as high, and earns $M_H(e_H)$, where

$$M_H(e) \equiv v_t^0(\theta_H \mid e, \mu_t = 1) = v_t(\theta_H, q_H) - \phi_1 e^2$$

(Lemma 5) is the high type's payoff from repurchasing e and being believed high. Let $M_L(e) \equiv v_t^0(\theta_L \mid e, \mu_t = 1)$ be the analogous payoff for the low type; both are continuous and strictly decreasing. We test each candidate deviation against the deviating type's own equilibrium action — $e = 0$ for the low type, e_H for the high type.

No $e_H > e_H^{\min}$ survives. Pick $\tilde{e} \in (e_H^{\min}, e_H)$. The low type's most favorable belief at $\tilde{e}$ is $\mu_t = 1$ — her payoff rises in μ_t, since a higher belief raises the debt price and lowers dilution — so the most she can obtain there is $M_L(\tilde{e})$. As M_L is decreasing and $M_L(e_H^{\min}) = v_t(\theta_L, q_L)$ by the binding (IC-low),

$$M_L(\tilde{e}) < M_L(e_H^{\min}) = v_t(\theta_L, q_L) : \tag{B.19}$$

even in the best case the deviation falls short of her equilibrium payoff, so $\tilde{e}$ is equilibrium-dominated for the low type. It is not for the high type, since $\tilde{e} < e_H$ gives

$$M_H(\tilde{e}) > M_H(e_H),$$

so at $\mu_t = 1$ the deviation beats her equilibrium payoff. When a deviation is dominated for one type but not the other, the Intuitive Criterion places all weight on the undominated type, $\mu_t(\theta_H \mid \tilde{e}) = 1$. Under that belief the high type strictly prefers $\tilde{e}$ to e_H, contradicting equilibrium.

The least-cost equilibrium survives. At $e_H = e_H^{\min}$ the interval $(e_H^{\min}, e_H)$ is empty, so the construction above is unavailable; we check the remaining deviations. For $e \in (0, e_H^{\min})$, monotonicity of M_L gives $M_L(e) > M_L(e_H^{\min}) = v_t(\theta_L, q_L)$, so the low type would gain at e if believed high: e is *not* equilibrium-dominated for her, the criterion leaves beliefs free, and $\mu_t(\theta_H \mid e) = 0$ supports the equilibrium, as neither type then wants the costly repurchase. For $e > e_H^{\min}$ the criterion forces $\mu_t = 1$, but $M_H(e) < M_H(e_H^{\min})$ leaves the high type preferring $e_H^{\min}$; and deviating to $e = 0$ is ruled out by (IC-high) at $e_H^{\min}$. The separating equilibrium with $e_L = 0$ and $e_H = e_H^{\min}$ therefore survives, and by the first part it is the only one; with Proposition 1, it is the unique PBE surviving the Intuitive Criterion. □

C Quantitative Model

This section provides more detail on the quantitative model.

C.1 Existence of the Balanced Growth Path

We show that a balanced growth path (BGP) exists in which all aggregate variables grow at a constant rate g. Let the gross growth rate of any aggregate variable Z_t be denoted by $g^Z \equiv Z_{t+1}/Z_t - 1$.

Output. From the final-good technology,

$$Y_t = L_t^{1-\alpha} \int_0^{Q_t} z_{jt}^{1-\alpha} x_{jt}^{\alpha}\, dj, \qquad L_t = 1,$$

and the optimal input demand $x_{jt} = z_{jt}\left(\frac{\alpha^2}{\psi}\right)^{\frac{1}{1-\alpha}}$, we obtain

$$Y_t = \left(\frac{\alpha^2}{\psi}\right)^{\frac{\alpha}{1-\alpha}} \int_0^{Q_t} z_{jt}\, dj = \left(\frac{\alpha^2}{\psi}\right)^{\frac{\alpha}{1-\alpha}} \bar{z}\, Q_t,$$

where $\bar{z} = \mathbb{E}[z_{jt}]$ is constant under a stationary distribution. Hence, $Y_t \propto Q_t$ and aggregate output grows at the same rate as Q_t along the BGP.

Varieties. From the law of motion for the stock of varieties,

$$\frac{Q_{t+1} - Q_t}{Q_t} = \frac{M_t}{Q_t},$$

the growth rate of aggregate varieties equals the ratio of new to existing varieties. Along the BGP this ratio is constant, implying $g^Q = g^M = g$.

Intermediate Expenditure. With constant marginal cost ψ, total final output used for intermediates is

$$X_t = \int_0^{Q_t} \psi\, x_{jt}\, dj = \left(\alpha^2\right)^{\frac{1}{1-\alpha}} \psi^{-\frac{\alpha}{1-\alpha}} \bar{z}\, Q_t.$$

Thus $X_t \propto Q_t$ and $g^X = g^Q = g$ along the BGP.

R&D Expenditure. With a unit mass of firms $k \in [0, 1]$,

$$W_t = \int_0^1 W_{kt}\, dk = \left(\int_0^1 \frac{W_{kt}}{Q_t}\, dk \right) Q_t = \bar{w}\, Q_t,$$

where $\bar{w}$ is a constant and $g^W = g^Q = g$ along the BGP.

Consumption. The goods-market clearing condition

$$Y_t \approx C_t + X_t + W_t$$

Since Y_t, X_t, and W_t are liner in Q_t, aggregate consumption must also grow at the same rate g along the BGP.

C.2 Balanced Growth Path

We characterize the equilibrium along a balanced growth path (BGP) on which all aggregate variables grow at the common rate g, determined by the law of motion of the variety stock Q_t. Detrended (per-variety) variables are defined as

$$x_{kt} \equiv X_{kt}/Q_t$$

for any firm-level variable X_{kt}, and are stationary along the BGP. Firms' revenues (scaled) for firm k from selling their portfolio of intermediate goods are

$$r_{kt} \equiv \frac{R_{kt}}{Q_t} = \pi^k_{jt}(z_{kt})\, m_{kt} = (1-\alpha)\, \alpha^{\frac{\alpha}{1-\alpha}}\, \psi^{-\frac{\alpha}{1-\alpha}}\, z_{jt}\, m_{kt} \tag{C.20}$$

Each firm invests $w_{kt} \equiv W_{kt}/Q_t$ units of the final good per existing variety in R&D to expand its portfolio of patented products in case of success

$$m_{kt+1} \equiv \frac{M_{kt+1}}{Q_{t+1}} = \frac{\bar{\xi}}{1+g}\, \theta_{kt} w_{kt}^{\gamma} \tag{C.21}$$

The equilibrium growth rate g is determined by the aggregation condition

$$g = \int_0^1 p_{kt} m_{kt}\, d\Phi \tag{C.22}$$

Firms' dividends to the shareholders are:

$$d_{kt} \equiv \frac{D_{kt}}{Q_t} = (1-\tau)\left[\pi(z_{kt})\, m_{kt} - w_{kt}\right] - b_{kt} + (1+g)[q_{kt} + \tau(1-q_{kt})]\, b_{kt+1}$$
$$- e_{kt} - (\phi_0 + \phi_1 e_{kt}^2)\mathbb{1}_{\{e_{kt}>0\}} \geq 0 \tag{C.23}$$

The first term represents net operating profits, while the remaining terms capture debt repayment, new borrowing (adjusted by growth) and cash out-flow from repurchasing.

Because firm dividends scale linearly with the aggregate stock of varieties the firm's value function is homogeneous of degree one in Q_t. This allows the dynamic problem to be expressed in stationary form, eliminating Q_t from the state space. Therefore, along the balanced growth path, we have $V_t = Q_t v_t$ for all t. This allows us to determine the value for shareholders as:

$$v_t^0(n_{kt}, z_{kt}, \theta_{kt}) = \max_{e_{kt}} \frac{1}{1 - s_{kt}(e_{kt})} v_t(e_{kt} \mid n_{kt}, z_{kt}, \theta_{kt}), \tag{C.24}$$

and the continuation value of the firm is:

$$v_t(e_{kt} \mid n_{kt}, z_{kt}, \theta_{kt}) = \max_{w_{kt}, b_{kt+1}} d_{kt} +$$
$$\frac{(1+g)}{R_{t+1}} \mathbb{E}_t\big[p_{kt}\, v_{t+1}^0(n_{kt+1}, z_{kt+1}, \theta_{kt+1}) + (1-p_{kt})\, v_{t+1}^0(0, z_{kt+1}, \theta_{kt+1})\big] \tag{C.25}$$

subject to equation (C.23) and the earnings-based debt constraint, which caps debt at after-tax profits in the lowest demand state $\underline{z}$, so that debt is riskless conditional on R&D success:

$$b_{kt+1} \leq (1-\tau)\, \pi(\underline{z})\, m_{kt+1} \tag{C.26}$$

Using $V_t = Q_t v_t$ and $b_{kt+1} = B_{kt+1}/Q_{t+1}$, then in the equity market:

$$e_{kt} = \frac{s_{kt}}{1 - s_{kt}} \mathbb{E}\Big[v(e_{kt} \mid n_{kt}, z_{kt}, \theta_{kt}) \mid \mu(\theta_{kt}; n_{kt}, z_{kt}, e_{kt})\Big] \tag{C.27}$$

and the price of debt is:

$$q_{kt}(e_t \mid n_{kt}, z_{kt}) = \frac{1}{R_{t+1}} \frac{\mathbb{E}\big[p_{kt}(w_{kt}^*(\theta_{kt}), \theta_{kt}) b_{kt+1}^*(\theta_{kt} \mid n_{kt}, z_{kt}) \,\big|\, \mu_t\left(\theta \mid n_{kt}, z_{kt}\right)\big]}{\mathbb{E}\big[b_{kt+1}^*(\theta_{kt} \mid n_{kt}, z_{kt}) \,\big|\, \mu_t\left(\theta \mid n_{kt}, z_{kt}\right)\big]} \tag{C.28}$$

Along the balanced growth path, the risk-free rate is constant. From the Euler equation,

$$\frac{1}{R_{t+1}} = \beta(1+g)^{-\eta}, \tag{C.29}$$

where g is the constant growth rate of consumption.

C.3 Characterizing the Equity-Market Equilibrium

Definition 1 (Stationary Balanced Growth Path Equilibrium)**.** A stationary balanced growth path equilibrium consists of a growth rate g, aggregate quantities $(C_t, L_t, M_t, Q_t, B_t)$, aggregate prices (R_t, P_t^L), a stationary firm distribution $\Phi(n, z)$, firm-level value functions and policies, the investment fund's dilution and debt-price schedules, and beliefs μ_t over project quality θ_{kt} such that:

(i) *Firm optimization*: given the dilution schedule s_t and debt price schedule q_t, the value functions and firm policies for repurchase e_t, R&D w_t, and debt b_{t+1} solve the Bellman equations (24)–(D.42).

(ii) *Investment fund break-even*: given firm policies and beliefs, s_t and q_t satisfy the zero-profit conditions (D.46) and (D.47).

(iii) *Belief consistency*: beliefs $\mu_t(\theta_{kt} \mid e_{kt}, n_{kt}, z_{kt})$ are consistent with firm policies through Bayes' rule on the equilibrium path and satisfy the D1 Criterion of Banks and Sobel (1987) off the equilibrium path.

(iv) *Household and final-good optimization*: consumption and savings satisfy the Euler equation, and $L_t = 1$.

(v) *Aggregation*: Φ is stationary in detrended units and consistent with firm policies and the i.i.d. realization of θ_{kt}.

(vi) *Aggregate growth and market clearing*: $g = \int m_{kt}\, d\Phi$, and the goods, debt, and equity markets clear.

We characterize the within-period signaling equilibrium along the balanced growth path, in parallel with the simple model of Appendix B. Three features distinguish the full model. First, private information is *repeated*: a fresh project quality θ_{kt} is drawn and privately observed each period, so the post-repurchase value functions are *not* additively separable, unlike the effectively one-shot two-period model of Appendix B. We therefore state the structural properties of the continuation value under which the characterization holds and verify them numerically at our estimated parameters. Second, project quality enters the *return* to R&D and the probability of success, so investment is type-dependent even under full information. Third, the repurchase cost carries a fixed component ϕ_0 absent from the simple model, which introduces an extensive margin: a cutoff $\underline{\theta}_t$ below which firms do not repurchase at all.

Throughout, (n, z) denotes a firm's publicly observable detrended state and θ its privately observed project quality. We write $v_t(e \mid n, z, \theta)$ for the post-repurchase continuation value, $v_t^0(n, z, \theta) = \max_{e \geq 0}[1 - s_t(e; n, z)]^{-1} v_t(e \mid n, z, \theta)$ for the value to incumbent shareholders, $s_t(e; n, z)$ and $q_t(e; n, z)$ for the dilution and debt-price schedules, $\mu_t(\theta; n, z, e)$ for the fund's posterior after observing e, and $\kappa(q) \equiv q + \tau(1 - q)$.

Assumption 1 (Regularity; verified numerically)**.** Fix the public state (n, z). The post-repurchase value $v_t(e \mid n, z, \theta)$ and the innovation technology satisfy:

(i) $\partial v_t / \partial e < 0$ and $\partial v_t / \partial \theta > 0$: a larger repurchase lowers the continuation value, while a higher type raises it;

(ii) $\partial^2 v_t / \partial e^2 \leq 0$: the value is concave in the repurchase;

(iii) $\partial^2 v_t / \partial e \, \partial \theta \geq 0$: the marginal cost of repurchasing falls with type;

Parts (i)–(iii) discipline the equity-market signaling game. Conditions (i)–(iii) hold in closed form in the one-shot model of Appendix B (where v_t is additively separable); in the full model all conditions are verified at the estimated parameters.

C.3.1 Full-Information Benchmark

Suppose the fund observes θ. A repurchase then conveys no information and is pure deadweight, so $e_t = 0$, and debt is fairly priced at the type-specific value $q_t = R^{-1} p(w_t^*, \theta)$. Because operating profits $(1 - \tau)\pi(z)m$ and the borrowing limit are linear in the (one-period) variety portfolio, the value is linear in detrended internal funds,

$$v_t^0(n, z, \theta) = n + J_t(z, \theta),$$

where the intangible value J_t collects the firm's R&D franchise and, when the dividend constraint is slack, is independent of n. Let $\bar{\pi}_t \equiv (1 - \tau)\mathbb{E}_t[\pi(z')]$ be the expected per-variety profit, $\underline{\pi}_t \equiv (1-\tau)\pi(\underline{z})$ its worst-case (pledgeable) counterpart, and $m'(w) = \frac{\bar{\xi}}{1+g}\theta w^\gamma$ the portfolio that R&D creates. Decomposing $v^0_{t+1} = n' + J_{t+1}$, its expected cash component $\mathbb{E}_t[n'] = p(w,\theta)\big(\bar{\pi}_t\, m'(w) - b'\big)$ enters the firm's problem directly—debt is repaid in full whenever R&D succeeds and $n' = 0$ on failure—so the intangible value solves

$$J_t(z,\theta) = \max_{w,\,b'\geq 0}\ \Big\{-(1-\tau)w+(1+g)\kappa(q_t)\,b'+\tfrac{1+g}{R}\,p(w,\theta)\big(\bar{\pi}_t\,m'(w)-b'\big)\Big\}+\tfrac{1+g}{R}\,\mathbb{E}_t\big[J_{t+1}(z',\theta')\big], \tag{C.30}$$

subject to $b' \leq \underline{\pi}_t\, m'(w)$, with $q_t = p(w,\theta)/R$.

Proposition 3 (Full-information benchmark)**.** *The solution to (C.30) satisfies:*

(i) Debt. *The borrowing constraint binds, $b^*_{t+1} = \underline{\pi}_t\, m'(w^*)$: the tax shield makes debt strictly valuable even at fair prices.*

(ii) R&D. *Optimal R&D solves the first-order condition*

$$1-\tau = (1+g)\,m'(w)\Big[\,\frac{\gamma}{w}\big(\tau(1-q_t)\,\underline{\pi}_t + \tfrac{p}{R}\,\bar{\pi}_t\big) + \frac{p_w(w,\theta)}{R}\big(\bar{\pi}_t - \tau\,\underline{\pi}_t\big)\Big], \tag{C.31}$$

which equates its after-tax marginal cost to its marginal value through two channels: a larger variety portfolio (scale) and a higher success probability, which also lowers the price of debt.[24]

(iii) Monotonicity. *Under Assumption 1(iv) the maximand is supermodular in (w,θ), so $w^*_t(z,\theta)$ is increasing in project quality.*

Proof. (i) Debt. Under full information the fund's belief is the true type, so the break-even condition (D.47) gives $q_t = p(w,\theta)/R$, a bond paying its face value only on success. Repayment is then certain conditional on success—the limit $b' \leq \underline{\pi}_t m' = (1-\tau)\pi(\underline{z})m'$ ensures $(1-\tau)\pi(z')m' \geq b'$ in every demand state—so non-repayment occurs only on R&D failure and q_t is independent of b'. The maximand in (C.30) is then linear in b' with slope $(1+g)\big[\kappa(q_t) - p/R\big] = (1+g)\tau(1-q_t) > 0$ (using $q_t = p/R$); the tax shield makes debt strictly valuable, so the constraint binds, $b^*_{t+1} = \underline{\pi}_t\, m'(w^*)$.

(ii) R&D. The inner maximand of (C.30) is

$$M(w,b') = -(1-\tau)w + (1+g)\kappa(q_t)\,b' + \tfrac{1+g}{R}\,p(w,\theta)\big(\bar{\pi}_t\,m' - b'\big).$$

[24] The tax-shield term depends on the *level* of R&D because innovation creates the collateral against which the firm borrows: the debt limit $b' \leq \underline{\pi}_t\, m'(w)$ scales with the portfolio $m'(w)$ that R&D produces. Investment thus carries a *collateral value*—it relaxes the financing constraint and expands tax-advantaged borrowing—over and above its direct expected profit.

By part (i) it is linear in b' with positive slope, so b' is pushed to the limit $b^*_{t+1} = \underline{\pi}_t\, m'$. Substituting it, the two terms in b' collect as

$$(1+g)\kappa(q_t)\,\underline{\pi}_t m' - \tfrac{1+g}{R}\,p\,\underline{\pi}_t m' = (1+g)\underline{\pi}_t m'\Big[\kappa(q_t) - \tfrac{p}{R}\Big] = (1+g)\,\tau(1-q_t)\,\underline{\pi}_t m',$$

where the last step uses $q_t = p/R$, so $\kappa(q_t) - \frac{p}{R} = q_t + \tau(1-q_t) - q_t = \tau(1-q_t)$. The remaining profit term is $\frac{1+g}{R} p\,\bar{\pi}_t m'$, giving the reduced objective

$$M(w) = -(1-\tau)w + (1+g)\,\tau(1-q_t)\,\underline{\pi}_t\, m'(w) + \tfrac{1+g}{R}\,p(w,\theta)\,\bar{\pi}_t\, m'(w),$$

in which the success-state term does *not* vanish: the firm pledges only $\underline{\pi}_t m'$ and keeps the upside $(\bar{\pi}_t - \underline{\pi}_t)m'$. Differentiating in w, with $\partial q_t/\partial w = p_w/R$ and $m'_w = \gamma m'/w$, the two value terms give

$$\frac{\partial}{\partial w}\Big[(1+g)\tau(1-q_t)\underline{\pi}_t m'\Big] = (1+g)\tau\underline{\pi}_t\Big[(1-q_t)\tfrac{\gamma m'}{w} - \tfrac{p_w}{R}m'\Big],$$
$$\frac{\partial}{\partial w}\Big[\tfrac{1+g}{R}\,p\,\bar{\pi}_t m'\Big] = \tfrac{1+g}{R}\bar{\pi}_t\Big[p_w m' + p\,\tfrac{\gamma m'}{w}\Big].$$

Setting $\partial M/\partial w = 0$ (their sum equals $1-\tau$) and collecting the γ/w terms into $\frac{\gamma}{w}\big(\tau(1-q_t)\underline{\pi}_t + \frac{p}{R}\bar{\pi}_t\big)$ and the p_w terms into $\frac{p_w}{R}\big(\bar{\pi}_t - \tau\underline{\pi}_t\big)$ yields (C.31).

(iii) Monotonicity. It suffices that the maximand be supermodular in (w,θ)—then w^*_t is increasing in θ. Up to a positive constant the dominant (expected-profit) term is $E(w,\theta) = \theta\, p(w,\theta)\, w^\gamma$, with $p(w,\theta) = 1 - e^{-\theta w^\chi}$, so that $p_w = \theta\chi w^{\chi-1}e^{-\theta w^\chi}$ and hence $p_w\, w = \chi\,\theta w^\chi e^{-\theta w^\chi}$. The marginal value of R&D is

$$\frac{\partial E}{\partial w} = \theta\big(p_w\, w^\gamma + \gamma\, p\, w^{\gamma-1}\big) = \theta\, w^{\gamma-1}\big(\chi\,\theta w^\chi e^{-\theta w^\chi} + \gamma\, p\big).$$

Differentiating once more in θ, with $\partial(\theta w^\chi)/\partial\theta = w^\chi$,

$$\frac{\partial^2 E}{\partial w\,\partial\theta} = w^{\gamma-1}\Big[\big(\chi\,\theta w^\chi e^{-\theta w^\chi} + \gamma\, p\big) + \theta w^\chi e^{-\theta w^\chi}\big(\chi(1-\theta w^\chi) + \gamma\big)\Big].$$

The first bracket is positive; the second carries the sign of $\chi(1-\theta w^\chi) + \gamma$, which is non-negative exactly when $\theta w^\chi \le 1 + \gamma/\chi$ —Assumption 1(iv). Under it the maximand is supermodular (the tax-shield term enters only at order τ and does not overturn this), so w^*_t is strictly increasing in θ. □

C.3.2 Single-Crossing

Higher-quality firms are more willing to bear a given repurchase: their indifference curves in repurchase–dilution space are flatter, so the curves of any two types cross at most once. This single-crossing property—the lever behind the recursive separating construction and its D1 refinement below—rests on the value-function regularity of Assumption 1(i)–(iii).

Lemma 7 (Single-crossing)**.** *Fix the public state (n, z) and the dilution schedule $s_t(\cdot)$. Under Assumption 1(i)–(iii), if type θ weakly prefers a repurchase e' to a smaller $e < e'$, then every higher type $\theta' > \theta$ strictly prefers e'.*

Proof. We suppress the public state (n, z) and fix the dilution schedule $s_t(\cdot)$; the value to incumbents of repurchasing e at type θ is then $[1 - s_t(e)]^{-1}\, v_t(e \mid \theta)$. Suppose type θ weakly prefers the larger repurchase e' to the smaller $e < e'$,

$$\frac{v_t(e' \mid \theta)}{1 - s_t(e')} \;\geq\; \frac{v_t(e \mid \theta)}{1 - s_t(e)}. \tag{C.32}$$

Collecting the schedule terms on one side and the value terms on the other, (C.32) is equivalent to

$$\frac{1 - s_t(e)}{1 - s_t(e')} \;\geq\; \frac{v_t(e \mid \theta)}{v_t(e' \mid \theta)} \;\equiv\; f(\theta). \tag{C.33}$$

We first show that f is strictly decreasing in θ. By the quotient rule, $f'(\theta)$ has the sign of its numerator,

$$\operatorname{sign} f'(\theta) = \operatorname{sign}\big[\, v_{t,\theta}(e \mid \theta)\, v_t(e' \mid \theta) - v_{t,\theta}(e' \mid \theta)\, v_t(e \mid \theta) \,\big], \qquad v_{t,\theta} \equiv \tfrac{\partial v_t}{\partial \theta}. \tag{C.34}$$

By the cross-partial property (iii), $v_{t,\theta}$ is increasing in e, so $v_{t,\theta}(e' \mid \theta) \geq v_{t,\theta}(e \mid \theta)$; replacing $v_{t,\theta}(e' \mid \theta)$ by this lower value can only raise the bracket in (C.34):

$$v_{t,\theta}(e \mid \theta)\, v_t(e' \mid \theta) - v_{t,\theta}(e' \mid \theta)\, v_t(e \mid \theta) \;\leq\; v_{t,\theta}(e \mid \theta)\, \big[v_t(e' \mid \theta) - v_t(e \mid \theta)\big]. \tag{C.35}$$

The two factors on the right have opposite signs by property (i): $v_{t,\theta}(e \mid \theta) > 0$, while v_t is decreasing in e, so $v_t(e' \mid \theta) - v_t(e \mid \theta) < 0$ for $e' > e$. Hence the right-hand side of (C.35) is negative, and $f'(\theta) < 0$.

Now take any higher type $\theta' > \theta$. Since f is strictly decreasing, $f(\theta') < f(\theta)$, and chaining this with (C.33),

$$\frac{v_t(e \mid \theta')}{v_t(e' \mid \theta')} = f(\theta') \;<\; f(\theta) \;\leq\; \frac{1 - s_t(e)}{1 - s_t(e')}. \tag{C.36}$$

Reversing the rearrangement that took (C.32) to (C.33)—now with a strict inequality—gives

$$\frac{v_t(e' \mid \theta')}{1 - s_t(e')} \;>\; \frac{v_t(e \mid \theta')}{1 - s_t(e)},$$

so type θ' strictly prefers e' to e, as claimed. □

C.3.3 Separating Equilibrium

Write $v_t^0(\theta \mid e, \mu)$ for the value to existing shareholders of a type-θ firm that repurchases e when the market holds belief μ about its type, so its debt is priced at $q_t(e; \mu)$ and its equity diluted at $s_t(e; \mu)$. This is the shareholder value v_t^0 introduced above, now written as a function of the repurchase and belief with the state (n, z) held fixed—the convention of the simple model in Appendix B—and we reserve $v_t^0(\theta)$ for its equilibrium level.[25] On a grid $\theta_1 < \cdots < \theta_N$, the equilibrium consists of a repurchase profile $\{e_\iota\}$ together with debt-price, dilution, and belief schedules of the following form. A bottom group $\theta_1, \ldots, \theta_m$ pools at $e = 0$; unable to tell them apart, the fund applies a single debt price and dilution set by the zero-profit condition (D.47) under the pooled posterior μ^{pool} (the conditional distribution of θ given $\theta \leq \theta_m$), so it breaks even in expectation over the pool. The cutoff is $\underline{\theta}_t \equiv \theta_{m+1}$, the lowest type whose separating gain covers the fixed cost ϕ_0. Separating types $\theta_{m+1} < \cdots < \theta_N$ repurchase $0 < e_{m+1} < \cdots < e_N$, each priced at its true type, with the profile defined recursively by the binding no-mimicking condition

$$v_t^0(\theta_\iota \mid e_\iota, \mu_\iota) = v_t^0(\theta_\iota \mid e_{\iota+1}, \theta_{\iota+1}), \qquad \mu_\iota = \begin{cases} \mu^{\text{pool}} & \iota = m, \\ \theta_\iota & \iota > m, \end{cases} \tag{C.37}$$

Here the left-hand side is type θ_ι's equilibrium payoff and the right-hand side its payoff from repurchasing the higher signal $e_{\iota+1}$ and passing for $\theta_{\iota+1}$, so (C.37) leaves θ_ι indifferent

[25] The belief enters v_t^0 through two prices: it sets the debt price $q_t(e; \mu)$ inside the continuation value and the dilution $s_t(e; \mu)$ in the multiplier $[1 - s_t(e; \mu)]^{-1}$. Being taken for a higher type raises q_t—a first-order gain, the lemons channel—while making the repurchase less accretive, since the firm retires fewer shares per unit of cash; the former dominates, so the binding incentive is to mimic upward. We therefore establish the construction from single-crossing alone, without positing a closed form for v_t^0.

to imitating the type above and pins $e_{\iota+1}$ as the smallest repurchase that deters it. The recursion starts from the lowest separating type, which repurchases just enough to deter the top of the pool. Off path, an unused repurchase $e \in (e_\iota, e_{\iota+1})$ is read pessimistically as the lower type θ_ι (the belief rises to $\theta_{\iota+1}$ only at the on-path signal $e_{\iota+1}$), a D1-consistent assignment established below. Because separating types are priced at their true type, the repurchase recovers its fair value on the equilibrium path, and the only residual cost is the deadweight $\phi_0 + \phi_1 e_\iota^2$.

For a single pair of types this problem is solved in closed form in Appendix B, where one high type repurchases $e_H^{\min}$ to separate from a low type. Two of its results transfer directly to each *adjacent* pair $(\theta_\iota, \theta_{\iota+1})$, and we invoke them rather than re-derive: the existence and uniqueness of the deterring repurchase (Lemmas 4–5) and the collapse of two-type pooling (Proposition 1). What the two-type model cannot supply—and what we develop below—are the *recursion* stringing the adjacent conditions into a profile over the whole grid, the D1 off-path beliefs across that grid, and the extensive-margin *cutoff* introduced by the fixed cost ϕ_0, the last absent from the simple model.

Lemma 8 (Construction of the separating profile)**.** *Under Assumption 1(i)–(iii):*

(a) for each $\iota \geq m$, (C.37) has a unique solution $e_{\iota+1} > e_\iota$, and $e_{\iota+1}$ is strictly increasing in ι;

(b) the equilibrium value $v_t^0(\theta_\iota) \equiv v_t^0(\theta_\iota \mid e_\iota, \mu_\iota)$ is strictly increasing in ι;

(c) on each interval $(e_\iota, e_{\iota+1})$ between consecutive on-path signals the type most willing to deviate is θ_ι, so D1 assigns the (pessimistic) belief θ_ι there, the belief rising to $\theta_{\iota+1}$ only at $e_{\iota+1}$.

Proof. (a) Existence, uniqueness, and monotonicity of $e_{\iota+1}$. The signal $e_{\iota+1}$ is pinned down by the firm most tempted to imitate $\theta_{\iota+1}$, namely the type just below it, θ_ι. We measure that temptation by the net gain to θ_ι from repurchasing e and being taken for $\theta_{\iota+1}$, relative to its own equilibrium payoff:

$$g_\iota(e) \;\equiv\; \underbrace{v_t^0(\theta_\iota \mid e, \theta_{\iota+1})}_{\theta_\iota \text{ imitates } \theta_{\iota+1}} \;-\; \underbrace{v_t^0(\theta_\iota \mid e_\iota, \mu_\iota)}_{\theta_\iota \text{ on its own path}} \;.$$

Note that the true type is θ_ι on both sides: only the signal and the market's belief differ. The no-mimicking condition (C.37) is exactly $g_\iota(e_{\iota+1}) = 0$, so $e_{\iota+1}$ is the repurchase at which θ_ι is just indifferent to imitating.

We show that g_ι changes sign once on (e_ι, ∞). *At the low type's own signal* $e = e_\iota$, the firm spends the same on the repurchase as on its own path but is now taken for the higher type. Two prices move in opposite directions: the debt price rises (a gain), while the buyback becomes *less accretive*—shares are retired at the inflated high-type price, a loss. The debt gain dominates, so $g_\iota(e_\iota) > 0$: imitation pays at a small signal. *At a large signal*, the firm must repurchase ever more to keep being taken for $\theta_{\iota+1}$, and now *both* costs grow in e—the convex repurchase cost $\phi_0 + \phi_1 e^2$ and the dilution from retiring ever more shares at the inflated price[26]—while the debt-price gain from a fixed belief stays bounded. Hence $g_\iota(e) < 0$ for e large enough: imitation no longer pays.

Since g_ι is continuous, positive at e_ι and negative for large e, it has a root $e_{\iota+1} > e_\iota$. With $(\theta_\iota, \theta_{\iota+1})$ in the roles of (θ_L, θ_H), this root solves the binding low-type incentive-compatibility condition (B.11)—the lower type's equilibrium payoff on the left, its mimicking payoff on the right—of which the lowest rung ($e_\iota = 0$, the pool against the first separating type) is literally the two-type problem of Appendix B. Lemma 4 then characterizes $e_{\iota+1}$ as the strictly positive least-cost separating signal, and Lemma 5 establishes that it is the unique such level; hence $e_{\iota+1}$ is well defined. Finally, $e_{\iota+1} > e_\iota$ at every rung: were $e_{\iota+1} \leq e_\iota$, then since θ_ι chooses the (weakly larger) e_ι in equilibrium, single-crossing (Lemma 7) would make the higher type $\theta_{\iota+1}$ *strictly* prefer e_ι to $e_{\iota+1}$, contradicting its own choice of $e_{\iota+1}$. Iterating from the pool gives $0 < e_{m+1} < \cdots < e_N$: higher types repurchase more.

(b) The equilibrium value rises with type. The value $v_t^0(\theta_\iota) \equiv v_t^0(\theta_\iota \mid e_\iota, \mu_\iota)$ is defined on two segments—the pool ($\iota \leq m$, with $e_\iota = 0$ and $\mu_\iota = \mu^{\text{pool}}$) and the separating types ($\iota > m$, with $\mu_\iota = \theta_\iota$)—and we establish monotonicity on each and across the cutoff.

Within the pool. All pooled types make the same choice $e = 0$ and face the same belief μ^{pool}, hence the same prices; only the true type differs. Thus $v_t^0(\theta_\iota) = v_t^0(\theta_\iota \mid 0, \mu^{\text{pool}})$, which is strictly increasing in θ_ι because a higher true type earns strictly more at a fixed signal and belief (Assumption 1(i), $\partial v_t / \partial \theta > 0$). So v_t^0 rises across $\iota = 1, \ldots, m$.

Across the cutoff and along the separating segment ($\iota \geq m$). By the indifference (C.37), type θ_ι's equilibrium payoff equals what it would earn by mimicking the type just above:

$$v_t^0(\theta_\iota) = v_t^0(\theta_\iota \mid e_{\iota+1}, \theta_{\iota+1}) < v_t^0(\theta_{\iota+1} \mid e_{\iota+1}, \theta_{\iota+1}) = v_t^0(\theta_{\iota+1}).$$

The inequality holds because, at the *same* signal $e_{\iota+1}$ and the *same* belief $\theta_{\iota+1}$, a higher

[26] Repurchasing e at the believed value $\mathbb{E}[v_t \mid \theta_{\iota+1}]$ returns, in accretion, only $v_t(e \mid \theta_\iota)/\mathbb{E}[v_t \mid \theta_{\iota+1}] < 1$ per unit of cash, as the shares are worth less to the true type θ_ι; the dilution cost is therefore $e\big(1 - v_t(e \mid \theta_\iota)/\mathbb{E}[v_t \mid \theta_{\iota+1}]\big)$, increasing in e.

true type earns strictly more (Assumption 1(i)); the last equality holds because $(e_{\iota+1}, \theta_{\iota+1})$ is precisely $\theta_{\iota+1}$'s own equilibrium choice. The case $\iota = m$ is the pool-to-separation step, where $\mu_m = \mu^{\text{pool}}$ and θ_m is the top of the pool. Combining the two segments, v_t^0 is strictly increasing in ι throughout.

(c) Off-path beliefs. It remains to say what the market believes when it sees a repurchase $e \in (e_\iota, e_{\iota+1})$ that neither θ_ι nor $\theta_{\iota+1}$ plays. Recall the objects: μ is the market's belief about the firm's type (which sets the price it faces); $v_t^0(\theta \mid e, \mu)$ is the payoff of a firm of *true* type θ that repurchases e and is believed to be μ; and $v_t^0(\theta)$ is θ's equilibrium payoff. The D1 criterion—a refinement of the Intuitive Criterion used for the two-type model in Appendix B, and the standard selection device once there are more than two types—attributes the off-path e to the type *most willing* to send it; we show this is the lower type θ_ι.

Reservation belief. Define type θ's *reservation belief* at e, $\mu_\theta^*(e)$, as the lowest belief that makes the deviation just worthwhile:

$$v_t^0\big(\theta \mid e, \mu_\theta^*(e)\big) = v_t^0(\theta).$$

Since v_t^0 increases in the belief, θ gains from deviating to e at any belief above $\mu_\theta^*(e)$; a *lower* reservation belief therefore marks a more willing type, and D1 selects the type with the smallest $\mu_\theta^*(e)$. What matters is thus the *level* of μ^*—which type's is lowest at a given e—and not its slope; we recover that level ordering on the gap from two facts about the reservation-belief curves $\mu_{\theta_\iota}^*(\cdot)$ and $\mu_{\theta_{\iota+1}}^*(\cdot)$: where they start, and how they diverge.

The two curves start together at $e_{\iota+1}$. Type $\theta_{\iota+1}$ plays $e_{\iota+1}$, so it is just willing there at its own belief: $\mu_{\theta_{\iota+1}}^*(e_{\iota+1}) = \theta_{\iota+1}$. The no-mimicking condition (C.37) makes θ_ι indifferent between e_ι and being taken for $\theta_{\iota+1}$ at $e_{\iota+1}$, so $\mu_{\theta_\iota}^*(e_{\iota+1}) = \theta_{\iota+1}$ too.

The low type's curve is steeper. Each $\mu_\theta^*(\cdot)$ slopes *up*: a larger repurchase must be offset by a more favorable belief to keep the firm just willing. Its slope is the extra belief needed to compensate one more unit of repurchase—the type's marginal distaste for repurchasing—and by single-crossing (Lemma 7) the lower type, being more reluctant to repurchase, has the larger slope.

Putting the two facts together—two upward-sloping curves that agree at $e_{\iota+1}$, the lower type's the steeper—the lower type's must lie below for $e < e_{\iota+1}$:

$$\mu_{\theta_\iota}^*(e) < \mu_{\theta_{\iota+1}}^*(e) \qquad \text{for every } e \in (e_\iota, e_{\iota+1}).$$

So θ_ι has the lower reservation belief and is the most willing type throughout the gap; D1 sets the off-path belief to θ_ι there, and the belief rises to $\theta_{\iota+1}$ only at the played signal $e_{\iota+1}$.

The content is intuitive: a smaller repurchase saves more for the type that finds repurchasing costlier—the low type—so the low type is the one tempted to slip into the gap, and the market reads any such deviation as low. Under this belief no deviation pays: a low type that shades up is still priced as θ_ι, and a high type that shades down is repriced below its quality. (No interior switch occurs because the full-information repurchase is zero: each type plays exactly the least-cost deterring signal, so beliefs jump only at played signals.) □

With the ingredients in hand—single-crossing (Lemma 7) and, from Lemma 8, the repurchase profile $\{e_\iota\}$ with its cutoff and monotonicity together with the off-path beliefs—the next result does the assembling: it certifies that the constructed objects form an equilibrium and that it is the one selected by D1. This is the counterpart, for the full type distribution, of the two-type separating equilibrium of Appendix B, and it is the equilibrium solved numerically and taken to the data below.

Proposition 4 (Separating equilibrium under private information)**.** *Under Assumption 1(i)–(iii), for each public state (n, z) the repurchase profile $\{e_\iota\}$ with cutoff $\underline{\theta}_t$, together with the debt-price schedule $q_t(\cdot)$, dilution schedule $s_t(\cdot)$, and beliefs $\mu_t(\cdot)$ constructed above, form a perfect Bayesian equilibrium that survives the D1 refinement. Specifically:*

(i) Optimality. *Each type's choice is optimal given the schedules and beliefs: types below $\underline{\theta}_t$ pool at $e = 0$, types above separate at a repurchase e_ι strictly increasing in θ, and no type gains from any deviation, on or off path.*

(ii) Break-even. *The debt-price and dilution schedules earn the fund zero expected profit at the equilibrium beliefs.*

(iii) Beliefs. *Beliefs follow Bayes' rule on path and the D1 criterion of Banks and Sobel (1987) off path; in particular, no pooling at a common positive repurchase $e^{\text{pool}} > 0$ survives.*

Proof. We check the three equilibrium conditions in turn: prices break even (ii), no type deviates—neither up nor down, nor into an off-path gap—(i), and beliefs are D1-consistent with no surviving pooling (iii).

Break-even. On the separating segment the market believes the firm's true type, so the debt price $q_t(e_\iota; \theta_\iota)$ and the dilution $s_t(e_\iota; \theta_\iota)$ each satisfy the fund's zero-profit condition at θ_ι; at $e = 0$ the pooled types are priced under μ^{pool}, again zero-profit in expectation over the pool. Both belief-sensitive prices—the debt price q_t and the equity dilution s_t—clear at the same belief, each by its own zero-profit condition.

No upward deviation. The adjacent constraint (C.37) leaves type θ_ι indifferent between its own e_ι and the next rung $e_{\iota+1}$. Single-crossing extends this to every higher rung: since (C.37) at $\iota+1$ makes $\theta_{\iota+1}$ indifferent between $e_{\iota+1}$ and $e_{\iota+2}$, and $\theta_\iota < \theta_{\iota+1}$, Lemma 7 makes θ_ι *strictly* prefer the smaller $e_{\iota+1}$ to $e_{\iota+2}$. Chaining the rungs,

$$v_t^0(\theta_\iota \mid e_\iota, \theta_\iota) = v_t^0(\theta_\iota \mid e_{\iota+1}, \theta_{\iota+1}) > v_t^0(\theta_\iota \mid e_{\iota+2}, \theta_{\iota+2}) > \cdots ,$$

so θ_ι prefers its own signal to every higher one; the same argument from the top of the pool rules out a pooled type's climbing to a separating signal.

No downward deviation. A separating type does not mimic a lower separating one: since (C.37) at $\iota-1$ leaves $\theta_{\iota-1}$ indifferent between $e_{\iota-1}$ and e_ι and $\theta_\iota > \theta_{\iota-1}$, Lemma 7 makes θ_ι strictly prefer its own, larger e_ι; iterating down the grid rules out every lower separating signal. The only remaining downward option—abandoning separation to join the pool—is settled by the cutoff below.

Cutoff. A positive repurchase incurs the fixed cost ϕ_0; pooling at $e=0$ does not. For a type θ_ι, write its net gain from separating as

$$\Gamma(\theta_\iota) \;\equiv\; \underbrace{v_t^0(\theta_\iota \mid e_\iota, \theta_\iota)}_{\text{separate: own price, net of } \phi_0} \;-\; \underbrace{v_t^0(\theta_\iota \mid 0, \mu^{\text{pool}})}_{\text{pool}},$$

where e_ι is its least-cost separating signal from part (a); the type separates iff $\Gamma(\theta_\iota) \geq 0$. We show $\{\theta : \Gamma(\theta) \geq 0\}$ is an upper interval, so a single cutoff splits poolers from separators.

Suppose $\Gamma(\theta_\iota) \geq 0$ and take any $\theta_{\iota'} > \theta_\iota$. Then θ_ι weakly prefers its separating point (e_ι, θ_ι) to the pool point $(0, \mu^{\text{pool}})$; the former carries the larger signal and the more favorable belief, so single-crossing (Lemma 7) makes the higher type $\theta_{\iota'}$ *strictly* prefer it:

$$v_t^0(\theta_{\iota'} \mid e_\iota, \theta_\iota) \;>\; v_t^0(\theta_{\iota'} \mid 0, \mu^{\text{pool}}).$$

By the no-downward-deviation step, $\theta_{\iota'}$ in turn prefers its own signal to mimicking the lower separator θ_ι, so $v_t^0(\theta_{\iota'} \mid e_{\iota'}, \theta_{\iota'}) \geq v_t^0(\theta_{\iota'} \mid e_\iota, \theta_\iota)$. Chaining the two inequalities, $v_t^0(\theta_{\iota'} \mid e_{\iota'}, \theta_{\iota'}) > v_t^0(\theta_{\iota'} \mid 0, \mu^{\text{pool}})$, i.e. $\Gamma(\theta_{\iota'}) > 0$. Hence the separating set is an upper interval; its lowest element is the cutoff $\underline{\theta}_t$, and the pool $\{\theta < \underline{\theta}_t\}$ is priced at $\mu^{\text{pool}} = \mathbb{E}[\theta \mid \theta < \underline{\theta}_t]$.

Beliefs. Off path, an unused repurchase $e \in (e_\iota, e_{\iota+1})$ is read pessimistically: by Lemma

8(c) the most willing type there is θ_ι, so D1 assigns the belief θ_ι. This sustains the construction—a lower type that shades up into the gap is still priced as θ_ι, and a higher type that shades down is repriced *below* its quality—so no off-path deviation pays.

No pooling at a positive signal. Suppose, finally, that a set of types $\mathcal{T}$ pooled at a common $e^{\text{pool}} > 0$. Unable to tell them apart, the fund applies a single debt price and dilution set by its zero-profit condition over $\mathcal{T}$; in particular the highest type $\bar{\theta} = \max \mathcal{T}$ is priced *below* its quality, since the break-even mix puts weight on the lower types in $\mathcal{T}$. Consider a deviation by $\bar{\theta}$ to $e^{\text{pool}} + \Delta e$, $\Delta e > 0$.

D1 prices it high. The signal $e^{\text{pool}} + \Delta e$ lies above every pooled type's, and by single-crossing (Lemma 7) the willingness to repurchase *more* rises with type; the most willing type to make this marginal upward deviation is therefore at least $\bar{\theta}$, so D1 assigns it a belief no lower than $\bar{\theta}$—strictly more favorable than the pooled price.

The deviation pays. Priced at this belief, the deviation yields at least $v_t^0(\bar{\theta} \mid e^{\text{pool}} + \Delta e, \bar{\theta})$, against the pooled payoff $v_t^0(\bar{\theta} \mid e^{\text{pool}}, \mathcal{T})$. As $\Delta e \to 0$ the former tends to $v_t^0(\bar{\theta} \mid e^{\text{pool}}, \bar{\theta})$, which strictly exceeds the pooled payoff: at the same signal, being correctly identified as $\bar{\theta}$ commands a better price than the pool, which prices $\bar{\theta}$ as a mix containing lower types—a *discrete* gain. The extra repurchase costs only $O(\Delta e)$, so for Δe small the deviation is strictly profitable, and no pool at a positive signal survives. This is the N-type counterpart of Proposition 1. $\square$

Above the cutoff, repurchases rise with project quality; the cutoff $\underline{\theta}_t$ is the selection-into-repurchasing margin that the estimation exploits.

C.4 Solution Algorithm

We compute the stationary balanced-growth equilibrium of the model by value function iteration, computing the distribution of firms across the idiosyncratic state space by the non-stochastic simulation of Young (2010). The algorithm consists of nested fixed-point loops and is used both for model estimation and for the counterfactuals in the paper. We work in stationary form, scaling variables by the variety stock Q_t; along the balanced growth path the household Euler equation (12) fixes the real interest rate at $R = \frac{1}{\beta}(1 + \hat{g})^{\eta}$. Two objects clear in general equilibrium: the R&D-productivity constant $\bar{\xi}$ and the growth rate. In estimation we fix the growth rate at its target $\hat{g}$ and solve for the $\bar{\xi}$ that reproduces it; in counterfactuals $\bar{\xi}$ is held fixed and the growth rate moves freely.

Grid. The firm's state (n, z, θ) is the one carried by the incumbent's problem (24): detrended internal funds n, the persistent demand shock z, and the private project quality θ. We discretize the demand process of Section 4 into a nine-state Markov chain with the method of Tauchen (1986), and draw θ from its log-normal distribution on a five-point grid normalized to unit mean and redrawn i.i.d. each period, so that expectations over (z', θ') are exact sums against the transition matrices. Internal funds are defined over 51 non-equally-spaced points, log-spaced away from a mass point at zero, with denser coverage in the lower range to capture financially constrained firms. The repurchase e is defined over 31 equally spaced points, and R&D is represented through the variety mass $m' = \bar{\xi}\,\theta\,w^{\gamma}$ implied by the innovation technology over 131 points; value functions are interpolated linearly in n. We verify that the ergodic distribution places negligible mass at the grid boundaries.

Algorithm. The equilibrium is computed through the following iterative procedure.

1. Guess the R&D-productivity constant $\bar{\xi}$ and set $R = \frac{1}{\beta}(1+\hat{g})^{\eta}$; solve the firm problem by value-function iteration accelerated by Howard policy improvement.

   (a) Guess an initial incumbent value $v^0(n, z, \theta)$.

   (b) For each state, sweeping the qualities in ascending order $\theta_1 < \cdots < \theta_N$:

      i. compute the least-cost separating repurchase $e(\theta)$ as the smallest signal solving the binding no-mimicking condition (C.37)—the recursive construction of Lemma 8—by a scan over the repurchase grid refined by bisection, with the associated policies (w, b', q, s); debt follows the bang–bang rule of Proposition 3 and is fairly priced at $q = p/R$;

      ii. for the bottom types, for which the fixed cost ϕ_0 makes the minimal separating signal unprofitable, solve the pooled sub-problem at a common break-even price q^{pool}—a damped fixed point of the zero-profit condition (D.47) under the pooled posterior *over those types*—and set the state-dependent cutoff $\underline{\theta}(n, z)$ at the lowest quality whose separating value exceeds its pooling value (Proposition 4);

      iii. update the incumbent value $v^0 = v/(1-s)$ of (24).

   (c) Iterate until $\max\|v^0 - v^0_{\text{old}}\| < \varepsilon$.

2. Given the policies, compute the stationary distribution $F(n, z, \theta)$ over the state space following Young (2010); firms whose R&D fails re-enter with zero internal funds.

3. Compute the implied growth rate $g(\bar{\xi}) = \int p\big(w(n,z,\theta),\theta\big)\, m'(n,z,\theta)\, dF$, the mass of successful new varieties.

4. If $g(\bar{\xi}) = \hat{g}$ the model is solved; otherwise update $\bar{\xi}$ by bisection and return to Step 1.

In the counterfactuals $\bar{\xi}$ is fixed and we instead loop on the growth rate g, with $R = \frac{1}{\beta}(1+g)^{\eta}$, until the implied and guessed rates coincide. We use bisection for the outer loop, grid search over the variety grid for R&D, and a damped fixed point for the pooled debt price; to improve efficiency we initialize from the full-information solution. The code is written in heavily parallelized Fortran, with OpenMP over the state space.

Simulation. We simulate a panel of 5,000 firms over 50 years, discarding the initial 25 years as a burn-in and holding the shock sequences fixed across parameter evaluations so that the objective is smooth. Target moments are computed from firm-level growth rates constructed with the arc formula of Davis and Haltiwanger (1992) and enter the SMM criterion (33); its weighting matrix is the efficient $W = \Sigma^{-1}$, where the moment covariance Σ is estimated by the Delta method, clustering by firm following Hansen and Lee (2019). Within each evaluation of (33) the R&D-productivity constant $\bar{\xi}$ is re-solved so that the model reproduces the target growth rate in general equilibrium, as above.

D Robustness

D.1 Project quality in imperfect Information

In this section, we consider a version of the quantitative model in which managers observe project quality with noise. Specifically, managers observe the signal

$$\tilde{\theta}_{kt} = \theta_{kt}\varepsilon_{kt}, \tag{D.38}$$

or equivalently

$$\log(\tilde{\theta}_{kt}) = \log(\theta_{kt}) + \log(\varepsilon_{kt}), \tag{D.39}$$

where $\log(\theta_{kt}) \overset{iid}{\sim} N(-\frac{1}{2}\sigma_\theta^2, \sigma_\theta^2)$ and $\log(\varepsilon_{kt}) \overset{iid}{\sim} N(-\frac{1}{2}\sigma_\varepsilon^2, \sigma_\varepsilon^2)$, independently of each other. This normalization implies $\mathbb{E}[\theta_{kt}] = \mathbb{E}[\varepsilon_{kt}] = 1$.

Given the signal, incumbent shareholders evaluate repurchase policies by integrating over the posterior distribution of true project quality. The value of equity held by incumbent shareholders is therefore

$$v_t^0(n_{kt}, z_{kt}, \tilde{\theta}_{kt}) = \max_{e_{kt} \geq 0} \frac{1}{1 - s_{kt}(e_{kt})} \mathbb{E}_{\theta_{kt}|\tilde{\theta}_{kt}}[v_t(e_{kt} \mid n_{kt}, z_{kt}, \theta_{kt})] \,. \tag{D.40}$$

The expectation is determined by the Gaussian posterior implied by the signal structure:

$$\log(\theta_{kt}) \mid \log(\tilde{\theta}_{kt}) \sim N\left(\kappa \log(\tilde{\theta}_{kt}), \frac{\sigma_\theta^2 \sigma_\varepsilon^2}{\sigma_\theta^2 + \sigma_\varepsilon^2}\right), \qquad \kappa = \frac{\sigma_\theta^2}{\sigma_\theta^2 + \sigma_\varepsilon^2}. \tag{D.41}$$

The continuation value v_t is given by

$$v_t(e_{kt} \mid n_{kt}, z_{kt}, \theta_{kt}) = \max_{w_{kt}, b_{kt+1}} d_{kt} + \frac{1}{R_{t+1}} \mathbb{E}_t \left[\sum_{s \in \{0,1\}} p_{kt}(s)\, v_{t+1}^0(n_{k,t+1}(s), z_{k,t+1}, \theta_{k,t+1}) \right] \tag{D.42}$$

subject to

$$d_{kt} = n_{kt} - (1-\tau) w_{kt} + [q_{kt} + \tau(1 - q_{kt})]\, b_{kt+1} - e_{kt} - (\phi_0 + \phi_1 e_{kt}^2) \mathbb{1}_{\{e_{kt} > 0\}}, \tag{D.43}$$

$$b_{kt+1} \leq (1-\tau)\, \mathbb{E}_t[\pi(z_{k,t+1})]\, m_{kt+1}, \tag{D.44}$$

$$d_{kt} \geq 0, \tag{D.45}$$

where $s = 1$ denotes the successful R&D state (probability $p_{kt}(1) = p_{kt}$) and $s = 0$ denotes the failure (probability $p_{kt}(0) = 1 - p_{kt}$) state.

A risk-neutral investment fund holds the debt and equity of intermediate-good firms on behalf of the representative household. At the beginning of each period, the fund observes the firm's public state (n_{kt}, z_{kt}), but not the manager's private signal $\tilde{\theta}_{kt}$. Upon observing the repurchase decision e_{kt}, the fund forms a posterior belief $\mu_t(\tilde{\theta}_{kt} \mid n_{kt}, z_{kt}, e_{kt})$ over the signal. Together with the signal structure above, this belief induces a posterior distribution over true project quality. The fund prices debt and equity competitively under risk neutrality using this posterior.

Equity pricing. The fund is indifferent between holding and tendering shares, so the dilution s_{kt} associated with repurchase e_{kt} satisfies

$$e_{kt} = \frac{s_{kt}(e_{kt} \mid n_{kt}, z_{kt})}{1 - s_{kt}(e_{kt} \mid n_{kt}, z_{kt})} \mathbb{E}[v_t(e_{kt} \mid n_{kt}, z_{kt}, \theta_{kt}) \mid \mu_t] \,. \tag{D.46}$$

The left-hand side is the cash paid out to tendering shareholders; the right-hand side is the market value of the surrendered equity given posterior beliefs.

Debt pricing. The fund prices one-period debt under a zero-profit condition. Because debt is repaid only in the success state, the equilibrium debt price q_{kt} satisfies

$$q_{kt}(e_t \mid n_{kt}, z_{kt}) = \frac{1}{R_{t+1}} \frac{\mathbb{E}\Big[p_{kt}(w^*_{kt}(\theta_{kt}), \theta_{kt}) b^*_{kt+1}(\theta_{kt} \mid n_{kt}, z_{kt}) \,\Big|\, \mu_t\left(\tilde{\theta} \mid n_{kt}, z_{kt}\right)\Big]}{\mathbb{E}\Big[b^*_{kt+1}(\theta_{kt} \mid n_{kt}, z_{kt}) \,\Big|\, \mu_t\left(\tilde{\theta} \mid n_{kt}, z_{kt}\right)\Big]}, \qquad \text{(D.47)}$$

where $w^*_{kt}(\theta_{kt})$ and $b^*_{kt+1}(\theta_{kt})$ are the firm's equilibrium R&D and debt policy. The debt price equals the discounted probability of repayment, where the expectation is taken over θ_{kt} under the posterior belief.

D.2 Short-termism and EPS-target pressure

The baseline model casts repurchases as a *signal* of project quality. A complementary and widely debated view holds that firms repurchase to *manage* reported earnings per share (EPS), buying back stock to meet analyst forecasts (Almeida et al., 2016b)—a form of short-termism that can distort real investment (Terry, 2023).

Earnings and earnings per share. Normalize the share count before the repurchase to one. After-tax operating earnings in period t are

$$\Pi_{kt} = (1-\tau)\,\pi(z_{kt})\,M_{kt}, \qquad \text{(D.48)}$$

and, since the repurchase retires a fraction $s_{kt}(e_{kt})$ of the shares, reported earnings per share are

$$\text{EPS}_{kt}(e_{kt}) = \frac{\Pi_{kt}}{1 - s_{kt}(e_{kt})}. \qquad \text{(D.49)}$$

The repurchase raises EPS purely through the share count: at given earnings, retiring the fraction s_{kt} lifts EPS by the same accretion factor $1/(1 - s_{kt})$ that multiplies the firm's continuation value.

The earnings target. The firm enters t with the portfolio created by the previous period's R&D, $M_{kt} = M^{\text{succ}}_{kt}\,\mathbb{1}\{\text{success}_{t-1}\}$ where $M^{\text{succ}}_{kt} = \bar{\xi}\,\theta_{kt-1}\,W^{\gamma}_{kt-1}Q^{1-\gamma}_{t-1}$, and failed R&D leaves

$M_{kt} = 0$. At the close of $t-1$ neither the demand z_{kt} nor the R&D outcome is yet known, so the rational earnings forecast—the analyst target—is the success-weighted expectation

$$\Pi^f_{kt} = \bar{\pi}_{t-1}\, p_{kt-1}\, M^{\text{succ}}_{kt}, \qquad \bar{\pi}_{t-1} \equiv (1-\tau)\, \mathbb{E}_{t-1}[\pi(z_{kt})]\,, \tag{D.50}$$

with p_{kt-1} the success probability chosen at $t-1$. The target depends only on the previous period's R&D policy and the persistence of demand.

The pre-repurchase earnings surprise. The gap between realized earnings and the target,

$$\text{SUE}_{kt} = \Pi_{kt} - \Pi^f_{kt} = M^{\text{succ}}_{kt}\Big[(1-\tau)\,\pi(z_{kt})\,\mathbb{1}\{\text{success}_{t-1}\} - \bar{\pi}_{t-1}\, p_{kt-1}\Big], \tag{D.51}$$

is driven by the model's two shocks: the demand realization z_{kt}—a low draw produces a shortfall—and the binary R&D outcome—failure sets $\Pi_{kt} = 0$ and guarantees a miss, while success typically delivers a beat because $p_{kt-1} < 1$. The forecast is unbiased, $\mathbb{E}_{t-1}[\text{SUE}_{kt}] = 0$.

Information structure. The investment fund knows the target Π^f_{kt} formed at $t-1$ and observes realized earnings Π_{kt} through the public state (n_{kt}, z_{kt}, M_{kt}); the surprise SUE_{kt} is therefore *public*. The only object that stays private is the current project quality θ_{kt}—a fresh draw that governs the *next* portfolio and is independent of SUE_{kt}. The fund prices securities under the posterior

$$\mu_t = \mu_t\big(\theta_{kt} \mid e_{kt},\, \text{SUE}_{kt},\, n_{kt}, z_{kt}\big), \tag{D.52}$$

inferring θ_{kt} from the repurchase while conditioning on the surprise it already sees.

Manager problem. Following Terry (2023), the manager bears a short-term clawback $\theta_\pi \geq 0$ whenever reported EPS falls below the forecast. The value of incumbent shareholders becomes

$$v^0_t(n_{kt}, z_{kt}, \theta_{kt}) = \max_{e_{kt} \geq 0} \left\{ \frac{1}{1 - s_{kt}(e_{kt})}\, v_t(e_{kt} \mid n_{kt}, z_{kt}, \theta_{kt}) \;-\; P_{kt}(e_{kt}) \right\}, \tag{D.53}$$

with the discontinuous penalty

$$P_{kt}(e_{kt}) = \theta_\pi\, \mathbb{1}\left\{ \frac{\Pi_{kt}}{1 - s_{kt}(e_{kt})} < \Pi^f_{kt} \right\}. \tag{D.54}$$

Adding accounting noise ν_{kt} that is unobserved when e_{kt} is chosen yields the smooth counterpart $P_{kt}(e_{kt}) = \theta_\pi \, F_\nu\big(\Pi^f_{kt} - \Pi_{kt}/[1 - s_{kt}(e_{kt})]\big)$, which converges to (D.54) as the noise vanishes and eases the numerical solution. Because the manager observes z_{kt} and the R&D outcome before choosing e_{kt}, the repurchase responds to the realized surprise—precisely the margin documented by Almeida et al. (2016b). The clawback θ_π is in detrended units (scaled by Q_t).

The signaling characterization survives. Earnings Π_{kt} and the target Π^f_{kt} are observable and do not depend on the current quality θ_{kt}, so given the surprise SUE_{kt} and a repurchase e the penalty (D.54) is *common across types*; quality enters (D.53) only through the continuation value $v_t(e \mid \cdot, \theta_{kt})$. The single-crossing property (Lemma 7) and the separating construction of Appendix C therefore go through *conditional on* the observable surprise: the equilibrium repurchase is a schedule $e_t(\theta_{kt}; \mathrm{SUE}_{kt})$, strictly increasing in θ_{kt} at each surprise level, with the surprise shifting the whole schedule through the EPS-management motive. The fund recovers θ_{kt} from the position of e_{kt} within the schedule, and the D1 criterion (Banks and Sobel, 1987) disciplines off-path beliefs as before. The two motives are orthogonal by construction: the EPS-driven component of the repurchase is a known function of the public surprise, and the residual reveals quality.

What the exercise delivers. The extension would confront three facts jointly. First, the clawback generates *bunching*: firms that would just miss the target (SUE_{kt} slightly negative) repurchase accretively to clear it, while firms with large shortfalls—in particular those whose R&D failed and hold no internal funds—cannot, reproducing the discontinuity at a zero pre-repurchase EPS surprise in Almeida et al. (2016b). Second, these EPS-motivated repurchases are financed partly by cutting R&D among low-quality firms, the structural counterpart of the selection margin already present in the baseline. Third, the short-term motive θ_π is identified separately from the mass of firms that just meet the target and the repurchase–surprise relation near zero, leaving the signaling cost parameters (ϕ_0, ϕ_1) to be pinned down by the remaining cross-section. Comparing growth and welfare with and without the short-term motive would quantify how much of the repurchase response is informative versus EPS-management.