Innovation, Financial Frictions, and Persistent Effects of Monetary Policy*

Aydan Dogan† Ozgen Ozturk†

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Abstract

We study how firms' financing of innovation shapes the transmission of monetary policy to productivity. Using a new panel of U.S. firms' balance sheets matched to loan contracts, we compare firms with and without access to cash flow-based borrowing, credit extended against earnings rather than physical collateral. Although contractionary monetary policy shocks reduce cash flow similarly for both groups, they lower R&D much more among firms without access to this form of financing. To interpret these findings, we develop a New Keynesian model with endogenous growth in which firms with access smooth R&D through debt issuance, while firms without access cut innovation investment more sharply. A 25-basis-point monetary tightening pushes output about 1 percent below its pre-shock trend on impact and leaves a persistent loss of about 0.12 percent. Extending cash flow-based borrowing to all firms reduces this persistent output loss by about one-third. The persistent decline falls disproportionately on firms without access, which are younger and produce more and higher-quality patents. The medium-run cost of monetary policy is therefore not only lower innovation, but also the misallocation of innovation away from successful innovators.

Key Words: Innovation; Monetary policy; Cash flow-based borrowing; Financial frictions; Productivity.

JEL Codes: E22, E32, E44, E52, G32.

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†Bank of England and the Centre for Macroeconomics. Emails: Aydan.Dogan@bankofengland.co.uk and Ozgen.Ozturk@bankofengland.co.uk.

1 Introduction

Monetary policy is conventionally presumed to have only transitory effects on real activity. A growing body of evidence, however, shows that its effects extend well beyond the short run (Jordà, Singh, and Taylor, 2024; Ma and Zimmermann, 2023). A key channel operates through firms' investment in research and development (R&D), a central driver of productivity growth. Contractionary shocks reduce firms' sales and internal funds, limiting their ability to finance innovation. This is particularly important because R&D is difficult to collateralize and relies heavily on cash flow (Hall and Lerner, 2009; Falato, Kadyrzhanova, Sim, and Steri, 2022). In this paper, we ask whether the way firms finance R&D shapes the transmission of monetary policy to innovation and productivity.

Internal funds are not the only source of finance that requires no physical collateral. Many firms borrow against their earnings rather than their assets through cash flow-based lending (Lian and Ma, 2021; Drechsel, 2023), in which debt capacity is set as a multiple of EBITDA. Because it pledges no physical assets, such borrowing can in principle fund exactly the intangible investment that collateral-based credit cannot reach. Whether firms use it to sustain innovation, and how access to it shapes the transmission of monetary policy, remains unexamined. We answer this question by combining new micro evidence on how access to cash flow-based borrowing shapes the R&D response to monetary policy with a quantitative model that traces the consequences for medium-run productivity and the distribution of persistent losses across firms.

We first show empirically that after a contractionary monetary policy shock, firms' R&D responses diverge sharply with their access to cash flow-based borrowing, even though their cash flows fall alike. To establish this, we construct a new firm-level dataset that links Compustat balance sheets with syndicated loan characteristics from DealScan, covering publicly traded U.S. firms with sustained R&D activity between 1997 and 2017, and estimate R&D responses to high-frequency identified monetary policy shocks (Jarociński and Karadi, 2020) across firms with and without cash flow-based contracts. On average, a 25-basis-point contractionary shock lowers R&D, with the response peaking at about one percent after seven to nine quarters. This average, however, conceals sharp heterogeneity. Firms without cash flow-based access cut R&D by about 1.8 percentage points more than firms with it. Since both groups experience similar cash-flow declines, the differential R&D response cannot be explained by internal funds alone. What separates the two groups is access to external finance. Cash flow-based borrowing supplies funds not tied to physical collateral, allowing firms to smooth innovation when earnings fall, while firms without it are forced to cut back.

A natural concern is that cash flow-based borrowers differ from other firms in ways that correlate with their sensitivity to monetary policy. Several pieces of evidence address this. The two groups are broadly similar in size, leverage, liquidity, and sales growth, although borrowers are somewhat older, consistent with lenders requiring an established earnings history before extending credit against cash flows. Their physical investment responds similarly to the same shocks, so borrowers are not simply more resilient across the board, and higher asset tangibility does not dampen the R&D response in either group, ruling out the possibility that firms substitute collateralized credit to fund innovation. The most direct test exploits within-firm variation: following firms around their first adoption of cash flow-based borrowing, we find that R&D volatility falls persistently after adoption, with no pre-trend, while cash-flow volatility and the R&D share of investment remain flat. These patterns are inconsistent with firms with inherently stable innovation selecting into cash flow-based contracts, with the contracts mechanically smoothing earnings, and with firms borrowing in anticipation of planned R&D. Taken together, the evidence isolates access to cash flow-based borrowing as the margin through which monetary policy transmits differentially to innovation.

To assess the medium-run consequences of these responses, we develop a New Keynesian model with endogenous growth and two types of firms, building on Benigno and Fornaro (2018), which extends Aghion and Howitt (1992). Borrowers finance R&D through cash flow-based borrowing, modeled as a constraint that caps debt at a multiple of earnings (Drechsel, 2023), while non-borrowers rely on internal funds alone. Both types adjust equity payouts subject to convex costs (Jermann and Quadrini, 2012), so the two differ only in their access to debt. Productivity growth is driven by firms' R&D investment, so a shock that depresses innovation today lowers the path of output tomorrow. We calibrate the parameters of the financing block from our loan-level data, setting the borrowing limit to the median debt-to-EBITDA covenant in DealScan. The one financial parameter that loan contracts cannot pin down, the sensitivity of borrowing spreads to refinancing pressure, is estimated by matching the differential R&D response in the first year after the shock. We show that, following a monetary tightening, earnings fall for both types of firms. Non-borrowers absorb the shortfall largely through R&D cuts because equity payouts are costly to adjust, whereas borrowers issue debt against future earnings and smooth innovation through the downturn, replicating the heterogeneous responses we document in the data.

Quantitatively, a 25-basis-point tightening pushes output about one percent below its pre-shock trend at the peak and leaves a persistent loss of 0.12 percent of trend. The persistence arises because forgone innovation is never made up, so the economy returns to trend growth from a permanently lower level. Financing access shapes the size of this loss. We vary its two margins in counterfactuals, the amount each borrower can raise and the share of firms that can borrow. Raising the borrowing limit protects borrowers further while leaving non-borrowers unaffected, so it concentrates the loss on firms without access more than shrinking it. Widening access instead lowers the aggregate loss, since it shifts weight toward firms that protect their R&D, and extending cash flow-based borrowing to all firms reduces the persistent loss by about 30 percent. Even then, most of the loss survives, because the higher real interest rate lowers the return to innovation for every firm. What financing access changes most is therefore who bears the loss, and the productivity shortfall of non-borrowers peaks at nearly twice that of borrowers.

Finally, we ask whether this concentration matters beyond distribution. If non-borrowers were the weaker innovators, shifting the R&D contraction onto them would leave the quality of aggregate innovation unaffected. The data suggest the opposite. Non-borrowers are younger and more R&D-intensive, and matching our panel to patent records (Kogan, Papanikolaou, Seru, and Stoffman, 2017; Kelly, Papanikolaou, Seru, and Taddy, 2021) shows that they produce roughly three times as many patents as borrowers, of higher measured quality, and more than four times as many breakthrough patents. Because cash flow-based lending requires a track record of stable earnings, the firms it excludes are precisely the young innovators that the literature identifies as the main source of frontier-shifting innovation (Akcigit and Kerr, 2018; Acemoglu, Akcigit, Alp, Bloom, and Kerr, 2018). The persistent loss from monetary tightening is therefore not merely redistributed but misallocated, falling on the firms whose innovation matters most for aggregate growth. This finding refines the case for offsetting the productivity cost of monetary tightening with fiscal support for R&D (Fornaro and Wolf, 2023). With the contraction concentrated where innovation quality is highest, support targeted at firms without access to cash flow-based borrowing would protect productivity more cost-effectively than a blanket subsidy.

Related Literature. This paper contributes to several strands of work. First, it adds to the literature on cash flow-based borrowing, which documents its prevalence in U.S. corporate debt (Lian and Ma, 2021) and its macroeconomic implications (Drechsel, 2023; Greenwald, 2019; Ozturk, 2024).[1] We provide evidence that firms use cash flow-based borrowing to sustain R&D and show that this access is central to how monetary policy

[1] A related literature studies the contractual features of these loans (Green, 2018; Gonzalez and Sy, 2024).

transmits to innovation and long-run productivity.

Second, because R&D is a form of intangible investment, our focus on its financing connects to work on the funding of intangible assets, which emphasizes internal funds and external equity (Brown, Fazzari, and Petersen, 2009; Falato et al., 2022; Brown, Martinsson, and Petersen, 2012, 2013). Döttling and Ratnovski (2023) show that intangible investment responds less to monetary policy than tangible investment, reflecting intangible-intensive firms' greater reliance on cash holdings and weaker reliance on collateral. We identify cash flow-based debt as a distinct margin for financing innovation, and show that within R&D-performing firms, access to it, rather than reliance on internal funds, determines how innovation responds to monetary policy.

Third, the paper speaks to the literature on heterogeneity in the transmission of monetary policy (Anderson and Cesa-Bianchi, 2024; Ottonello and Winberry, 2020; Cloyne, Ferreira, Froemel, and Surico, 2023; Caglio, Darst, and Kalemli-Özcan, 2021; Ferreira, Ostry, and Rogers, 2023). While this literature emphasizes how firms' financial positions shape their investment responses, we show that the relevant margin for innovation is access to cash flow-based credit, which amplifies the sensitivity of R&D, and hence of productivity, to monetary shocks for firms without such access.

Fourth, our results connect to the literature on the long-run, or hysteresis, effects of monetary policy. A growing body of evidence shows that temporary contractions leave lasting marks on output (Cerra and Saxena, 2008; Jordà et al., 2024) and that monetary policy shifts innovation activity persistently (Ma and Zimmermann, 2023; Schmöller, Goldfayn-Frank, and Schmidt, 2025; Sampaolesi, 2025), and parallel work finds long-horizon productivity effects of fiscal policy operating through R&D (Antolin-Diaz and Surico, 2025; Cloyne, Martinez, Mumtaz, and Surico, 2022). On the theory side, Ikeda and Kurozumi (2019), Garga and Singh (2021), and Alves and Violante (2023) study how monetary policy should be conducted when temporary downturns leave persistent losses, and Fornaro and Wolf (2023) show that supply shocks scar productivity through lower R&D and that pairing the monetary tightening with a subsidy to innovation prevents the scarring. We contribute the finding that the way firms finance innovation is a key determinant of these effects. The R&D contraction is concentrated among firms without access to external finance, so such support is more effective when targeted at those firms than when paid uniformly.

Finally, the paper builds on the tradition linking short-run fluctuations to long-run growth (Romer, 1990; Aghion and Howitt, 1992; Comin and Gertler, 2006), and in particular on models in which weak demand or tight credit depresses productivity through R&D

(Benigno and Fornaro, 2018; Moran and Queralto, 2018; Anzoategui, Comin, Gertler, and Martinez, 2019; Bianchi, Kung, and Morales, 2019; Queralto, 2020; Duval, Hong, and Timmer, 2020; de Ridder, 2016). Relative to this work, we introduce heterogeneity in how firms finance innovation and show that it determines not only the size of the persistent loss but where it falls. The loss falls on the strongest innovators, which also connects our results to work on the allocation of innovation across firms and its aggregate cost (Klette and Kortum, 2004; Akcigit and Kerr, 2018; Acemoglu et al., 2018; Ottonello and Winberry, 2024).

Outline. The remainder of the paper proceeds as follows. Section 2 describes the data and presents the evidence on how access to cash flow-based borrowing shapes the transmission of monetary policy to R&D. Section 3 develops the model, and Section 4 describes its calibration. Section 5 quantifies the persistent effects of a monetary tightening, and Section 6 examines who bears the resulting productivity loss. Section 7 concludes.

2 Empirical Framework

In this section, we document how monetary policy shocks affect firms' R&D spending and show that the response depends on access to external finance via cash flow-based contracts. We begin by describing the data and the measurement of financing access. We then estimate the effects of monetary policy on R&D and examine the heterogeneity induced by firms' financing access. Finally, we present a series of identification exercises that distinguish the role of access to cash flow-based borrowing from alternative explanations.

2.1 Data

Our analysis combines firm-level balance sheet and R&D data from Compustat, syndicated-loan information from DealScan, and high-frequency monetary policy shocks from Jarociński and Karadi (2020). Below, we briefly describe each of these and report further details in Appendix A.

Firm level variables. We construct firm-level controls from Compustat. These include firm size, age, leverage, Tobin's Q, sales growth, current-asset share and dividend status. Cash flow is measured as EBITDA scaled by total assets, consistent with the underwriting metric used in cash flow-based lending contracts. The specific Compustat items and timing conventions are described in Appendix A.

We use Compustat item XRDQ to measure R&D expenditures. Following Chiavari and Goraya (2024), we construct firm j's R&D stock as

$$k_{j,t}^{RD} = (1-\delta)\, k_{j,t-1}^{RD} + \texttt{XRDQ}_{j,t}, \tag{1}$$

where $\delta = 0.15$ is consistent with U.S. Bureau of Economic Analysis estimates.[2]

Cash flow-based borrowing. R&D is difficult to finance externally because it generates little pledgeable collateral (Hall and Lerner, 2009; Falato et al., 2022). Cash flow-based lending, secured against a firm's earnings rather than its physical assets, is not subject to this limit.

We measure access to this form of credit using syndicated-loan contracts from DealScan, which covers roughly 75% of the U.S. commercial loan market by volume. Following Drechsel (2023), we treat a firm-quarter as *cash flow-based* (CFB) if the firm has an active loan carrying a *maximum Debt-to-EBITDA* covenant, and as non-CFB otherwise. This covenant, which caps a firm's debt at a multiple of its earnings, is the single most common financial covenant in the data, present in roughly half of the covenanted loan packages in our sample and, weighted by loan value, in 60.5% of covenanted loans in the sample of Drechsel (2023).[3]

Monetary policy shocks. We measure monetary policy innovations using the high-frequency shocks of Jarociński and Karadi (2020), which separate policy surprises from central-bank information shocks. All impulse responses are scaled to a 25-basis-point increase in the one-year Treasury rate. Appendix A reports the aggregation and scaling details.

Sample construction. We merge Compustat and DealScan using the linking table of Chava and Roberts (2008). Our baseline quarterly sample spans 1997Q1–2017Q3. Limited pre-1997 covenant coverage motivates the start date (Greenwald, 2019); the endpoint

[2] Following Chiavari and Goraya (2024), we exclude the first five years of each firm's panel to mitigate sensitivity of the stock recursion to initial conditions; results are robust to alternative truncation lengths.

[3] We focus on loans rather than bonds for two reasons. First, DealScan reports covenants at the facility level, making cash flow-based status directly observable. Second, loan covenants bind more tightly: a concentrated syndicate monitors and renegotiates them, whereas the dispersed bondholders of public debt rarely enforce maintenance covenants (Roberts and Sufi, 2009; Kahan and Tuckman, 1993; Kermani and Ma, 2020).

is the last quarter covered by the link table. We exclude observations with negative assets or sales, as well as firms in financial, insurance, real estate, and regulated utility industries. Finally, we retain firms with at least 16 consecutive quarters of non-missing R&D data, thereby focusing the analysis on firms with sustained R&D activity rather than occasional expenditures. The resulting baseline sample contains 895 R&D-performing firms.[4]

2.2 Monetary Policy Transmission

2.2.1 Average Effects

We estimate the average response of firm-level cash flow and R&D to a contractionary monetary policy shock by local projection (Jordà, 2005), following recent applications to firm-level monetary transmission (Ottonello and Winberry, 2020; Cloyne et al., 2023):

$$y_{j,t+h} - y_{j,t-1} = \alpha_j^h + \beta^h \epsilon_t^m + \Gamma_z^h \mathbf{Z}_{j,t-1} + \Gamma_x^h \mathbf{X}_{t-1} + e_{j,t+h}, \tag{2}$$

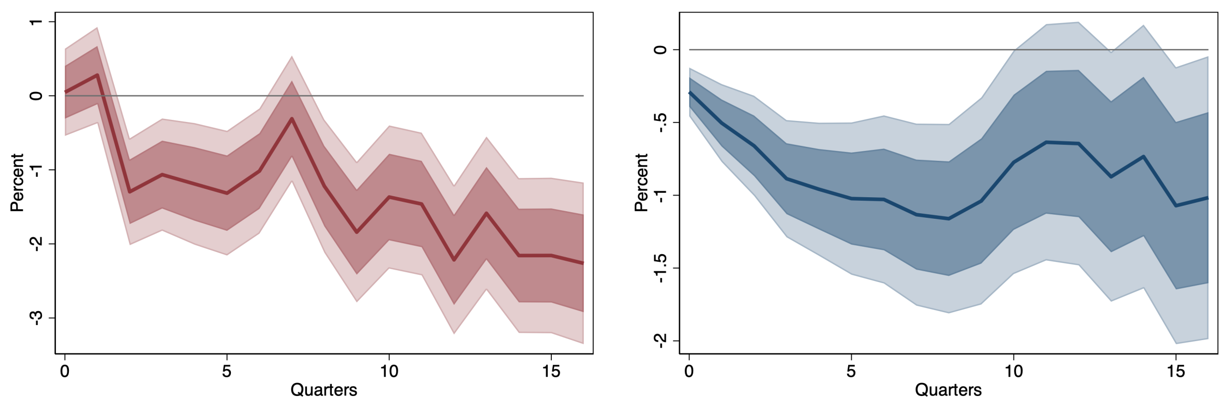
where ϵ_t^m is the monetary policy shock series of Jarociński and Karadi (2020), $y_{j,t+h}$ denotes the log of the outcome (R&D or cash flow), and α_j^h is a firm fixed effect. $\mathbf{Z}_{j,t-1}$ is a vector of firm-level controls (leverage, firm size, Tobin's Q, dividend-payer status, current-asset share, sales growth, and a fiscal-quarter indicator); $\mathbf{X}_{t-1}$ is a vector of aggregate controls (GDP, inflation, VIX). The coefficient β^h traces the cumulative response of y at horizon $h = 0, 1, \ldots, 16$ quarters, with inference via Driscoll–Kraay standard errors (Driscoll and Kraay, 1998).

Figure 1 presents the IRFs over a 16-quarter horizon. Following a 25 basis point monetary tightening, cash flow declines significantly after two quarters and remains depressed over most of the horizon. R&D expenditures also fall sharply, with the effect becoming significant immediately and peaking between 7 and 9 quarters (around -1%), before becoming statistically indistinguishable from zero after approximately 10 quarters.

The joint decline in cash flow and R&D is consistent with the monetary transmission mechanisms documented in the literature (Ma and Zimmermann, 2023). Monetary tightening can reduce innovation by weakening demand and profitability, thereby lowering the expected returns to R&D (Benigno and Fornaro, 2018). Weaker demand also compresses sales and hence the internal cash flow on which R&D heavily relies (Hall and Lerner, 2009; Falato et al., 2022). These average responses alone cannot separate the demand channel from the financing heterogeneity; we do so next by comparing firms with

[4] Results are robust to a less restrictive requirement of eight consecutive quarters of non-missing R&D data.

Figure 1
AVERAGE RESPONSES



(a) Cash flow **(b) R&D Expenditures**

NOTE. Cumulative impulse responses of firm-level cash flow (Panel a) and R&D expenditures (Panel b) to a 25-basis-point contractionary shock, scaled to the 1-year Treasury rate. Estimates are the coefficients β^h from equation (2) over horizons $h = 0, \ldots, 16$ quarters, with firm fixed effects, firm-level controls (leverage, size, Tobin's Q, dividend-payer status, current-asset share, sales growth, fiscal-quarter indicator), and aggregate controls (GDP, inflation, VIX); shocks are from Jarociński and Karadi (2020). Shaded areas denote 90% confidence intervals from Driscoll–Kraay standard errors (Driscoll and Kraay, 1998).

and without access to CFB borrowing.

2.2.2 Financing Frictions and the R&D Response

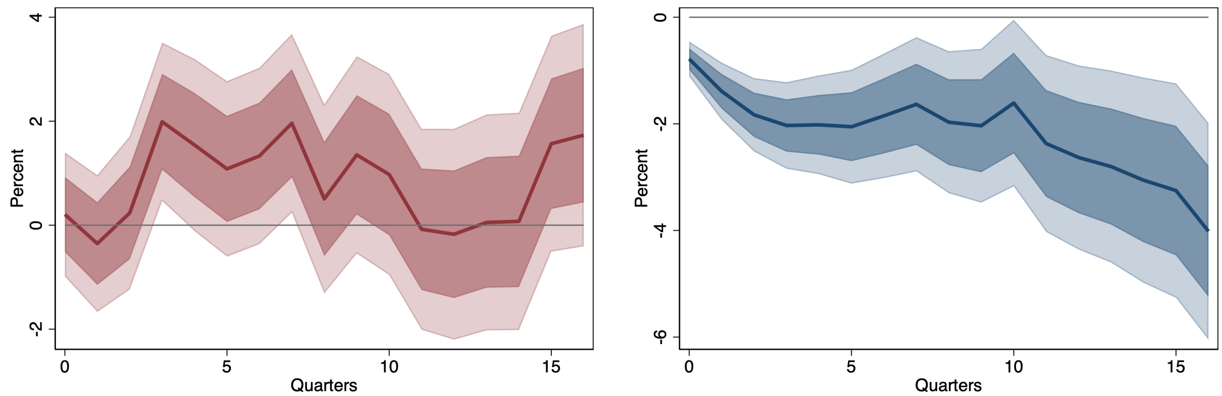
We now examine whether monetary policy transmission to innovation differs by firms' access to cash flow-based borrowing. We estimate the relative response by augmenting equation (2) with a CFB-status interaction:

$$y_{j,t+h} - y_{j,t-1} = \alpha_j^h + \beta^h \left(\epsilon_t^m \mathbf{1}_{j,t-1}^{\text{Non-CFB}}\right) + \gamma^h \epsilon_t^m + \Gamma_z \mathbf{Z}_{j,t-1} + \Gamma_x \mathbf{X}_{t-1} + e_{j,t+h}, \quad (3)$$

where $\mathbf{1}_{j,t-1}^{\text{Non-CFB}}$ equals 1 if a firm is *not* a cash flow-based borrower at time $t-1$, and takes 0 otherwise. Lagging the CFB indicator by one period ensures that financing status is predetermined with respect to the monetary shock, addressing the concern that a policy surprise could contemporaneously alter firms' loan contracts. The specification includes firm fixed effects α_j^h, firm-level controls $\mathbf{Z}$, and aggregate controls $\mathbf{X}$ as before.

Figure 2 reports relative responses from our heterogeneous specification. The relative cash-flow response of non-CFB firms is small and statistically indistinguishable from zero, while the relative R&D response is clearly negative: non-CFB firms cut R&D significantly

Figure 2
Relative Response of Non-CFB



(a) Cash flow **(b) R&D Expenditures**

Note. Relative (non-CFB minus CFB) responses of cash flow (Panel a) and R&D expenditures (Panel b) to a 25-basis-point contractionary shock, from the interacted specification in equation (3); the plotted coefficient is β^h on $\epsilon_t^m \times \mathbf{1}_{j,t-1}^{\text{Non-CFB}}$, with the CFB indicator lagged one quarter. Controls, fixed effects, and shock series are as in Figure 1. Shaded areas denote 90% confidence intervals from Driscoll–Kraay standard errors (Driscoll and Kraay, 1998).

more than CFB firms after a contractionary shock, by about 1.8 percentage points in the first year.

This pattern is difficult to reconcile with a demand-driven explanation in which monetary policy affects R&D primarily through internal funds. The fact that R&D responses differ despite similar cash flow responses instead points to differences in firms' ability to access external finance as the relevant margin. CFB access may relax this constraint by providing additional financing capacity that is not tied to physical collateral, allowing firms to smooth innovation spending over the cycle. These results are robust to absorbing sector-time shocks via sector-quarter fixed effects and to allowing observable firm characteristics to load differentially on monetary shocks (Appendix B, Figures B.1–B.2).

2.3 Identification

The differential R&D response reported in Figure 2 suggests that access to external finance allows firms to sustain innovation when an adverse shock hits. However, it may also reflect pre-existing differences in firm characteristics that correlate with CFB status; the following exercises address this concern.

2.3.1 Generic firm-level resilience

A first concern is that CFB firms may be systematically less sensitive to monetary policy across all margins. Figure 2, Panel (a) shows that cash-flow responses are similar across groups, suggesting comparable exposure to the macroeconomic shock. We extend this analysis to physical investment by re-estimating the baseline specification with capital investment as the outcome.

Figure 3 shows that the relative physical investment response is economically small at every horizon and statistically insignificant over the first six quarters, precisely the window in which the relative R&D response, plotted on the same scale, is large and significantly negative (Panel (b)). Physical investment thus shows no comparable differential where R&D diverges most; the gap turns marginally significant only at longer horizons and even there remains a fraction of the R&D gap. The differential transmission of monetary policy is therefore concentrated in R&D rather than physical investment, contrary to the interpretation that non-CFB firms are generically more responsive to monetary policy.[5]

2.3.2 Summary Statistics

We next examine whether the cross-sectional differences between CFB and non-CFB firms reflect financing access or pre-existing firm characteristics.

Table 1 shows that the two groups are broadly similar along standard dimensions such as size, leverage, liquidity, and sales growth. At the median, cash-flow volatility is also comparable across groups. Two differences stand out: CFB firms exhibit lower R&D volatility and are notably older. The age difference is consistent with selection into CFB contracts based on observable earnings histories: older firms, which have accumulated longer track records of positive cash flows, are more likely to hold earnings-based debt than younger firms (Cloyne et al., 2023; Lian and Ma, 2021). We address this concern using within-firm variation around CFB adoption in the event-study analysis below.

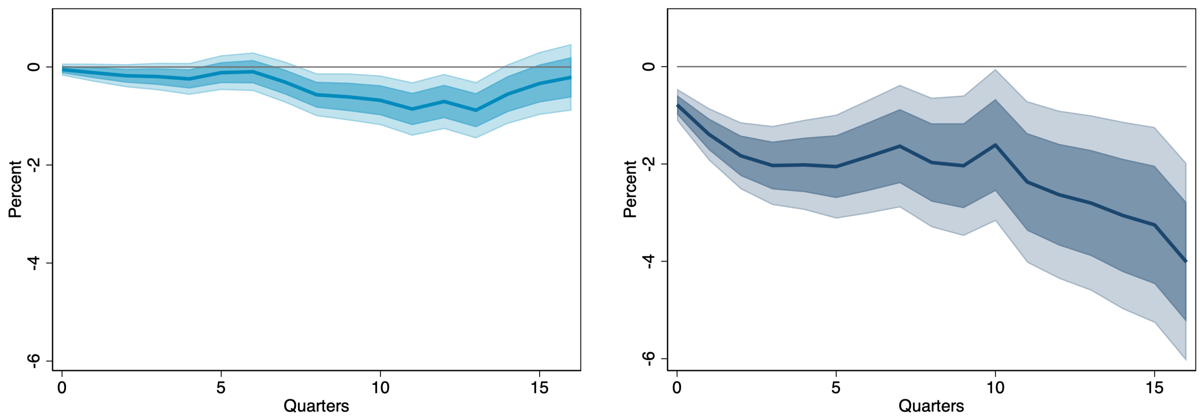
2.3.3 Event Study Analysis

The descriptive statistics in Table 1 show that CFB firms have lower R&D volatility, but this is consistent with two very different interpretations: cash flow-based borrowing may

[5] A natural concern is that non-CFB firms could borrow against their existing tangible assets and use the proceeds to fund R&D, substituting collateralized debt for cash flow-based credit. Appendix B.2 rules this out directly: interacting firm tangibility with the monetary shock, higher tangibility does not attenuate the R&D response in either the CFB or the non-CFB subsample.

Figure 3

Relative Physical Investment Response: Non-CFB Firms



(a) Physical Investment **(b) R&D Expenditures**

Note. Relative (non-CFB minus CFB) responses of physical investment (Panel a) and R&D expenditures (Panel b, reproduced from Figure 2 on the same scale) to a 25-basis-point contractionary shock, from equation (3). Controls, fixed effects, and shock series are as in Figure 1. Shaded areas denote 90% confidence intervals from Driscoll–Kraay standard errors (Driscoll and Kraay, 1998).

help firms smooth innovation spending, or firms with inherently stable R&D may select into CFB contracts. Our local projections so far are cross-sectional, comparing CFB with non-CFB firms. We now complement them with a within-firm design that follows the same firm before and after its own adoption of cash flow-based borrowing. Exploiting the timing of each firm's first transition into a CFB contract, we ask whether R&D volatility changes around adoption: under the selection interpretation, a firm's volatility should be unchanged by the switch, whereas a smoothing role for CFB access should appear as a within-firm decline after adoption.

Cash flow-based status is highly persistent but not absorbing: a firm's CFB indicator carries over from one quarter to the next about 97% of the time (roughly 92% year-on-year), yet about 40% of firms switch regime at least once over the sample, with entries and exits both common. This combination is what makes the within-firm design feasible: status is sticky enough that adoption is a meaningful event, but enough firms switch to identify its effect.[6]

The event is defined as the first quarter in which a firm obtains a CFB loan. We estimate dynamic effects using a standard event-study specification with firm and time fixed effects. Formally, we estimate:

[6] Appendix A reports the full transition dynamics.

Table 1
DESCRIPTIVE STATISTICS

	CFB			Non-CFB		
	Median	Mean	SD	**Median**	Mean	SD
Total Assets (log)	**6.88**	6.85	1.57	**6.85**	6.89	2.23
Age (years)	**18.50**	20.92	13.54	**15.75**	20.30	15.38
Leverage	**0.25**	0.28	0.22	**0.24**	0.28	0.23
Liquidity	**0.03**	0.03	0.04	**0.03**	0.02	0.04
Sales Growth	**0.02**	0.01	0.18	**0.02**	0.01	0.20
R&D / Assets	**0.01**	0.015	0.02	**0.01**	0.018	0.02
Cash flow Volatility (10^{-3})	**17.36**	30.53	51.09	**17.88**	37.77	74.95
R&D Volatility (10^{-3})	**0.83**	1.79	3.60	**1.08**	2.66	4.94
Observations		**10,655**			**16,328**	

NOTE. This table reports summary statistics (median, mean, and standard deviation) for cash flow-based borrower (CFB) and non-CFB firm-quarters in the matched DealScan–Compustat panel, 1997Q1–2017Q3; the panel comprises 895 R&D-performing firms. Following Lian and Ma (2021), the median is emphasized because the firm-level distributions are right-skewed. Full distributional statistics (P25, P75) are in Table A.2; variable definitions in Appendix A.2.

$$Y_{it} = \sum_{\tau=-k}^{k} \beta_\tau \cdot \mathbf{1}[\text{EventTime}_{it} = \tau] + \mathbf{X}'_{it}\gamma + \alpha_i + \lambda_t + \varepsilon_{it}, \tag{4}$$

where Y_{it} denotes the outcome for firm i at time t, and $\mathbf{1}[\text{EventTime}_{it} = \tau]$ is an indicator for being τ quarters away from the event quarter ($\tau = 0$). The vector $\mathbf{X}_{it}$ collects firm-level controls, which are identical to those in the local-projection specification of Section 2.2, and α_i and λ_t are firm and time fixed effects. The event quarter $\tau = 0$ is the first quarter in which the firm holds a CFB contract. Following standard event-study practice, we omit the quarter immediately preceding adoption, $\tau = -1$, as the base period, so that coefficients β_τ are measured relative to the last pre-adoption quarter. By focusing on within-firm changes around the adoption of CFB loans, this design removes time-invariant firm characteristics and allows us to trace pre-trends and post-adoption dynamics in innovation outcomes.

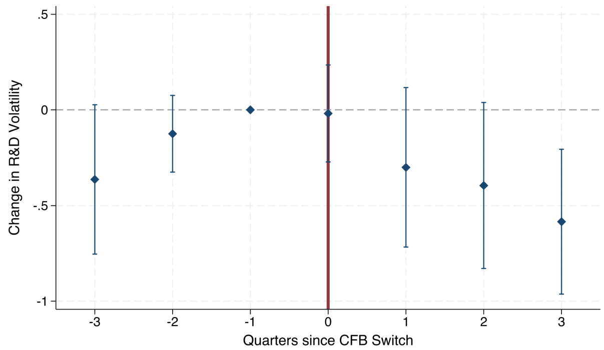
R&D volatility. Panel (a) of Figure 4 shows that R&D volatility declines persistently following CFB adoption. Pre-adoption coefficients are statistically indistinguishable from zero, ruling out differential pre-trends and the interpretation that inherently less volatile firms select into CFB contracts. The post-adoption decline is consistent with firms smoothing innovation behavior after gaining access to earnings-based borrowing. Two alternative explanations remain, however: a mechanical change in the earnings process itself, or anticipatory investment planning around adoption. We address each in turn.

Cash flow volatility. One alternative interpretation of the R&D volatility result is mechanical: CFB contracts could themselves smooth firms' underlying earnings process, in which case the R&D volatility decline would simply inherit smoother cash flow rather than reflect a change in how firms convert earnings into R&D. Panel (b) of Figure 4 rules this out: cash flow volatility is flat around adoption. CFB access therefore changes how firms translate cash flow fluctuations into R&D investment, without affecting the earnings process itself.

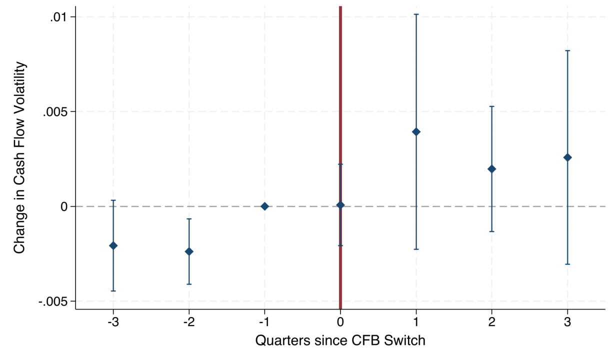
Anticipation. A further concern is that the timing runs the other way: firms might take on cash flow-based borrowing in anticipation of expanding R&D, rather than R&D volatility falling because of the borrowing itself. Were that the case, the R&D share of total investment would rise around adoption. Figure B.4 shows it does not: the R&D share is essentially flat around adoption, with no pre-adoption trend, indicating that CFB access stabilizes innovation spending without a planned shift in investment composition toward R&D.

Taken together, the evidence isolates access to cash flow-based borrowing as the margin that shapes how monetary policy transmits to innovation. A contractionary shock lowers cash flow and R&D on average; the R&D contraction is concentrated in firms without cash flow-based access, even though both groups experience similar cash-flow declines. A series of further exercises rules out the leading alternatives: the response is specific to R&D and absent for physical investment, so it does not reflect generic resilience or collateral capacity; tangibility does not attenuate it, ruling out a substitution channel; and a within-firm event study shows that R&D volatility falls after a firm adopts cash flow-based borrowing, while cash-flow volatility and the R&D investment share remain flat, ruling out selection on stable earnings, anticipation, and shifts in investment composition. What remains is the financing channel itself: cash flow-based loans give firms an external buffer with which to smooth innovation spending when internal funds contract. We now formalize this mechanism in a model that quantifies its medium-run implications for productivity and output.

Figure 4
EVENT STUDY
R&D VOLATILITY AND CASH FLOW VOLATILITY AROUND CFB ADOPTION



(a) R&D Volatility



(b) Cash Flow Volatility

NOTE. Event-study coefficients β_τ from equation (4) for R&D volatility (Panel a) and cash-flow volatility (Panel b) around a firm's first adoption of a CFB contract, with firm and time fixed effects and the same firm-level controls as the local-projection specification (Section 2.2). The base period is the quarter immediately preceding adoption, $\tau = -1$, so coefficients are relative to the last pre-adoption quarter. Shaded areas denote 90% confidence intervals from standard errors clustered at the firm level. The R&D share of total investment, flat around adoption, is reported in Appendix B.2.

3 Theoretical Setup

We develop a New Keynesian model with endogenous growth and heterogeneous firms. Firms differ in their access to external finance for R&D investment. Borrowers (B firms) can finance R&D through cash flow-based borrowing, whereas Non-borrowers (NB firms) rely exclusively on internal funds. Productivity growth is endogenous, driven by firms' R&D investment decisions. We introduce nominal wage rigidities generating a role for monetary policy.

The framework builds on Benigno and Fornaro (2018), which extends Aghion and Howitt (1992), and is consistent with the vertical-innovation evidence of Garcia-Macia, Hsieh, and Klenow (2019). Relative to this benchmark, we introduce firm heterogeneity in access to external finance for R&D investment. Specifically, borrower firms finance R&D through cash flow-based borrowing constraints (Drechsel, 2023), are subject to equity payout adjustment costs (Jermann and Quadrini, 2012), and face state-dependent borrowing spreads in the spirit of Bernanke, Gertler, and Gilchrist (1999) and Cúrdia and Woodford (2016). Non-borrower firms instead rely exclusively on internal funds and distribute equity payouts directly.

3.1 Households

The representative household maximizes expected lifetime utility:

$$\mathbb{E}_t \sum_{t=0}^{\infty} \beta^t \log C_t \tag{5}$$

where $\beta \in (0,1)$ is the discount factor.

The aggregate consumption bundle C_t is a Cobb-Douglas composite of Borrower and Non-borrower output:

$$C_t = \frac{(C_t^B)^\rho (C_t^{NB})^{1-\rho}}{\rho^\rho (1-\rho)^{1-\rho}},$$

where ρ is the expenditure share on Borrower output. The corresponding aggregate price index is

$$P_t = (P_t^B)^\rho (P_t^{NB})^{1-\rho}.$$

Nominal prices are normalized by the aggregate price index such that $p_t^B \equiv P_t^B/P_t$ and $p_t^{NB} \equiv P_t^{NB}/P_t$ denote relative prices. Household demand for each bundle is then given by

$$C_t^B = \rho \frac{1}{p_t^B} C_t, \qquad C_t^{NB} = (1-\rho)\frac{1}{p_t^{NB}} C_t.$$

The household's budget constraint is

$$C_t + \frac{B_{t+1}}{R_t} + S_{t+1}p_t^s + T_t = w_t L_t + B_t + S_t(D_t + p_t^s)$$

where w_t is the real wage, $R_t = i_t/\pi_{t+1}$ is the gross real interest rate, B_t is real bond holdings, S_t are equity shares, D_t are dividends, p_t^s is the share price normalized by the CPI, and T_t denotes lump-sum taxes.

The household maximization problem yields the bond Euler equation

$$\frac{1}{R_t} = \beta \mathbb{E}_t \frac{C_t}{C_{t+1}}. \tag{6}$$

3.2 Final Good Producer

There are two types of perfectly competitive final-goods firms, B and NB, indexed by $i \in \{B, NB\}$, that produce Y^i by combining labor L^i and a continuum of intermediate inputs x_j^i of type i:

$$Y_t^i = (L_t^i)^{1-\alpha} \int_0^1 (A_{j,t}^i)^{(1-\alpha)} (x_{j,t}^i)^\alpha \, dj$$

where $A_{j,t}^i$ denotes the productivity of input j of firm type i. The parameter $\alpha \in (0,1)$ is common across firm types, so that both types share the same production technology. Profit maximization by the final goods producer yields the demand for intermediate input j

$$x_{j,t}^i = \left(\frac{P_{j,t}^i}{P_t^i \alpha (L_t^i)^{1-\alpha} (A_{j,t}^i)^{1-\alpha}} \right)^{1/(\alpha-1)} .$$

3.3 Intermediate Producers

3.3.1 Production

Each type of intermediate input is produced by a monopolist and producing one unit of intermediate good requires one unit of the final good. Then the monopolist sets

$$P_{j,t}^i = \frac{1}{\alpha} P_t^i \tag{7}$$

implying a constant markup $1/\alpha$ over marginal cost.

Equilibrium profits are then

$$\Pi_{j,t}^i \equiv P_{j,t}^i x_{j,t}^i - P_t^i x_{j,t}^i = P_t^i \varphi A_{j,t}^i L_t^i, \qquad \text{where} \quad \varphi = \left(\frac{1}{\alpha} - 1 \right) \alpha^{\frac{2}{1-\alpha}} . \tag{8}$$

The profit composite φ is the same across both types of firms because α is common, so heterogeneity in profitability arises only through differences in employment L_t^i and productivity $A_{j,t}^i$.[7]

3.3.2 Innovation Process

Since profits are proportional to productivity (8), intermediate producers have an incentive to invest in R&D to improve the quality of their input. The productivity of an intermediate producer investing $I_{j,t}^i$ units of the final good in R&D evolves according to:

$$A_{j,t+1}^i = A_{j,t}^i + \chi^i I_{j,t}^i \tag{9}$$

[7] Derivations for equations (7) and (8) are provided in Appendix C.1.

where $\chi^i > 0$ is the R&D effectiveness parameter, which differs across firm types: $\chi^B \neq \chi^{NB}$. Since α and therefore φ are common across two types of firms, all heterogeneity in innovation outcomes is driven by differences in χ^i and access to borrowing.

Each intermediate producer maximizes the present discounted value of dividends subject to its financing constraints. The two types of firm face distinct constraints: B firms access external finance subject to an earnings-based borrowing constraint, while NB firms rely exclusively on internal funds. We describe each problem in turn.

3.3.3 Financing Frictions

Both firm types can issue equity subject to quadratic adjustment costs following Jermann and Quadrini (2012)

$$\Phi(D^i_{j,t}) = \kappa(D^i_{j,t} - \overline{D}^i_j)^2, \tag{10}$$

where $\overline{D}^i_j$ denotes steady state payouts. These costs imply that equity payouts adjust smoothly over time, making internal funds an important source of financing.

Non-borrowers do not have access to debt markets, so their debt position satisfies

$$\frac{B^{NB}_{j,t+1}}{R_t} \leq 0, \tag{11}$$

and therefore finance R&D using retained earnings and equity issuance only. Their flow of funds is

$$D^{NB}_{j,t} + \kappa(D^{NB}_{j,t} - \bar{D}^{NB}_j)^2 = p^{NB}_t \left(\varphi A^{NB}_{j,t} L^{NB}_t - I^{NB}_{j,t}\right). \tag{12}$$

Borrowers can additionally issue debt.[8] Debt is long-term: only a fraction $\delta_B \in (0,1]$ of outstanding debt matures each period, while the remaining share is rolled over.[9] The borrower's flow of funds is

$$D^B_{j,t} + \kappa(D^B_{j,t} - \bar{D}_j{}^B)^2 + \delta_B \mathcal{B}_{j,t} = p^B_t(\varphi A^B_t L^B_t - I^B_{j,t}) + \frac{\mathcal{B}_{j,t+1} - (1-\delta_B)\mathcal{B}_{j,t}}{R^{b,B}_{j,t}}, \tag{13}$$

where net debt issuance equals $\mathcal{B}_{j,t+1} - (1-\delta_B)\mathcal{B}_{j,t}$.

Debt issuance is subject to a cash flow-based borrowing constraint

$$\frac{\mathcal{B}_{j,t+1} - (1-\delta_B)\mathcal{B}_{j,t}}{R_t} \leq \theta \, \frac{\delta_B}{R_t} \, p^B_t(\varphi A^B_t L^B_t - I^B_{j,t}), \tag{14}$$

[8]The symbol B denotes the *borrowers* firm-type, while $\mathcal{B}_t$ denotes debt as a quantity.

[9]Following Chen, Cúrdia, and Ferrero (2012) and Carlstrom, Fuerst, and Paustian (2017), firms' long-term debt is held by a competitive pass-through intermediary that resolves the maturity mismatch between household bonds and firm debt at zero profit; see Appendix C.3 for details.

so stronger earnings support a larger debt position: the constraint bounds net debt issuance, and because a fraction δ_B of the stock matures each period, the parameter θ equals the borrower's steady-state debt-to-EBITDA ratio, calibrated to the DealScan covenant median (Section 4). Following Cúrdia and Woodford (2016), the borrowing rate is state-dependent and linear in refinancing pressure

$$R^{b,B}_{j,} = R^b_t + \psi\left(\frac{\delta_B \mathcal{B}_{j,t}}{\omega L^B_t} - \bar{x}\right), \tag{15}$$

where $\psi \geq 0$ governs the sensitivity of the spread to refinancing pressure (maturing debt $\delta_B \mathcal{B}_{j,t}$ scaled by operating size ωL^B_t), and $\bar{x}$ is the steady-state reference level at which the spread vanishes. This mechanism is standard in the external-finance-premium literature (Bernanke et al., 1999; Gertler and Karadi, 2011): when earnings fall and refinancing needs rise relative to operating scale, debt financing becomes more expensive.

The firms' dividend maximization problem yields the following first-order conditions for each firm type.[10]

Non-borrowers. A non-borrower's payout and R&D conditions are

$$1 = \mu^{NB}_t\left[1 + 2\kappa(D^{NB}_t - \bar{D}^{NB})\right] \tag{16}$$

$$\frac{\mu^{NB}_t}{\chi^{NB}} = \frac{\pi^{NB}_{t+1}}{\pi_{t+1}} \frac{\mu^{NB}_{t+1}}{R_t\, g^{NB}_{t+1}}\left(\varphi L^{NB}_{t+1} + \frac{1}{\chi^{NB}}\right), \tag{17}$$

where μ^{NB}_t is the shadow value of internal funds and $g^i_{t+1} \equiv A^i_{t+1}/A^i_t$ is gross productivity growth. Equation (16) pins μ^{NB}_t from the cost of adjusting dividends away from target. Equation (17) is the R&D Euler: the firm invests until the marginal cost of R&D in terms of foregone internal funds equals its discounted return through higher future earnings and saved future R&D costs. The non-borrower adjusts along two margins: dividends and R&D.

[10] In equilibrium all firms of a given type are identical, so we drop the firm index j.

Borrowers. A borrower's payout, R&D, and debt conditions are

$$1 = \mu_t^B \Big[1 + 2\kappa (D_t^B - \bar{D}^B) \Big] \tag{18}$$

$$\frac{\mu_t^B + \theta\lambda_t}{\chi^B} = \frac{\pi_{t+1}^B}{\pi_{t+1}} \frac{\mu_{t+1}^B + \theta\lambda_{t+1}}{R_t\, g_{t+1}^B} \left(\varphi L_{t+1}^B + \frac{1}{\chi^B} \right) \tag{19}$$

$$\frac{\mu_t^B}{R_t^{b,B}} - \frac{\lambda_t}{R_t} = \frac{\delta_B}{R_t}\, \mu_{t+1}^B, \tag{20}$$

where $\lambda_t \geq 0$ is the multiplier on the borrowing constraint (14). Equation (18) is identical in form to (16). The R&D Euler (19) replaces μ_t^B with $\mu_t^B + \theta\lambda_t$: since R&D is expensed against pledgeable earnings, each unit of R&D tightens the borrowing limit by θ, raising the effective cost of innovation when the constraint binds. Firms' borrowing choice, equation (20), implies that the marginal benefit of new debt is equal to its discounted repayment cost, which rises with rollover pressure through the spread (15). The borrower therefore has a third margin alongside dividends and R&D: net debt issuance.

3.4 Wage Setting and the Phillips Curve

Following Fornaro and Wolf (2023), which builds on Galí and Gambetti (2020), nominal wages evolve according to a single economy-wide wage setting equation:

$$\frac{W_t}{W_{t-1}} = g_{ss} \left(\frac{L_t}{\bar{L}} \right)^{\xi} (\pi_{t-1})^{\varsigma} \tag{21}$$

where $\bar{L}$ is the total labor endowment, g_{ss} is the steady state productivity growth rate, $\xi > 0$ governs the sensitivity of wages to employment, and $\varsigma > 0$ controls inflation indexation. Wages are common across NB and B. Aggregate employment is:

$$L_t = L_t^B + L_t^{NB} \leq \bar{L}.$$

Although wages are common, inflation across the two types of firms differs because each group experiences different productivity growth rates. This asymmetry plays an important role in the model: when R&D responses diverge following a monetary shock, productivity growth diverges across B and NB firms, generating different inflation dynamics even under a common wage.

Using the final good producer's labor demand condition and the wage setting equation (21), the corresponding Phillips curves are:

$$\pi_t^B = \frac{g_{ss}}{g_t^B}\left(\frac{L_t}{\bar{L}}\right)^{\xi}(\pi_{t-1})^{\varsigma} \tag{22}$$

$$\pi_t^{NB} = \frac{g_{ss}}{g_t^{NB}}\left(\frac{L_t}{\bar{L}}\right)^{\xi}(\pi_{t-1})^{\varsigma}. \tag{23}$$

Both Phillips curves share the same labor market tightness and inflation inertia terms, but differ through firm-specific productivity growth g_t^i.

The aggregate price index implies:

$$\pi_t = \left(\pi_t^B\right)^{\rho}\left(\pi_t^{NB}\right)^{1-\rho} = \frac{g_{ss}}{g_t}\left(\frac{L_t}{\bar{L}}\right)^{\xi}(\pi_{t-1})^{\varsigma} \tag{24}$$

where $g_t = (g_t^B)^{\rho}(g_t^{NB})^{1-\rho}$ is the aggregate productivity growth factor. This aggregate Phillips curve mirrors the structure in Fornaro and Wolf (2023), extended to an economy in which aggregate productivity growth reflects the weighted combination of two firms with heterogeneous R&D financing conditions.

3.5 Government and Monetary Policy

Government. The government provides a tax advantage on corporate interest, so borrowers face the subsidized gross real rate

$$R_t^b = R_t(1-\tau) + \tau, \qquad \tau \in (0,1),$$

financed by lump-sum taxes on households,

$$T_t = \frac{B_{t+1}}{R_t^b} - \frac{B_{t+1}}{R_t}. \tag{25}$$

Monetary policy. The central bank sets the gross nominal rate i_t by a smoothed Taylor rule,

$$\ln i_t = \rho_i \ln i_{t-1} + (1-\rho_i)\Big[\ln(g_{ss}/\beta) + \phi_\pi \ln \pi_t + \phi_L \ln(L_t/\bar{L})\Big] + \epsilon_t^M, \tag{26}$$

with smoothing $\rho_i \in (0,1)$, inflation response $\phi_\pi > 1$, employment-gap response $\phi_L > 0$, and an exogenous monetary-policy shock ϵ_t^M.

3.6 Equilibrium Dynamics and Balanced Growth

We now characterize the equilibrium conditions in stationary form and describe the balanced growth path of the economy.

Aggregation and detrending. Detrended variables are denoted with tildes. Firm-type-specific variables are normalized by their respective productivity levels A_t^i, aggregate variables by

$$A_t \equiv (A_t^B)^\rho (A_t^{NB})^{1-\rho},$$

and borrower debt by A_t^B. The key aggregate conditions are

$$\begin{aligned}
\omega L_t^B &= \tilde{C}_t^B + \tilde{I}_t^B \\
\omega L_t^{NB} &= \tilde{C}_t^{NB} + \tilde{I}_t^{NB} \\
g_t &= (g_t^B)^\rho (g_t^{NB})^{1-\rho} \\
q_{t+1} &= q_t \frac{g_{t+1}^{NB}}{g_{t+1}^B},
\end{aligned}$$

where $\omega = \alpha^{2\alpha/(1-\alpha)}(1-\alpha^2)$ is net output after intermediate-input costs, $q_t \equiv A_t^{NB}/A_t^B$ denotes relative productivity, and g_t is the aggregate productivity growth factor.

Balanced growth path. Along the balanced growth path, output, consumption, dividends, investment, and debt grow at the common rate g_{ss}, while labor and relative prices remain stationary. Common growth across sectors is required for stationarity under Cobb–Douglas aggregation. Sectoral growth rates satisfy

$$g_{ss}^i = 1 + \chi^i \left(\frac{I^i}{A^i} \right)_{ss},$$

and the common-growth restriction $g_{ss}^B = g_{ss}^{NB}$ implies

$$\chi^B L_{ss}^B = \chi^{NB} L_{ss}^{NB}.$$

Although sectoral growth rates coincide along the balanced growth path, transitional dynamics differ across firm types over the business cycle. A contraction that lowers employment and earnings reduces R&D investment, slowing productivity growth through (9). Because borrowers and non-borrowers adjust R&D differently, temporary monetary shocks generate persistent differences in productivity and output dynamics across sectors.

Equilibrium. Given initial productivity levels $\{A_0^B, A_0^{NB}\}$, an initial debt stock $\mathcal{B}_0$, and a monetary-policy process $\{\epsilon_t^M\}$, an equilibrium is a sequence of allocations, prices, and shadow values satisfying household and firm optimality, market clearing, the government budget constraint, the wage-setting equation, and the monetary policy rule. The complete stationary system of equations is reported in Appendix D.4.

4 Calibration

The model is calibrated at annual frequency; Table 2 summarizes the calibration, grouped into externally set parameters, parameters calibrated using firm-level data and aggregate targets, and one parameter estimated by impulse-response matching.

Externally calibrated parameters. The discount factor is set to $\beta = 0.995$, implying a steady-state annual real interest rate of approximately 2.5%. The labor share in gross output is fixed at $\alpha = 0.84$, following Fornaro and Wolf (2023), which pins down the production-side scaling terms (α and ω) in the model.

The corporate tax rate is set to $\tau = 0.35$, corresponding to the average U.S. statutory rate over our sample period and consistent with Jermann and Quadrini (2012). We adopt their value for the equity payout adjustment cost parameter, $\kappa = 0.146$.

Within the nominal block, the Phillips curve slope is set to $\xi = 0.19$ as in Galí and Gambetti (2020), and the inflation-indexation parameter to $\varsigma = 0.50$ following Barnichon and Mesters (2020), as also adopted by Fornaro and Wolf (2023). Monetary policy follows a Taylor-type rule with $\phi_\pi = 1.25$, $\phi_L = 0.30$, and smoothing $\rho_i = 0.50$, in line with the standard literature. The aggregate labor endowment is normalized to $\bar{L} = 1$.

Data-disciplined parameters. In our model, the relative R&D effectiveness parameter maps directly into the steady-state ratio of R&D investment across sectors:[11]

$$\frac{\tilde{I}_{ss}^{NB}}{\tilde{I}_{ss}^{B}} = \frac{\chi^B}{\chi^{NB}}.$$

Table A.2 reports a median R&D intensity of 0.012 for non-CFB (NB) firms and 0.010 for CFB (B) firms, so that $\chi^B/\chi^{NB} = \tilde{I}_{ss}^{NB}/\tilde{I}_{ss}^{B} = 0.012/0.010 = 1.20$, and thus non-borrowers have higher R&D intensity. Since both types achieve the same balanced growth

[11]The derivation is given in Appendix D, equation (D.40).

Table 2
CALIBRATION

Parameter	Description	Value	Source
Externally calibrated			
β	Discount factor	0.995	Standard
α	Labor share parameter	0.84	Fornaro and Wolf (2023)
τ	Corporate tax rate	0.35	Jermann and Quadrini (2012)
κ	Equity payout adjustment cost	0.146	Jermann and Quadrini (2012)
ϕ_π	Inflation response	1.25	Standard
ϕ_L	Labor-gap response	0.30	Standard
ρ_i	Interest-rate smoothing	0.50	Standard
ξ	Phillips curve slope	0.19	Galí and Gambetti (2020)
ς	Inflation indexation	0.50	Barnichon and Mesters (2020)
Data-disciplined			
g_{ss}	Steady-state growth	1.02	2% annual TFP growth
θ	Earnings-based borrowing limit	3.50	DealScan covenant median
δ_B	Debt amortization rate	0.20	DealScan median maturity
χ^B/χ^{NB}	Relative R&D efficiency	1.20	Compustat R&D intensity ratio
Estimated			
ψ	Rollover spread sensitivity	2.79	IRF matching

NOTE. The model is calibrated at annual frequency. Externally calibrated parameters are taken from the literature; data-disciplined parameters are set to match firm-level (DealScan, Compustat) and aggregate moments; the rollover-spread sensitivity ψ is estimated by impulse-response matching, targeting the impact-year (year 0) differential R&D response to a monetary policy shock (Figure 5). The loan-term distributions underlying δ_B and θ are reported in Table A.1.

rate g_{ss}, the firm spending more per unit of output must convert each unit of R&D into productivity growth less efficiently: $\chi^{NB} < \chi^B$.

The level of the innovation parameters is pinned by an aggregate growth target. The balanced growth path implies

$$g_{ss}^2 = \beta\Big(\chi^B \varphi L_{ss}^B + 1\Big)\,,$$

which we target at $g_{ss} = 1.02$, corresponding to an annual TFP growth rate of 2%, the same target as in Fornaro and Wolf (2023). Together with χ^B/χ^{NB} and the steady-state labor allocation this pins down χ^B and χ^{NB}. The expenditure share ρ is determined endogenously from steady-state output shares,

$$\rho = \frac{\tilde{C}^B_{ss}}{\tilde{C}^B_{ss} + \tilde{C}^{NB}_{ss}},$$

ensuring consistency between household demand and equilibrium allocations. Our calibration implies that the expenditure share of borrowers' output is 0.45.

We exploit DealScan loan-contract data for R&D firms to parameterize the financial block. Table A.1 in Appendix A reports the distribution of maturities, spreads, leverage, and earnings-based covenants for these firms alongside the full sample. Two contract terms map directly into model parameters. First, the median loan maturity of five years pins the amortization rate at $\delta_B = 1/5 = 0.20$, consistent with the geometric long-term debt structure in which a fraction δ_B of the outstanding stock matures each period. Second, the median maximum debt-to-EBITDA covenant, the real-world contractual counterpart of the model's earnings-based borrowing limit, pins down θ. The borrowing constraint (14) scales pledgeable earnings by δ_B/R, so that at the steady state the pledgeable debt stock is $\mathcal{B}_{ss} = \theta\,(\varphi L^B_{ss} - I^B_{ss})$ and θ is exactly the borrower's steady-state debt-to-EBITDA ratio. We set $\theta = 3.50$, in line with the full-sample covenant median of 3.75 reported by Drechsel (2023).[12]

Estimated parameter. The rollover-spread sensitivity ψ is not directly observable, so we discipline it by impulse-response matching. In the model, the first-year gap between the R&D responses of non-borrowers and borrowers widens monotonically in ψ: a higher ψ makes refinancing more costly after a contractionary shock, so borrowers lean harder on the debt margin to protect R&D, while non-borrowers, lacking that margin, absorb the shock through R&D itself. This monotonicity identifies ψ.

Its empirical counterpart is the differential R&D response of non-CFB relative to CFB firms in the first year after the shock, estimated from the heterogeneous local projection (3) and scaled to a 25-basis-point tightening. Because one model period is a year, this first-year differential, the cumulative response over four quarters, maps directly to the impact period of the model.

Formally, we choose ψ such that

$$\mathcal{W}^{\text{mod}}_1(\psi; \Theta_{\text{fixed}}) = \widehat{\mathcal{W}}^{\text{LP}}_1, \tag{27}$$

where $\mathcal{W}^{\text{mod}}_1$ is the model-implied impact-year response of $100 \cdot (\widehat{\text{inv}}^{NB} - \widehat{\text{inv}}^{B})$ and $\widehat{\mathcal{W}}^{\text{LP}}_1$

[12] Because the constraint bounds net issuance and a fraction δ_B of the stock matures each period, the parameter entered in the replication code is the equivalent net-issuance multiple $\theta\,\delta_B/R \approx 0.68$; the two describe the same constraint (Appendix C.2).

is its empirical counterpart.

This yields $\hat{\psi} = 2.79$, matching the impact-year local-projection differential by construction and implying a statistically significant rollover-spread channel.[13] At this estimate, the 25 basis-point tightening raises the borrower's rollover spread by about 40 basis points on impact.

Figure 5 reports the impulse-response fit. At horizons of years 1, 2, and 3, the model response lies within the 90% confidence bands throughout and within the 68% band at year 1, declining slightly faster than the point estimates at longer horizons. The specification therefore matches the impact differential closely but exhibits somewhat faster medium-run reversion than in the data.

5 Persistent Effects of Monetary Policy

We study the response of the economy to a 25 basis point contractionary monetary policy shock solved as a perfect-foresight transition from the balanced growth path over a 12-year horizon.

5.1 Dynamic Transmission of Monetary Policy Shocks

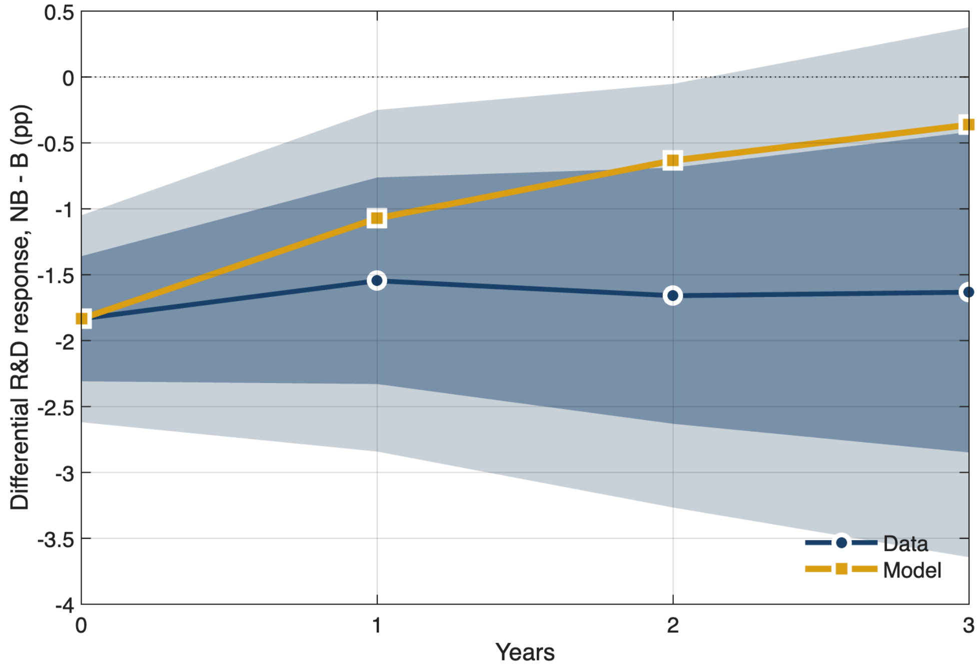
Figure 6 shows the response of aggregate variables. The shock raises the real interest rate, reducing demand and compressing firm earnings. Aggregate R&D investment falls, slowing productivity growth during the transition. Because growth is endogenous, the economy returns to trend growth along a permanently lower path even after the shock dissipates: a temporary demand contraction becomes a persistent level loss in output relative to the pre-shock trend.[14] The aggregate picture masks a sharp asymmetry in how the two firm types absorb the shock, and that asymmetry turns on the set of adjustments available to each.

Non-borrowers face two margins: cut dividends or cut R&D. Both are costly. Reducing dividends away from target incurs the quadratic payout friction (10); cutting R&D destroys future productivity through the law of motion (9). When earnings fall, non-borrowers must balance these costs. Because equity adjustment is sluggish, R&D bears a large share of the adjustment.

[13] The standard error is 0.76 ($t \approx 3.7$), obtained by the delta method combining the local-projection standard error (0.48) with the model sensitivity $\partial \mathcal{W}_1^{\text{mod}}/\partial\psi \approx -0.63$.

[14] A variable expressed as a percentage of the pre-shock trend equals its percent deviation from steady state plus the cumulative growth shortfall $\sum_{j=1}^{t} 100(g_j - g_{ss})/g_{ss}$. This differs from the percent deviation from steady state, which converges to zero and misses the persistent level loss.

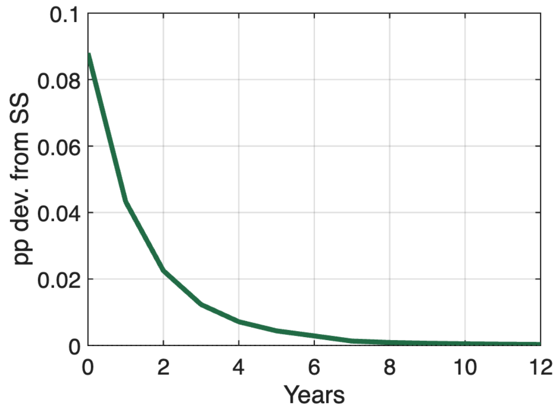
Figure 5
IMPULSE-RESPONSE MATCHING OF ψ



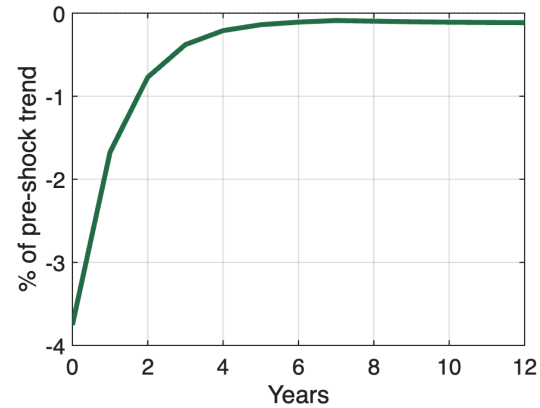
NOTE. Year-by-year differential R&D response (NB minus B, in percentage points) to a 25-basis-point contractionary monetary policy shock; year 0 is the impact year. The blue line is the empirical local-projection estimate, with its 68% and 90% confidence bands shaded; the gold line is the model-implied differential at the calibrated $\hat{\psi} = 2.79$. The sensitivity ψ is chosen to match the impact-year differential.

Borrowers have a third margin: net debt issuance. When earnings fall, they issue debt against future earnings to cover part of the shortfall, smoothing R&D over time rather than cutting it. This remains feasible even as the contraction makes debt more expensive, for two reasons. First, the rollover spread on outstanding debt $R_t^{b,B}$ jumps on impact (Figure 7, Panel (a)); through the debt Euler (20), the higher spread lowers the net return to holding borrowing capacity and so reduces the shadow cost of the constraint λ_t (Panel (b)). This is not the constraint going slack; rather, the marginal value of borrowing capacity falls when the spread rises. Because the effective cost of R&D for a borrower is $\mu_t^B + \theta\lambda_t$, where $\theta\lambda_t$ is the borrowing capacity given up by expensing R&D against pledgeable earnings, a lower λ_t makes R&D relatively cheap to protect at exactly the moment earnings are under pressure. Second, because debt is long-term (only a fraction δ_B of the outstanding stock matures each period), most of the borrower's debt is not up for refinancing when earnings fall. The constraint bounds only *net* new issuance against current pledgeable earnings, not the outstanding stock, so the borrower keeps its existing debt-financed R&D in place and spreads the earnings shortfall over several periods rather than

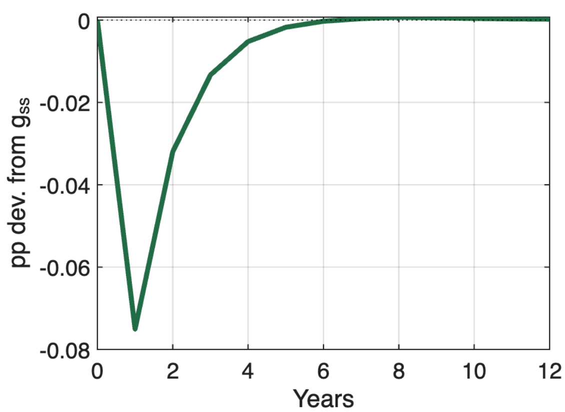
Figure 6
AGGREGATE TRANSMISSION



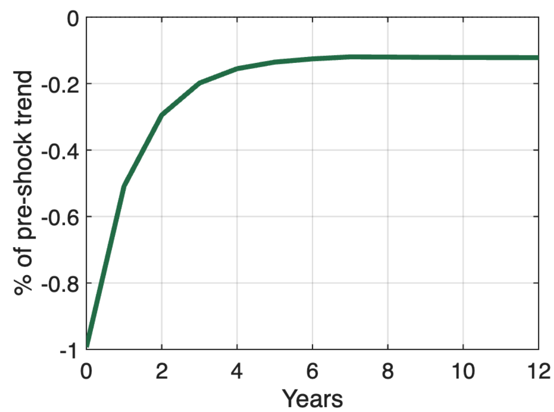
(a) Real interest rate R_t



(b) Aggregate R&D investment



(c) Aggregate productivity growth g_t



(d) Aggregate output Y_t

NOTE. Impulse responses to a 25-basis-point contractionary monetary policy shock at the benchmark calibration; 12-year horizon. Rate variables (Panels a, c) are in percentage-point deviations from steady state; aggregate R&D and output (Panels b, d) as a percentage of the pre-shock trend.

deleveraging all at once (Panel (c)). Non-borrowers have no such margin: they absorb the shock through dividends and R&D, and R&D bears the larger share.

In our model, the cash flow-based borrowing friction differs from a standard financial accelerator: there is no asset-price or net-worth channel through which the contraction mechanically tightens financing for all firms and amplifies the aggregate shock.[15] What

[15]In asset-based lending, by contrast, collateral values are set by asset prices that move with the aggregate shock, so the firm's own investment does not directly alter its borrowing base. The comparison throughout the paper is between firms with and without access to cash flow-based credit, not between cash flow-based and asset-based lending as competing technologies.

is distinctive is instead internal to the borrower's problem: the borrowing base is EBITDA measured net of R&D, so innovation spending itself reduces contemporaneous pledgeable earnings, placing the financed activity in direct tension with the capacity to finance it. Rather than amplifying the aggregate shock, the friction shapes how the R&D contraction is distributed across firm types and propagates those differences into persistent productivity losses.

The bottom row of Figure 7 shows the relative responses. The key distinction is that borrowers can temporarily smooth the earnings shortfall through the debt margin, whereas non-borrowers have to absorb it immediately through dividends and R&D expenditure. As a result, borrowers cut R&D by significantly less than non-borrowers (Panel (d)). The differential innovation activity translates directly into diverging productivity growth paths (Panel (e)): firms that can borrow sustain higher productivity growth. The relative inflation differential (Panel (f)) reflects the same asymmetry: through the Phillips curves (22)–(23), the sharper productivity-growth decline of non-borrowers raises their marginal costs and hence their inflation relative to borrowers.

The financial heterogeneity channel therefore shapes both who bears the R&D contraction and how much is lost in aggregate. Access to cash flow-based borrowing allows firms to absorb the earnings shortfall through net debt issuance rather than R&D cuts, mitigating the persistent productivity and output losses generated by monetary tightening. How large this aggregate loss is, and how it divides between the two groups, is the question we turn to next.

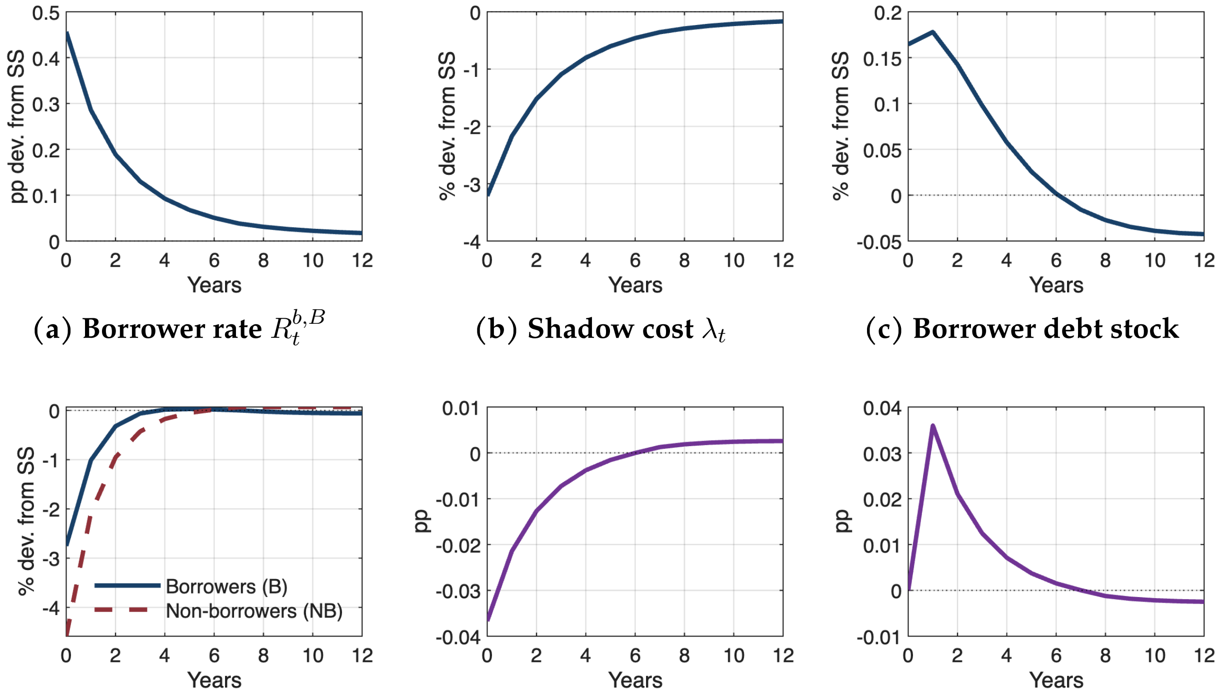
5.2 Quantifying the Persistent Loss

At the benchmark calibration, a 25 bp contractionary shock generates a peak output gap of -0.99% in the first year and a persistent output loss of 0.12% relative to the pre-shock trend.

Figure 8 decomposes this loss by firm type. The distribution is sharply asymmetric: the non-borrower productivity shortfall peaks at just over twice that of borrowers around year seven and remains nearly twice by year twelve. This asymmetry follows directly from the differential R&D responses documented in Section 5.1: firms with access to the debt margin protect their innovation spending and, through it, their productivity path, while firms relying solely on internal funds absorb the earnings shortfall primarily through R&D cuts.

Understanding what drives the size of this loss and its concentration on non-borrowers requires characterizing two structural margins of financial access, the depth of borrowing

Figure 7
FINANCIAL HETEROGENEITY



(a) Borrower rate $R_t^{b,B}$ **(b) Shadow cost** λ_t **(c) Borrower debt stock**

(d) R&D: I^B **vs** I^{NB} **(e) Growth differential** $g^{NB} - g^B$ **(f) Relative inflation** $\pi^{NB} - \pi^B$

NOTE. Impulse responses to a 25-basis-point contractionary monetary policy shock; 12-year horizon. Top row: the borrower's financial margins; bottom row: differential outcomes, with borrowers (B, blue solid) and non-borrowers (NB, red dashed) in Panel (d). Rate and growth-rate variables (Panels a, e, f) are in percentage-point deviations from steady state; quantities (Panels b, c, d) in percent deviations from steady state. R&D (Panel d) is shown as a deviation from steady state to isolate the impact response, whereas aggregate R&D in Figure 6 is on the pre-shock-trend basis to display the persistent level loss.

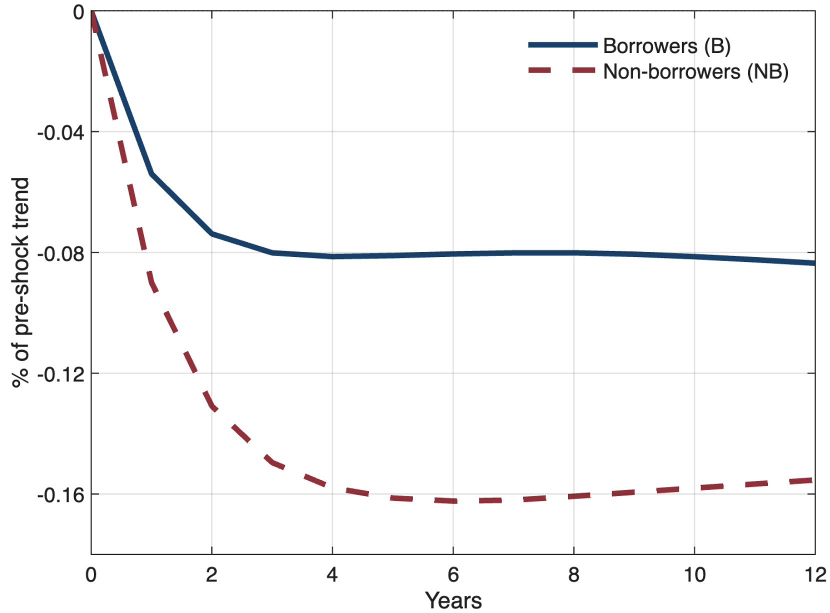
(θ) and its breadth across firms (ρ), and asking whether the firms bearing the larger share are also the stronger innovators. Section 6 takes up both questions.

6 Who Bears the Persistent Loss

We showed in Section 5 that non-borrowers absorb the larger share of the persistent loss. Whether this asymmetry carries costs beyond distribution depends on which firms innovate better: if non-borrowers were the weaker innovators, the asymmetry would be purely distributional; if they are the stronger ones, it can lead to misallocation. This section establishes both the structure of the loss and the identity of those who bear it.

Figure 8

Persistent Productivity Loss by Firm Type



Note. Each series plots productivity by firm type as a percentage of its pre-shock trend (equivalently, the cumulative productivity-growth shortfall) over the 12-year horizon, following a 25-basis-point contractionary monetary policy shock. Borrowers (B, blue solid) and non-borrowers (NB, red dashed).

6.1 Anatomy of the loss

The size of the aggregate productivity loss and its concentration on non-borrowers are properties of the model that can be characterized analytically. We derive a linear representation that disentangles what governs the aggregate size from what governs how the loss falls across firm types.

Let $\mathcal{L}_H^j \equiv \sum_{t=1}^{H}(\ln g_t^j - \ln g_{ss})$ denote the cumulative productivity growth shortfall of firm type $j \in \{B, NB\}$ over horizon H, and $\mathcal{L}_H \equiv \sum_{t=1}^{H}(\ln g_t - \ln g_{ss})$ the aggregate analogue. Let $\mathcal{I}_H^j \equiv \sum_{t=1}^{H-1} \widehat{I}_t^j$, where $\widehat{I}_t^j \equiv (\tilde{I}_t^j - \tilde{I}_{ss}^j)/\tilde{I}_{ss}^j$, denote the cumulative R&D response of j type firm, with expenditure-weighted aggregate $\bar{\mathcal{I}}_H \equiv \rho\,\mathcal{I}_H^B + (1-\rho)\,\mathcal{I}_H^{NB}$. The cross-sectional wedge $\mathcal{W}_H \equiv \mathcal{I}_H^{NB} - \mathcal{I}_H^B < 0$ is the cumulative analogue of the impact-year differential matched in Section 4; it is negative because non-borrowers cut R&D by more.

Lemma 1. *Up to first order, the cumulative productivity loss of each firm type is proportional to its cumulative R&D response, with the same factor of proportionality applying to the aggregate:*

$$\mathcal{L}_H^j = \zeta\,\mathcal{I}_H^j \quad (j \in \{B, NB\}), \qquad \mathcal{L}_H = \zeta\,\bar{\mathcal{I}}_H, \qquad \zeta \equiv \frac{g_{ss}-1}{g_{ss}}, \tag{28}$$

The slope ζ is common to all firms, as both firm types grow at the common rate g_{ss} on the balanced growth path.

Equation (28) is the log-linear representation of the productivity loss: access to financing affects the aggregate loss only through $\bar{\mathcal{I}}_H$, the expenditure-weighted average of the two firm types' cumulative R&D responses. The two margins of financial access operate on different components of this average. The depth θ does not enter non-borrowers' problem: they finance R&D from earnings alone, so $\mathcal{I}_H^{NB}$ is approximately invariant to θ, and depth reaches the aggregate only through the borrower response $\mathcal{I}_H^B$.[16] The breadth ρ does not affect either firm type's individual response; it enters $\bar{\mathcal{I}}_H$ as a weight, shifting the aggregate toward whichever type responds more.

Proposition 1. *To first order around the balanced growth path:*

(*i*) (***Breadth resizes.***) $\partial \mathcal{L}_H / \partial \rho = -\zeta\, \mathcal{W}_H > 0$*: breadth moves the aggregate size by reweighting the two firm types, leaving the distribution across firm types unchanged.*

(*ii*) (***Depth concentrates.***) $\partial \mathcal{I}_H^{NB} / \partial \theta \approx 0$*, so* $\partial \mathcal{L}_H / \partial \theta \approx \zeta\, \rho\, \partial \mathcal{I}_H^B / \partial \theta$*: depth eases the aggregate only through the borrowers it protects, concentrating the loss further on non-borrowers.*

Proof: *See Appendix E.*

Proposition 1 establishes that the aggregate loss and its concentration on non-borrowers are governed by the two margins: breadth ρ moves the aggregate size without changing the distribution across firm types, while depth θ determines how the loss is concentrated, easing the borrower loss without lifting the non-borrower floor. The two counterfactual exercises below vary θ and ρ in turn and demonstrate each result in the full nonlinear model.

Counterfactual I: A more relaxed financing constraint. What if firms with cash flow-based borrowing could borrow a larger multiple of EBITDA? Panel (a) of Figure 9 varies θ at the calibrated ρ. A higher θ allows borrowers to smooth R&D more effectively: the borrower contribution to the aggregate loss roughly halves over the range. The non-borrower contribution is approximately invariant to θ, as the borrowing limit does not enter their problem directly. The aggregate consequently eases by about 5 basis points across this range, driven almost entirely by the borrower response.

[16] The non-borrower is affected by θ only through general equilibrium, an order of magnitude smaller than the direct borrower effect at the calibration (Figure 9a).

As θ rises, borrowers protect more of their R&D while the non-borrower loss remains approximately unchanged. The gap between the two firm types widens: greater depth of borrowing concentrates the loss further on non-borrowers, protecting those with access to external finance while leaving those without it exposed.

Counterfactual II: Broader access to cash flow-based borrowing. What if a larger share of firms had access to cash flow-based borrowing? Figure 9, Panel (b) varies the borrower share ρ at the calibrated θ. The per-firm loss for each firm type is approximately unchanged as ρ moves, since the individual R&D responses are independent of the population mix. What changes is the aggregate, a weighted average $\rho\,\mathcal{L}^B + (1-\rho)\,\mathcal{L}^{NB}$: as ρ rises, more weight falls on the smaller borrower loss. Moving from the calibrated $\rho \approx 0.45$ to universal access ($\rho = 1$) reduces the persistent aggregate loss by approximately 30 percent.

Breadth governs size, depth governs concentration. The two counterfactuals deliver a clean separation. Deepening the borrowing limit reshapes the relative weight of the loss across firm types but moves the aggregate only modestly. Expanding access shifts the population mix toward firms that smooth R&D better, reducing the aggregate loss more efficiently. For a policymaker targeting aggregate productivity, breadth is the more powerful margin. But aggregate size is not the only thing that matters: the concentration of the loss on non-borrowers raises an efficiency question that the size margin alone cannot answer. If non-borrowers are the stronger innovators, the concentration carries costs beyond redistribution. We investigate this in Section 6.2.

6.2 From reallocation to misallocation

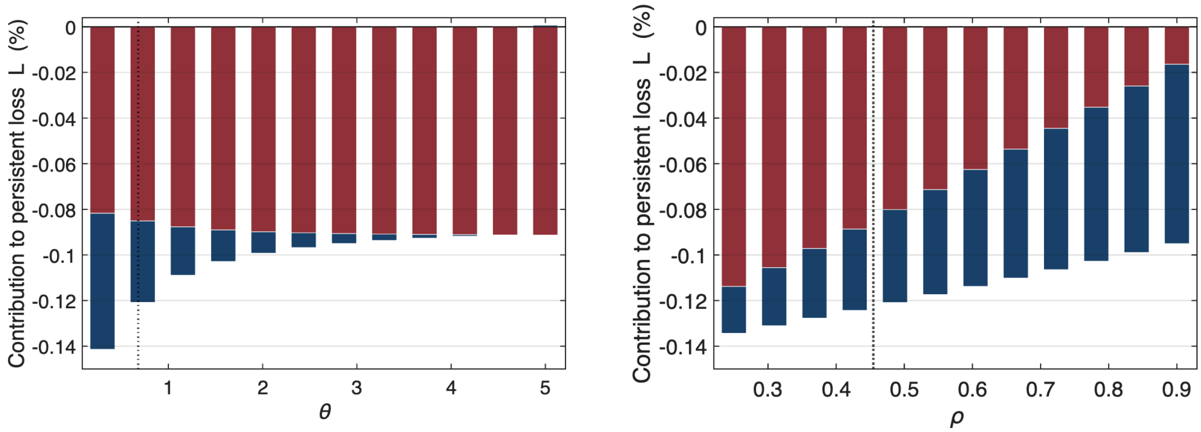
The representation of productivity loss (Equation (28)) treats a unit of borrower and non-borrower R&D as equally valuable for aggregate growth. Our model follows the homogeneous-quality benchmark of the Schumpeterian firm-dynamics literature (Klette and Kortum, 2004), under which reallocating R&D across firms at a fixed total leaves growth unchanged. Under that benchmark, the concentration of Proposition 1 is purely distributional: it determines who bears the loss, not its aggregate size.

Our model takes the heterogeneity in financing access as given and traces its consequences for aggregate productivity, without taking a stance on the quality of innovation each firm type produces.[17] From a policymaker's standpoint, what matters is not only

[17]The calibration implies $\chi^B > \chi^{NB}$: borrowers convert a unit of R&D into productivity growth more

Figure 9

Persistent Loss: Depth and Breadth of Financial Access



(a) Depth: the borrowing limit (θ) **(b) Breadth: the borrower share (ρ)**

Note. Stacked decomposition of the 12-year persistent productivity loss $\mathcal{L} = \sum_{t=1}^{12}(\ln g_t - \ln g_{ss})$ (%) after a 25-basis-point contractionary monetary policy shock, into the borrower contribution $\rho\,\mathcal{L}^B$ (blue) and the non-borrower contribution $(1-\rho)\,\mathcal{L}^{NB}$ (red). Panel (a) varies the borrowing limit θ (depth) at the calibrated ρ; Panel (b) varies the borrower share ρ (breadth) at the calibrated θ. The gray dotted line marks the benchmark calibration ($\theta = 3.50$, $\rho \approx 0.45$).

how large the R&D contraction is but where it falls. Acemoglu et al. (2018) show that reallocation of innovation activity away from more productive firms carries efficiency costs; whether the same logic applies here depends on whose innovation is more important for aggregate productivity growth. If non-borrowers are the stronger innovators, the concentration of the loss is a misallocation rather than a redistribution. We investigate this through firm type and patent-based innovation outcomes.

Firm type. In our sample, non-CFB firms are younger by roughly four years from IPO and have higher R&D intensity; Table 1 reports the full distributional comparison.[18] Cash flow-based borrowing requires a track record of stable, pledgeable earnings (Lian and Ma, 2021; Drechsel, 2023). Younger firms typically lack this and rely instead on collateral-based credit, which Cloyne et al. (2023) show makes their investment unusually sensitive

efficiently, since non-borrowers are more R&D-intensive yet reach the same balanced-growth rate. This efficiency gap does not drive our results. Setting $\chi^B = \chi^{NB}$, so that the two sectors are symmetric except for financing access, leaves the headline numbers essentially unchanged: the peak output loss remains 0.99 percent, the persistent loss is 0.120 percent of trend (baseline 0.123), and the non-borrower loss is still about twice the borrower loss, 2.02 times at its peak and 1.86 at year twelve.

[18] Throughout this section, CFB and non-CFB (the data labels) correspond to borrowers and non-borrowers in the model; both labels refer to the same partition of firms.

to monetary policy. Because R&D generates little physical collateral, these firms are left without a natural external financing margin for innovation. Akcigit and Kerr (2018) and Acemoglu et al. (2018) document that young firms are the primary source of radical, frontier-shifting innovations. The firm type bearing the larger share of the loss is thus the segment whose innovation tends to matter most for aggregate productivity growth.

Innovation quality. We measure patent quality using the text-based importance score of Kelly et al. (2021) (KPST), which captures a patent's influence on subsequent research and its novelty relative to prior art.[19] We match patents to firms through the Kogan et al. (2017) bridge and merge with the DealScan-Compustat panel.

Table 3 shows that non-CFB firms outperform on every innovation margin. They produce roughly three times as many patents as CFB firms and accumulate nearly four times the total KPST importance score. The quality advantage persists within patenting firms: non-CFB firms have higher average and maximum importance scores. The pattern is sharpest for breakthroughs: non-CFB firms produce more than four times as many breakthrough patents and are more likely to produce at least one (10.8% versus 7.6%).

Patent-based innovation outcomes confirm that the firms bearing the larger share of the persistent loss are also the stronger innovators. The financing friction concentrates the R&D contraction where innovation quality is highest, so the aggregate productivity cost of monetary policy is not a uniform reduction in R&D but a reallocation away from its most productive margin. The homogeneous-quality loss of Section 5 is therefore a conservative lower bound on the welfare-relevant cost. The evidence is descriptive and does not establish a causal effect of financing access on patent outcomes, but the direction of the correlation is in line with the misallocation channel.

Policy implications. Fiscal R&D support has been proposed as an instrument to offset the medium-run productivity cost of contractionary monetary policy. Fornaro and Wolf (2023) show that a blanket R&D subsidy restores aggregate productivity growth to its pre-shock trend. The misallocation finding here refines that prescription. Because non-borrowers absorb the largest share of the R&D contraction and are also the stronger innovators, the case for spreading support uniformly across firms is weaker than it would be if the concentration of the loss and innovation quality were unrelated, pointing instead toward targeting R&D support at non-borrowers rather than a blanket subsidy. Broadening access to cash flow-based borrowing works through the same channel, consistent

[19] Full data construction is in Appendix A; we use the five-year KPST score in the baseline and the ten-year version for robustness.

Table 3
PATENT-BASED INNOVATION OUTCOMES

	Non-CFB	CFB
Patent Count	17.15	5.83
Any Patent (%)	24.6	20.9
Total Importance	4.87	1.14
Avg Importance	0.29	0.19
Max Importance	0.52	0.35
Breakthrough Count	3.81	0.89
Any Breakthrough (%)	10.8	7.6
Breakthrough Share	0.15	0.14

NOTE. Firm-year means of patent-based innovation outcomes for cash flow-based borrower (CFB) and non-CFB firms in the matched patent–DealScan–Compustat panel (patents issued through 2015); *Any Patent* and *Any Breakthrough* are percentages. *Patent Count* is the number of patents issued to the firm; *Any Patent* is the corresponding indicator. *Total Importance* sums the KPST five-year importance score across the firm's patents; *Avg Importance* and *Max Importance* are the mean and maximum across the firm's patents, conditional on patenting. *Breakthrough* measures are based on the KPST breakthrough flag, which identifies patents in the upper tail of the importance distribution; *Breakthrough Share* is conditional on patenting. Full data construction is in Appendix A.

with the breadth margin (ρ); widening the pool of borrowers shifts weight toward the firm that can smooth R&D better intertemporally.

7 Conclusion

This paper studies how cash flow-based borrowing shapes the transmission of monetary policy to innovation and medium-run productivity. We first show that firms with access to cash flow-based loans sustain R&D significantly better than non-borrowers following a contractionary monetary shock, despite similar cash flow declines. We then build a two-firm New Keynesian model with endogenous growth in which a monetary tightening generates a persistent productivity loss through the innovation channel. Non-borrowers bear the larger share of this loss: without access to external finance, they absorb the earnings shortfall through R&D cuts rather than debt issuance. The concentration of the R&D contraction on non-borrowers has significant productivity costs, as patent evidence shows they are also the stronger innovators, implying a misallocation of R&D away from its most productive margin.

These findings also have important policy implications. In the model, firms with cash flow-based borrowing smooth R&D through the debt margin when earnings fall, attenuating the persistent productivity loss; firms without it absorb the shock through R&D cuts. This suggests that protection of R&D from monetary contractions is most effective when targeted at firms without such loans. A subsidy directed at non-borrowers would concentrate support where both the R&D contraction and innovation quality are highest, protecting productivity at lower fiscal cost than a blanket subsidy. Broadening access to cash flow-based credit would work through the same channel, shrinking the pool of exposed firms at its source. More generally, how widely firms can finance innovation externally is an overlooked determinant of the medium-run cost of monetary tightening, and a cross-country investigation of how the development of cash flow-based credit shapes the cost of monetary policy tightening is a natural direction for future research.

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Online Appendix
"Innovation, Financial Frictions, and Persistent Effects of Monetary Policy"
by Aydan Dogan and Ozgen Ozturk

The appendix collects the material supporting the empirical and theoretical results. Appendices A and B support the empirical analysis. The first describes the Compustat–DealScan firm-quarter panel, the variable and outcome definitions, the sample filters, and the construction of the monetary policy shock and the patent data; it also reports the loan-contract moments (loan maturities and earnings-based covenants) that discipline the model's amortization rate and borrowing limit. The second establishes that the differential R&D response is robust to sector-time controls and to interacting firm characteristics with the shock, and survives direct tests against collateral substitution and a mechanical earnings channel, so that the cross-sectional pattern reflects financing access rather than composition or risk.

The remaining appendices develop the model. Appendix C collects the model's derivations and closure: it works out the closed-form production block, states the borrower's problem and its first-order conditions, and characterizes the competitive pass-through intermediary, which lets borrowers hold long-term debt against households' safe one-period claims at no intermediation rent. Appendix D establishes the balanced growth path, stationarizes the economy, states the full detrended equilibrium system, solves the steady state in closed form, and describes the numerical solution. Appendix E proves the results of Section 6.1: linearizing around the balanced growth path, it shows that the persistent loss collapses to a single sufficient statistic, the expenditure-weighted R&D response, which the financing parameters reach only through the cross-sectional *distribution* of the loss, not its *size*.

A Data and Sample Construction

This appendix documents the empirical dataset, variable definitions, and sample filters used in the paper. The objective is to construct a quarterly firm-level panel that combines financial statements, loan-contract information, and macroeconomic shocks in a way that is consistent with the institutional distinction between asset-based and cash flow-based borrowing.

A.1 Data sources and panel structure

The core micro data are Compustat (firm balance sheet and income statement items, including R&D expenditures) and DealScan (loan-level contract characteristics, including covenant/restriction information). We merge these datasets using the standard Compustat–DealScan link framework in Chava and Roberts (2008), and organize the data at the firm-quarter level. Cash flow-based status is highly persistent but not absorbing: within the estimation sample a firm's CFB indicator carries over from one quarter to the next about 97% of the time and, year on year, a CFB firm-quarter remains CFB roughly 92% of the time; yet about 40% of firms switch regime at least once over the sample, with entries into and exits from cash flow-based borrowing both common and roughly balanced. We therefore treat CFB access as a slow-moving but genuinely time-varying firm-quarter state rather than a fixed firm characteristic. The merged panel is then enriched with macro controls from FRED and high-frequency identified monetary policy shocks from Jarociński and Karadi (2020), aggregated to quarterly frequency.

DealScan is observed at the facility level, while the empirical design is at the firm-quarter level. We therefore map each contract into calendar quarters using contract start and end dates, and aggregate to firm-quarter contract status. When a firm has multiple active facilities within a quarter, we retain the full financing menu but classify the quarter by the binding financing regime relevant for innovation financing. This aggregation step is central for interpreting contract access as a state variable in the local projections.

A.2 Variable definitions, capital stocks, and outcome transformation

The variables used in the descriptive-statistics tables (Tables 1 and A.2) are constructed from quarterly Compustat as follows. All ratio variables are winsorized at the 1st and 99th percentiles within the estimation sample.

- *Total Assets (log)*: natural log of book assets (`ATQ`, in $M).
- *Age (years)*: years elapsed since the firm's first appearance in Compustat.
- *Leverage*: total debt (short-term plus long-term, `DLCQ`+`DLTTQ`) divided by total assets.
- *Liquidity*: cash and short-term investments (`CHEQ`) divided by total assets.
- *Sales Growth*: quarter-on-quarter log change in sales (`SALEQ`).
- *R&D / Assets*: quarterly R&D expenditure (`XRDQ`) divided by total assets; firms with missing `XRDQ` are treated as zero R&D when explicitly indicated.[20]

[20] Although SG&A embeds R&D outlays on the income statement, it also aggregates non-innovation ex-

- *Cash Flow Volatility* (10^{-3}): rolling four-quarter standard deviation of operating cash flow (EBITDA scaled by total assets) over quarters $t-3$ to t, reported in units of 10^{-3}.
- *R&D Volatility* (10^{-3}): rolling four-quarter standard deviation of XRDQ/ATQ over the same window, in units of 10^{-3}.

R&D flow is measured by quarterly R&D expenditures. To capture innovation capital, we construct an R&D stock using the perpetual-inventory recursion

$$K_{j,t}^{RD} = (1 - \delta_{RD})K_{j,t-1}^{RD} + \texttt{XRDQ}_{j,t}, \qquad \delta_{RD} = 0.15. \tag{A.1}$$

Physical capital is constructed analogously by anchoring each firm at its first available gross capital observation and cumulating subsequent changes in net capital. Firm controls, entering lagged in both the baseline local-projection and event-study specifications, are leverage, firm size, Tobin's Q, dividend-payer status, current-asset share, sales growth, and a fiscal-quarter indicator. Firm age, used in the descriptive comparison of Table 1, is constructed as the number of years since the firm's first observation in Compustat.

A.3 Loan terms and calibration discipline

Table A.1 reports the distribution of loan-contract terms (maturities, spreads, leverage, and earnings-based covenants) for R&D firms and for the full sample. Two moments discipline the model's debt block: the median loan maturity of five years pins down the amortization rate $\delta_B = 1/5 = 0.20$, and the median maximum debt-to-EBITDA covenant pins down the earnings-based borrowing limit $\theta = 3.50$, which sits within the covenant distribution reported by Drechsel (2023).

A.4 Financing-regime classification

The key cross-sectional object is whether a firm has access to cash flow-based (CFB) borrowing in quarter t. A firm-quarter is classified as CFB when at least one active contract is cash flow-based (earnings-backed), and as non-CFB otherwise. This asymmetric classification reflects the institutional feature that CFB contracts are typically governed by a *max Debt-to-EBITDA* covenant, which applies at the borrower (firm) level rather than only to a single facility. As a result, even if a firm simultaneously holds some asset-backed facilities, one active CFB contract can still relax (or bind) firm-wide debt capacity through

penses such as marketing and administration. Following the literature, we exclude SG&A and use XRDQ alone.

Table A.1

DealScan Loan Terms: R&D Firms and Full Sample

	Mean	St. Dev.	P25	Median	P75	N
Panel A: R&D firms						
Loan maturity (years)	5.28	2.63	4.58	5.00	5.25	33,054
All-in-drawn spread (bps)	184.1	126.1	87.5	155.0	255.0	28,213
Book leverage	0.27	0.33	0.10	0.23	0.36	32,162
Max. debt-to-EBITDA covenant	3.62	1.21	3.00	3.50	4.00	1,982
Panel B: Full sample						
Loan maturity (years)	5.58	2.92	4.42	5.00	6.42	106,535
All-in-drawn spread (bps)	197.3	129.8	100.0	175.0	275.0	89,265
Book leverage	0.34	0.33	0.16	0.30	0.45	102,542
Max. debt-to-EBITDA covenant	4.02	1.51	3.00	3.50	4.75	12,955

Note. Loan maturity, all-in-drawn spread, and leverage are computed at the firm-quarter level over active syndicated-loan terms. The maximum debt-to-EBITDA covenant is the initial covenant threshold at the loan package level, taken from the DealScan `Financial Covenant` table and linked to Compustat via the Chava and Roberts (2008) link; it is winsorized at the 1st and 99th percentiles. The reporting window (1990–2020) is broader than the 1997Q1–2017Q3 estimation sample so as to characterize the full contract universe. R&D firms are those with positive R&D expenditure.

the cash flow-based covenant. For this reason, the quarter is classified as CFB whenever at least one CFB contract is active. In the heterogeneous local projections, the treatment indicator is the non-CFB dummy $\mathbf{1}\{\text{Non-CFB}_{j,t}\} = 1 - \mathbf{1}\{\text{CFB}_{j,t}\}$.

A.5 Sample design, cleaning, and outlier treatment

The baseline monetary-policy transmission exercises use the period 1997Q1–2017Q3, which aligns with covenant coverage quality in DealScan and the effective merged sample used in the local projections. Table A.2 reports the full distributional summary (mean, standard deviation, and the 25th, 50th, and 75th percentiles) of the cash flow-based versus non-CFB firm-quarter comparison shown in compact form in the main text (Table 1).

In all specifications, we use an unbalanced panel and let sample composition be determined by data availability for the outcome, controls, and horizon-specific leads/lags. This is standard in local-projection designs and avoids imposing ad hoc balanced-panel restrictions that would materially reduce sample size.

We apply standard sample restrictions used in the corporate-finance and monetary-transmission literature: exclusion of financial and utility firms, exclusion of non-U.S. firms, and removal of observations with economically implausible accounting values (for example, negative assets/capital or negative R&D outlays). We also trim extreme observations in investment and financing variables, and winsorize key variables (with robustness to alternative winsorization thresholds). To reduce measurement noise from very short reporting histories, we impose minimum spell-length requirements when constructing physical and intangible investment series.

To preserve economic comparability across firms, ratio variables are scaled by lagged assets when appropriate, and macro controls enter in lagged form. This timing convention reduces contemporaneous mechanical correlations between firm choices and aggregate shocks.

A.6 Monetary policy shock and scaling

Our baseline shock is the Jarociński and Karadi (2020) identified monetary policy innovation. In all impulse-response figures, coefficients are scaled so that the reported responses correspond to a 25-basis-point increase in the 1-year Treasury rate. The shock series is normalized to this benchmark by regressing the 1-year Treasury yield on the raw Jarociński and Karadi (2020) surprise series and rescaling, which facilitates direct economic interpretation across outcomes and specifications.

A.7 Patent-data construction

The patent measures used in Section 6.2 are built from the text-based KPST patent importance file of Kelly et al. (2021) and the KPSS patent-firm bridge of Kogan et al. (2017). The link is constructed in three steps. First, KPSS assigns each patent to a publicly traded firm through patent assignee information and CRSP identifiers (`PERMNO`, `PERMCO`). Second, CRSP identifiers are mapped to Compustat firms via the CRSP/Compustat link table from WRDS. Third, the matched patent records are aggregated to the Compustat firm-year level using `GVKEY` and the patent issue year; issue year, rather than application year, is used because the KPST quality variables are defined on the issued patent and because this timing is consistent with realized innovation output. We use the five-year KPST importance score in the baseline and retain the ten-year version for robustness.

For each `GVKEY-YEAR` we construct quantity and quality margins. *Patent Count* is the number of matched patents issued to the firm in the year, and *Any Patent* is the corresponding indicator. *Total Importance* sums the five-year KPST scores across the firm-year's patents, and *Avg Importance* and *Max Importance* are the within-firm-year mean and maximum. Breakthrough patents are identified by the KPST breakthrough flag, which selects

Table A.2
DESCRIPTIVE STATISTICS: FULL DISTRIBUTION

	Mean	St. Dev.	P25	**Median**	P75
CFB					
Total Assets (log)	6.850	1.571	5.897	**6.877**	7.968
Age (years)	20.925	13.536	10.500	**18.500**	27.750
Leverage	0.282	0.223	0.132	**0.252**	0.380
Liquidity	0.028	0.037	0.013	**0.028**	0.045
Sales Growth	0.010	0.182	-0.046	**0.016**	0.076
R&D / Assets	0.015	0.015	0.005	**0.010**	0.020
Cash flow Volatility (10^{-3})	30.532	51.094	8.209	**17.357**	34.030
R&D Volatility (10^{-3})	1.786	3.600	0.397	**0.833**	1.771
Observations: 10,655					
Non-CFB					
Total Assets (log)	6.885	2.225	5.308	**6.854**	8.430
Age (years)	20.301	15.379	7.500	**15.750**	31.000
Leverage	0.279	0.229	0.131	**0.245**	0.367
Liquidity	0.023	0.044	0.007	**0.027**	0.044
Sales Growth	0.013	0.203	-0.054	**0.018**	0.086
R&D / Assets	0.018	0.019	0.006	**0.012**	0.024
Cash flow Volatility (10^{-3})	37.769	74.947	7.525	**17.881**	38.252
R&D Volatility (10^{-3})	2.659	4.944	0.443	**1.077**	2.604
Observations: 16,328					

NOTE. This table reports the full distributional summary statistics (Mean, St. Dev., P25, Median, P75) for cash flow-based borrower (CFB) and non-CFB firm-quarters in the matched DealScan–Compustat panel, 1997Q1–2017Q3, computed on a listwise sample (observations with all displayed variables non-missing). Following Lian and Ma (2021), the **Median** column is emphasized because firm-level distributions are right-skewed. Cash Flow Volatility and R&D Volatility are rolling four-quarter standard deviations of EBITDA/Assets and R&D/Assets respectively, in units of 10^{-3}. The compact version is presented in the main text as Table 1.

the upper tail of the importance distribution net of issue-year effects; we then construct *Breakthrough Count*, the *Any Breakthrough* indicator, and the *Breakthrough Share* among the firm's patents. Patent measures are then merged with the DealScan-Compustat panel at the `GVKEY-YEAR` level. Because the patent outcomes are annual while the main financing-R&D panel is quarterly, we collapse the patent comparison to one observation per firm-year to avoid mechanically repeating an annual outcome across four quarters. A firm-year is classified as CFB if the firm holds a cash flow-based contract in any quarter of that year. Firm-years with no matched issued patent are assigned zero counts and zero total importance; *Avg Importance*, *Max Importance*, and *Breakthrough Share* are interpreted as conditional quality margins among patent-producing firm-years. Finally, because the public-firm link through KPSS in the files used here is reliable through the mid-2010s, we restrict the matched-patent construction to patents issued through 2015. The resulting patent table is descriptive and should be read as a quality comparison of innovation outcomes across the CFB classification, not as a causal estimate of the effect of CFB borrowing on patent production.

B Additional Empirical Results

This appendix reports robustness exercises and channel-discriminating tests for the heterogeneous local-projection results in the main text. Across all exercises, the main pattern remains intact: differential responses are more pronounced for R&D than for cash outcomes, and the result is not an artifact of sector-time composition, differential shock loadings, or collateral substitution.

B.1 Robustness of the heterogeneous local projection

We re-estimate the heterogeneous specification in two ways. First, we add sector-quarter fixed effects:

$$y_{j,t+h} - y_{j,t-1} = \alpha_j^h + \beta^h(\epsilon_t^m \mathbf{1}\{\text{Non-CFB}_{j,t}\}) + \mathbf{\Gamma}_Z^h \mathbf{Z}_{j,t-1} + \delta_{s(j),t}^h + e_{j,t+h}, \tag{B.1}$$

where $\delta_{s(j),t}^h$ denotes sector-quarter fixed effects. Second, we allow the firm-level controls to be interacted with the monetary policy shock:

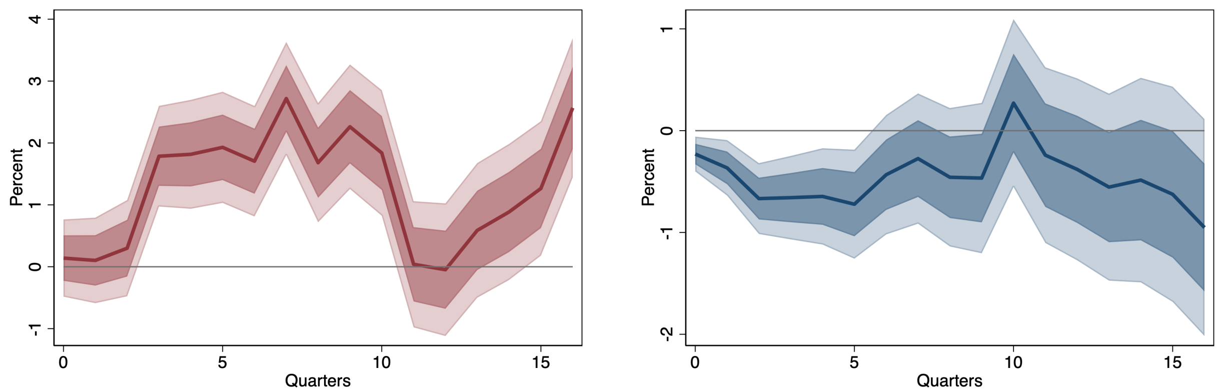
$$y_{j,t+h} - y_{j,t-1} = \alpha_j^h + \gamma^h \epsilon_t^m + \beta^h(\epsilon_t^m \mathbf{1}\{\text{Non-CFB}_{j,t}\}) + \mathbf{\Gamma}_Z^h \mathbf{Z}_{j,t-1} + \mathbf{\Pi}^h(\mathbf{Z}_{j,t-1} \times \epsilon_t^m) + e_{j,t+h}. \tag{B.2}$$

In both cases, the coefficient of interest is β_{NC}^h.

The estimates in Figures B.1 and B.2 support the baseline interpretation. Under sector-quarter fixed effects (B.1), the non-CFB relative response in R&D remains more negative than the corresponding cash response over medium horizons. When controls are additionally interacted with the monetary policy shock (B.2), cash-flow responses are no longer uniform across financing types: at some horizons, CFB firms exhibit sharper cash-flow declines than non-CFB firms. Even in that case, non-CFB firms still cut R&D ex-

Figure B.1

ROBUSTNESS: SECTOR-QUARTER FIXED EFFECTS



(a) Cash **(b) R&D Expenditures**

NOTE. Relative (non-CFB minus CFB) responses of cash flow (Panel a) and R&D expenditures (Panel b) over a 16-quarter horizon, from the heterogeneous local projection of equation (3) augmented with sector-quarter fixed effects (equation (B.1)). Shaded areas denote 90% confidence intervals from standard errors clustered at the firm and quarter level.

penditures more strongly. This contrast indicates that the heterogeneous R&D response is not a mechanical reflection of contemporaneous cash-flow differences, but reflects differences in external financing capacity for intangible investment. Overall, these exercises indicate that the stronger sensitivity of R&D expenditures is not driven by sector-time composition effects or by differential shock loadings on observed firm controls.

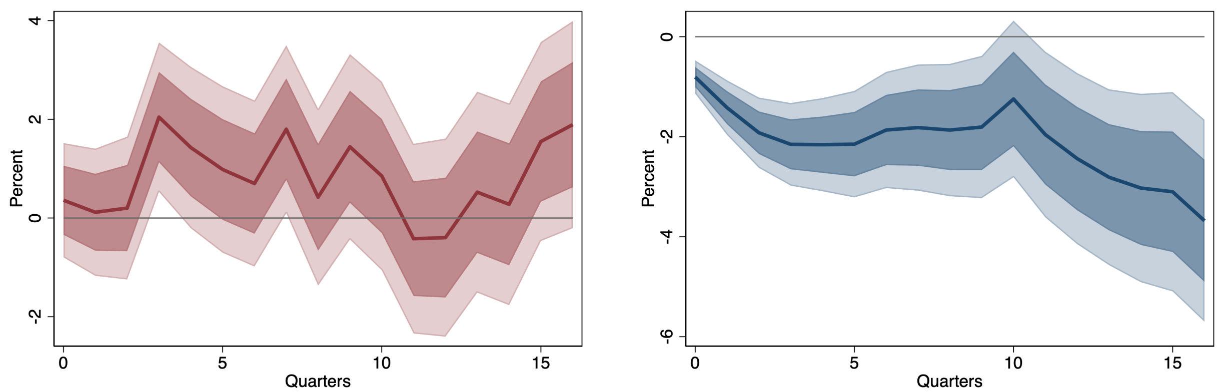
B.2 Ruling out alternative channels

Tangibility and the R&D response: ruling out the substitution channel. The physical-investment placebo in Section 2.3 rules out the interpretation that the R&D heterogeneity reflects differences in collateral capacity or generic firm-level resilience. A more direct test of the related *substitution* channel, that non-CFB firms could borrow against existing physical assets and use the proceeds to finance R&D, is to interact firm tangibility with the monetary shock and re-estimate the average local projection separately for CFB and non-CFB firms:

$$y_{j,t+h} - y_{j,t-1} = \alpha_j^h + \beta^h \epsilon_t^m + \theta^h \left(\epsilon_t^m \cdot \text{Tang}_{j,t-1}\right) + \gamma^h \text{Tang}_{j,t-1} + \Gamma_z \mathbf{Z}_{j,t-1} + \Gamma_x \mathbf{X}_{t-1} + e_{j,t+h}, \tag{B.3}$$

Figure B.2

ROBUSTNESS: INTERACTING CONTROLS WITH MONETARY POLICY SHOCKS



(a) Cash **(b) R&D Expenditures**

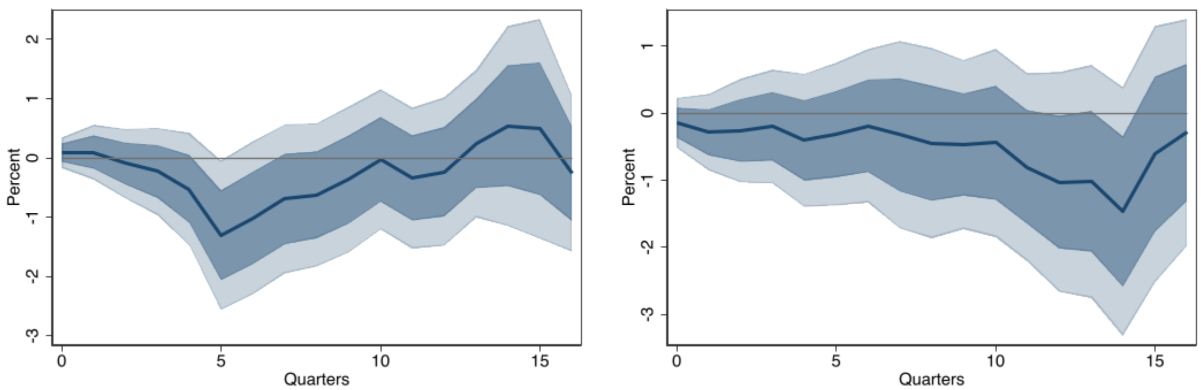
NOTE. Relative (non-CFB minus CFB) responses of cash flow (Panel a) and R&D expenditures (Panel b) over a 16-quarter horizon, from the heterogeneous local projection with firm-level controls interacted with the monetary policy shock (equation (B.2)). Shaded areas denote 90% confidence intervals from standard errors clustered at the firm and quarter level.

where $\text{Tang}_{j,t-1}$ is the firm's tangibility ratio, (PPE+Inventories+Receivables)/Total Assets, lagged and standardized. The coefficient of interest is θ^h: if the substitution channel operates, higher-tangibility firms should cut R&D less during monetary tightening, generating $\theta^h > 0$.

Figure B.3 reports θ^h estimated separately on the CFB subsample and the non-CFB subsample. The coefficient is statistically indistinguishable from zero at every horizon in both samples. Point estimates oscillate around zero in the CFB sample and trend mildly negative in the non-CFB sample, but no horizon yields a positive and significant estimate. The data therefore rule out the substitution channel directly: tangibility does not attenuate the R&D response to monetary policy in either group. CFB borrowing helps R&D in a way that does not depend on the firm's tangible-asset base.

Event study: R&D share of total investment around CFB adoption. The main-text event study (Figure 4) shows that R&D volatility falls within-firm after a firm first adopts a cash flow-based contract. One alternative interpretation is that CFB adoption shifts firms' overall investment composition toward or away from R&D, so that the observed stability reflects a change in scale rather than in the smoothness of innovation spending. Figure B.4 addresses this by re-estimating the event-study specification of equation (4) with the R&D share of total investment as the outcome. The R&D share is essentially

Figure B.3
Tangibility and the R&D response, by CFB status



(a) CFB sample **(b) Non-CFB sample**

Note. Each panel plots θ^h from equation (B.3), the coefficient on the interaction of tangibility with the monetary policy shock. Panel (a) estimates θ^h on the CFB subsample; Panel (b) estimates it on the non-CFB subsample. Tangibility is the lagged ratio of (PPE + Inventories + Receivables) to total assets, winsorized and standardized. The outcome is the cumulative log change in R&D expenditures at horizon h. Shaded areas denote 90% confidence intervals from standard errors clustered at the firm and quarter level. Both confidence bands cover zero at every horizon, indicating that tangibility does not attenuate the R&D response to a contractionary monetary policy shock in either subsample.

unchanged around adoption: the pre-adoption coefficients are flat and statistically indistinguishable from zero, and no post-adoption coefficient departs significantly from the omitted quarter. This confirms that the within-firm decline in R&D volatility documented in the main text reflects a change in the stability of innovation spending rather than a shift in investment composition.

C Model: Derivations and Closure

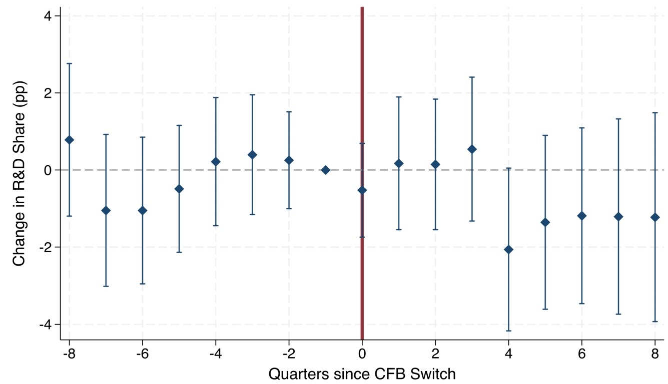
C.1 Intermediate-goods block: pricing, profits, output, and value added

This appendix derives the closed-form production-block objects, equilibrium input use, profits, output, value added, and the labor-demand (wage) condition, used in the main text for each firm type $i \in \{B, NB\}$. Final-good producers are perfectly competitive and combine labor L_t^i and a continuum of intermediate inputs $x_{j,t}^i$:

$$Y_t^i = (L_t^i)^{1-\alpha} \int_0^1 (A_{j,t}^i)^{1-\alpha} (x_{j,t}^i)^{\alpha} \, dj. \tag{C.1}$$

Figure B.4

Event Study: R&D Share of Total Investment Around CFB Adoption



Note. LP-DiD coefficients β_h from equation (4) for the R&D share of total investment around firms' first adoption of a CFB contract, estimated over 1997Q1–2017Q3 with time effects and the same firm-level controls as the local-projection specification (Section 2.2), comparing newly adopting firms against never- and not-yet-adopting clean controls. The base period is the quarter immediately preceding adoption, $h = -1$, so coefficients are relative to the last pre-adoption quarter. Vertical bars denote 90% confidence intervals from standard errors clustered at the firm level.

Cost minimization yields the inverse demand for each variety,

$$x^i_{j,t} = \left(\frac{P^i_{j,t}}{P^i_t \alpha (L^i_t)^{1-\alpha} (A^i_{j,t})^{1-\alpha}} \right)^{\frac{1}{\alpha-1}}, \tag{C.2}$$

where P^i_t is the aggregate final-good price. Each intermediate variety is produced one-for-one from the final good, so its marginal cost is P^i_t and the monopolist charges the constant markup $P^i_{j,t} = P^i_t/\alpha$ derived in the main text (eq. 7). We take the demand curve (C.2) and this markup as given and derive the remaining objects.

Equilibrium input use. Substituting $P^i_{j,t} = P^i_t/\alpha$ into (C.2),

$$\frac{1}{\alpha} = \alpha (L^i_t)^{1-\alpha} (A^i_{j,t})^{1-\alpha} (x^i_{j,t})^{\alpha-1} \quad \Rightarrow \quad (x^i_{j,t})^{1-\alpha} = \alpha^2 (L^i_t)^{1-\alpha} (A^i_{j,t})^{1-\alpha},$$

so that

$$x^i_{j,t} = \alpha^{\frac{2}{1-\alpha}} A^i_{j,t} L^i_t. \tag{C.3}$$

Profits. Using the markup and (C.3),

$$\Pi^i_{j,t} = (P^i_{j,t} - P^i_t) x^i_{j,t} = P^i_t \left(\frac{1}{\alpha} - 1 \right) \alpha^{\frac{2}{1-\alpha}} A^i_{j,t} L^i_t = P^i_t \, \varphi \, A^i_{j,t} L^i_t,$$

where the profit composite is

$$\varphi \equiv \left(\frac{1}{\alpha} - 1\right) \alpha^{\frac{2}{1-\alpha}}. \tag{C.4}$$

Aggregate output. Substituting (C.3) into the production technology (C.1),

$$Y_t^i = (L_t^i)^{1-\alpha} \int_0^1 (A_{j,t}^i)^{1-\alpha} \left(\alpha^{\frac{2}{1-\alpha}} A_{j,t}^i L_t^i\right)^\alpha dj = \alpha^{\frac{2\alpha}{1-\alpha}} L_t^i \int_0^1 A_{j,t}^i \, dj.$$

Defining aggregate productivity $A_t^i \equiv \int_0^1 A_{j,t}^i \, dj$,

$$Y_t^i = \alpha^{\frac{2\alpha}{1-\alpha}} A_t^i L_t^i. \tag{C.5}$$

Value added. Total intermediate expenditure is $\int_0^1 x_{j,t}^i dj = \alpha^{\frac{2}{1-\alpha}} A_t^i L_t^i$, so

$$Y_t^i - \int_0^1 x_{j,t}^i dj = \left(\alpha^{\frac{2\alpha}{1-\alpha}} - \alpha^{\frac{2}{1-\alpha}}\right) A_t^i L_t^i = \alpha^{\frac{2\alpha}{1-\alpha}}(1-\alpha^2) A_t^i L_t^i,$$

where the last step uses $\alpha^{\frac{2}{1-\alpha}} = \alpha^{\frac{2\alpha}{1-\alpha}} \alpha^2$. Defining the net-output composite $\Omega \equiv \alpha^{\frac{2\alpha}{1-\alpha}}(1 - \alpha^2)$,

$$Y_t^i - \int_0^1 x_{j,t}^i dj = \Omega \, A_t^i L_t^i. \tag{C.6}$$

Labor demand and the wage equation. The final-good producer's first-order condition for labor equates the wage to the marginal revenue product of labor, $W_t = P_t^i \, \partial Y_t^i / \partial L_t^i$. Differentiating (C.1) and substituting the equilibrium input (C.3),

$$W_t = P_t^i (1-\alpha)(L_t^i)^{-\alpha} \int_0^1 (A_{j,t}^i)^{1-\alpha} (x_{j,t}^i)^\alpha dj = P_t^i (1-\alpha) \, \alpha^{\frac{2\alpha}{1-\alpha}} A_t^i,$$

so that

$$W_t = P_t^i \, \Gamma \, A_t^i, \qquad \Gamma \equiv (1-\alpha)\alpha^{\frac{2\alpha}{1-\alpha}}. \tag{C.7}$$

The nominal wage is common across firm types, while sectoral productivities A_t^i differ; this is the link that generates type-specific inflation in the Phillips block and underlies the balanced-growth argument of Appendix D.

From the wage equation to the Phillips curves. Writing (C.7) as $P_t^i = W_t / (\Gamma A_t^i)$, sectoral gross inflation is

$$\pi_t^i = \frac{P_t^i}{P_{t-1}^i} = \frac{W_t}{W_{t-1}} \cdot \frac{A_{t-1}^i}{A_t^i} = \frac{W_t / W_{t-1}}{g_t^i}, \qquad g_t^i \equiv A_t^i / A_{t-1}^i.$$

Substituting the economy-wide wage-setting rule $W_t/W_{t-1} = g_{ss}(L_t/\bar{L})^{\xi}\pi_{t-1}^{\varsigma}$ (21) yields the sectoral Phillips curves used in the main text,

$$\pi_t^i = \frac{g_{ss}}{g_t^i}\left(\frac{L_t}{\bar{L}}\right)^{\xi}\pi_{t-1}^{\varsigma}, \qquad i \in \{B, NB\}, \tag{C.8}$$

with the aggregate Phillips curve following from the price index $\pi_t = (\pi_t^B)^{\rho}(\pi_t^{NB})^{1-\rho}$.

Equations (C.3), (C.4), (C.5), and (C.6) are the closed-form equilibrium expressions used in the main text for each firm type $i \in \{B, NB\}$.

C.2 Borrower's Problem and First-Order Conditions

A borrower chooses payouts D_t^B, R&D I_t^B, and next-period debt $\mathcal{B}_{t+1}$ to maximize the present value of dividends, discounted by the household stochastic discount factor. Under perfect foresight the relevant one-period factor is the risk-free discount $1/R_t = \beta\,(C_t/C_{t+1})/g_{t+1}$ from the household Euler equation (6); let $M_t \equiv \prod_{s=0}^{t-1} R_s^{-1}$ denote the cumulative discount factor, so that $M_{t+1}/M_t = 1/R_t$. In equilibrium all borrowers are identical, so we drop the firm index. The borrower solves

$$\max_{\{D_t^B, I_t^B, \mathcal{B}_{t+1}\}} \sum_{t\geq 0} M_t\, D_t^B$$

subject to the flow of funds (multiplier μ_t^B), the earnings-based borrowing constraint (multiplier $\lambda_t \geq 0$), and the innovation technology (co-state ν_t):

[**Flow of funds** (μ_t^B)] $\quad D_t^B + \kappa(D_t^B - \bar{D}^B)^2 + \delta_B\mathcal{B}_t = p_t^B(\varphi A_t^B L_t^B - I_t^B) + \dfrac{\mathcal{B}_{t+1} - (1-\delta_B)\mathcal{B}_t}{R_t^{b,B}},$

[**Borrowing constraint** (λ_t)] $\quad \dfrac{\mathcal{B}_{t+1} - (1-\delta_B)\mathcal{B}_t}{R_t} \leq \theta\,\dfrac{\delta_B}{R_t}\,p_t^B(\varphi A_t^B L_t^B - I_t^B),$

[**Law of motion** (ν_t)] $\quad A_{t+1}^B = A_t^B + \chi^B I_t^B.$

The Lagrangian is

$$\mathscr{L} = \sum_t M_t\Big\{\, D_t^B - \mu_t^B[\text{Flow of Funds}]_t - \lambda_t[\text{Borrowing Constraint}]_t - \nu_t[\text{Law of Motion}]_t\Big\}.$$

Dividends. $\partial\mathscr{L}/\partial D_t^B = 0$ gives, as in the main text (eq. 18),

$$1 = \mu_t^B[1 + 2\kappa(D_t^B - \bar{D}^B)].$$

R&D. $\partial\mathscr{L}/\partial I_t^B = 0$ gives the shadow value of installed productivity, $\nu_t = (\mu_t^B + \theta\lambda_t)\, p_t^B/\chi^B$: because R&D is expensed against pledgeable earnings, a unit of R&D tightens the borrowing limit by θ and so carries the effective cost $\mu_t^B + \theta\lambda_t$. Eliminating ν_t with the co-state recursion $\partial\mathscr{L}/\partial A_{t+1}^B = 0$ yields the R&D Euler equation (19),

$$\frac{\mu_t^B + \theta\lambda_t}{\chi^B} = \frac{1}{R_t}(\mu_{t+1}^B + \theta\lambda_{t+1})\Big(\varphi L_{t+1}^B + \frac{1}{\chi^B}\Big),$$

up to the sectoral inflation and growth factors that appear once the system is written in stationary variables.

Debt. The debt choice $\mathcal{B}_{t+1}$ enters four places: today's flow of funds (as a source), today's constraint (which it tightens), and next period's flow of funds and borrowing constraint. Collecting $\partial\mathscr{L}/\partial\mathcal{B}_{t+1} = 0$ gives

$$\frac{\mu_t^B}{R_t^{b,B}} - \frac{\lambda_t}{R_t} = \frac{1}{R_t}\Big[\mu_{t+1}^B\Big(\delta_B + \frac{1-\delta_B}{R_{t+1}^{b,B}}\Big) - \lambda_{t+1}\frac{1-\delta_B}{R_{t+1}}\Big]. \tag{C.9}$$

Steady state and the mapping to the covenant. At the steady state ($\mathcal{B}_{t+1} = \mathcal{B}_t$, $p^B = 1$, $R^{b,B} = R^b$) the binding constraint gives the debt stock

$$\mathcal{B}_{ss} = \theta\,(\varphi L_{ss}^B - I_{ss}^B), \qquad \text{so} \qquad \frac{\mathcal{B}_{ss}}{\varphi L_{ss}^B - I_{ss}^B} = \theta.$$

The δ_B/R factor in the constraint makes θ exactly the borrower's steady-state debt-to-EBITDA ratio, which we set to the DealScan covenant median $\theta = 3.50$. The debt first-order condition (C.9) implies the steady-state multiplier

$$\lambda_{ss} = \frac{R}{R^b} - \frac{R\,\delta_B}{R + \delta_B - 1}.$$

C.3 Pass-through financial intermediary

To close the model, we introduce a competitive pass-through financial intermediary that resolves the maturity mismatch between households' one-period bonds and firms' long-term debt. The intermediary funds itself by issuing one-period deposits to households at the risk-free rate R_t and holds firms' long-term debt at the state-dependent rate $R_t^{b,B}$, with balance sheet

$$B_t^h = \mathcal{B}_t, \tag{C.10}$$

where $\mathcal{B}_t \equiv \int_0^1 \mathcal{B}^B_{j,t}\, dj$ denotes aggregate firm debt. The financial intermediary earns zero profit in equilibrium. Deposits are held by households as one-period bonds, so $B^h_t = B_t$, and the intermediary balance sheet implies $B_t = \mathcal{B}_t$ in equilibrium. The intermediary warehouses firms' amortizing long-term debt against one-period deposits, but holds no net worth and earns zero profit by construction, so it cannot absorb a maturity gain or loss. Because the borrowing rate $R^{b,B}_t$ and the deposit rate R_t reset together each period, an unanticipated shock revalues neither side of its book: the rate change is borne by borrowers (whose cost of debt rises) and savers (whose deposit return rises), not by the intermediary. The maturity it transforms is the amortization/rollover horizon, governed by δ_B and the state-dependent spread, not interest-rate duration. Households hold only safe one-period claims and firms hold their preferred long maturity, with the competitive intermediary bridging the gap at no rent. The state-dependent rate $R^{b,B}_t$ in (D.32) is accordingly *not* a return to the intermediary but a borrower-side pricing wedge: it enters the borrower's debt Euler equation, raising the perceived marginal cost of debt as refinancing pressure mounts, while new debt is issued at $R^{b,B}_t$ and the spread never enters the aggregate resource constraint $\Omega L_t = \tilde{c}_t + \tilde{I}_t$. It is a reduced-form external-finance premium borne by borrowers, in the spirit of Bernanke et al. (1999) and Cúrdia and Woodford (2016), rather than a real intermediation cost. We follow Chen et al. (2012) and Carlstrom et al. (2017) in adopting this device; none of our results depends on the intermediary having an independent balance-sheet friction, from which we abstract.

D Equilibrium and Steady State

Since productivity grows endogenously across both firm types, the model has no stationary equilibrium in levels. We first establish conditions for the existence of a balanced growth path (BGP), then stationarize the model, list the detrended equilibrium conditions, derive the steady state analytically, and describe the numerical solution.

D.1 Existence of a common balanced growth path

From the final good producer's labor demand condition (C.7), the nominal wage satisfies $W_t = P^i_t \Gamma A^i_t$ with $\Gamma = (1-\alpha)\alpha^{\frac{2\alpha}{1-\alpha}}$. Since the nominal wage is common across firms and grows at rate g_{ss} in steady state (from the wage setting equation), this condition implies that price levels for each type of firm are stationary if and only if $g^i_{ss} = g_{ss}$ for both i. A well-defined BGP therefore requires:

$$g_{ss}^{B} = g_{ss}^{NB} = g_{ss}. \tag{D.1}$$

To see why, define the relative productivity ratio $q_t \equiv A_t^{NB}/A_t^{B}$, which evolves according to $q_{t+1} = q_t \cdot g_{t+1}^{NB}/g_{t+1}^{B}$. If $g_{ss}^{B} \neq g_{ss}^{NB}$, then q_t trends to zero or infinity, one sector eventually dominates, relative prices become non-stationary, and the model has no well-defined BGP. Condition (D.1) ensures $q_t \to q_{ss}$ is finite and positive, with $q_{ss} = 1$ under the normalization $A_{ss}^{B} = A_{ss}^{NB}$.

D.2 Restriction on χ^B, χ^{NB} from the balanced growth path

From the non-borrower firm's productivity FOC in steady state with $\mu_{ss}^{NB} = 1$ and $\pi^{NB}/\pi = 1$:

$$g^2 = \beta(\chi^{NB}\varphi L_{ss}^{NB} + 1). \tag{D.2}$$

From the borrower firm's productivity FOC (the $\theta\lambda$ terms cancel in steady state):

$$g^2 = \beta(\chi^{B}\varphi L_{ss}^{B} + 1). \tag{D.3}$$

Equating these two expressions gives the key restriction:

$$\chi^{NB} L_{ss}^{NB} = \chi^{B} L_{ss}^{B}. \tag{D.4}$$

Combined with full employment $L_{ss}^{B} + L_{ss}^{NB} = \bar{L}$, this yields the unique sectoral employment allocation:

$$L_{ss}^{B} = \frac{\bar{L}\chi^{NB}}{\chi^{B} + \chi^{NB}} \tag{D.5}$$

$$L_{ss}^{NB} = \frac{\bar{L}\chi^{B}}{\chi^{B} + \chi^{NB}}. \tag{D.6}$$

The sector with higher R&D effectiveness employs fewer workers in steady state because higher innovation productivity means less labor is needed to sustain the common growth rate. The steady state growth rate then follows from either FOC:

$$g_{ss} = \sqrt{\beta(\chi^{NB}\varphi L_{ss}^{NB} + 1)} = \sqrt{\beta(\chi^{B}\varphi L_{ss}^{B} + 1)}. \tag{D.7}$$

The financing parameters (θ, ψ, δ_B) do not appear in this BGP formula: in the borrower's productivity FOC the effective marginal value of funds $\mu^B + \theta\lambda$ enters symmetrically on both sides and cancels in steady state. The BGP is therefore characterized by the household discount rate β and the R&D technology alone, consistent with Fornaro and Wolf (2023).

D.3 Stationarization

Since A_t^i grows at rate g_{ss} along the BGP, we stationarize sector-specific quantities by dividing by A_t^i:

$$\tilde{C}_t^i = \frac{C_t^i}{A_t^i}, \quad \tilde{I}_t^i = \frac{I_t^i}{A_t^i}, \quad \tilde{D}_t^i = \frac{D_t^i}{A_t^i}. \tag{D.8}$$

Aggregate quantities are divided by $A_t = (A_t^B)^\rho (A_t^{NB})^{1-\rho}$, and debt is detrended by A_t^B since only borrower firms borrow: $\tilde{B}_t = B_t / A_t^B$. The relative prices $p_t^i = P_t^i / P_t$ satisfy:

$$p_t^B = q_t^{-(1-\rho)}, \qquad p_t^{NB} = q_t^\rho \tag{D.9}$$

and are stationary since q_t is stationary. The aggregate growth factor is:

$$g_t = (g_t^B)^\rho (g_t^{NB})^{1-\rho}. \tag{D.10}$$

In steady state $q_{ss} = 1$, $p_{ss}^i = 1$, and $g_{ss}^B = g_{ss}^{NB} = g_{ss}$.

D.4 Detrended equilibrium conditions

The full set of detrended equilibrium conditions is listed below, in the borrower/non-borrower (B/NB) notation of the main text. All quantities carry tildes to denote stationarization by the appropriate productivity trend; prices, inflation rates, growth rates, interest rates, and employment are stationary on the BGP without normalization. Borrower firms (B) have access to cash flow-based borrowing and face the collateral constraint; non-borrower firms (NB) rely on internal funds.

Households.

$$\frac{1}{R_t} = \frac{\beta}{g_{t+1}} \frac{\tilde{C}_t}{\tilde{C}_{t+1}} \tag{D.11}$$

$$\tilde{C}_t^B = \rho \frac{q_t^{1-\rho}}{p_t^B} \tilde{C}_t \tag{D.12}$$

$$\tilde{C}_t^{NB} = (1-\rho) \frac{q_t^{-\rho}}{p_t^{NB}} \tilde{C}_t \tag{D.13}$$

Non-borrower Firms.

$$g_{t+1}^{NB} = 1 + \chi^{NB} \tilde{I}_t^{NB} \tag{D.14}$$

$$\tilde{D}_t^{NB} + \kappa(\tilde{D}_t^{NB} - \bar{\tilde{D}}^{NB})^2 = p_t^{NB}\Big(\varphi L_t^{NB} - \tilde{I}_t^{NB}\Big) \tag{D.15}$$

$$1 = \mu_t^{NB}\Big[1 + 2\kappa(\tilde{D}_t^{NB} - \bar{\tilde{D}}^{NB})\Big] \tag{D.16}$$

$$\frac{\mu_t^{NB}}{\chi^{NB}} = \frac{\pi_{t+1}^{NB}}{\pi_{t+1}} \frac{\mu_{t+1}^{NB}}{R_t g_{t+1}^{NB}} \left(\varphi L_{t+1}^{NB} + \frac{1}{\chi^{NB}}\right) \tag{D.17}$$

Borrower Firms.

$$g_{t+1}^{B} = 1 + \chi^{B} \tilde{I}_t^{B} \tag{D.18}$$

$$\tilde{D}_t^{B} + \kappa(\tilde{D}_t^{B} - \bar{\tilde{D}}^{B})^2 + \delta_B \tilde{B}_t = p_t^{B}\Big(\varphi L_t^{B} - \tilde{I}_t^{B}\Big) + \frac{\tilde{B}_{t+1} - (1-\delta_B)\tilde{B}_t}{R_t^{b,B}} \tag{D.19}$$

$$\frac{\tilde{B}_{t+1} - (1-\delta_B)\tilde{B}_t}{R_t} = \theta \, \frac{\delta_B}{R_t} \, p_t^{B}\Big(\varphi L_t^{B} - \tilde{I}_t^{B}\Big) \tag{D.20}$$

$$1 = \mu_t^{B}\Big[1 + 2\kappa(\tilde{D}_t^{B} - \bar{\tilde{D}}^{B})\Big] \tag{D.21}$$

$$\frac{\mu_t^{B} + \theta\lambda_t}{\chi^{B}} = \frac{\pi_{t+1}^{B}}{\pi_{t+1}} \frac{\mu_{t+1}^{B} + \theta\lambda_{t+1}}{R_t g_{t+1}^{B}} \left(\varphi L_{t+1}^{B} + \frac{1}{\chi^{B}}\right) \tag{D.22}$$

$$\frac{\mu_t^{B}}{R_t^{b,B}} - \frac{\lambda_t}{R_t} = \frac{1}{R_t}\left[\mu_{t+1}^{B}\left(\delta_B + \frac{1-\delta_B}{R_{t+1}^{b,B}}\right) - \lambda_{t+1}\frac{1-\delta_B}{R_{t+1}}\right] \tag{D.23}$$

Equations (D.19)–(D.23) describe long-term, amortizing debt: a fraction δ_B of the outstanding stock matures each period, so net new issuance is $\tilde{B}_{t+1} - (1-\delta_B)\tilde{B}_t$. New issuance is priced at the borrower's state-dependent rate $R_t^{b,B}$ in the flow of funds (D.19), while the collateral constraint (D.20) limits net issuance, discounted at the risk-free rate R_t, to a multiple θ of pledgeable earnings. The borrowing first-order condition (D.23) equates the marginal benefit of relaxing the constraint to the discounted amortization cost $\delta_B \mu_{t+1}^B / R_t$.

Phillips Curves.

$$\pi_t^B = \frac{g_{ss}}{g_t^B}\left(\frac{L_t}{\bar{L}}\right)^{\xi}(\pi_{t-1})^{\varsigma} \tag{D.24}$$

$$\pi_t^{NB} = \frac{g_{ss}}{g_t^{NB}}\left(\frac{L_t}{\bar{L}}\right)^{\xi}(\pi_{t-1})^{\varsigma} \tag{D.25}$$

$$\pi_t = (\pi_t^B)^{\rho}(\pi_t^{NB})^{1-\rho} \tag{D.26}$$

Aggregate and Policy Block.

$$q_{t+1} = q_t \cdot \frac{g_{t+1}^{NB}}{g_{t+1}^B} \tag{D.27}$$

$$g_t = (g_t^B)^{\rho}(g_t^{NB})^{1-\rho} \tag{D.28}$$

$$p_t^B = q_t^{-(1-\rho)}, \quad p_t^{NB} = q_t^{\rho} \tag{D.29}$$

$$L_t = L_t^B + L_t^{NB} \tag{D.30}$$

$$R_t^b = R_t(1-\tau) + \tau \tag{D.31}$$

$$R_t^{b,B} = R_t^b + \psi(x_t - x_{\text{ref}}), \qquad x_t \equiv \frac{\delta_B \tilde{B}_t}{\Omega L_t^B} \tag{D.32}$$

$$R_t = \frac{i_t}{\pi_{t+1}} \tag{D.33}$$

$$\ln(i_t) = \rho_i \ln(i_{t-1}) + (1-\rho_i)\left[\ln\left(\frac{g_{ss}}{\beta}\right) + \phi_\pi \ln(\pi_t) + \phi_L \ln\left(\frac{L_t}{\bar{L}}\right)\right] + \epsilon_t^M \tag{D.34}$$

$$\Omega L_t^B = \tilde{C}_t^B + \tilde{I}_t^B \tag{D.35}$$

$$\Omega L_t^{NB} = \tilde{C}_t^{NB} + \tilde{I}_t^{NB} \tag{D.36}$$

The rollover spread (D.32) links the borrower's refinancing rate to the ratio x_t of maturing debt $\delta_B \tilde{B}_t$ to borrower value added ΩL_t^B. The reference level x_{ref} is set to the steady-state value of x_t, so the spread vanishes at the steady state and $R_{ss}^{b,B} = R_{ss}^b$.[21]

The system comprises 27 independent equations in the 27 endogenous variables

$$\{\tilde{C}, \tilde{C}^B, \tilde{C}^{NB}, \tilde{I}^B, \tilde{I}^{NB}, g^B, g^{NB}, g, \tilde{D}^B, \tilde{D}^{NB}, \mu^B, \mu^{NB}, \lambda, \tilde{B}, L^B, L^{NB}, L, p^B, p^{NB}, q, \pi^B, \pi^{NB}, \pi, R, R^b, R^{b,B}, i\}.$$

[21] The replication code implements the more general convex form $R_t^{b,B} = R_t^b + \psi(x_t - x_{\text{ref}}) + \psi_2(x_t - x_{\text{ref}})^2$; the baseline calibration sets $\psi_2 = 0$, so the operative spread is linear with slope $\psi = 0.328$ (Section 4). The convex term is retained for robustness, in the spirit of the convex external-finance premium in Cúrdia and Woodford (2016).

The predetermined variables are g_t^B, g_t^{NB}, q_t, $\tilde{B}_t$, and the lagged policy rate i_{t-1}.[22] The collateral constraint (D.20) is imposed as a binding equality; it binds in the steady state ($\lambda_{ss} > 0$, Appendix D.5) and along the contractionary transitions we study (Appendix D.6).

D.5 Steady-state solution

The steady state is fully analytical and recursive. We solve it in the following order, with all variables expressed in detrended form.

Step 1: Employment. From equations (D.5)–(D.6).

Step 2: Technology composites. Since α is common across sectors:

$$\varphi = \left(\frac{1}{\alpha} - 1\right) \alpha^{2/(1-\alpha)} \qquad \text{(profit composite)} \tag{D.37}$$

$$\Omega = \alpha^{2\alpha/(1-\alpha)}(1-\alpha^2) \qquad \text{(net output composite)} \tag{D.38}$$

Both composites are scalars that apply identically to both sectors.

Step 3: Growth and interest rates. g_{ss} from equation (D.7); $R_{ss} = g_{ss}/\beta$; $R_{ss}^b = R_{ss}(1-\tau) + \tau$; and $R_{ss}^{b,B} = R_{ss}^b$, since the rollover spread (D.32) vanishes at the steady state.

Step 4: Investment. Evaluating the stationarized innovation law of motion $g_{t+1}^i = 1 + \chi^i \tilde{I}_t^i$ at the steady state and imposing the common balanced-growth rate $g_{ss}^B = g_{ss}^{NB} = g_{ss}$ from equation (D.1) gives detrended R&D investment

$$\tilde{I}_{ss}^i = \frac{g_{ss} - 1}{\chi^i}, \qquad i \in \{B, NB\}. \tag{D.39}$$

Taking the cross-sectional ratio of equation (D.39), the common growth factor $g_{ss} - 1$ cancels, leaving a direct mapping from relative R&D effectiveness to relative steady-state R&D investment:

$$\frac{\tilde{I}_{ss}^{NB}}{\tilde{I}_{ss}^B} = \frac{(g_{ss}-1)/\chi^{NB}}{(g_{ss}-1)/\chi^B} = \frac{\chi^B}{\chi^{NB}}. \tag{D.40}$$

Intuitively, because both sectors must sustain the same balanced-growth rate, the less R&D-effective sector invests proportionally more; this is the identity used to discipline χ^B/χ^{NB} from cross-sectional R&D intensities in Section 4.

[22] The replication code carries the lagged policy rate as a separate auxiliary variable, giving 28 equations.

Step 5: Consumption and endogenous ρ. From goods market clearing: $\tilde{C}^i_{ss} = \Omega L^i_{ss} - \tilde{I}^i_{ss}$. The consumption expenditure share is determined endogenously:

$$\rho = \frac{\tilde{C}^B_{ss}}{\tilde{C}^B_{ss} + \tilde{C}^{NB}_{ss}}. \tag{D.41}$$

This ensures the household demand equations $\tilde{C}^B_{ss} = \rho\,\tilde{C}_{ss}$ and $\tilde{C}^{NB}_{ss} = (1-\rho)\,\tilde{C}_{ss}$ are exactly satisfied at steady state, avoiding the overdetermination that would arise from treating ρ as a free calibration parameter.

Step 6: Debt and dividends. At the steady state the net-issuance constraint (D.20) reduces to $\delta_B \tilde{B}_{ss}/R_{ss} = \theta(\varphi L^B_{ss} - \tilde{I}^B_{ss})$, so the debt stock is

$$\tilde{B}_{ss} = \frac{\theta R_{ss}\left(\varphi L^B_{ss} - \tilde{I}^B_{ss}\right)}{\delta_B}. \tag{D.42}$$

Dividends follow from the flow of funds. For non-borrower firms,

$$\tilde{D}^{NB}_{ss} = \varphi L^{NB}_{ss} - \tilde{I}^{NB}_{ss}, \tag{D.43}$$

and for borrower firms, using $R^{b,B}_{ss} = R^b_{ss}$ and net issuance $\delta_B \tilde{B}_{ss}$,

$$\tilde{D}^B_{ss} = \varphi L^B_{ss} - \tilde{I}^B_{ss} - \delta_B \tilde{B}_{ss}\left(1 - \frac{1}{R^b_{ss}}\right). \tag{D.44}$$

Step 7: Shadow cost of borrowing. From the borrowing first-order condition (D.23) with $\mu^B_{ss} = 1$ and $R^{b,B}_{ss} = R^b_{ss}$:

$$\lambda_{ss} = R_{ss}\left(\frac{1}{R^b_{ss}} - \frac{\delta_B}{R_{ss}}\right) = \frac{R_{ss}}{R^b_{ss}} - \delta_B. \tag{D.45}$$

Because $\tau \geq 0$ implies $R^b_{ss} = R_{ss}(1-\tau) + \tau \leq R_{ss}$, we have $R_{ss}/R^b_{ss} \geq 1 > \delta_B$, so $\lambda_{ss} > 0$ and the collateral constraint binds in the steady state. With long-term debt ($\delta_B < 1$) the shadow cost is economically sizeable, because only a fraction δ_B of the stock is refinanced each period and each unit of borrowing capacity is therefore valuable. This contrasts with a one-period-debt economy ($\delta_B = 1$), in which $\lambda_{ss} = R_{ss}/R^b_{ss} - 1 = \tau(R_{ss} - 1)/R^b_{ss}$ is negligibly small at annual interest rates.

Feasibility conditions. The steady state is economically meaningful provided: $\tilde{C}^i_{ss} > 0$ (positive consumption in both sectors), $\tilde{D}^B_{ss} > 0$ (positive dividends for borrower firms), and $g_{ss} > 1$ (positive growth). These conditions place implicit restrictions on the calibration of χ^B, χ^{NB}, θ, δ_B, and τ.

D.6 Numerical solution

The model has no closed-form transition path, so we solve it non-linearly under perfect foresight. We compute the deterministic transition induced by an unanticipated (MIT) innovation to the monetary policy rule (D.34), using a Newton-based stacked-time solver over a horizon long enough for the economy to return to the balanced growth path (100 periods). Impulse responses are reported as deviations of the transition path from the steady state of Appendix D.5, scaled so that the monetary innovation corresponds to a 25-basis-point increase in the policy rate. The collateral constraint (D.20) is imposed as a binding equality throughout: it binds in the steady state ($\lambda_{ss} > 0$) and remains binding along the contractionary transitions we study, so treating it as an equality is without loss for these experiments. The financial parameters δ_B and θ are disciplined by the loan-term distributions in Appendix A (Table A.1), and the rollover-spread slope ψ is estimated by impulse-response matching in Section 4.

E Proofs for the Incidence of the Persistent Loss

This appendix proves the results of Section 6.1: the aggregate representation (28), Lemma 4, and Proposition 1. We linearize the detrended equilibrium of Appendix D.4 around the common balanced growth path (BGP). For a generic variable X, $\widehat{X}_t \equiv \ln(X_t/X_{ss})$; for R&D we use the proportional deviation $\widehat{I}^j_t \equiv (\tilde{I}^j_t - \tilde{I}^j_{ss})/\tilde{I}^j_{ss}$ and write the aggregate (expenditure-weighted) R&D response as $\widehat{I}_t \equiv \rho\,\widehat{I}^B_t + (1-\rho)\,\widehat{I}^{NB}_t$ and the cross-sectional gap as $w_t \equiv \widehat{I}^B_t - \widehat{I}^{NB}_t$. Let $\zeta \equiv (g_{ss}-1)/g_{ss}$.

Objects. Fix a medium-run horizon H. Define the persistent productivity loss of sector $j \in \{B, NB\}$ and of the aggregate by the cumulative growth shortfall,

$$\mathcal{L}^j_H \equiv \sum_{t=1}^{H} (\ln g^j_t - \ln g_{ss}), \qquad \mathcal{L}_H \equiv \sum_{t=1}^{H} (\ln g_t - \ln g_{ss}), \tag{E.1}$$

and the cumulative proportional R&D responses

$$\mathcal{I}_H^j \equiv \sum_{t=1}^{H} \widehat{I}_t^j, \qquad \bar{\mathcal{I}}_H \equiv \rho\, \mathcal{I}_H^B + (1-\rho)\, \mathcal{I}_H^{NB}, \qquad \mathcal{W}_H \equiv \mathcal{I}_H^{NB} - \mathcal{I}_H^B = -\sum_{t=1}^{H} w_t. \tag{E.2}$$

Aggregate representation (proof of equation (28)).

Lemma 2 (*Exact aggregation*). $\mathcal{L}_H = \rho\, \mathcal{L}_H^B + (1-\rho)\, \mathcal{L}_H^{NB}$.

Proof. Taking logs of the aggregate growth identity $g_t = (g_t^B)^\rho (g_t^{NB})^{1-\rho}$ gives $\ln g_t = \rho \ln g_t^B + (1-\rho) \ln g_t^{NB}$; subtract $\ln g_{ss}$ and sum over $t \le H$. The identity is exact. ∎

Lemma 3 (*R&D–to–loss mapping; sectoral productivity cancels*). *To first order around the BGP,* $\mathcal{L}_H^j = \zeta\, \mathcal{I}_H^j + O(\|\cdot\|^2)$ *with* $\zeta = (g_{ss}-1)/g_{ss}$ common across sectors.

Proof. From $g_{t+1}^j = 1 + \chi^j \tilde{I}_t^j$ and $g_{ss} = 1 + \chi^j \tilde{I}_{ss}^j$, $\ln g_{t+1}^j - \ln g_{ss} = \dfrac{\chi^j}{g_{ss}}(\tilde{I}_t^j - \tilde{I}_{ss}^j) + O(\|\cdot\|^2) = \zeta\, \widehat{I}_t^j + O(\|\cdot\|^2)$, using $\chi^j \tilde{I}_{ss}^j = g_{ss} - 1$. Summing over the horizon gives the claim; χ^j cancels because both sectors grow at the common rate g_{ss}. ∎

Combining the two lemmas yields equation (28), $\mathcal{L}_H \approx \zeta\, \bar{\mathcal{I}}_H$. The breadth derivative in Proposition 1 is then immediate, $\partial \mathcal{L}_H / \partial \rho = \zeta(\mathcal{I}_H^B - \mathcal{I}_H^{NB}) = -\zeta\, \mathcal{W}_H > 0$; it remains to prove the depth claim, part (ii) of Proposition 1, that depth concentrates the loss without resizing it, which rests on the following dichotomy.

Lemma 4 (*Where the financial parameters enter; the non-borrower floor*). *To first order around the BGP, the financial parameters (θ, ψ) enter the equilibrium only through the borrower firms' financing block: the collateral constraint, the borrowing first-order condition and the rollover spread. The non-borrower block and the complementary aggregate block, the consumption Euler equation, the resource constraint, the growth–R&D identity, the aggregate Phillips curve, the policy rule and the Fisher equation, contain neither θ nor ψ. Consequently θ is absent from the non-borrower's problem: holding the common aggregates fixed, its cumulative response $\mathcal{I}_H^{NB}$ is a* floor, *invariant to depth up to the general-equilibrium spillover that runs through the common aggregates, and depth reaches the loss only through the borrower leg $\mathcal{I}_H^B$.*

The remaining steps prove Lemma 4 and, building on it, establish the depth comparative static of Proposition 1(ii), $\partial \mathcal{L}_H / \partial \theta \approx \zeta \rho\, \partial \mathcal{I}_H^B / \partial \theta$.

A useful steady-state property. Under the BGP restriction $L^{NB}/L^B = \chi^B/\chi^{NB}$ imposed in Appendix D, the borrower sector's shares of labor, consumption and R&D coincide and all equal ρ. Indeed $\tilde{I}^j_{ss} = (g_{ss} - 1)/\chi^j$ gives $\tilde{I}^B_{ss}/\tilde{I}^{NB}_{ss} = \chi^{NB}/\chi^B = L^B/L^{NB}$, and since $\chi^B L^B_{ss} = \chi^{NB} L^{NB}_{ss}$ one has $\tilde{I}^j_{ss}/L^j_{ss}$ equal across sectors, so $\tilde{c}^B_{ss}/\tilde{c}^{NB}_{ss} = L^B_{ss}/L^{NB}_{ss}$ as well. Consequently the proportional response of *total* R&D equals the expenditure-weighted response, $(\tilde{I}_t - \tilde{I}_{ss})/\tilde{I}_{ss} = \hat{I}_t$.

The aggregate block. Log-linearizing the household Euler equation, the aggregate resource constraint $\Omega L_t = \tilde{c}_t + \tilde{I}_t$, the law of motion $g^j_{t+1} = 1 + \chi^j \tilde{I}^j_t$ together with the growth aggregator $g_t = (g^B_t)^\rho (g^{NB}_t)^{1-\rho}$, the aggregate Phillips curve $\pi_t = (g_{ss}/g_t)(L_t/\bar{L})^\xi \pi^\varsigma_{t-1}$, the policy rule and the Fisher equation gives

$$\widehat{R}_t = \widehat{g}_{t+1} + \widehat{c}_{t+1} - \widehat{c}_t, \tag{E.3}$$

$$\widehat{L}_t = s_c\,\widehat{c}_t + s_I\,\widehat{I}_t, \qquad s_c = \frac{\tilde{c}_{ss}}{\Omega L_{ss}}, \quad s_I = 1 - s_c, \tag{E.4}$$

$$\widehat{g}_{t+1} = \zeta\,\widehat{I}_t, \tag{E.5}$$

$$\widehat{\pi}_t = -\widehat{g}_t + \xi\,\widehat{L}_t + \varsigma\,\widehat{\pi}_{t-1}, \tag{E.6}$$

$$\widehat{\imath}_t = \rho_i\,\widehat{\imath}_{t-1} + (1 - \rho_i)(\phi_\pi \widehat{\pi}_t + \phi_L \widehat{L}_t) + \varepsilon_t, \tag{E.7}$$

$$\widehat{R}_t = \widehat{\imath}_t - \widehat{\pi}_{t+1}. \tag{E.8}$$

Equation (E.5) uses $\widehat{g}^j_{t+1} = \zeta\,\widehat{I}^j_t$ (from $\chi^j \tilde{I}^j_{ss} = g_{ss} - 1$) and $\widehat{g}_t = \rho \widehat{g}^B_t + (1 - \rho)\widehat{g}^{NB}_t$. *None of* (E.3)–(E.8), *nor their coefficients, contains θ or ψ:* the steady-state shares s_c, s_I, the slope ζ and the policy and Phillips parameters are invariant to the financing parameters (in particular $\lambda_{ss} = R_{ss}(1/R^b_{ss} - \delta_B/R_{ss})$ does not depend on θ). The six equations involve the seven aggregates $\{\widehat{c}, \widehat{L}, \widehat{g}, \widehat{I}, \widehat{R}, \widehat{\pi}, \widehat{\imath}\}$ and are closed by one further relation, the aggregate R&D-supply (Euler) condition derived next.

The R&D-supply closure and the single financial channel. Log-linearizing the two sectoral productivity first-order conditions and taking the $(\rho, 1 - \rho)$-weighted sum yields

$$\widehat{V}_t = \widehat{V}_{t+1} - \widehat{R}_t - \widehat{g}_{t+1} + \widehat{A}_{t+1}, \qquad \widehat{V}_t \equiv \rho\,\widehat{m}^B_t + (1 - \rho)\,\widehat{\mu}^{NB}_t, \tag{E.9}$$

where $\widehat{A}_t \equiv \rho\, a^B \widehat{L}^B_t + (1 - \rho)\, a^{NB} \widehat{L}^{NB}_t$ with $a^j = \varphi L^j_{ss}/(\varphi L^j_{ss} + 1/\chi^j)$, and $\widehat{m}^B_t = s_\mu\,\widehat{\mu}^B_t + s_\lambda\,\widehat{\lambda}_t$ is the borrower firm's effective marginal value of funds, with $s_\lambda = \theta\lambda_{ss}/(1 + \theta\lambda_{ss})$ and $s_\mu = 1 - s_\lambda$. The intersectoral inflation terms cancel because $\widehat{\pi}_t = \rho\widehat{\pi}^B_t + (1 - \rho)\widehat{\pi}^{NB}_t$ and the sectoral Phillips curves share the common $\widehat{L}_t, \widehat{\pi}_{t-1}$, and the common real rate

$\widehat{R}_t$ factors out. *The financing parameters* (θ, ψ) *enter the entire linearized system only through* (E.9), via the weight $s_\lambda(\theta)$, the shadow cost $\widehat{\lambda}_t$, the dividend value $\widehat{\mu}_t^B$ and the sectoral labor split in $\widehat{A}_t$, all of which are determined by the borrower firm's financing block (the borrowing first-order condition $\mu_t^B/R_t^{b,B} - \lambda_t/R_t = \delta_B \mu_{t+1}^B/R_t$, the collateral constraint and the rollover spread), the only equations in which θ and ψ appear. This establishes Lemma 4: (E.3)–(E.8) are free of (θ, ψ) and pin the loss $\mathcal{L}_H = \zeta \sum_{t \le H} \widehat{I}_t$ once the path of $\widehat{I}_t$ is known; the financing block enters only through the closure (E.9).

The relative block in closed form. We now solve the relative block explicitly and exhibit the loading on the gap. *Sectoral allocation.* Linearizing the sectoral demands $c_t^B = \rho\, q_t^{1-\rho} c_t/p_t^B$ and $c_t^{NB} = (1-\rho) q_t^{-\rho} c_t/p_t^{NB}$ with the relative prices $p_t^B = q_t^{-(1-\rho)}$, $p_t^{NB} = q_t^\rho$ gives

$$\widehat{c}_t^B = \widehat{c}_t + 2(1-\rho)\,\widehat{q}_t, \qquad \widehat{c}_t^{NB} = \widehat{c}_t - 2\rho\,\widehat{q}_t. \tag{E.10}$$

Sectoral goods-market clearing $\Omega L_t^j = c_t^j + \tilde{I}_t^j$ inherits the common shares s_c, s_I (the calibration property makes c_{ss}^j/L_{ss}^j equal across sectors), so $\widehat{L}_t^j = s_c \widehat{c}_t^j + s_I \widehat{I}_t^j$ and, by (E.10),

$$\widehat{L}_t^B - \widehat{L}_t^{NB} = 2 s_c\,\widehat{q}_t + s_I\, w_t. \tag{E.11}$$

The same restriction $\chi^B L_{ss}^B = \chi^{NB} L_{ss}^{NB}$ equalises the two productivity-FOC elasticities, $a^B = a^{NB} \equiv a = \varphi L_{ss}^B \chi^B/(\varphi L_{ss}^B \chi^B + 1)$, so the labor term in the relative FOC is $a\,(2 s_c \widehat{q}_{t+1} + s_I w_{t+1})$.

The effective-value gap. Differencing the two sectoral productivity conditions and using $\widehat{g}_{t+1}^B - \widehat{g}_{t+1}^{NB} = \zeta w_t$ and $\widehat{\pi}_{t+1}^B - \widehat{\pi}_{t+1}^{NB} = -\zeta w_t$ (the common real rate, aggregate inflation and aggregate labor cancel) gives, for $\Delta_t \equiv \widehat{m}_t^B - \widehat{\mu}_t^{NB}$,

$$\Delta_t = \Delta_{t+1} - 2\zeta\, w_t + a(2 s_c\,\widehat{q}_{t+1} + s_I\, w_{t+1}), \tag{E.12}$$

which, solving forward with $\Delta_\infty = 0$, yields

$$\Delta_t = -2\zeta\, w_t + \sum_{s \ge 1} (a s_I - 2\zeta) w_{t+s} + 2 a s_c \sum_{s \ge 1} \widehat{q}_{t+s}. \tag{E.13}$$

Relative productivity is itself the running sum of the gap, $\widehat{q}_{t+1} = \widehat{q}_t - \zeta w_t$ (from $q_{t+1} = q_t\, g_{t+1}^{NB}/g_{t+1}^B$), so $\widehat{q}_{t+s} = -\zeta \sum_{r < t+s} w_r$. Substituting, Δ_t is a linear functional of the *gap path alone*, with coefficients built from (ζ, a, s_c, s_I) and no dependence on θ or ψ.

The closure and the explicit loading. Because $\widehat{V}_t = \rho\,\widehat{m}_t^B + (1-\rho)\,\widehat{\mu}_t^{NB} = \widehat{\mu}_t^{NB} + \rho\,\Delta_t$, and the non-borrower firm carries no financing block (its value follows from the dividend condition $\widehat{\mu}_t^{NB} = -2\kappa\,(d_t^{NB} - \bar{d}^{NB})$ and the flow of funds $d_t^{NB} - \bar{d}^{NB} = \overline{\text{earn}}^{NB}\rho\,\widehat{q}_t + \varphi L_{ss}^{NB}\widehat{L}_t^{NB} - \tilde{I}_{ss}^{NB}\widehat{I}_t^{NB}$, with $\overline{\text{earn}}^{NB} = \varphi L_{ss}^{NB} - \tilde{I}_{ss}^{NB}$, a θ-free function of $(\widehat{c}_t, \widehat{q}_t, \widehat{I}_t^{NB})$ via (E.10)), the closure (E.9) becomes

$$\widehat{V}_t = \underbrace{\widehat{\mu}_t^{NB}}_{\theta\text{-free}} + \rho\,\Delta_t, \qquad \rho\,\Delta_t = \underbrace{-2\rho\zeta\,w_t}_{\text{contemp.}} + \underbrace{\rho\sum_{s\geq 1}(as_I - 2\zeta)w_{t+s}}_{\text{forward gap}} + 2\rho a s_c\sum_{s\geq 1}\widehat{q}_{t+s}. \tag{E.14}$$

This is the explicit version of (E.9): the gap enters with contemporaneous loading $\Gamma_0 = -2\rho\zeta$ and forward loadings $\Gamma_s = \rho(as_I - 2\zeta)$, $s \geq 1$; the $\widehat{q}$ terms reduce to further gap loadings through $\widehat{q}_{t+s} = -\zeta\sum_{r<t+s} w_r$. *Every coefficient in* (E.14) *is a function of* $(\rho, \zeta, a, s_c, s_I, \kappa)$ *and none involves* θ *or* ψ.

Conclusion: the non-borrower floor and the two margins. Appending (E.14) to the aggregate block (E.3)–(E.8) yields a determinate linear system in which θ and ψ appear only in the borrower closure (E.9), through the weight $s_\lambda(\theta)$ and the shadow cost $\widehat{\lambda}_t$. Two consequences follow. First, the non-borrower block and the aggregate block are free of (θ, ψ), so, holding the common aggregates fixed, $\partial\mathcal{I}_H^{NB}/\partial\theta = 0$: the non-borrower loss $\mathcal{L}_H^{NB} = \zeta\,\mathcal{I}_H^{NB}$ is a *floor*. Depth therefore moves the aggregate only through the borrower leg,

$$\frac{\partial\mathcal{L}_H}{\partial\theta}\bigg|_\psi = \zeta\Big[\rho\,\frac{\partial\mathcal{I}_H^B}{\partial\theta} + (1-\rho)\,\frac{\partial\mathcal{I}_H^{NB}}{\partial\theta}\Big] \approx \zeta\,\rho\,\frac{\partial\mathcal{I}_H^B}{\partial\theta}, \tag{E.15}$$

the breadth-weighted shadow of the borrower response; the residual $(1-\rho)\,\partial\mathcal{I}_H^{NB}/\partial\theta$ is the general-equilibrium spillover through the common $(\widehat{R}, \widehat{c}, \widehat{L}, \widehat{q})$, an order of magnitude smaller than the borrower term at the calibration (Figure 9a). This establishes Proposition 1(ii). Second, the breadth derivative is exact at first order: differentiating $\mathcal{L}_H = \zeta[\rho\,\mathcal{I}_H^B + (1-\rho)\,\mathcal{I}_H^{NB}]$ in ρ at fixed sectoral responses gives $\partial\mathcal{L}_H/\partial\rho = \zeta(\mathcal{I}_H^B - \mathcal{I}_H^{NB}) = -\zeta\,\mathcal{W}_H > 0$ (Proposition 1(i)), and leaves the incidence ratio $\mathcal{L}_H^{NB}/\mathcal{L}_H^B$ untouched. ■