THE FIRM BALANCE SHEET CHANNEL OF UNCERTAINTY SHOCKS *

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Abstract

The Federal Open Market Committee has repeatedly underlined uncertainty as a key factor in US recessions. This paper shows both empirically and theoretically how macro uncertainty shocks affect the real economy through firms' balance sheet adjustments and highlights its novel policy implications. I document that following an increase in uncertainty, firm-level capital stock and outstanding debt fall while cash holdings increase, and such capital drop and cash buildup are more pronounced among *ex-ante* more indebted firms. I develop a quantitative heterogeneous firm model with financial frictions to illustrate the mechanisms. In the model, liquidity shortages in the face of debt repayment are costly. Thus, firms trade off capital investment for lower debt burdens as heightened uncertainty creates greater downside risk. Firms also trade off capital for cash, especially more indebted firms, because cash preserves internal funds for both debt repayment and potential growth opportunities triggered by increased uncertainty. A calibrated model featuring the transmission mechanism reproduces the observed impacts of macro uncertainty shocks at both micro and macro levels. Quantitative experiments suggest that conventional stimulus policies, like investment tax credits, yield only modest effects in counteracting the adverse impact of uncertainty shocks. In sharp contrast, credit interventions, such as debt relief, can strongly and effectively stabilize uncertainty-driven recessions.

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1 Introduction

Macroeconomic uncertainty rises sharply after extreme events, such as the 9/11 terrorist attacks, the collapse of Lehman Brothers, and the recent COVID-19 pandemic. High macro uncertainty is recessionary, generating sharp and protracted drops in aggregate output.[1] It also leads to weak monetary policy transmission, contributing to slow recoveries from economic downturns.[2] The adverse effects of elevated macro uncertainty have made it important to understand (i). how macro uncertainty shocks transmit to the real economy, and (ii). how to stabilize uncertainty-driven recessions.

At the micro level, elevated macro uncertainty is followed by balance sheet adjustments across firms. Using firm-level data, I document that following an increase in uncertainty, firm-level capital stock and outstanding debt fall while cash holdings increase. In the cross-section, such capital drop and cash buildup are more pronounced among more indebted firms. The empirical patterns point to the importance of firms' cash demand and their *ex-ante* financial conditions in shaping their responses to uncertainty shocks while existing theories of uncertainty transmission abstract from these forces. [3]

In this paper, I show that accounting for corporate cash demand reveals a new transmission mechanism of uncertainty shocks. The new mechanism not only provides a unified explanation for the observed capital, cash, and debt dynamics following macro uncertainty shocks but also has novel policy implications. I first formalize the mechanism by constructing a quantitative heterogeneous firm model that features empirically consistent corporate borrowing and saving behavior. I then study policy counterfactuals in a calibrated model that reproduces the observed impacts of uncertainty shocks at both micro and macro levels.

The central feature of the mechanism is the interaction between elevated uncertainty and firms' precautionary behavior driven by financial frictions. My model captures two forces at play. On the one hand, an increase in uncertainty creates a greater

[1] An extensive literature has provided ample empirical evidence of the negative impact of heightened uncertainty on real economic activities. Seminal examples include Bloom (2009), Gilchrist et al. (2014), and Jurado et al. (2015)

[2] A growing literature has shown that monetary stimulus is less effective at stimulating output during periods of high uncertainty both empirically (see, e.g., Castelnuovo and Pellegrino 2018 and Aastveit et al. 2017) and theoretically (See, e.g., Vavra 2014, Baley and Blanco 2019, and Fang 2020).

[3] Existing transmission mechanisms include the 'real-options' channel driven by non-convex capital costs (See, e.g., Bloom (2009) and Bloom et al. (2018)), and the 'credit spreads' channel emphasizing higher borrowing costs driven by high uncertainty (See, e.g. Gilchrist et al. (2014) and Arellano et al. (2012)). In both frameworks, firms do not hold cash, and corporate saving motives and financial conditions have no role in uncertainty transmission.

downside risk, leading firms to cut capital investment in favor of lower debt burdens and higher savings to avoid costly liquidity shortages in the face of debt repayment. On the other hand, the higher uncertainty also triggers a greater upside potential, further spurring corporate savings. This occurs because firms use cash as their marginal source of funding when facing credit and equity market frictions and therefore save cash for future investment opportunities. The two forces thereby stimulate corporate savings while dampening borrowing, leading to large investment drops. Responses to these forces also depend on firms' *ex-ante* balance sheet conditions: more indebted firms build up more cash for large stocks of outstanding debt while waiting for potential investment opportunities. I refer to the transmission of uncertainty shocks through such joint capital, cash, and debt adjustments as *the firm balance sheet channel of uncertainty shocks*.

The balance sheet channel has two important lessons for policy. On one hand, heightened uncertainty elevates corporate cash demand, thereby reducing firms' responsiveness to investment stimulus policies. On the other hand, uncertainty-induced cash buildup and deleveraging could be mitigated through credit interventions. I simulate an uncertainty-driven recession in the quantitative model and show that conventional stimulus policies, like investment tax credits, yield only modest effects in counteracting the adverse impact of uncertainty shocks, while credit interventions, such as debt relief, can strongly and effectively stabilize the recession. These results shed novel light on the policy responses to uncertainty shocks and recent debates on credit interventions as stabilization tools.

The paper begins by presenting new empirical evidence on firms' balance sheet adjustments following macro uncertainty shocks. Exploiting a panel local projection approach that combines COMPUSTAT firm-level data with the Macro Uncertainty Index of Jurado et al. (2015), I show that an increase in macroeconomic uncertainty is followed by declines in physical capital and outstanding debt alongside a cash buildup. A one-standard-deviation increase (4.5 %) in the index predicts a 0.8% lower capital stock, 2.0% lower outstanding debt, and 2.2% higher cash holdings on average across U.S. public firms six quarters after the initial shock. Such balance sheet changes reflect significant changes in firms' investment, borrowing, and saving decisions in response to elevated macro uncertainty. The results are robust to a wide set of firm and aggregate controls.

Importantly, *ex-ante* balance sheet conditions yield heterogeneous responses of capital and cash to uncertainty shocks across firms. A firm that is one standard deviation

(measured by net leverage ratio) more indebted than its industry average has a larger decline in its capital stock and a larger increase in cash holdings. The heterogeneous responses also hold when using the within-firm variation over time, suggesting that firms respond more to shocks when they are more indebted. These results are robust to controlling for other firm-level heterogeneity, such as investment opportunities (proxied by Tobin's q and firm size), cash flows, debt maturity, and business cycle sensitivities.

To further confirm the empirical findings, I conduct an event study exploiting the 9/11 terrorist attacks as a plausibly exogenous increase in macro uncertainty (e.g., Bloom 2009; Kim and Kung 2017). I find that observed firm behavior around the 9/11 terrorist attacks aligns with the baseline results.

To illustrate the underlying mechanisms behind the data patterns and study policy counterfactuals, I incorporate corporate cash choice into a conventional heterogeneous firm model with capital and debt choices under financial frictions. In the model, firms invest in physical capital, borrow via long-term debt, and save using cash, subject to idiosyncratic productivity shocks, corporate taxation, financial frictions, and exogenous entry and exit. Firms borrow to enjoy the tax benefits of debt and to finance investment. As in conventional models, firms face collateral constraints imposed by creditors and equity issuance costs. Financial frictions, along with exogenous entry and exit, enable the model to generate an endogenous and non-trivial mass of firms that differ in capital, cash, and debt.

The key innovation of the model is that it breaks the prevalent 'net debt' assumption in the macro-finance literature by introducing empirically consistent corporate borrowing and saving behavior.[4] Instead of being either savers or borrowers, firms in this model hold cash while having outstanding debt. The model relies on two additional financial frictions relative to conventional models. First, liquidity shortages when facing debt repayments incur cash flow penalties in the model.[5] The liquidity shortage penalty increases the marginal costs of borrowing, lowering firms' demand for debt. On the other hand, it motivates firms to hold cash in preparation for future debt repayment. Second, firms face debt issuance costs when they have outstanding debt that

[4] Jeenas (2019) introduces frictions in debt issuance, which makes cash-holding the marginal source of funding for firms, and studies its implication for monetary transmission. This paper features an additional cash-holding motive, saving for debt repayment, and finds both cash-holding motives are essential for understanding corporate cash choices in response to uncertainty shocks.

[5] This type of costly liquidity shortfall captures real-world difficulties that firms face in dealing with customers, employees, and strategic partners during liquidity distress.

has not matured yet in the model. These costs capture the restrictive covenants existing creditors impose in a reduced-form way. The debt issuance frictions, along with conventional collateral constraints and equity issuance costs, motivate firms to hold cash for future investment opportunities. Specifically, when an investment opportunity is realized, cash holdings enable firms to finance investment internally without paying financing costs. Thus, firms hold cash as their marginal source of funding. I estimate the model parameters that govern firms' financial behavior to match firm-level moments on profitability, leverage ratio, cash ratio, and equity financing.

The key theoretical contribution of the paper is to show how elevated macro uncertainty, interacting with the frictions shaping corporate borrowing and saving behavior, leads to joint capital, cash, and debt adjustments across firms. The model captures two forces at work. On the one hand, elevated uncertainty implies a higher likelihood of low productivity tomorrow, resulting in a higher risk of liquidity shortages. This larger downside risk motivates firms to cut capital investment in favor of lower debt burdens and higher savings. On the other hand, elevated uncertainty also implies a larger chance of drawing high productivity, motivating firms to expand. Cash holdings play a unique role in such episodes: cash preserves internal funds for both debt repayment and investment opportunities, addressing not only the downside risk but also the upside potential triggered by higher uncertainty. As a result, the greater upside potential triggered by heightened uncertainty further spurs corporate savings, especially for firms with larger stocks of outstanding debt.

I study the stationary equilibrium of a calibrated model and validate the model by showing its ability to reproduce observed investment, saving, and borrowing behavior, which are not targeted in the calibration. First, the calibrated model generates an endogenous mass of firms that differ in their balance sheet conditions, reproducing the observed cross-sectional variation in leverage and cash holdings in the data. Second, firms in the calibrated model save cash for future debt repayment, and the saving motive is stronger for more indebted firms. I show that in both the data and the model, conditional on investment opportunities, more indebted firms are associated with less capital investment and new borrowing but larger cash growth. Third, firms hold cash as their marginal source of funding in the model. Therefore, they draw down their cash reserves to fund capital investment when growth opportunities arise. I show that, in both the data and the model, idiosyncratic productivity growth is positively correlated with capital investment and debt growth, while negatively correlated with cash growth. Further, I show that models without the costly liquidity shortages or debt

issuance frictions highlighted in this paper fail to reproduce these empirical patterns.

I then study the responses of the model economy to an unexpected uncertainty shock and show that the calibrated model reproduces the observed impacts of macro uncertainty shocks at both firm and aggregate levels. As standard in the literature, I compute the perfect foresight transition path of the economy to a mean-preserving spread in the productivity distribution. In the calibrated model, a sharp surge in macro uncertainty leads to significant balance sheet adjustments across firms that align well with the data patterns documented in the empirical exercises. It also generates a sharp and protracted drop in aggregate output along with a spike in the cross-sectional dispersion of sales growth, consistent with the empirical findings in the literature. Notably, existing uncertainty literature takes the observed increase in the dispersion of sales growth following uncertainty shocks as exogenous. Understanding the variable is important since it has been used to characterize periods of high uncertainty. The balance sheet channel suggests that the increased dispersion reflects heterogeneous responses to elevated uncertainty across differently indebted firms.

Finally, I exploit the calibrated model to illustrate the novel policy implications of the balance sheet channel. Two findings stand out. Stimulus policy, such as investment tax credits, that simulates aggregate output by 0.5% on impact during normal times can barely drive up aggregate output following an uncertainty shock. The weak effect of stimulus policy in uncertainty-driven recessions arises since heightened uncertainty motivates firms to hoard cash, thereby depressing firms' use of cash for policy-induced capital investments. In sharp contrast, the debt relief program that stimulates aggregate output by 0.5% on impact during normal times can drive up aggregate output by 1.5% following uncertainty shocks. The net present value of the debt relief program also exceeds one when implemented following uncertainty shocks. By reducing corporate deleveraging and cash buildup in response to elevated macro uncertainty, debt relief mitigates the balance sheet transmission of uncertainty shocks, thereby strongly and effectively stabilizing uncertainty-driven recessions.

My policy experiments provide novel insights into the recent debate on credit interventions as stabilization tools. First, existing work abstracts from the elevated uncertainty during recessions and argues credit interventions as ineffective stabilization tools. This paper contributes to the growing literature by highlighting the ability of credit interventions to counteract the adverse impact of uncertainty shocks. Second, I also show that credit interventions yield much weaker effects in a TFP-driven recession than in an uncertainty-driven recession, which suggests the nature of the recessions in

shaping policy impacts. Third, I show that corporate cash choice is important for understanding the effects of credit interventions. A counterfactual simulation that fails to capture cash buildup following elevated uncertainty underestimates the stimulative effects of debt relief by more than 30%.

The rest of the paper is organized as follows. Section 1.1 presents a literature review. Section 2 provides empirical evidence. Section 3 develops a quantitative heterogeneous-firm model with financial frictions. Section 4 discusses model calibration. Section 5 presents model mechanics and model validation. Section 6 studies the transmission mechanism of uncertainty shocks in the model. Section 7 examines the policy implications of the model. Section 8 concludes.

1.1 Literature and Contributions

The paper fits into a new research agenda discussed in Brunnermeier and Krishnamurthy (2020), which aims to integrate firm-level corporate financing considerations in quantitative macroeconomic models to study the macroeconomic implications of corporate financial decisions. In particular, this paper joins and contributes to four strands of literature in macroeconomics and finance.

Financial frictions and aggregate shocks. The paper contributes to a large macro-finance literature that studies the role of financial frictions and corporate financial decisions in transmitting and amplifying aggregate shocks. Seminal examples include Bernanke et al. (1999), Cooley and Quadrini (2006),Khan and Thomas (2013), Gomes et al. (2016), Crouzet et al. (2016), Jungherr and Schott (2019), and Ottonello and Winberry (2020). This paper studies the role of corporate financial considerations in transmitting uncertainty shocks. Gilchrist et al. (2014) and Arellano et al. (2019) highlight corporate deleveraging in propagating uncertainty shocks. Like most macro-finance models, they abstract from corporate cash choice.[6]I build a model with joint capital, cash, and debt choices, which generates both deleveraging and cash buildup observed in the data. The paper highlights the importance of accounting for corporate cash behavior in understanding the transmission of uncertainty shocks and the stabilizing effects of credit interventions in an uncertainty-driven recession.

Impact of uncertainty shocks. This paper contributes to an extensive literature in

[6] Alfaro et al. (2019) shows that financial frictions amplify the 'real options' effects of uncertainty shocks on capital investment in a model with capital and cash choice. The core mechanism of their model is still the 'real options' effects of uncertainty shocks.

macroeconomics and finance that studies the impact of heightened uncertainty on firm behavior. On the empirical front, I first provide new empirical evidence on the effects of uncertainty shocks on firms' capital, cash, and debt choices. My results echo some existing findings in the literature: a negative investment-uncertainty relationship (Leahy and Whited (1996), Bloom et al. (2007), Gulen and Ion (2016), Kim and Kung (2017), Kermani and Ma (2020)), a positive cash-uncertainty relationship (Opler et al. (1999), Bates et al. (2009), Gao et al. (2017), Smietanka et al. (2018), a negative debt-uncertainty relationship (Rashid (2013), Gilchrist et al. (2014). This paper also adds to the empirical literature by documenting heterogeneous responses of capital and cash to elevated uncertainty across differently indebted firms.

On the theoretical front, this paper illustrates how corporate saving motives and ex-ante financial conditions determine firms' responses to uncertainty shocks. The mechanism differs significantly from existing transmission mechanisms. The 'real-options' effect of uncertainty shocks emphasizes the delays in capital investment driven by non-convex investment technology (see, e.g. Bloom 2009, Bloom et al. 2018). Another strand of the theoretical literature emphasizes the positive effect of uncertainty shocks on credit spreads, which leads firms to cut investment and employees (see, e.g. Gilchrist et al. (2014) and Arellano et al. (2019)). Alfaro et al. 2019 incorporates corporate cash choice into a 'real-options' framework. They show that adding cash choice amplifies the classical 'real-options' effects. The driving force of their models is still the 'real-options' effect. As they show in the paper, once the 'real-options' effect is shut down, heightened uncertainty does not affect capital investment. I see my mechanism as a third one in the literature, and my mechanism is motivated by different aspects of the data.

Empirical and theoretical corporate finance. The paper joins and builds on empirical and theoretical corporate finance literature. First, a large empirical corporate finance literature studies corporate cash-holding motives and finds empirical evidence on the role of cash holding in overcoming both financial distress and financing frictions. Some prominent examples include Opler et al. (1999), Faulkender and Wang (2006), Bates et al. (2009). This paper incorporates the two cash-holding motives into a structural model and shows their roles in rationalizing firm responses to uncertainty shocks. Second, the model framework builds upon existing dynamic corporate finance models, for example, Hennessy and Whited (2005), Titman and Tsyplakov (2007), Gamba and Triantis (2008), Riddick and Whited (2009), Eisfeldt and Muir (2016), Chen et al. (2021), Gomes and Schmid (2021) and Gao et al. (2021). I contribute to the literature by show-

ing both empirically and theoretically how indebtedness shapes firms' choices between physical capital and cash holding, a trade-off faced by firms that have received relatively little attention in the literature so far.

Recessions and Credit interventions. Large-scale fiscal support for the corporate sector during the recent Covid crisis sparked a rapidly growing literature studying the efficacy of credit interventions using quantitative macro models, for example, Ebsim et al. (2020), Elenev et al. (2022), Crouzet and Tourre (2021), and Guntin (2022). Existing work focuses on recessions driven by first-moment shocks, such as a negative productivity shock, have very modest effects in recessions driven by aggregate productivity shocks. This paper instead emphasizes second-moment shocks in recessions and shows that credit interventions are powerful in stabilizing aggregate output drops driven by high uncertainty. This result sheds novel insights on the design of stabilization policies in recessions since heightened uncertainty has been a key feature of U.S. recessions ignored by existing work. Furthermore, I highlight the importance of models used to analyze policy impacts. Models that fail to capture observed cash buildup substantially underestimate output responses to debt relief programs.

2 Empirical Evidence

In this section, I provide new empirical evidence on firm-level responses to heightened uncertainty. The empirical analysis highlights two key empirical patterns:

(1). Following a macro uncertainty shock, physical capital and outstanding debt fall while cash builds up.

(2). Firm indebtedness predicts heterogeneous asset choices in response to uncertainty shocks. The declines in physical capital and the buildup of cash holding are much more pronounced among *ex-ante* more indebted firms.

In Section 2.2, I exploit a Jordà (2005)-style local projection approach with firm-quarter data to estimate dynamic firm-level responses to changes in Macro Uncertainty Index by Jurado et al. (2015). In Section 2.3 and 2.4, I show that the baseline results hold both across and within firms and are robust to a wide set of controls and specifications.

2.1 Data

Measure of aggregate uncertainty. I employ the Macro Uncertainty Index developed by Jurado et al. (2015) as the baseline measure of macroeconomic uncertainty faced by U.S. firms, which captures forecast volatility of major macroeconomic variables implied by a large-scale time-series model. I take the quarterly average of their 1 month-ahead macroeconomic uncertainty index and use it as a proxy for quarterly macroeconomic uncertainty. Uncertainty shocks, or changes in aggregate uncertainty, are measured as the log growth of the index.

Firm-level variables. I draw firm-quarter observations from Compustat Quarterly. Compustat is ideal for this study: First, it contains rich balance sheet information, which allows me to study firms' financial behavior and measure firms' financial positions. Second, it includes detailed information on firms' sales and cash flows. This is important to a study that examines the effects of uncertainty (second-moment) on firm behavior, in which controlling for changes in first-moment variables, i.e. investment opportunities becomes essential. To the best of my knowledge, Compustat is the only U.S. dataset that satisfies these requirements. The sample period is 1990q1 to 2018q4, which avoids changes in accounting rules in the late 1990s and in 2019. Firms in the financial (SIC code 6000-6999), utilities (SIC code 4900-4949), and government-regulated industries (SIC code $>$ 9000) are excluded since the study focuses on non-financial corporate business. The key dependent variables include firm-level growth in physical capital, cash holding, and total outstanding debt. I also construct widely used firm-level control variables such as Tobin's Q, Sales Growth, Firm Size, Cash Flows, and Debt Maturity. All variables are deflated by the 2012 GDP deflator. Sample selection and variable construction follow standard practices in the literature, which is detailed in Appendix A. Table A1 presents summary statistics of key firm-level variables.

Firm indebtedness. Firm indebtedness is defined as the net leverage of firms, total outstanding debt of firms *minus* their cash holding and then scaled by their total assets. To capture cross-sectional variation in indebtedness in each quarter, I standardize each of the firm-quarter observations of indebtedness for a firm i in quarter t by its industry-level average and standard deviation in quarter t. Therefore, the firm-level indebtedness measure used in the following regressions captures how one firm is more or less indebted than its industry average in each quarter. As documented by Kim and Kung (2017) and Gulen and Ion (2016), the impact of uncertainty varies across industries that feature different levels of capital irreversibility. Since the levels of indebt-

edness also vary across industries, the heterogeneous effects driven by differences in indebtedness might be simply driven by firms that operate in certain industries that feature both high indebtedness and high sensitivity to uncertainty shocks. The use of the 'within-industry cross-sectional variation' in indebtedness addresses this concern.

2.2 Firm-Level Responses to Uncertainty Shocks

Baseline local projection. I employ a Panel Local Projection empirical specification to estimate both the average responses to uncertainty shocks across all sample firms, as well as heterogeneous responses across differently indebted firms:

$$\underbrace{\Delta_h \log(y_{i,t+h})}_{\text{Cumulative growth}} = \alpha_{i,h} + \alpha_{fq,h} + \Big(\underbrace{\boldsymbol{\beta_h}}_{\text{Average}} + \underbrace{\gamma_h}_{\text{Heterogeneous}} \text{Indebtedness}_{i,t-1} \Big) \cdot \underbrace{\Delta \log \sigma_t}_{\text{Uncertainty Shock}} \tag{1}$$

$$+\eta_h \text{Indebtedness}_{i,t-1} + \Gamma_h' \underbrace{\mathbf{Z}_{i,t-1}}_{\text{Firm controls}} + \sum_{l=0}^{4} \Lambda_{l,h}' \underbrace{\mathbf{Y}_{t-l}}_{\text{Macro controls}} + \mu_{i,t+h}$$

$$\forall i, h = 0, 1, 2, 3, ..., 12$$

where $h \geq 1$ denotes the horizon at which the impact is being estimated, $\Delta_h \log(y_{i,t+h}) = \log(y_{i,t+h}) - \log(y_{i,t})$ is the cumulative growth in firm-level outcomes over horizon h. $\Delta \log \sigma_t$ denotes the growth in the Macro Uncertainty Index in quarter t. The coefficient of interest β_h, therefore, captures average growth in dependent variables across firms at quarter $t + h$ following a change in the Macro Uncertainty Index at quarter t. $\text{Indebtedness}_{i,t}$ measures how many standard deviations of firm i's net leverage at t is away from its industry average. The industry is defined as 1-digit SIC level. Hence, the coefficient of interest $\boldsymbol{\gamma_h}$ captures differences in firm growth at quarter $t+h$ among firms with differential indebtedness following a change in Macro Uncertainty Index at quarter t. If firm indebtedness affects how firms react to uncertainty shocks, then $\boldsymbol{\gamma_h}$ should be statistically significantly different from zero. Firm fixed effects $\alpha_{i,h}$ are included to absorb unobserved permanent differences across firms. Fiscal-quarter dummy $\alpha_{fq,h}$ is included to absorb the impact of differences in fiscal-quarter across firms on firm behavior. I cluster standard errors in two ways to account for correlation within firms and within quarters.

One common concern in estimating the effects of aggregate uncertainty is that changes in firm behavior following a rise in aggregate uncertainty might be driven by

changes in other macroeconomic conditions that are correlated with changes in uncertainty. Recent literature has shown that uncertainty is counter-cyclical, and large rises in uncertainty tend to occur in recessions, see e.g. Bloom et al. (2018). To mitigate these concerns, I control both current and lagged macroeconomic variables $\sum_{l=0}^{4} \Lambda_{l,h}' \mathbf{Y}_{t-l}$, including real GDP growth rate, inflation rate, real federal funds rate, and credit spreads to absorb the effects of confounding macroeconomic forces on firm behavior. In addition, I include a vector of firm-level variables $\mathbf{Z}_{i,t-1}$ to control for cross-sectional differences in investment opportunities and financial conditions at the firm level: Tobin's Q, Sales Growth, Firm size, Cash Flows, and Debt Maturity, which are widely used in the empirical literature.

Baseline results. Figure 1 plots both average and heterogeneous responses of (a) physical capital, (b) cash holding, and (c) outstanding debt to a one-standard-deviation growth in Macro Uncertainty Index. Figure 1 shows that following a one-standard-deviation growth (4.5 %) in the Macro Uncertainty Index, average firm-level physical capital drops, cash holding grows, and outstanding debt falls. The average responses are statistically significant at the 5% significance level and persist for more than three years, with the peak appearing two years after the shock. The estimated average responses echo previous findings in the literature.

I find that variation in *ex-ante* firm indebtedness foreshadows a statistically significant shift in firms' asset choices following heightened uncertainty. Panel (A) and (B) of Figure 1 show that following a one-standard-deviation growth (4.5 %) in the Macro Uncertainty Index, the decline in physical capital is around 0.5% larger and the buildup of cash is around 1.5% larger for firms that are one-standard-deviation more indebted than their industry averages. Moreover, Panel (C) of Figure 1 shows that there is no statistically significant difference in debt growth across differently indebted firms. Taken together, instead of cutting more debt, *ex-ante* more indebted firms respond to heightened uncertainty by reallocating more of their assets towards cash holding. A key takeaway of the empirical analysis is that cash build-up is a salient feature of firm responses to an elevated uncertainty in the data, while conventional macro-finance models typically abstract from corporate cash choice when firms have outstanding debt.

2.3 Heterogeneous Responses by Firm indebtedness

Extended local projection. To mitigate concerns on the differential responses driven by variation in firm indebtedness, I estimate the following specification:

$$\Delta_h \log(y_{i,t+h}) = \alpha_{i,h} + \alpha_{fq,h} + \alpha_{s,t,h} + \underbrace{\boldsymbol{\gamma_h}\text{Indebtedness}_{i,t-1} \cdot \Delta \log \sigma_t}_{\text{Heterogeneous responses}} + \beta_h \text{Indebtedness}_{i,t-1} \tag{2}$$

$$+ \underbrace{\boldsymbol{\Psi_h'}\mathbf{Z}_{i,t-1} \cdot \Delta \log \sigma_t + \Gamma_h' \mathbf{Z}_{i,t-1}}_{\text{Firm controls}} + \underbrace{\boldsymbol{\eta_h}\text{Indebtedness}_{i,t-1} \cdot \Delta \log GDP_t}_{\text{Cyclical sensitivity}} + \mu_{i,t+h}$$

$$\forall i, h = 0, 1, 2, 3, ..., 12$$

where $h \geq 1$ denotes the horizon at which the impact is being estimated, $\frac{1}{h}\Delta_h \log(y_{i,t+h}) = \log(\frac{y_{i,t+h}}{y_{i,t}})$ is the average cumulative growth in firm-level outcomes over horizon h. $\Delta \log \sigma_t$ measures log growth in Macro Uncertainty Index at quarter t, and $\Delta \log GDP_t$ measures real GDP growth at quarter t. $\alpha_{i,h}$ indicate firm fixed effects. Fiscal-quarter dummy $\alpha_{fq,h}$ is included to absorb the impact of differences in fiscal-quarter across firms on firm behavior. Since the focus is heterogeneous responses across firms, I include industry-by-quarter fixed effects $\alpha_{s,t,h}$ to absorb differences in how broad industries are exposed to aggregate shocks. The industry is defined at 1-digit SIC level. $\text{Indebtedness}_{i,t-1}$ measures how many standard deviations of firm i's net leverage at $t-1$ is away from its industry average at quarter $t-1$. $Z_{i,t-1}$ indicates a vector of firm-level control variables. The main coefficients of interest $\boldsymbol{\gamma_h}$ capture heterogeneous responses to changes in the Macroeconomic Uncertainty Index driven by pre-shock variation in corporate indebtedness across firms.

Regression (2) addresses two major concerns on the heterogeneous responses to uncertainty shocks driven by variation in firm indebtedness. First, Firm indebtedness is endogenous and might vary systematically with other dimensions of firms. For example, more indebted firms might simply have fewer investment opportunities, and thus the heterogeneous responses across differently indebted firms might be driven by cross-sectional variation in investment opportunities. To mitigate this type of concern, I interact $\boldsymbol{\Delta \log \sigma_t}$ with **Firm controls** that have been found to be important drivers of firms' investment and financial behavior: Tobin's Q, Sales Growth, Firm Size, Cash flows, and Debt Maturity. Hence, the extended specification also allows firms' responses to differ along other dimensions of firms. The second type of concern is that more indebted firms might be more sensitive to fluctuations in business cycles, which

are negatively correlated with aggregate uncertainty. To mitigate this concern, I include an interaction term $\text{Indebtedness}_{i,t-1} \cdot \Delta \log GDP_t$ to absorb potential heterogeneity in cyclical sensitivity across firms with differential indebtedness.

Figure 2 shows that the baseline results are robust to including heterogeneous responses along other dimensions of firms and heterogeneous cyclical sensitivity across firms. Consistent with the baseline results, the response of capital growth is more negative, and the response of cash growth is more positive for *ex-ante* more indebted firms.

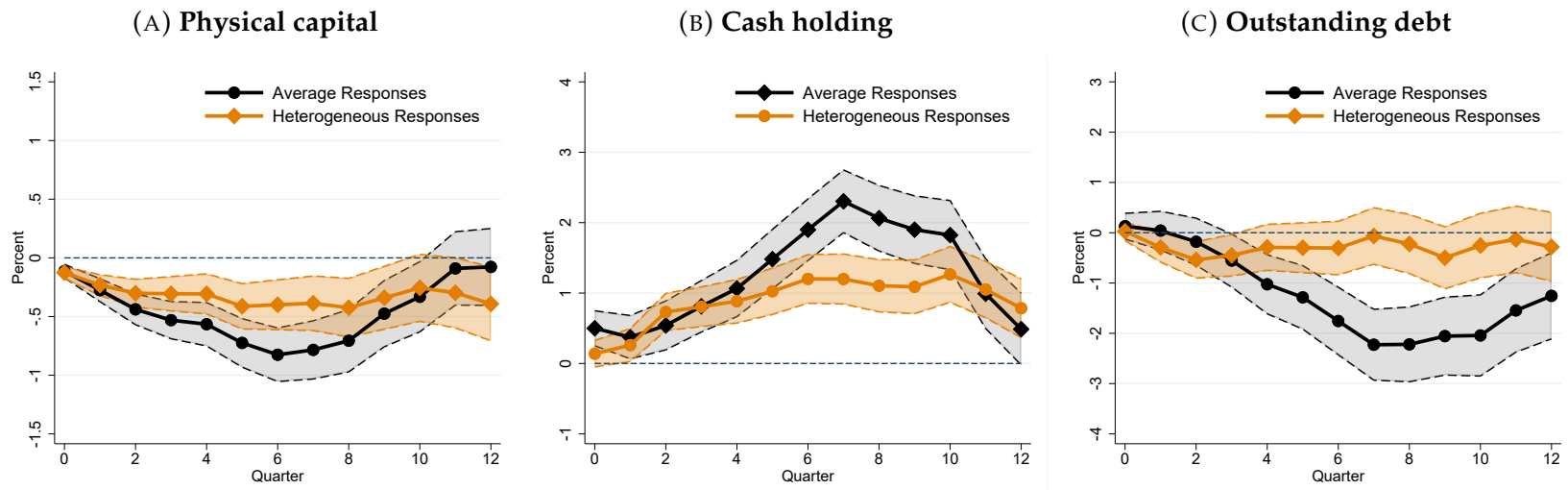
2.4 Additional Empirical Results

I conclude the empirical analysis with additional results and robustness exercises.

Within-firm variation. The baseline results suggest that cross-sectional variation in firm indebtedness predicts differential responses to uncertainty shocks. In Appendix B.1, I show that similar patterns emerge when using within-firm variation in indebtedness over time. I compute the deviation of firm's net leverage from its unconditional firm-specific average, and interact it with uncertainty shocks. Figure A1 shows that the responses of physical capital and cash holding to changes in the Macro Uncertainty Index are also stronger when firms are more indebted than their own average levels. These results provide additional evidence on the role of firm indebtedness in shaping firm responses to uncertainty shocks.

Event study: 9/11 terrorist attacks. To further confirm the interpretation of the empirical findings, I conduct an event study that follows the uncertainty literature exploiting 9/11 terrorist attacks as a plausibly exogenous increase in aggregate uncertainty (e.g. Bloom (2009); Kim and Kung (2017)). Appendix B.2 details the empirical design. I find that the firm behavior observed around the 9/11 terrorist attacks accords well with the baseline results. Panel A of Figure A2 shows that the post-9/11 period features statistically significant declines in physical capital and outstanding debt, as well as a large buildup in cash holding on average across firms. Panel B of Figure A2 shows that differences in lagged indebtedness predict differential asset choices in the post-911 period.

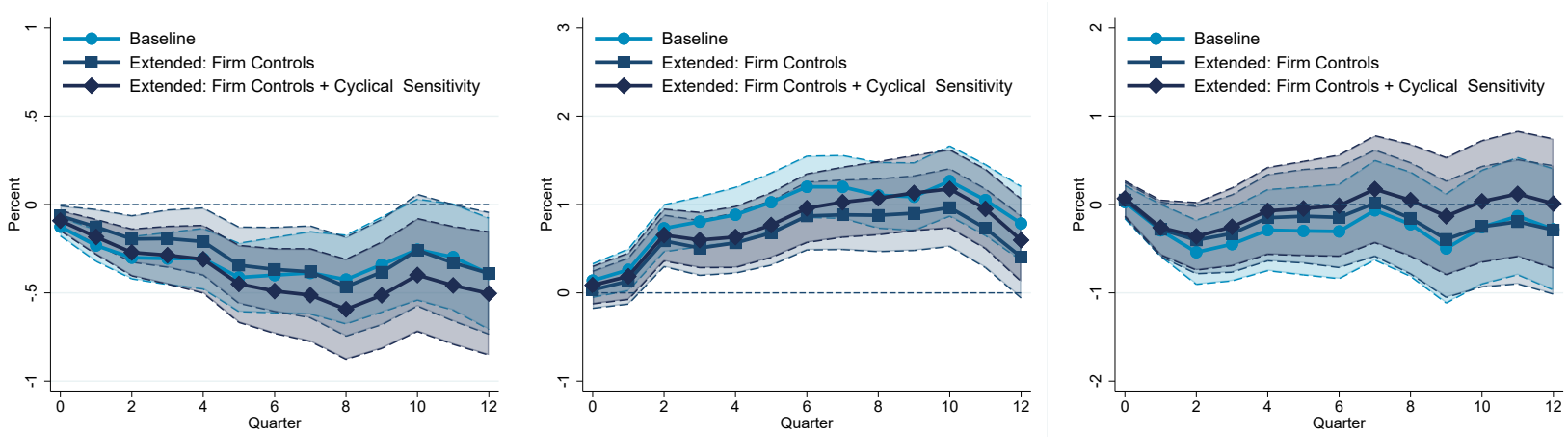
FIGURE 1: **Baseline Local Projection: Firm-Level Responses to 1 S.D. Growth in Macro Uncertainty Index**



Notes: the figure plots both the average and heterogeneous responses of (a) physical capital, (b) Cash holding, and (c) outstanding debt to a one-standard-deviation growth in Macro Uncertainty Index by Jurado et al. (2015) at quarter t. The heterogeneous responses are driven by cross-sectional variation in indebtedness at quarter $t-1$. Indebtedness$_{i,t-1}$ measures how many standard deviations of firm i's net leverage at $t-1$ is away from its industry average at quarter $t-1$. Point estimates and 95% confidence intervals for β_h and γ_h are plotted. Standard errors are two-way clustered at both firm and time levels. The sample period is from 1990Q1 to 2018Q4.

FIGURE 2: **Extended Local Projection: Heterogeneous Responses by Firm indebtedness**

(A) **Physical capital** (B) **Cash holding** (C) **Outstanding debt**



Notes: this figure plots both the heterogeneous responses of (a) physical capital, (b) cash holding, and (c) outstanding debt to a one-standard-deviation growth in Macro Uncertainty Index by Jurado et al. (2015) at quarter t. The heterogeneous responses are driven by cross-sectional variation in indebtedness at quarter $t-1$. Indebtedness$_{i,t-1}$ measures how many standard deviations of firm i's net leverage at $t-1$ is away from its industry average at quarter $t-1$. I interact $\boldsymbol{\Delta \log \sigma_t}$ with **Firm controls** that have been found to be important drivers of firms' investment and financial behavior: Tobin's Q, Sales Growth, Firm Size, Cash flows and Debt Maturity. Hence, the extended specification also allows firms' responses to differ along other dimensions of firms. I also include an interaction term Indebtedness$_{i,t-1} \cdot \boldsymbol{\Delta \log GDP_t}$ to absorb potential heterogeneity in cyclical sensitivity across firms with differential indebtedness. Point estimates and 95% confidence intervals for β_h and γ_h are plotted. Standard errors are two-way clustered at both firm and time levels. The sample period is from 1990Q1 to 2018Q4.

3 Quantitative Model

In this section, I develop a quantitative heterogeneous-firm model in which firms make optimal capital, cash, and debt choices in the presence of financial market frictions. Relative to the existing heterogeneous firm model with financial frictions, the model features empirically consistent corporate borrowing and saving behavior. To do so, my model incorporates two additional financial frictions motivated by corporate finance literature : (i). costly liquidity shortages in the face of debt repayment; (ii). debt issuance frictions when firms have an outstanding debt that has not matured. In this section, I first describe the details of the model in a stationary industry equilibrium. I study the perfect transition path of the economy to uncertainty shocks in Section 6,.

3.1 Environment

Time is discrete and the horizon is infinite. The economy is populated by a continuum of heterogeneous firms that make optimal investment and financial decisions in the presence of idiosyncratic productivity shocks and financial market frictions. Firms produce a homogeneous good in a competitive market and sell their products at a price of 1. They hire labor in the labor market at a wage rate W determined by labor market clearing.

There is a representative household that has preferences over the final consumption good and supplies labor according to

$$L^s(W) = \psi W^{\zeta}, \tag{3}$$

where $\psi > 0$ denotes the disutility of working, and $\zeta > 0$ is the labor supply elasticity. There is also a mass of risk-neutral/deep-pocketed financial intermediaries who provide financial services.

I first study a stationary equilibrium in which there is no aggregate shock and all aggregate variables are constant. I then study the perfect foresight transition path in response to unexpected uncertainty shocks. I drop subscripts for a firm i and period t, and adopt the recursive timing convention, except in parts where such choice may jeopardize the clarity of exposition.

3.2 Firm's Setup

Firms are **risk-neutral** and discount the future at an exogenous risk-free interest rate r. Firms have access to the same production and financing technologies. In each period, each firm's risk-neutral manager maximizes the expected present value of dividends to equity holders by choosing capital, cash, and debt.

Technology. Each firm combines physical capital k and labor l to produce a homogeneous good y using a decreasing return to scale production technology. Firm production is subject to idiosyncratic productivity shocks z. The production function is as follows:

$$y = z^{1-\nu} k^{\alpha} l^{\nu}, \alpha + \nu < 1 \tag{4}$$

α is the value-added share of capital, and ν is the value-added share of labor.

Productivity. Firm-specific productivity shock z_{it} evolves according to

$$\log(z_{i,t+1}) = \mu_t + \rho \log(z_{it}) + \sigma_t \epsilon_{i,t+1} \tag{5}$$

where the innovations $\epsilon_{i,t+1} \sim N(0,1)$ are independent across firms. μ_t denotes an adjustment to the level of firms' productivity. σ_t denotes the volatility of the innovations.

Equation (5) implies that the level of volatility σ_t today determines the distribution of next-period idiosyncratic productivity $z'(\sigma_t)$. Thus, from the perspective of firms in the model, high volatility σ_t today indicates a more widely spread distribution of tomorrow's idiosyncratic productivity. That is, during a period of high volatility σ_t, firms are more likely to draw both high and low idiosyncratic productivity, a scenario where firms face both higher downside risk (due to a higher probability of bad productivity shock) and larger growth potential (due to higher probability of good productivity shock). As in Gilchrist et al. (2014), the volatility term σ_t is common across firms and thus an increase in σ_t affects all firms and hence captures "uncertainty" shock in the aggregate sense.

Importantly, μ_t is chosen to be $\frac{-\sigma_t^2}{2}$, and consequently the conditional mean of firms' productivity $E[\log(z_{i,t+1})|\log(z_{i,t}), \sigma_t]$ is not affected by the level of volatility σ_t. In other words, changes in σ_t do not affect the expected aggregate productivity of the economy. Therefore, a change in σ_t is also considered as a "Second-moment Shock" or a "Dispersion Shock". In this paper, I first solve for a stationary equilibrium by fixing σ_t at σ_L to study firms' optimal investment and financial decisions. I then study a perfect

foresight transition path in response to unexpected jumps in σ_t, i.e. uncertainty shocks.

Operating profits. Physical capital k is owned by firms and chosen one period before. After the realization of idiosyncratic productivity z each period, firms hire labor from a competitive labor market at a wage rate W to maximize their operating profits. As in Gilchrist et al. (2014) and Xiao (2018), firms also pay operating costs each period. To account for the fact that bigger firms tend to incur larger operating costs, these costs are scaled by firms' existing stock of physical capital. Thus, a firm with physical capital k will pay operating costs $f_o k$. [7] Firms' per-period operating profits are therefore given by the solution to the following static profit-maximization problem:

$$\begin{aligned}\pi(z,k;W) &= \max_{l}\{z^{1-\nu}k^{\alpha}l^{\nu} - f_o k - Wl\} \\ &= (1-\nu)\left(\frac{\nu}{W}\right)^{\frac{\nu}{1-\nu}} z k^{\frac{\alpha}{1-\nu}} \\ &= z\psi(W)k^{\gamma} - f_o k\end{aligned}$$

where W denotes the (real) wage and

$$\gamma = \frac{\alpha}{1-\nu} \qquad \text{and} \qquad \psi(W) = (1-\nu)\left(\frac{\nu}{W}\right)^{\frac{\nu}{1-\nu}}$$

This setup ensures that the firm's profit function is linear in its productivity, as in Gilchrist et al. (2014). The detailed solution to the problem is shown in Appendix C.1.

Asset structure. Firms own physical capital, which depreciates at a constant rate $\delta > 0$. Each period firms have an opportunity to choose their next period's capital stock, k'. The law of motion for firms' capital stock is given by

$$k' = (1-\delta)k + i \tag{6}$$

where i denotes the net capital (dis)investment of firms.

In addition to holding physical capital k, firms can also save in liquid assets c at an exogenous risk-free rate r. I interchangeably refer to liquid assets as "cash" throughout the paper.

Entry and Exit. As in Khan and Thomas (2013), firms are forced to exit the economy after production with a fixed probability π^e, This assumption precludes all firms from

[7] The operating cost f_o helps to match the average operating profits of firms in the data, which further affects average cash held by firms, as in Xiao (2018).

overcoming the financial frictions in the steady state of the economy, which leads to an unrealistic and uninteresting firm distribution. The exit shock is i.i.d across firms and time. Equity holders of exiting firms receive the residual firm value, i.e. book value of total assets net of all debt obligations. Exiting firms are then replaced by entrants such that there is always a unit mass of firms. Entrants' problems are discussed in greater detail in Section 3.5. Firms that survive the exit shocks choose next-period physical capital, cash holding, and outstanding debt and enter the next period with entrants.

3.3 Sources of Funds and Financial frictions

Firms can finance their assets and operation through three different sources of funds: internal liquidity, debt, and outside equity. Firms enter the period with their physical capital k, liquid assets holding c, and outstanding debt b.

Internal liquidity. Each period, after production and tax, the internal liquidity available to the firms includes after-tax operating profits, liquid assets holding, and tax rebates:

$$\underbrace{l(z,k,c,b)}_{\text{Internal liquidity}} = (1-\tau) \underbrace{\pi(z,k)}_{\text{Operating profits}} + \underbrace{[1+(1-\tau)r]c}_{\text{Liquid assets}} + \underbrace{\tau(rb+\delta k)}_{\text{Tax rebates}} \tag{7}$$

where τ denotes the corporate tax rate. Note that interest income rc from corporate cash savings are taxed, and interest expenses rb and depreciation δk are tax-deductible.

Debt financing. Firms in the model take on debt to finance their asset choices or to enjoy the tax shield of debt. Risk-neutral deep-pocket lenders impose a collateral constraint ensuring that the outstanding debt obligation is not larger than the value of the capital stock, and thus debt service only requires a coupon rate equal to the risk-free rate r. Consequently, firms' choice of next-period debt b' must satisfy the borrowing constraint:

$$\underbrace{(1+r)b'}_{\text{debt obligation}} \leq \theta \underbrace{(1-\delta)k'}_{\text{collateral value}}, 0<\theta<1 \tag{8}$$

where θ denotes the pledgeability of physical capital.

Debt maturity and adjustment. As in Gomes and Schmid (2021) and Chen et al. (2021), corporate debt is modeled as long-term debt that matures randomly with a given probability λ. Specifically, with probability λ, the firm's outstanding debt matures, and with

probability $1-\lambda$, the firm's outstanding debt continues, and firms only repay coupon payments. The expected debt maturity is, therefore, $\frac{1}{\lambda}$. This setup keeps the model tractable while allowing the model to generate a more realistic debt maturity process: (i). The average maturity of outstanding debt of non-financial firms is significantly longer than one period. (ii). Firms pay coupon payments before maturity and repay the principal at maturity.

When existing debt matures, firms cannot take on new debt until they have repaid their debt obligations in full,[8] and importantly, firms are in liquidity shortfalls if internal liquidity is insufficient to meet their maturing debt obligations.[9] The liquidity gap for debt repayment is given by:

$$\underbrace{m}_{\text{Liquidity gap}} = \underbrace{l(z,k,c,b)}_{\text{Internal liquidity}} - \underbrace{(1+r)b}_{\text{Maturing debt obligations}}$$

where $m<0$ indicates the event of liquidity shortfalls. When liquidity shortfalls arise, a penalty is triggered. Specifically, firms suffer a cash flow penalty proportional to their liquidity gap, as in Titman and Tsyplakov (2007). In these scenarios, firms' cash flows after taking into account costly liquidity shortfalls can be written as:

$$m - s \cdot |m| \cdot \mathbf{1}_{m<0} \tag{9}$$

where s is the parameter that governs the costs of liquidity shortfalls. Firms can then finance their liquidity shortfalls by disinvestment or new debt/equity issuance.

Prior to debt maturity, indebted firms can adjust their outstanding debt, that is, debt is callable at par.[10] Firms can lower their debt level without any costs while increasing debt level entails issuance costs proportional to additional debt issued η. The debt adjustment of firms with non-maturing debt can be summarized as follows:

$$\underbrace{R(b,b')}_{\text{Debt adjustment}} = \begin{cases} b' - (1+r)b - (1-\eta)\left|b'-b\right|, & \text{if } b' > b \\ b' - (1+r)b, & \text{if } b' < b \end{cases} \tag{10}$$

[8] This timing convention follows Hennessy and Whited (2005), Titman and Tsyplakov (2007), Gamba and Triantis (2008), and so on.

[9] Hennessy and Whited (2005) abstracts from corporate cash holding, and thus firms are considered in liquidity shortfalls as long as firms' realized operating profits are insufficient to cover their debt burdens. This paper models cash holding explicitly and highlights firms' liquidity management.

[10] Conceptually, debt restructuring, as in Goldstein et al. (2001), requires firms to call back all of their outstanding debt first and then issue new debt at the desired level. Therefore, there is always only one vintage of debt from the firm's most recent restructuring.

The debt issuance costs capture the difficulties of issuing new debt when firms have debt outstanding. For example, restrictive covenants and seniority rules in debt contracts make new debt issuance especially costly.

Equity financing. Firms' choices of next-period physical capital k', liquid assets holding c', and outstanding debt b', together with their internal liquidity $l(z,k,c,b)$ and undepreciated capital stock $(1-\delta)k$, determine firms' cash flows to their equity holders d. When $d \geq 0$, it represents dividend payout to the equity holders. When $d < 0$, firms issue new equity. Following Hennessy and Whited (2007) and Eisfeldt and Muir (2016), the equity issuance cost is as follows:

$$\Phi(d) = \mathbf{1}_{d<0} \cdot \left(\kappa_0 + \frac{\kappa_1}{2} d^2\right) \tag{11}$$

where κ_0 captures the fixed costs of equity issuance and κ_1 captures the variable costs of equity issuance. The equity issuance costs reflect agency problems in financial markets.

3.4 Timing

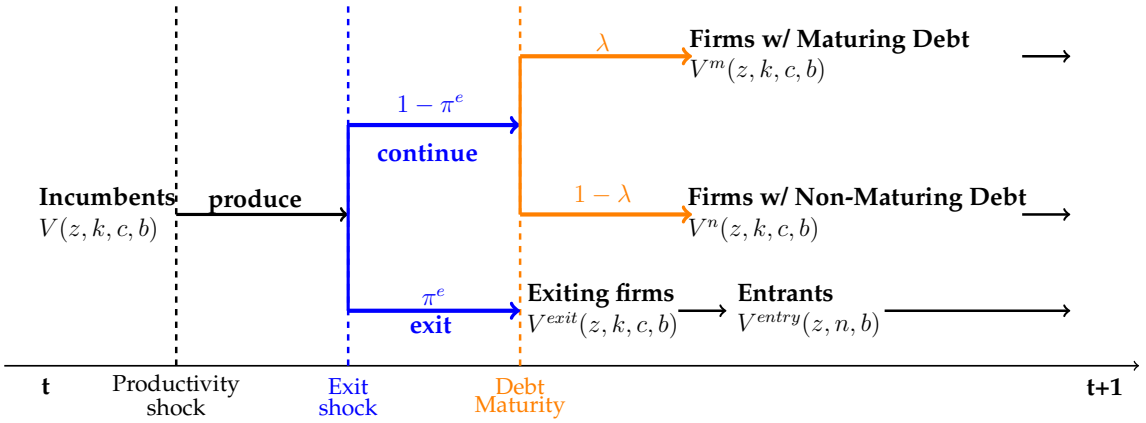
The timing of events within each period is as follows:

(1) Firms enter the period with physical capital k, liquid assets holding c, and outstanding debt b. After observing their idiosyncratic productivity z, firms hire labor to maximize their current operating profits. Firms also observe aggregate uncertainty σ_t and thus form beliefs about tomorrow's idiosyncratic productivity.

(2) After production, exit shocks realize. π^e fraction of firms that are hit by exit shocks exit the economy permanently. $(1-\pi^e)$ fraction of incumbent firms continue to the next stage.

(3) With probability λ, firm's outstanding debt b matures. Continuing firms with maturing debt repay their debt first, then choose next-period capital k'/cash c' /new debt b'. Continuing firms with non-maturing debt can choose next-period capital k', cash c', and debt $R(b,b')$.

(4) Potential entrants replace exiting firms and solve entrants' problems. They then enter the next period with continuing firms.



3.5 Firms' Problems

I now characterize firms' problems recursively in detail.

Begin-the-period firm value. Let $V(z,k,c,b)$ represent the expected discounted value of a firm that enters the period with productivity z, physical capital k, liquid assets holding c, and outstanding debt b before it learns whether it will exit and whether its outstanding debt will mature.

$$\underbrace{V(z,k,c,b)}_{\text{Begin-the-period Firm Value}} = \pi^e \underbrace{V^{exit}(z,k,c,b)}_{\text{Value of Exiting Firms}} + (1-\pi^e)\Big[\underbrace{\lambda V^m(z,k,c,b) + (1-\lambda)V^n(z,k,c,b)}_{\text{Value of Continuing Firms}}\Big] \tag{12}$$

Value of existing firms. Equity holders of exiting firms receive the residual firm value, i.e. book value of total assets net of all debt obligations. Therefore, the value of exiting firm is defined as follows:

$$\underbrace{V^{exit}(z,k,c,b)}_{\text{Value of Exiting Firms}} = \underbrace{l(z,k,c,b) + (1-\delta)k}_{\text{Asset value}} - \underbrace{(1+r)b}_{\text{debt value}} \tag{13}$$

Value of continuing firms w/ maturing debt. Conditional on survival, firms with maturing debt today need to pay off their maturing debt obligations. As discussed in Section 3.3, when their internal liquidity is insufficient to cover debt repayment, they suffer a reduction in their cash flows. They then choose next period's capital k', cash c', and new debt b' to maximize:

$$V^m(z,k,c,b) = \max_{k',c',b'} d - \Phi(d) + \frac{1}{1+r} E_{z'|z}[V(z',k',c',b')] \tag{14}$$

subject to

$$\text{[Liquidity gap]:} \quad m = \underbrace{l(z,k,c,b)}_{\text{Internal liquidity}} - \underbrace{(1+r)b}_{\text{Maturing debt obligations}}$$

$$\text{[Dividend flow]:} \quad d = m - \underbrace{\mathbf{s} \cdot |m| \cdot \mathbf{1}_{m<0}}_{\textbf{Liquidity shortfalls}} - \underbrace{[k' - (1-\delta)k]}_{\text{Investment}} - \underbrace{c'}_{\text{Cash}} + \underbrace{b'}_{\text{new debt}}$$

$$\text{[Borrowing constraint]:} \quad (1+r)b' \leq \theta(1-\delta)k', 0 < \theta < 1$$

$$\text{[Equity issuance costs]:} \quad \Phi(d) = \mathbf{1}_{d<0} \cdot \left(\kappa_0 + \frac{\kappa_1}{2} d^2\right)$$

Value of continuing firms w/ non-maturing debt. Continuing firms with non-maturing debt can choose next-period capital k', cash c', and debt $R(b,b')$ to maximize:

$$V^n(z,k,c,b) = \max_{k',c',b'} d - \Phi(d) + \frac{1}{1+r} E_{z'|z}[V(z',k',c',b')] \tag{15}$$

subject to

$$\text{[Dividend flow]:} \quad d = \underbrace{l(z,k,c,b)}_{\text{Internal liquidity}} + \underbrace{R(b,b')}_{\textbf{Debt adjustment}} - \underbrace{[k' - (1-\delta)k]}_{\text{Investment}} - \underbrace{c'}_{\text{Cash}}$$

$$\text{[Debt adjustment]:} \quad R(b,b') = \begin{cases} (1-\boldsymbol{\eta})(b'-b) - rb, & \text{if } b' > b \\ b' - (1+r)b, & \text{if } b' < b \end{cases}$$

$$\text{[Borrowing constraint]:} \quad (1+r)b' \leq \theta(1-\delta)k', 0 < \theta < 1$$

$$\text{[Equity issuance costs]:} \quad \Phi(d) = \mathbf{1}_{d<0} \cdot \left(\kappa_0 + \frac{\kappa_1}{2} d^2\right)$$

Value of entrants. Every period, entrants will replace exiting firms. Entrants draw an initial realization of the idiosyncratic shock z from the long-run invariant distribution implied by Equation (5), denoted by $\mu^{Entry}(z)$. They know about their initial asset size n_0, and initial leverage ratio $\frac{b_0}{n_0}$, and then choose their next period's asset portfolio k' and c':

$$V^{entry}(z,n_0,b_0) = \max_{c',k'} \beta E_{z'}[V(z',k',c',b_0)] \tag{16}$$

$$k' + c' = n_0$$

where n_0 and b_0 will be calibrated to match the size of entrants and the average entrant's leverage ratio in the data.

3.6 Equilibrium

Firm distribution. I begin by defining $\mu(z,k,c,b)$ as the cross-sectional distribution of firms over idiosyncratic productivity z, physical capital k, liquid assets holding c, and outstanding debt b. The evolution of the distribution of firms $\mu_{t+1}(z,k,c,b)$ is given by

$$\mu_{t+1}(z',k',c',b') = \tag{17}$$
$$(1-\pi_e)\Bigg[\int\int_{z'} \underbrace{\lambda \mathbf{1}\{\hat{k}_t^m(z,k,c,b)=k'\}\times\mathbf{1}\{\hat{c}_t^m(z,k,c,b)=c'\}\times\mathbf{1}\{\hat{b}_t^m(z,k,c,b)=b'\}}_{\text{transition of continuing firms with maturing debt}}$$
$$+\underbrace{(1-\lambda)\mathbf{1}\{\hat{k}_t^n(z,k,c,b)=k'\}\times\mathbf{1}\{\hat{c}_t^n(z,k,c,b)=c'\}\times\mathbf{1}\{\hat{b}_t^n(z,k,c,b)=b'\}}_{\text{transition of continuing firms with non-maturing debt}} dF(z'|z)d\mu_t(z,k,c,b)\Bigg]$$
$$+\pi_e\Bigg[\int\int_{z'} \underbrace{\mathbf{1}\{\hat{k}_t^o(z,n_0,b_0)=k'\}\times\mathbf{1}\{\hat{c}_t^o(z,n_0,b_0)=c'\}\times\mathbf{1}\{\hat{b}_t^o(z,n_0,b_0)=b_0\}}_{\text{transition of entry firms}} dF(z'|z)d\mu^{Entry}(z)\Bigg]$$

where $\{\hat{k}^m,\hat{c}^m,\hat{b}^m\}$ denote the policy functions of firms with maturing debt, $\{\hat{k}^n,\hat{c}^n,\hat{b}^n\}$ denote the policy functions of firms with non-maturing debt, and $\{\hat{k}^o,\hat{c}^o,\hat{b}^o\}$ denote the policy functions of entrants.

Aggregation. Given the firm distribution $\mu_t(z,k,c,b)$, I aggregate firm-level variables to aggregate variables. The aggregate output and aggregate labor demand are given by:

$$Y_t=\int y_t(z,k,c,b)d\mu_t(z,k,c,b) \quad \text{and} \quad L_t^d=\int n_t(z,k,c,b)d\mu_t(z,k,c,b)$$

Similarly, other variables can be aggregated, such as aggregate capital stock, liquid assets, and outstanding debt.

Equilibrium definition. *A stationary industry equilibrium in this economy consists of (i). aggregate prices: wage W and interest rate r, (ii). firm value functions* $\{V,V^m,V^n,V^{entry},V^{exit}\}$,
related firms policy functions, (iii). firm distribution $\mu(z,k,c,b)$, and a measure of entrants $\mu^{entry}(z)$ such that

(1). *Given W and r, $V(z,k,c,b),V^e(z,k,c,b),V^m(z,k,c,b),V^n(z,k,c,b)$ solve the continuing firms' problems (14) - (15) with related policy functions.*

(2). *Given r, $\tilde{V}(z,n_0,b_0)$ solve the entrants' problem (16) with related policy functions.*

(3). *The labor market clears:*

$$L_t^d = \int n_t(z,k,c,b)d\mu_t(z,k,c,b) = L^s(W) = \psi W^{\zeta}, \forall t$$

(4). *The distribution of firms satisfies (17). In a steady state, the distribution's law of motion is a fixed point.*

3.7 Optimal Firm Policies

In this subsection, I analyze firms' optimal investment and financial policies in detail, tracing their costs and benefits. For illustration purposes, I assume firms' value functions are differentiable.[11] For simplicity, I set the exogenous exit probability $\pi^e = 0$ in this section. Details on the analytical derivations below can be found in Appendix C.1.

Optimal payout policy. In an economy without equity issuance costs, the marginal value of cash flows to shareholders is always equal to one. On the other hand, the marginal value of firms' cash flows to shareholders might be greater than one in the presence of costly external finance. The first-order condition for dividends reveals the marginal value of firms' cash flows to shareholders in the model :

$$\Lambda(d) = \begin{cases} 1, & \text{if } d \geq 0 \\ 1 + \kappa_1 |d|, & \text{if } d < 0 \end{cases} \tag{18}$$

Formally, the marginal value of firms' cash flows to shareholders equals one when firms payout dividends $d \geq 0$, while it becomes larger than one when firms issue new equity $d < 0$ due to the equity issuance costs. In the model, an additional unit of internal funds might help firms avoid and reduce costly external finance. Thus firms can benefit from liquidity management in anticipation of future funding needs.

Optimal cash policy. Corporate cash holding allows firms to transfer internal resources across time and states where the marginal values of firms' cash flows to share-

[11] Firms' value functions are not everywhere due to equity issuance costs, liquidity shortfalls, and debt issuance costs.

holders differ. The condition for optimal cash holding is as follows:

$$\overbrace{\Lambda(d)\cdot\mathbf{1}}^{\text{marginal cost of cash}} \geq \overbrace{\frac{1}{1+r}E_{z'|z}\Bigg[\Lambda(d') \quad \underbrace{[1+(1-\tau)r]}_{\text{increase in internal liquidity}} \quad (1+\lambda\cdot s\cdot\mathbf{1}_{m'<0})\Bigg]}^{\text{marginal benefit of cash}} \tag{19}$$

The left-hand side of Equation (19) represents the firm's marginal cost of carrying one additional dollar of cash into the subsequent period. When firm payouts dividends, this cost is the marginal value of foregone dividends, which equals one. When firm issues equity, one additional unit of cash saving implies an additional unit of equity issuance, and thus its marginal cost is given by one plus the equity issuance costs. The right-hand side of Equation (19) represents the firm's marginal benefit of holding cash. Carrying one more unit of cash leads to an increase in next-period internal liquidity by $1+(1-\tau)r$ and thus increase dividends payout or reduces the amount of costly equity issuance. When a firm faces a liquidity shortfall for debt repayment $m'<0$, the increased internal liquidity further helps to reduce the amount of liquidity penalty firms need to cover.

Cash holding helps firms to avoid and reduce equity issuance costs in anticipation of both good and bad productivity shocks: (i). when firms are hit by good productivity shocks and thus have high investment needs, cash holding allows firms to fund investment without tapping frictional financial markets. (ii). when firms are hit by bad productivity shocks and thus generate low operating profits, cash holding allows firms to avoid and reduce liquidity shortfalls for debt repayment. These two cash-holding motives are consistent with the empirical patterns documented by a large empirical corporate finance literature.

Optimal investment policy. In the model with financing frictions, liquidity management is intimately intertwined with firms' capital investment decisions. The optimality condition pertaining to firms' investment policies is given by:

$$\overbrace{\Lambda(d)\cdot 1}^{\text{marginal cost of capital}} = \overbrace{\mu_b\theta(1-\delta)+\frac{1}{1+r}E_{z'|z}\Bigg[\Lambda(d')\Bigg[\underbrace{\Big[(1-\tau)\frac{\partial\pi(z,k)}{\partial k}+\tau\delta\Big]}_{\text{increase in internal liquidity}}(1+\lambda\cdot s\cdot\mathbf{1}_{m'<0})+(1-\delta)\Bigg]\Bigg]}^{\text{marginal benefit of capital}} \tag{20}$$

The left-hand side of Equation (20) represents the marginal cost of capital investment. Similar to cash saving, investing in one more unit of physical capital today reduces

current dividends or increases equity issuance, which is valued at the marginal value of current cash flows to shareholders $\Lambda(d)$. The right-hand side of Equation (20) represents the marginal benefit of capital investment, which has several components. Specifically, investing today builds up collateral and thus relaxes a firm's borrowing constraint (first component), and increases future internal liquidity (second component) and capital stock (third component). μ_b indicates the shadow value of collateral constraint.

Optimal debt policy. Increasing leverage, on the one hand, allows the firm to improve its current cash flows to shareholders, reflecting either increased dividends or lower equity issuance. On the other hand, it increases the firm's debt service tomorrow, thereby raising the likelihood that it will have to issue costly new shares in the future. The first-order conditions with respect to debt choice b' for firms with maturing and non-maturing debt are as follows:

$$\overbrace{\Lambda(d)\cdot 1-\mu_b}^{\text{marginal benefit of debt}} = \overbrace{\frac{1}{1+r}E_{z'|z}\left[\Lambda(d')\left[[1+(1-\tau)r](1+\lambda\cdot s\cdot \mathbf{1}_{m'<0})-(1-\lambda)\cdot\eta\cdot\mathbf{1}_{b''>b'}\right]\right]}^{\text{marginal cost of debt}} \tag{21}$$

$$\overbrace{\Lambda(d)\cdot(1-\eta)-\mu_b}^{\text{marginal benefit of debt}} = \overbrace{\frac{1}{1+r}E_{z'|z}\left[\Lambda(d')\left[[1+(1-\tau)r](1+\lambda\cdot s\cdot \mathbf{1}_{m'<0})-(1-\lambda)\cdot\eta\cdot\mathbf{1}_{b''>b'}\right]\right]}^{\text{marginal cost of debt}} \tag{22}$$

Equation (21) represents the first-order condition with respect to debt for firms with maturing debt obligations. Equation (22) represents the first-order condition with respect to debt for firms with non-maturing debt. The left-hand side of Equation (21) and Equation (22) is the marginal benefit of one more unit of borrowing today which increases firms' current cash flows to shareholders while reducing firms' future debt capacity. Since firms with non-maturing debt face debt issuance frictions, the proceeds from their debt issuance are reduced by the proportional issuance costs η. The right-hand side of Equation (21) and Equation (22) represent the marginal costs of outstanding debt firms face. Servicing an additional unit of debt tomorrow reduces next-period cash flows to shareholders, especially when a firm's internal liquidity is insufficient to meet its maturing debt obligations.

4 Calibration

This section describes the calibration strategy. The model is calibrated at a quarterly frequency. There are two groups of parameters. The first group consists of externally set parameters, which are either standard parameters in the literature or parameters that have a natural data counterpart. The second group of parameters is calibrated internally to minimize the difference between model-simulated moments and their empirical counterparts. Details on model simulation are described in Appendix C.2.

4.1 Externally Set Parameters

Panel A of Table 1 displays the values for fixed parameters and their sources.

TABLE 1: **Externally Set Parameters**

Parameter	Description	Value	Source/Targets
	(a). **Technology**		
α	Capital share	0.30	Gilchrist et al. (2014)
χ	Decreasing returns-to-scale	0.85	Gilchrist et al. (2014)
δ	Depreciation rate	0.025	Standard
	(b). **Productivity**		
ρ_z	Persistence	0.90	Foster et al. (2008)
σ_z	Volatility	0.051	Bloom et al. (2018)
	(c).**Institutions**		
r_f	Risk-free interest rate	0.0121	$\beta = 0.988 = 1/(1+r)$
τ	Effective corporate tax rate	0.20	CBO (2017)
π^e	Exogenous exit rate	0.025	Annual exit rate=0.10 (BED)
λ	Debt maturity	0.07	Maturity $\frac{1}{\lambda}$= 3.5 years
θ	Pledgeability	0.71	$P_{95}(Leverage)$

Technology and productivity. Capital share α is set to $\alpha = 0.30$, and capital depreciates at rate $\delta = 0.025$ quarterly. Return-to-scale is set to $\chi = 0.85$. These parameter choices are fairly standard in the literature. As suggested by Foster et al. (2008), the persistence of firm-specific productivity is set to $\rho_z = 0.90$. Following Bloom et al. (2018), I set the low uncertainty state as σ_L as 0.51.

Institutions. Parameters in this group have natural data counterparts, which capture features of the U.S. economy outside the model. The quarterly risk-free interest rate is chosen to be $r = 0.121$, which implies the subjective discount factor $\beta = 0.988$. As reported by Congressional Budget Office in 2017, the marginal effective corporate tax

rate is 0.20. Following the survey of Business Employment Dynamics, the quarterly firm exit rate is $\pi^e = 0.025$, which implies an average 10-year corporate duration, in line with Khan and Thomas (2013).

Debt maturity. Expected maturity of debt is set to be 3.5 years, which implies that $\lambda = 0.07$. The average maturity of outstanding debt for samples of U.S. public firms calculated by empirical literature varies from 3 years to 4 years.

Assets pledgeability. I set the assets pledgeability θ to 0.71, which corresponds to the 95th percentile of the leverage distribution calculated using my sample. This parameter value helps the model generate a realistic leverage distribution. The value is slightly lower than the average recovery rate of corporate loans and bonds reported by Moody's Ultimate Recovery Database, 0.75, which is used in Begenau and Salomao (2019).

4.2 Internally Calibrated Parameters.

Panel B of Table 2 displays the values for internally calibrated parameters as well as the calibration targets. I use 8 empirical moments to estimate 7 parameters using Simulated Methods of Moments. This choice produces an overidentified model by one degree of freedom. Appendix C.3 details how the empirical targets are computed from a firm-quarter panel and their model counterparts. I also discuss the empirical targets used in the literature. While every targeted moment is simultaneously affected by all parameters, in what follows I provide some intuition for their identification. Table 2 displays the values for internally calibrated parameters and shows that the model matches the targeted moments reasonably well.

TABLE 2: **Internal Calibrated Parameters and Model Fit**

Parameter	Data	Value	Targets	Data	Model
		(a). **Financial Frictions**			
s	Liquidity penalty	0.51	Mean leverage ratio	0.26	0.27
η	Debt issuance costs	0.09	SD leverage ratio	0.15	0.15
			Mean cash-to-asset ratio	0.10	0.10
f_o	Production costs	0.09	Mean operating income-to-assets	0.10	0.11
κ_0	Fixed equity issuance cost	0.02	Fraction of net equity issuer	0.05	0.04
κ_1	Convex equity issuance cost	0.21	Mean equity-issuance-to-assets	0.13	0.14
		(b). **Firm Life Cycle**			
n_0	Entrant' assets	0.34	Entrants' Relative Size	0.23	0.24
b_0	Entrant' debt	0.24	Entrants' Debt/Assets	0.45	0.47

Financial frictions. The first set of parameters governs the financial behaviors of firms, therefore they are calibrated to match key financial ratios. As shown in 3.7, the expected marginal costs of debt is directly affected by liquidity penalty s. Since the costs of liquidity shortfalls grow as liquidity penalty s increases, the average leverage ratio decreases. It also shapes the cross-sectional difference in leverage ratio: when liquidity penalty s is low, all firms, regardless of their productivity, will use debt to take advantage of its tax benefits, implying a small standard deviation of leverage ratio across firms. In the presence of debt issuance frictions, corporate cash is used as the marginal source of funding for firms, therefore, the average cash-to-assets ratio increases in debt issuance costs. I set the operating costs f_o that firms pay after production to reproduce the average EBITDA-to-assets ratio of firms, which is the empirical counterpart of firms' operating profits in the model. Fixed equity issuance cost κ_0 and convex equity issuance cost κ_1 directly affect firms' equity issuance behavior in the model. Fixed equity issuance cost κ_0 is calibrated to reproduce the average fraction of firms that issue (net) equity across quarters. The convex equity issuance cost κ_1 is calibrated to match the average size of equity issuance (equity issuance over total firm assets).

Entrants. Two salient empirical patterns on entrants documented by firm dynamic literature is that entrants are smaller in size than the incumbents while entrants tend to have a higher leverage ratio.[12] Therefore, the entrants' size and leverage ratio in the model are calibrated to reproduce these empirical patterns. Specifically, I calibrate entrants' total asset n_0 by targeting an entrant's size of 0.23 relative to the average firm's size in the economy, as in Begenau and Salomao (2019). Entrants' debt b_0 is targeted to match the average firm-level leverage of 0.45 at age 0-2. Note that the model period is one quarter, while the statistics reported in the literature are calculated using annual data. Hence, I aggregate the simulated data to annual frequency appropriately before computing the simulated moments to make sure they are indeed comparable to data moments.

4.3 Relation to Capital Structure Theory

This subsection discusses the implications of the baseline calibration for firms' financing choices in the model. First, the calibrated model features larger frictions in the equity market than the credit market as well as tax advantage of debt, and thus firms

[12] A recent empirical study can be seen in Kochen (2022).

prioritize debt financing over equity financing. Second, the existence of debt issuance frictions implies that corporate internal liquidity is the cheapest source of funding. As a result, firms in the model hold cash holding for potential future growth opportunities. Taken together, financing behavior in the calibrated model closely follows the *Pecking Order Theory*: when a firm finances an investment opportunity, firms prefer internal financing to external financing. In terms of external financing, firms prefer to use debt over equity.

5 Firm Behavior in Steady State

Before testing the ability of the calibrated model to replicate the observed firm-level transmission of uncertainty shocks, in this section, I show that the steady state of the calibrated model generates salient cross-sectional heterogeneity in firms' balance sheets and dynamic investment, saving, borrowing behavior consistent with the data, which validates the model mechanisms. Importantly, the steady-state firm behavior sheds light on how firms behave in the presence of financial frictions, which helps to understand firms' responses to elevated uncertainty.

5.1 Cross-Sectional Implications

Balance-sheet heterogeneity. Figure 3 shows the unconditional distribution of leverage ratio and cash ratio in the model and the data. The calibrated model generates empirically-plausible cross-sectional variation in firm balance sheets, which are not directly targeted in the calibration. In the model, firms experience different paths of productivity realization and debt maturity, and thereby choose different stocks of physical capital, cash holding, and outstanding debt.

Life-cycle patterns. Both corporate finance and firm dynamics literature has documented life-cycle patterns of firms' real and financial behavior.

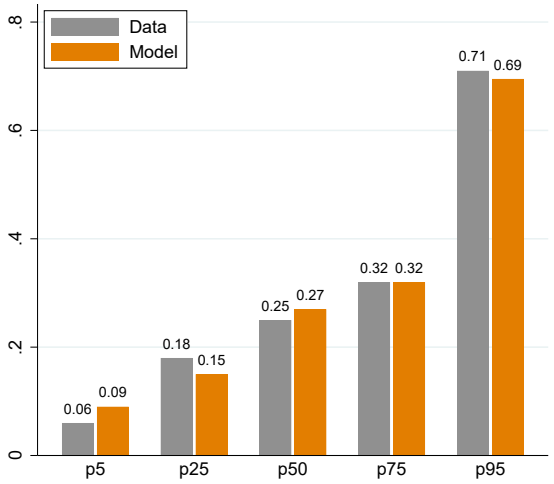
(i). Real behavior: younger firms are smaller, more profitable, and experience larger growth in output.

(ii). Financial behavior, younger firms tend to have a larger leverage ratio, lower cash ratio, and lower dividend ratio.

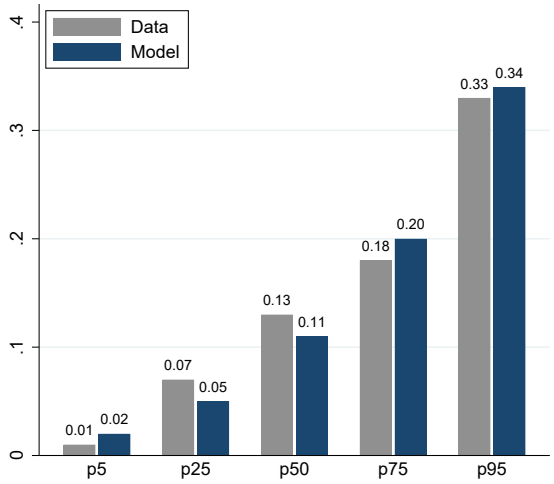
As shown in Table 3, the model does a good job of reproducing these empirical pat-

FIGURE 3: **Non-Targeted Cross-Sectional Moments: Data versus Model**

(A) **Leverage ratio**



(B) **Cash ratio**



Notes: This figure compares the 5 percentile, 25 percentile, 50 percentile, 75 percentile, and 95 percentile of leverage ratio distribution (panel a) and liquidity ratio distribution (panel b) from Compustat panel and simulated panel.

terns. In the model, due to the financing frictions, small entrant firms build up their assets slowly. When firms are young, they are far from their optimal production scales and thus borrow to invest in physical capital. As they approach their optimal scales, they rely less on external financing, save in liquid assets, and pay out dividends. Furthermore, consistent with empirical literature, firm age is important in understanding firm heterogeneity: in the model, firm age can explain around 16% variation in firm size and around 10% variation in profitability, leverage ratio, and cash ratio.

TABLE 3: **Life-Cycle Patterns of Firms in the Model**

	(1) Firm Size	(2) Profitability	(3) Output Growth	(4) Leverage ratio	(5) Cash ratio	(6) Dividend ratio
Age	0.0393***	-0.0041***	-0.0055***	-0.0060***	0.0029***	0.0074***
	(0.0001)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0001)
R-Squared	0.161	0.111	0.075	0.124	0.102	0.009

Notes: This table reports the estimated relationship between firm age and firms' real and financial behavior using univariate OLS and simulated panel.

5.2 Dynamic Investment and Financial Behavior

In this subsection, I show that the full-fledged model reproduces non-targeted investment and financial behavior consistent with those observed in the data. I discuss the role of key model ingredients in shaping firm behavior and illustrate how alternative models fail to reproduce salient features of the data.

5.2.1 Firm Behavior and Firm Characteristics

Model-implied policy functions. To understand the key forces that drive firm behavior in the model, I estimate model-implied policy functions using a model-simulated firm panel, which characterizes firms' optimal decisions based on the states of the firms. As in Bazdresch et al. (2018), I transform the actual state and control variables of the model into widely-used variables in the empirical literature, which allows me to directly compare model predictions and observed data patterns. Using both Compustat and model-simulated data, I run the following fixed-effect panel regressions:

$$\Delta \ln y_{i,t+1} = \alpha_i + \alpha_{s,t} + \alpha_{fq,t} + \beta_1 \textbf{Tobin's Q}_{i,t} + \beta_2 \textbf{Size}_{i,t} + \beta_3 \textbf{Indebtedness}_{i,t} + \epsilon_{i,t} \quad (23)$$

For Compustat sample, I control for firm fixed effects α_t, fiscal-quarter dummy $\alpha_{fq,t}$, and industry-quarter fixed effects $\alpha_{s,t}$ to absorb permanent heterogeneity across firms, fiscal-quarter effects, and impact of aggregate shocks that do not exist in the stationary equilibrium of the model. Standard errors are two-way clustered to account for correlation within firms and within quarters in regressions using Compustat data. Table **??** details the construction of the firm characteristics variables. Note that I standardize firm i' indebtedness$_{i,t}$ (net leverage) using its 1-digit industry average and standard deviation. Table 4 reports the estimated relation between firm characteristics and the firm's capital investment, cash growth, and debt growth.

Tobin's Q. First, firms in the model differ in their idiosyncratic productivity. All else equal, more productivity firms have higher Tobin's Q. With decreasing-to-return technology, higher productivity also implies a higher optimal scale of production. Therefore, firms with higher Tobin's Q have large investment demand and hence invest and borrow more. The larger growth in debt today means a larger debt burden tomorrow, and thus these firms also save more. The model predicts a positive relationship between Tobin's Q and capital investment, cash growth, and debt growth, consistent with the data pattern shown in Table 4.

TABLE 4: **Firm Characteristics and Firm Behavior: Data Versus Model**

$\Delta \ln y_{i,t+1}$	$\Delta\text{Capital}_{i,t+1}$		$\Delta\text{Cash}_{i,t+1}$		$\Delta\text{Debt}_{i,t+1}$	
	Data	**Model**	**Data**	**Model**	**Data**	**Model**
Indebtedness$_{i,t}$	**-0.023***** (0.001)	**-0.027***** (0.000)	**0.122***** (0.003)	**0.110***** (0.001)	**-0.080***** (0.003)	**-0.060***** (0.001)
Tobin's $Q_{i,t}$	0.022*** (0.000)	0.056*** (0.000)	0.038*** (0.001)	0.008*** (0.001)	0.013*** (0.002)	0.033*** (0.000)
Firm Size$_{i,t}$	-0.003*** (0.001)	-0.012*** (0.000)	-0.043*** (0.002)	-0.051*** (0.001)	-0.015*** (0.002)	-0.044*** (0.001)
Firm FE	✓	—	✓	—	✓	—
Sector-Quarter FE	✓	—	✓	—	✓	—
R^2	0.098	0.784	0.055	0.045	0.054	0.144

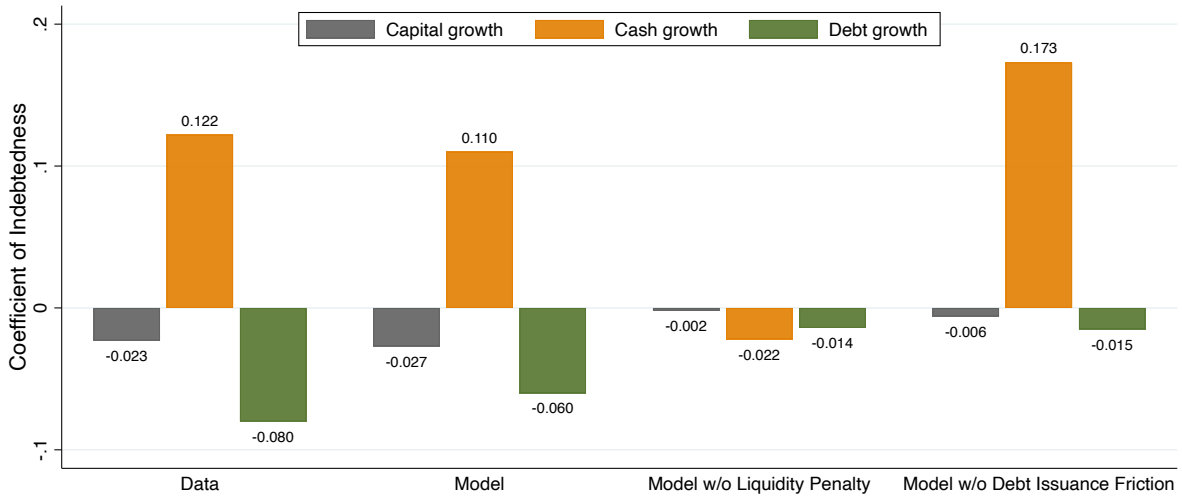
Notes: This table reports the estimated relationship between firm behavior and firm indebtedness using Compustat data and model-simulated data. $*$, $**$, and $***$ represent results significant at the 10%, 5%, and 1% levels, respectively.

Firm Size. Conditional on productivity and outstanding debt, larger firms in the model tend to be closer to their optimal capital level, leading to lower investment demand. The larger size of firms also means larger internal funds and, therefore, smaller demand for external finance. Therefore, larger firms invest and borrow less, and, consequently, save less. Both in the data and the model, conditional on firm indebtedness and Tobin's Q, Firm Size is negatively correlated with growth in capital, cash, and debt.

Indebtedness. In the model, everything else equal, firms with more outstanding debt today are closer to the collateral constraints and have more pre-existing debt burdens compared to their less indebted counterparts. Since liquid assets holding can reduce the likelihood of incurring the liquidity penalty when running out of internal liquidity for maturing debt obligations, more indebted firms, therefore, have larger cash demand for future debt repayment. The smaller borrowing capacity and larger cash demand among more indebted firms lead to lower debt borrowing and higher cash saving today, which results in less capital investment. As shown in Table 4, both in the data and the model, conditional on Firm Size and Tobin's Q, one-standard-deviation higher indebtedness is associated with smaller capital investment, larger cash growth, and smaller debt growth.

Role of model ingredients. To illustrate the role of model ingredients in driving the impact of firm indebtedness on firms' investment and financial choices, I run the

FIGURE 4: **Firm Indebtedness and Firm Behavior: Data versus Model**



Notes: This figure plots the estimated relationship between firm behavior and firm indebtedness using Compustat data and model-simulated data, conditional on Tobin's Q and Firm Size.

same regressions while using simulated data from alternative models without liquidity penalty ($s = 0$) or debt issuance frictions ($\eta = 0$). Appendix A4 reports the full estimation results. Note that models without liquidity penalty or credit frictions still exhibit the positive effects of Tobin's Q and negative effects of Firm Size on firm behavior, since these effects are mostly driven by productivity heterogeneity and decreasing-to-scale technology. Figure 4 compares the estimated relationship between firm indebtedness and firm behavior using Compustat data and simulated data from different models.

The liquidity penalty has two effects in the full-fledged model. First, it motivates firms to save in liquid assets to avoid liquidity shortfalls for debt repayment, leading to a positive relation between firm indebtedness and liquid assets growth. In a model without liquidity penalty, firms can repay their maturing debt using new debt/disinvestment/new equity without any additional cash flow penalty, which substantially reduces firms' cash demand. More indebted firms in this case borrow less due to their smaller debt capacity and hence have fewer funds for liquid assets holding, resulting in a negative relation between firm indebtedness and liquid assets growth. As shown in Figure 4, in a model without liquidity penalty, indebtedness is negatively associated with liquid assets growth, which is in sharp contrast to the positive association observed in the data and the full-fledged model. Second, as shown in Equation (21) and (22), liquidity penalty increases the expected marginal costs of debt, leading to a much stronger negative relation between firm indebtedness and debt growth in the

full-fledged model relative to a model without liquidity penalty. The higher demand for cash and larger costs of debt triggered by liquidity penalty induce less capital investment among firms in the full-fledged model, resulting in a stronger negative relation between firm indebtedness and capital investment, relative to that of a model without liquidity penalty.

In addition to liquidity penalty, firms with non-maturing debt in the full-fledged model also face proportional debt issuance costs that directly reduce the marginal benefits of borrowing. The lower marginal benefits of borrowing make more indebted firms in the full-fledged model borrow, invest, and save less, which on the one hand, amplifies the negative effects of firm indebtedness on capital investment and borrowing, and on the other hand, dampens the positive effects of firm indebtedness on cash saving. As shown in Figure 4, the full-fledged model shows a stronger negative correlation between firm indebtedness and capital investment and debt growth while a weaker positive association between indebtedness and liquid assets growth, relative to a model without debt issuance frictions.

5.2.2 Cash as Marginal Source of Funding

In the presence of uncertainty and financial market frictions, firms save in cash holding for future growth opportunities. The idea is simple: when a good productivity shock is realized, cash holding allows firms to fund capital investment internally and thus avoid incurring the transaction costs associated with new security issuance in the financial market. In this subsection, I show that the model is able to reproduce these empirical patterns.

Firm responses to productivity shocks. I examine how firms respond to growth in their firm-level TFP by running the following regression using both Compustat data and simulated data :

$$\Delta \ln y_{i,t+1} = \alpha_i + \alpha_{s,t} + \alpha_{fq,t} + \beta \Delta \ln \text{TFP}_{i,t} + \Gamma' X_{i,t} + \epsilon_{i,t} \tag{24}$$

where $\Delta \ln \text{TFP}_{i,t}$ denotes measured firm-level productivity growth. Appendix A.3 discusses the construction of firm-level productivity using Compustat Quarterly. $X_{i,t}$ denotes a vector of control variables that include Indebtedness, Tobin's Q, and Firm Size. For the Compustat sample, I control for firm fixed effects α_t, fiscal-year dummy $\alpha_{fq,t}$, and industry-year fixed effects $\alpha_{s,t}$ to absorb permanent heterogeneity across firms,

fiscal-year effects, and impact of aggregate shocks that do not exist in the stationary equilibrium of the model. Standard errors are two-way clustered to account for correlation within firms and within quarters in regressions using Compustat data.

TABLE 5: **Firm Responses to Idiosyncratic Productivity Growth: Data versus Model**

	Data			**Model**		
$\Delta \ln y_{i,t+1}$:	$\Delta\text{Capital}_{i,t+1}$	$\Delta\text{Cash}_{i,t+1}$	$\Delta\text{Debt}_{i,t+1}$	$\Delta\text{Capital}_{i,t+1}$	$\Delta\text{Cash}_{i,t+1}$	$\Delta\text{Debt}_{i,t+1}$
$\Delta \ln \text{TFP}_{i,t}$	0.27***	**-0.15*** **	0.26***	0.849***	**-0.955*** **	0.381***
	(0.001)	(0.005)	(0.003)	(0.002)	(0.021)	(0.012)
Firm Controls	✓	✓	✓	✓	✓	✓
Firm FE	✓	✓	✓	—	—	—
Sector-Quarter FE	✓	✓	✓	—	—	—
R^2	0.176	0.080	0.084	0.896	0.112	0.171

Notes: This table reports estimated firm responses to an idiosyncratic productivity growth using Compustat data and model-simulated data. $*$, $**$, and $***$ represent results significant at the $10\%, 5\%$, and 1% levels, respectively.

TABLE 6: **Firm Responses to Idiosyncratic Productivity Growth: Alternative Models**

	Model w/o liquidity penalty			**Model w/o debt issuance frictions**		
$\Delta \ln y_{i,t+1}$:	$\Delta\text{Capital}_{i,t+1}$	$\Delta\text{Cash}_{i,t+1}$	$\Delta\text{Debt}_{i,t+1}$	$\Delta\text{Capital}_{i,t+1}$	$\Delta\text{Cash}_{i,t+1}$	$\Delta\text{Debt}_{i,t+1}$
$\Delta \ln \text{TFP}_{i,t}$	0.890***	-0.347***	0.538***	0.803***	**1.439*** **	0.859***
	(0.002)	(0.012)	(0.004)	(0.003)	(0.019)	(0.008)
Firm Controls	✓	✓	✓	✓	✓	✓
R^2	0.903	0.201	0.684	0.857	0.334	0.376

Notes: This table reports estimated firm responses to an idiosyncratic productivity growth using simulated data from alternative models. $*$, $**$, and $***$ represent results significant at the $10\%, 5\%$, and 1% levels, respectively.

Table 5 shows that both in the data and the model, firm-level productivity growth is positively correlated with capital investment and debt growth while negatively correlated with liquid assets growth. Firms in the model save in liquid assets and use them as the marginal funding source, allowing them to save on transaction costs in the financial markets. In contrast, in Table 6, firm-level productivity growth is positively correlated with liquid assets growth in a model without debt issuance frictions. This occurs because firms with larger productivity growth borrow more, and therefore they also save more for future debt repayment.

6 The Model-implied Transmission of Uncertainty Shocks

In this section, I first show the calibrated model reproduces both firm-level and aggregate-level impacts of uncertainty shocks observed in the data and then inspect the transmission mechanisms. In Section 6.1, I show that the calibrated model accounts well for the observed firm-level response to uncertainty shocks documented in Section 2. In Section 6.2, I inspect the transmission mechanisms by shutting down key model ingredients emphasized in Section 5. In Section 6.3, I show the calibrated model also reproduces the macro-level impacts of uncertainty shocks documented in the literature and provides novel interpretations of the data patterns.

The economy is initially in a steady state and unexpectedly receives a shock to the distribution of productivity shocks. Specially, all firms in the economy suddenly receive a jump in the dispersion of their productivity shocks $\sigma_t = \sigma_H$, which reverts back to σ_L according to σ_{t+1} = 0.5 σ_t. The jump in the dispersion is common across firms, and note that the expected productivity is always kept constant. I calibrate the initial jump to induce a 2.5% drop in aggregate output on impact. [13]

6.1 Firm-level Responses to Uncertainty Shocks in the Model

I study the transmission of uncertainty shocks within the model by estimating firm-level responses to uncertainty shocks using a simulated panel. I compute the perfect foresight transition path of the economy as it converges back to a steady state. I simulate a panel of 10,000 firms and estimate the following specification using data from one year before the initial shock to two years after the initial shock:

$$\Delta \ln y_{i,t+1} = \alpha + \left(\boldsymbol{\beta} + \boldsymbol{\gamma}\text{Indebtedness}_{i,t}\right) \cdot \Delta \log \sigma_t + \eta \text{Indebtedness}_{i,t} \tag{25}$$
$$+ \boldsymbol{\Psi'}\mathbf{Z}_{i,t} \cdot \Delta \log \sigma_t + \Gamma' \mathbf{Z}_{i,t} + \mu_{i,t}$$

where $\Delta \log(\sigma_t)$ measures the log deviation of σ_t from the steady-state level σ_L. A high $\log(\sigma_t)$ implies a more widely spread distribution of next-period idiosyncratic productivity shocks compared to the steady state level. $\text{Indebtedness}_{i,t}$ measures how many standard deviations firm i's net leverage is away from industry mean. $\mathbf{Z}_{i,t}$ is a vector of the control variable that captures firms' growth opportunity in the context

[13] The choice of 2.5% decrease in aggregate output driven by uncertainty shocks on impact follows Bloom et al. (2018). The persistence of the shock 0.5 is standard in the literature on MIT shocks.

of the model: Tobin's Q and Firm Size. Note that Equation (25) indeed resembles the empirical specification Equation (2) since there is no permanent unobserved heterogeneity across firms, fiscal-quarter differences, and other confounding macro shocks in the model environment.

TABLE 7: **Model-Implied Transmission of Uncertainty Shocks**

$\Delta \ln y_{i,t+1} \times 100$:	ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$
$\Delta \log \sigma_{t+1}$	-0.214***	0.753***	-0.193***
	(0.016)	(0.026)	(0.069)
$\Delta \log \sigma_{t+1} \times$ Indebtedness$_{i,t}$	-0.280***	0.257***	0.086
	(0.025)	(0.039)	(0.103)
R-Squared	0.796	0.069	0.158
Firm Controls$_{i,t}$	✓	✓	✓
$\Delta \log \sigma_{t+1} \times$ Z$_{i,t}$	✓	✓	✓

Notes: This table reports estimated firm responses to uncertainty shocks using simulated data from the full-fledged model. $*$, $**$, and $***$ represent results significant at the $10\%, 5\%$, and 1% levels, respectively. $\Delta \log(\sigma_t)$ measures the log deviation of σ_t from the steady-state level σ_L. Indebtedness$_{i,t}$ measures how many standard deviations firm i's net leverage is away from mean. Firm control variables include Indebtedness$_{i,t}$ and $Z_{i,t}$. $Z_{i,t}$ includes Tobin's Q and Firm Size, which captures firms' growth opportunity in the context of the model.

Table 7 reports the estimated firm-level responses to uncertainty shocks using simulated data. The full-fledged model does a good job of reproducing the observed firm-level responses to uncertainty shocks in the data: an increase in aggregate uncertainty facing firms is followed by capital investment drops, cash buildups, and deleveraging. In the cross-section, the decline in capital investment and the increase in cash holding are much more pronounced among more indebted firms.

Two forces are at work: on the one hand, an increase in uncertainty implies a higher probability of having a bad productivity shock, which generates a higher likelihood of liquidity shortfalls due to lower operating profits. This motivates firms to deleverage and hold more cash to avoid potential liquidity penalties in the face of debt repayment. On the other hand, an increase in uncertainty also implies a larger chance of drawing a good productivity shock. This upside potential amplifies firms' saving motives while counteracting the deleveraging pressure since deleveraging shrinks firms' internal funds for future expansion. That is, cash holding plays a unique role in the face of the two forces: it preserves internal funds for both future debt repayment and investment opportunities, thereby addressing both the downside risk and upside potential triggered by uncertainty shocks: it allows firms to avoid potential liquidity

penalties for debt repayment and also enables firms to preserve enough internal funds for growth potential. In the face of the two forces triggered by a higher uncertainty, firms re-structure their balance sheets by deleveraging and accumulating cash holding, both of which divert firms' internal funds away from capital investment. *Ex-ante* more indebted firms choose to accumulate more cash holding since they face a higher likelihood of liquidity shortfalls due to large stocks of outstanding debt.

6.2 Inspecting the Transmission Mechanisms

To better understand each of the two underlying forces at play, I conduct three experiments to explore the transmission of uncertainty shocks in alternative setups. I find that liquidity penalty is the key to generating the negative impact of uncertainty shocks on capital and debt, while frictions in debt issuance are the key to generating the salient liquidity buildup in response to uncertainty shocks. Further, the severity of debt issuance frictions shapes how differently indebted firms react to heightened uncertainty.

Role of liquidity penalty. I first shut down the liquidity penalty by setting $s = 0$. In a model without liquidity penalty, firms can repay their maturing debt using new debt/-disinvestment/new equity without any additional costs. Consequently, firms have no concern over the elevated likelihood of liquidity shortfalls, that is, the deleveraging pressure is muted. As shown in Panel (A) of Table 8, uncertainty shocks, in this case, have no statistically significant effects on firms' outstanding debt. Since firms do not need to trade off capital investment for cash holding to reduce the likelihood of incurring liquidity penalty, the strong precautionary saving motive triggered by the elevated uncertainty motivates firms to increase both their capital investment and cash holding today in an effort to generate large internal liquidity for future investment. As a result, both capital investment and cash holding rise following uncertainty shocks.[14] To sum up, this model predicts a positive effect of heightened uncertainty on capital investment and an insignificant effect on debt, contradicting the empirical findings.

Role of debt issuance frictions. I shut down the debt issuance frictions by setting $\eta = 0$. In this case, firms can issue debt without any additional costs when a good productivity shock realizes, thereby eliminating firms' precautionary saving motives

[14]Note that the average increase in cash holding across firms, in this case, is completely driven by a decrease in dividend payout due to better growth potential, while in the full-fledged model, cash buildup is also partly driven by capital investment cut for future debt repayment. As shown in Section 5.2, liquidity penalty is the key to generating a trade-off between capital and cash for debt repayment.

for growth opportunities. As a result, when uncertainty rises, the firms are only concerned about the larger downside risk caused by an elevated uncertainty, and thus they deleverage to prevent liquidity shortfalls. The decrease in firms' debt obligations also reduces their cash demand for debt repayment, and therefore firms in this model also decrease their cash holding in response to heightened uncertainty. As shown in Panel (B) of Table 8, cash holding drops following uncertainty shocks in this model, contradicting the salient buildup of corporate liquidity observed in the data.

Degrees of debt issuance frictions. To further understand how frictions in debt issuance shape firm responses to uncertainty shocks by governing firms' precautionary saving motives, I experiment with two different levels of debt issuance costs relative to the baseline calibration. As shown in Table 9, when debt issuance costs are 50% lower than the baseline level, in response to uncertainty shocks, more indebted firms also deleverage more relative to their less indebted counterparts. This occurs since reduced debt issuance frictions mitigate firms' precautionary saving motives. Specifically, more indebted firms, in this case, can deleverage first and issue new debt cheaply to fund capital investment if a good productivity shock realizes. By contrast, when debt issuance costs are at the baseline level or 50% higher than the baseline level, issuing new debt is especially costly, and thus more indebted firms choose to hold more cash to reduce their higher likelihood of liquidity shortfalls rather than cut more debt. To sum up, the severity of debt issuance frictions plays a key role in shaping the heterogeneous responses to uncertainty shocks across differently indebted firms.

TABLE 8: **Model-Implied Transmission of Uncertainty Shocks: Alternative Models**

	(A) Model w/o liquidity penalty			**(B) Model w/o debt issuance frictions**		
$\Delta \log y_{i,t+1} \times 100$:	$\Delta\text{Capital}_{i,t+1}$	$\Delta\text{Cash}_{i,t+1}$	$\Delta\text{Debt}_{i,t+1}$	$\Delta\text{Capital}_{i,t+1}$	$\Delta\text{Cash}_{i,t+1}$	$\Delta\text{Debt}_{i,t+1}$
$\Delta \log \sigma_{t+1}$	0.033**	0.239***	-0.018	-0.389***	-2.426***	-5.447***
	(0.016)	(0.008)	(0.022)	(0.017)	(0.158)	(0.152)
Firm Controls$_{i,t}$	✓	✓	✓	✓	✓	✓
R^2	0.727	0.084	0.589	0.716	0.059	0.086

Notes: This table reports estimated firm responses to uncertainty shocks using simulated data from alternative models. $*$, $**$, and $***$ represent results significant at the $10\%, 5\%$, and 1% levels, respectively. $\Delta \log(\sigma_t)$ measures the log deviation of σ_t from the steady-state level σ_L. Firm control variables include Indebtedness, Tobin's Q and Firm Size.

TABLE 9: **Debt Issuance Frictions and Firm Responses to Uncertainty Shocks**

	Low Debt Issuance Frictions $= 0.5 \cdot \eta_{\textbf{baseline}}$			**High Debt Issuance Frictions** $= 1.5 \cdot \eta_{\textbf{baseline}}$		
$\Delta \ln y_{i,t+1} \times 100$:	ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$	ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$
$\Delta \log \sigma_{t+1}$	-0.205***	0.813***	-0.187**	-0.260***	0.775***	-0.261**
	(0.028)	(0.036)	(0.094)	(0.030)	(0.042)	(0.119)
$\Delta \log \sigma_{t+1} \times$ Indebtedness$_{i,t}$	-0.342***	0.201***	**-0.213****	-0.314***	0.468***	**0.209**
	(0.027)	(0.035)	(0.091)	(0.032)	(0.045)	(0.127)
R-Squared	0.725	0.115	0.182	0.675	0.091	0.102
Firm Controls$_{i,t}$	✓	✓	✓	✓	✓	✓
$\Delta \log \sigma_{t+1} \times Z_{i,t}$	✓	✓	✓	✓	✓	✓

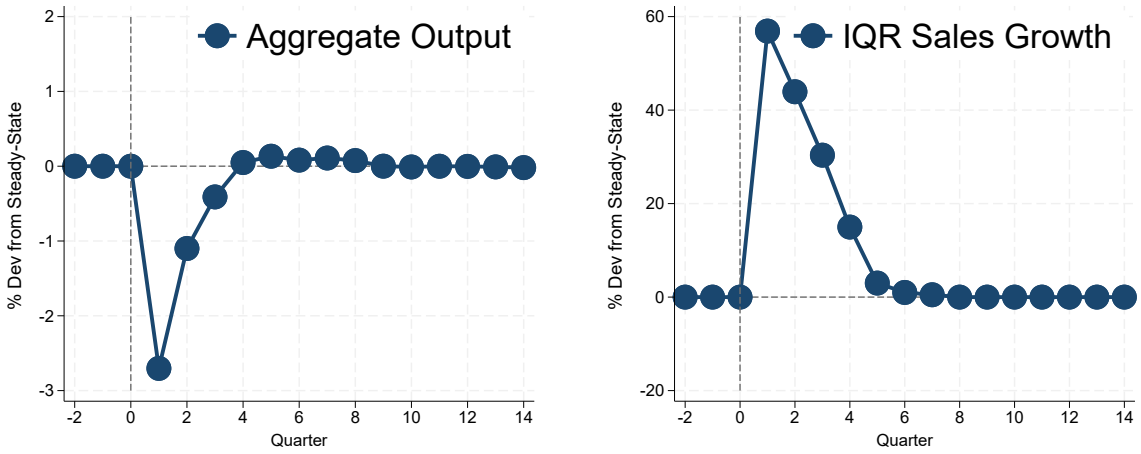
Notes: This table reports estimated firm responses to uncertainty shocks using simulated data from the full-fledged model. $*$, $**$, and $***$ represent results significant at the $10\%, 5\%$, and 1% levels, respectively. $\Delta \log(\sigma_t)$ measures the log deviation of σ_t from the steady-state level σ_L. Indebtedness$_{i,t}$ measures how many standard deviations firm i's net leverage is away from mean. Firm control variables include Indebtedness$_{i,t}$ and $Z_{i,t}$. $Z_{i,t}$ includes Tobin's Q and Firm Size, which captures firms' growth opportunity in the context of the model.

6.3 Aggregate Impacts of Macro Uncertainty Shocks in the Model

The previous sections showed that the calibrated model accounts well for the observed firm-level balance sheet transmission of uncertainty shocks. In this subsection, I show that the calibrated model also reproduces the aggregate impacts of macro uncertainty shocks. As shown in Figure 5, a macro uncertainty shock in the calibrated model generates a sharp and protracted drop in aggregate output along with a spike in the cross-sectional dispersion of sales growth, consistent with the empirical findings in the literature.

Notably, existing uncertainty literature takes the observed increase in the dispersion of sales growth during periods of high uncertainty as exogenous. The balance sheet channel suggests the increased dispersion of sales growth is an endogenous response of the economy to elevated macro uncertainty due to heterogeneous adjustments across differently indebted firms. Understanding the increased dispersion of sales growth is important since the variable has been used widely to identify and characterize periods of high macro uncertainty in the empirical literature and to calibrate the size of macro uncertainty shocks in structural models.

FIGURE 5: **The Macro Impact of Uncertainty Shocks**



Notes: This figure plots the responses of aggregate output and cross-sectional dispersion of sales growth to uncertainty shocks. As standard in the literature, cross-sectional dispersion is measured by the Interquartile range.

7 Policy Implications of the Balance Sheet Channel

In this section, I discuss the novel policy implications of the balance sheet channel of uncertainty shocks. In Section 7.1, I show that investment stimulus policies, like investment tax credit, yield modest effects in counteracting the adverse impact of uncertainty shocks. In Section 7.2, I show that credit interventions, like debt relief, are powerful in stabilizing uncertainty-driven recessions. The reason behind the results is that high uncertainty dampens the effects of investment stimulus policies while amplifying the effects of credit interventions. In Section 7.3, I study two extensions that further illustrate how the nature of recessions and corporate cash choices shape policy impacts.

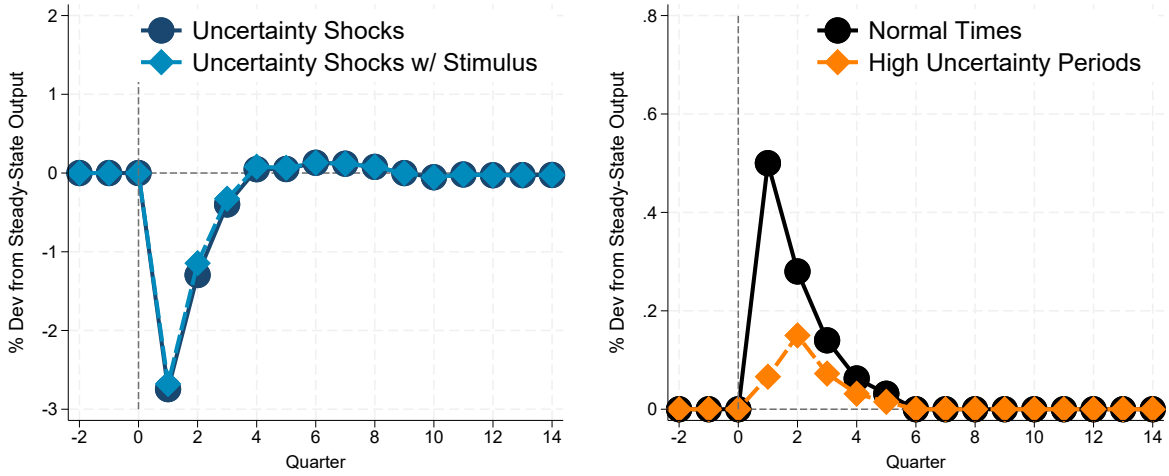
7.1 Stimulus Policies in Uncertainty-driven Recessions

Research in macroeconomics found that monetary stimulus has weak effects in recessions, advocating more fiscal or credit policies to stabilize the economy in recessions (see, e.g., Tenreyro and Thwaites 2016, Fang (2020)). In this subsection, I examine whether a common investment stimulus policy in the United States, the investment tax credit, can help to counteract the aggregate output drops driven by uncertainty shocks. The idea is simple: investment tax credits lower the effective marginal costs of investment, and thus, it might stimulate aggregate investments and then aggregate output.

Investment tax credit In this policy, a x_t fraction of investment costs can be rebated back to firms as tax credits when firms make the investments. Therefore, the effective investment cost for I amount of capital investment is $(1 - \tau x_t)I$ with the policy and $x_t = 0$ in steady state. I consider an unexpected and temporary policy with $x_t = 0.07$ at time 0, which fades at a rate of 0.5. I calibrate the initial size of program $x_t = 0.07$ to generate a 0.5% increase in aggregate output during normal times at impact.

FIGURE 6: **Uncertainty-driven Recessions and Stimulus Policy**

(A) **Output Responses to Uncertainty Shocks** (B) **Output Responses to Stimulus Policy**



Notes: Panels (A) plots the aggregate output responses to an uncertainty shock with and without investment tax credits. Panels (B) plots the aggregate output responses to the policy intervention during normal times and periods of high uncertainty. Appendix C.3 details the computation of aggregate impulse response functions.

Stimulus policies in uncertainty-driven recessions. Panel (A) of Figure 6 plots the impact of uncertainty shocks on aggregate output with and without investment tax credit. Both uncertainty shocks and policy interventions happen at time 0 and fade at a rate of 0.5. The key finding is that investment tax credit has very limited effects in counteracting the adverse impact of uncertainty. To see this clearly, Panel (B) of Figure 6 plots the output responses to the investment tax credit program during normal times and periods of high uncertainty. The orange line is simply the percentage difference between the two aggregate output responses in Panel (A). Panel (B) shows that the stimulative impact of the same investment tax credit program is much weaker during periods of high uncertainty than normal times. The reason is that heightened uncertainty motivates firms to hoard cash, thereby depressing firms' use of cash for policy-induced capital investments. In Appendix D.4, I show that aggregate cash goes down by more than 8% in response to the policy during normal times, while aggregate cash only goes down by 3% in response to the policy during periods of high uncer-

tainty. The impact of high uncertainty on policy effect can also be seen in the shapes of impulse response functions. During normal times, the positive effects of the policy decrease with policy intensity. During periods of high uncertainty, as uncertainty decreases, firms start to respond to the investment stimulus, leading to a larger output response at time 2 than at time 1, even though the policy intensity is cut by half.

7.2 Credit Interventions in Uncertainty-driven Recessions

The recent COVID-19 pandemic has seen aggressive credit interventions provided to corporate sectors around the world. The Paycheck Protection Program (PPP) in the U.S. provided corporate businesses with more than $800 billion in the form of debt relief and forgivable loans. In this subsection, I study the stabilizing effects of credit interventions in uncertainty-driven recessions.

Credit interventions. I focus on two credit inventions during the recent COVID crisis. I consider one-time policy interventions in the model simulation, which resembles the implementation of loan programs observed in 2020. As shown in Cho et al. (2022), the distribution of PPP loans is untargeted and prioritizes speedy loan disbursement.

(i). Debt relief programs: a fraction of each firm's outstanding debt is unexpectedly written off at time 0.

(ii). Cash grant programs: each firm unexpectedly receives a cash grant at time 0, which equals a fraction of the steady-state wage bills they pay.

I calibrate the size of each program to generate a 0.5% increase in aggregate output during normal times at impact. Note that the one-time credit interventions have persistent effects on output since credit interventions directly increase firms' net worth, and thus, firms become less financially constrained for the rest of their lifecycle.

Credit interventions in uncertainty-driven recessions. Panel (A) and (C) of Figure 7 plot the impact of uncertainty shocks on aggregate output with and without credit interventions. Panel (B) and (D) of Figure 7 plot the output responses to policy interventions during normal times and periods of high uncertainty. Three patterns emerge. First, credit interventions substantially mitigate the negative effects of uncertainty shocks. With debt relief or cash grant programs, aggregate output drops by only 1% or 1.5%, respectively. The workings of the policies are simple: debt relief and cash grant programs directly reduce firms' need to reduce debt and hoard cash in response

to heightened uncertainty, thereby mitigating the decrease in capital investment and the negative effects of uncertainty shocks. Second, as shown in Panel (B) and (D) of Figure 7, output responses to credit interventions are much larger during periods of high uncertainty than during normal times. The debt relief and cash grants programs that stimulate aggregate output by 0.5% during normal times can drive up aggregate output in an uncertainty-driven recession by 1.5% and 1.0%, respectively. This is because credit interventions during periods of high uncertainty not only increase firms' net worth but also directly alleviate the balance sheet adjustments of firms in response to heightened uncertainty. Third, the response of aggregate output to debt relief is stronger than its response to cash grants during periods of high uncertainty, despite similar effects during normal times. This occurs since debt relief programs reduce firms' debt burdens, and this, in turn, lowers firms' cash demand for debt repayment, thereby freeing up firms' cash holding for more capital investment. The effect of debt relief programs on firms' cash choices is critical for the strong stabilizing effects of debt relief in uncertainty-driven recessions. In Section 7.3, I show that a counterfactual simulation failing to capture the observed cash buildup underestimates output response to debt relief by more than 30%.

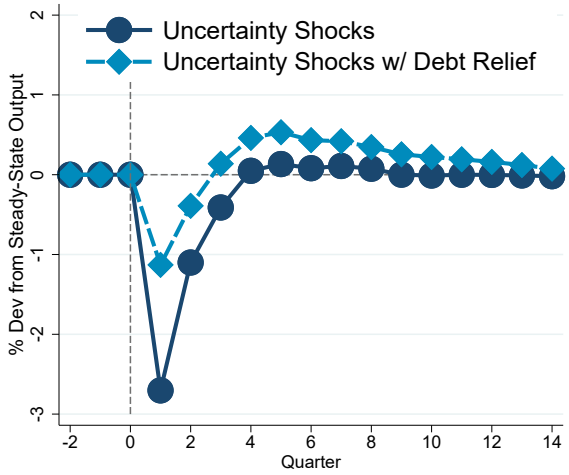
Policy effectiveness. To gauge the effectiveness of credit interventions, I compute the present value of all the output gains using the discount factor and then divide it by the total fiscal cost of the program, which measures the expected output gain per unit of fiscal costs. Figure 8 plots the effectiveness of both programs during normal times and uncertainty-driven recessions. Since output responses increase during periods of high uncertainty, the estimated output gain per dollar rises from 0.74 to 1.13 for debt relief programs. It also goes up from 0.64 to 0.85 for cash grants programs. The debt relief program is more effective since it not only directly reduces firms' debt burdens but also indirectly lowers firms' cash demand, freeing up firms' internal funds for more capital investment, as discussed before. The difference in effectiveness between the two interventions becomes especially pronounced, as output response to debt relief rises substantially following uncertainty shocks.

7.3 Extentions

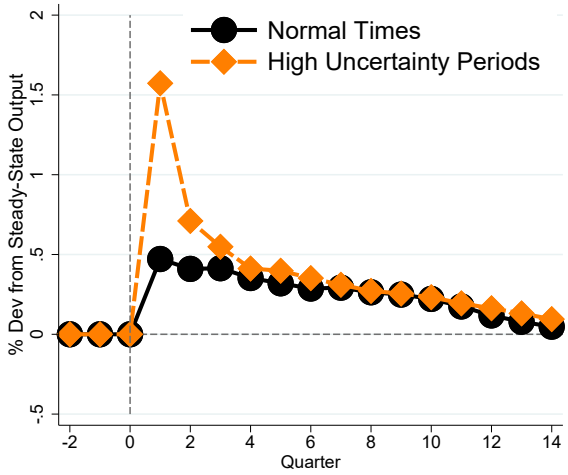
The unprecedented credit interventions during the recent COVID crisis sparked a rapidly growing literature that evaluates the effects of credit interventions using quantitative models. The previous section adds to the literature by demonstrating the strong

FIGURE 7: **Uncertainty-driven Recessions and Credit Interventions**

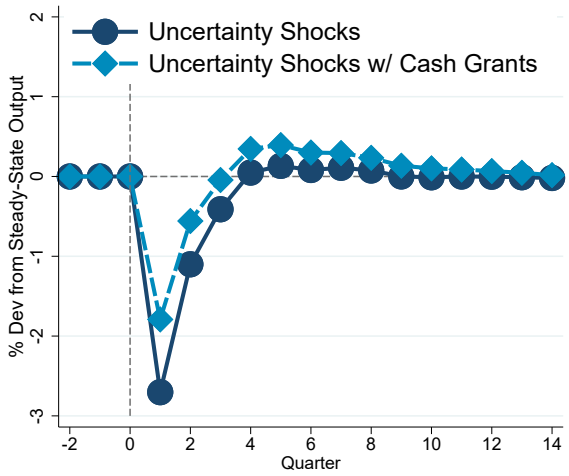
(A) **Output Responses to Uncertainty Shocks**



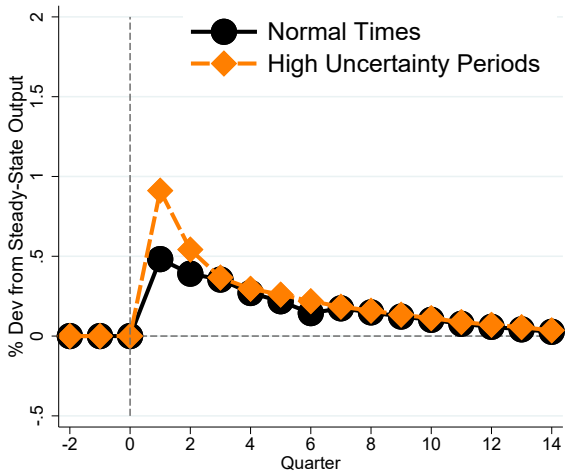
(B) **Output Responses to Debt Relief**



(C) **Output Responses to Uncertainty Shocks**



(D) **Output Responses to Debt Relief**



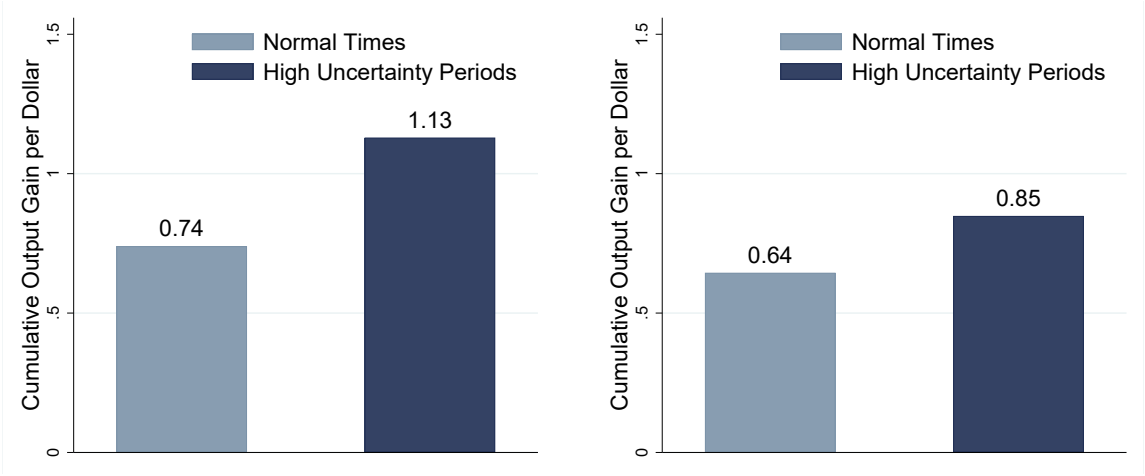
Notes: Panels (A) and (C) plot the aggregate output responses to an uncertainty shock with and without credit interventions. Panels (B) and (D) plot the aggregate output responses to policy interventions during normal times and periods of high uncertainty. Appendix C.3 details the computation of aggregate impulse response functions.

effects of credit interventions in uncertainty-driven recessions. This subsection adds to the growing literature in two ways. First, I highlight the importance of corporate cash choice in shaping policy impacts by showing that a counterfactual simulation failing to capture the observed cash buildup underestimates the stabilizing effects of debt relief in uncertainty-driven recessions. Second, I highlight the nature of the recessions in shaping policy impacts by showing that credit interventions have modest effects in a recession driven by negative productivity shocks.

Credit interventions in TFP-driven recessions. Panel (A) and (C) of Figure 9 plot

FIGURE 8: **Policy Effectiveness of Credit Interventions**

(A) **Debt Relief Policy** (B) **Cash Grants Policy**



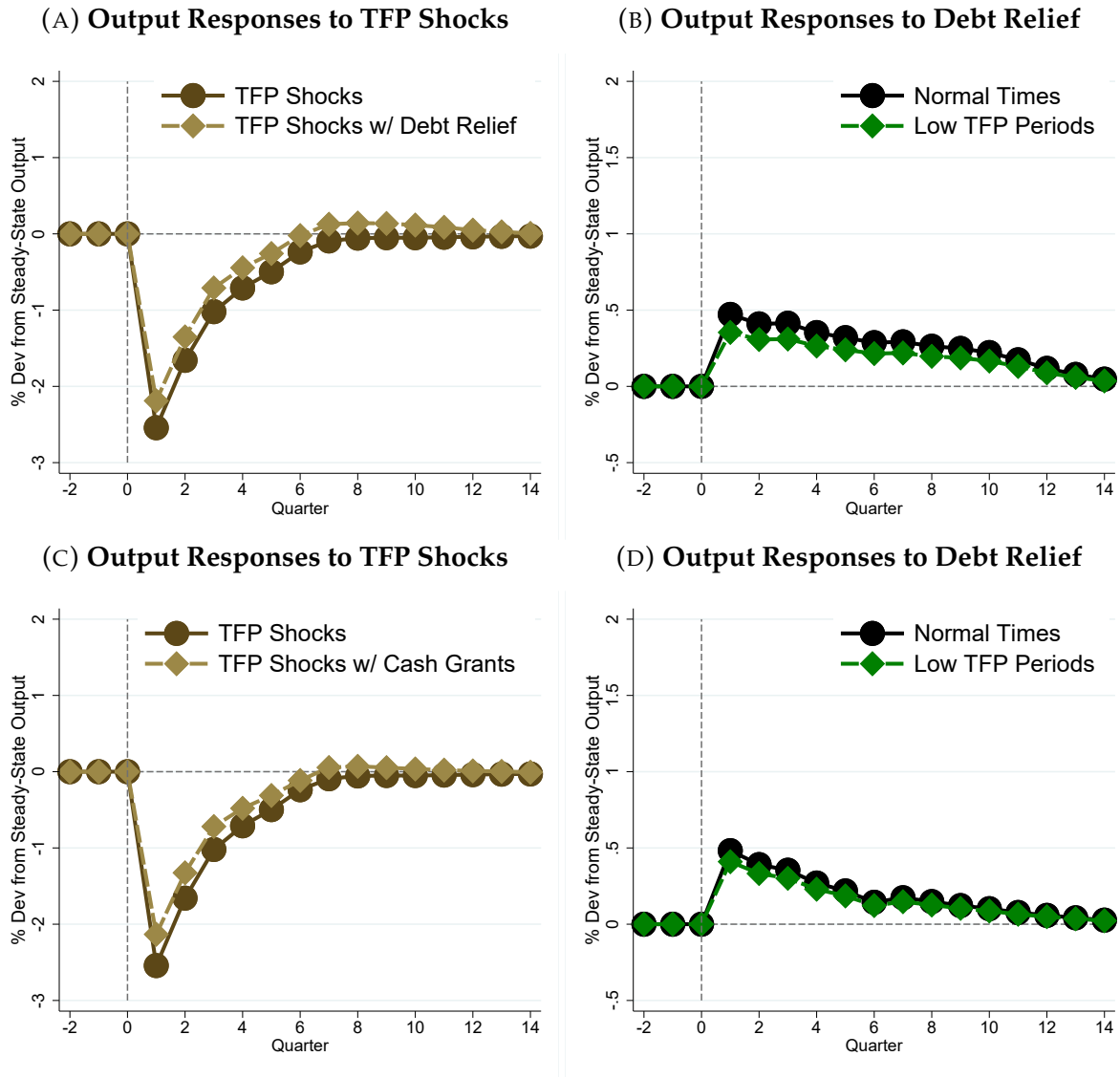
Notes: This figure plots the effectiveness of credit interventions during normal times and uncertainty-driven recessions. To gauge the effectiveness of credit interventions, I compute the present value of all the output gains using the discount factor and then divide it by the total fiscal cost of the program, which measures the expected output gain per unit of fiscal costs.

aggregate output responses to negative productivity shocks with and without credit interventions. Panel (B) and (D) of Figure 9 show that output responses to the interventions in TFP-driven recessions turn out to be slightly smaller than those in normal times. This is because lower aggregate productivity reduces firms' investment demand and financial needs, thereby mitigating the role of credit interventions in relaxing firms' financial constraints.[15] In sharp contrast, credit interventions directly mitigate the balance sheet transmissions of uncertainty shocks, thereby strongly stabilizing aggregate output drops in an uncertainty-driven recession. This result echoes Crouzet and Tourre (2021), where they find that credit interventions have larger stabilizing effects in a TFP-driven recession accompanied by financial market disruptions. Therefore, the nature of the recession plays an important role in shaping policy effectiveness.

Implications of Corporate Cash Choice. Conventional macro-finance models typically treat firms' cash holding as 'net debt'. In this class of models, firms either borrow or save, but not both. To illustrate the importance of modeling firms' cash choices for understanding the effects of debt relief, I shut down the debt issuance frictions by setting $\eta = 0$, which eliminates cash buildup in response to heightened uncertainty as shown in Section 6. In this case, the negative effects of uncertainty shocks are com-

[15] In Appendix D.5, I show that output responses to credit interventions are slightly larger during booms when investment demand is high and firms have larger financial needs.

FIGURE 9: **TFP-driven Recessions and Credit Interventions**



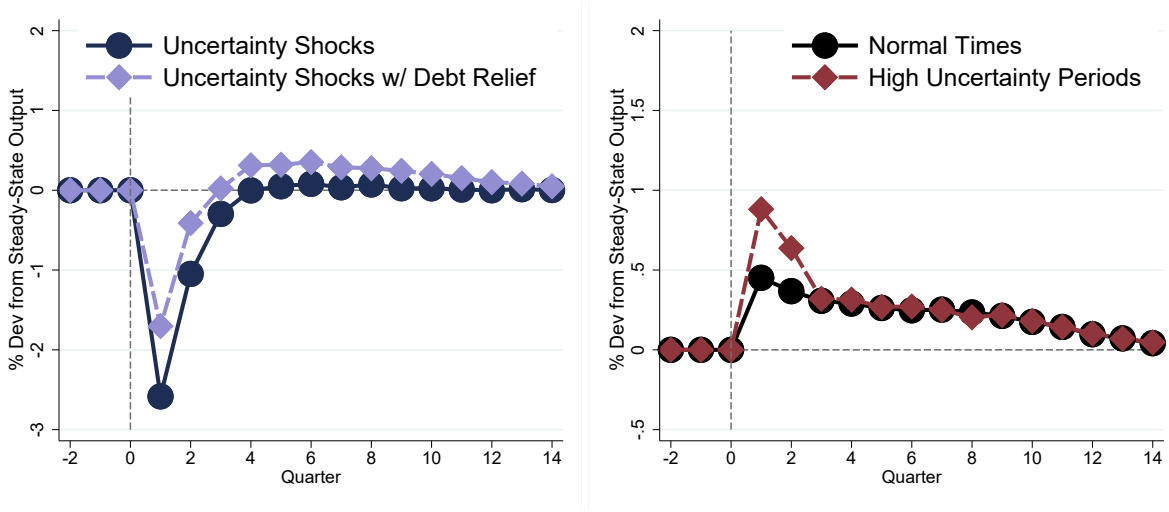
Notes: Panels (A) and (C) plot the aggregate output responses to a negative aggregate TFP shock with and without credit interventions. Panels (B) and (D) plot the aggregate output responses to policy interventions during normal times and periods of low aggregate productivity. Appendix C.3 details the computation of aggregate impulse response functions.

pletely due to the deleveraging of firms. The initial jump in uncertainty and the sizes of policy interventions are re-calibrated to ensure compatibility with the baseline simulation. Panel (A) and (C) of Figure 10 plot the impact of uncertainty shocks on aggregate output with and without debt relief. Panel (B) and (D) of Figure 10 plot the output responses to debt relief during normal times and periods of high uncertainty. The effects of debt relief policy are much weaker in this counterfactual simulation without cash buildup: estimated output response to the debt relief program following uncertainty

shocks is around 1.0 % upon impact in contrast to the 1.5% in the baseline simulation. In this case, the effects of debt relief programs in mitigating firms' cash buildup are missing, leading to an underestimation of policy effects.

FIGURE 10: **Credit Interventions in a Counterfactual Economy**

(A) **Output Responses to Uncertainty Shocks** (B) **Output Responses to Debt Relief**



Notes: Panels (A) and (C) plot aggregate output responses to uncertainty shocks with and without credit interventions. Panels (B) and (D) plot the output responses to policy interventions during normal times and periods of high uncertainty. Note that in the model without frictions in debt issuance ($\eta = 0$), Appendix C.3 details the computation of aggregate impulse response functions.

8 Concluding Remarks

The Federal Open Market Committee has repeatedly underlined uncertainty as a key factor in US recessions. Understanding how uncertainty shocks transmit to the real economy is key to the design of stabilization policies.

In this paper, I show both empirically and theoretically how elevated macro uncertainty affects the real economy through the balance sheet adjustments of firms. My model mechanism illustrates how corporate saving motives and ex-ante financial conditions determine firms' responses to uncertainty shocks, which differs significantly from existing transmission mechanisms. Importantly, the new mechanism provides a unified explanation for the observed capital, cash, and debt dynamics following macro uncertainty shocks and has novel policy implications. Exploiting a calibrated model that reproduces both firm-level and aggregate impacts of uncertainty shocks, I show that conventional stimulus policies have modest effects in counteracting the adverse effects of uncertainty shocks, while credit interventions, in particular debt relief, strongly

and effectively stabilize uncertainty-driven recessions.

My model abstracts from other uncertainty transmission mechanisms in order to demonstrate the ability of the new mechanism to reproduce data patterns. An interesting question to ask is which transmission channel is the most important channel in determining the aggregate effect of uncertainty shock. Answering this question requires a model with additional real and financial frictions, which substantially increases the computational burden. I leave the task for future research. Moreover, my model can be used to understand the transmission of other macroeconomic shocks. For example, to what extent do corporate cash holdings buffer financial shocks? Answering such questions needs a quantitative model that captures empirically consistent corporate cash behavior, like the one presented in this paper.

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A Data Appendix

A.1 Macro Time Series Data

For the macro data, I use data from the Federal Reserve Bank of St. Louis (FRED) for the United States.

Definition	Code	Unit
GDP	GDP	Billions of Dollars
GDP Deflator	GDPDEF	Index 2012=100
Effective Federal Funds Rate	FEDFUNDS	Percentage
Credit Spread	BAA10Y	Percentage

The aggregate variables used in the panel local projection include Real GDP Growth measured as the log growth of real GDP, Inflation Rate measured as the log difference in GDP deflator, Real Federal Funds Rate measured as the difference between Effective Federal Funds Rate and Inflation Rate, and Credit Spread.

A.2 Firm-level Data

This subsection describes the firm-level variables used in the empirical analysis of the paper, based on quarterly Compustat data. The variable definition and sample selection follow standard practices in the literature, for example, Kim and Kung (2017), and Ottonello and Winberry (2020).

Variable Construction: All variables are deflated by the 2012 GDP deflator.

1. *Capital Investment*: defined as $\Delta \log(k_{i,t+1})$, where $k_{i,t+1}$ denotes the capital stock of firm I at the end of period t. For each firm, we set the first value of $k_{i,t+1}$ to be the level of Gross Plant, Property, and Equipment $PPEGTQ$ in the first period in which this variable is reported in Compustat. From this period onwards, I compute the evolution of $k_{i,t+1}$ using the changes of Net Plant, Property, and Equipment $PPENTQ$, which is a measure of net investment with significantly more observations than $PPEGTQ$.

2. *Leverage Ratio*: measured as Total Debt divided by Total Assets ATQ, with Total Debt computed as the sum of Debt in Current Liabilities and Total Long-Term Debt ($DLCQ + DLTTQ$).

3. *Cash Ratio*: measured as the ratio of Cash and Short-term Investments $CHEQ$ to Total Assets ATQ.

4. *Net Leverage*: measured as the ratio of Total Debt minus Cash and Short-term Investments $CHEQ$ to Total Assets ATQ.

5. *Firm Size*: measured as the log of Total Assets ATQ.

6. *Tobin's Q*: is defined as follows:

$$Tobin's\ Q = \frac{ATQ + CSHOQ \times PRCCQ - CEQQ}{ATQ}$$

   where $CSHOQ$ is the number of Common Shares Outstanding, $PRCCQ$ is the Share Price (Close), $CEQQ$ is Common/Ordinary Equity - Total, and ATQ is Total Assets.

7. *Real Sales Growth*: measured asthe year-on-year growth in quarterly sales $SALEQ$.

8. *Cash Flows*: measured as the sum of Income before Extraordinary Items IBQ and Depreciation and Amortization DPQ divided by lagged Total Assets ATQ.

9. *Debt Maturity*: measured as (1 – Debt Maturing within a Year $DD1$) / Debt in Current Liabilities and Total Long-Term Debt ($DLCQ + DLTTQ$).

10. *(Net) Equity Issuance*: measured as $(SSTKQ - PRSTKCQ)$, where $SSTKQ$ is the quarterly Sale of Common and Preferred Stock, constructed based on the Compustat reported Year-to-date Sale of Common and Preferred Stock $SSTKY$; $PRSTKCQ$ is the quarterly Purchase of Common and Preferred Stock, constructed based on the Compustat reported Year-to-date Purchase of Common and Preferred Stock $PRSTKCY$. I normalize these quarterly net issuances by lagged Total Assets ATQ, as in Hennessy and Whited (2007).

Panel Local Projection: The sample covers the period from 1990Q1 to 2018Q4 at a quarterly frequency.

1. I exclude firms in finance (SIC codes 6000-6999), utility (SIC codes 4900-4949), and government-related sectors (SIC codes 9000-9999).

2. I exclude firms that are not incorporated in the United States.

3. I exclude firm-quarter observations with negative values for non-negative accounting items.

4. I exclude firm-observations with net property, plant, and equipment of less than \$1M and total assets of less than \$3M. This eliminates extremely small firms that might be very sensitive to aggregate shocks. These only account for less than 1% of total firm-quarter observations.

5. I include firm-quarter observations from firms that are observed for at least 20 quarters during the sample period (a reasonably long time dimension is required for firm-level fixed effects and within the estimator).

6. I winsorize observations of all variables at the top and bottom 1% of the distribution to exclude extreme observations, e.g., those driven by mergers and acquisitions.

APPENDIX TABLE A1: Summary Statistics of Key Firm-level Variables

	Mean	S.D.	P25	P50	P75
$\Delta log(Capital_{i,t})$	0.01	0.10	-0.02	-0.00	0.03
$\Delta log(Cash_{i,t})$	0.02	0.69	-0.24	-0.00	0.24
$\Delta log(Debt_{i,t})$	0.01	0.35	-0.06	-0.00	0.05
$\Delta_8 log(Capital_{i,t+8})$	0.08	0.45	-0.13	0.04	0.27
$\Delta_8 log(Cash_{i,t+8})$	0.12	1.15	-0.47	0.09	0.66
$\Delta_8 log(Debt_{i,t+8})$	0.13	1.06	-0.26	0.03	0.48
Tobin's Q	1.81	1.29	1.08	1.42	2.04
Firm Size	6.12	2.11	4.55	6.12	7.60
Sales Growth	0.02	0.24	-0.06	0.02	0.10
Cash flows	0.01	0.05	0.01	0.02	0.03

Notes: this table presents summary statistics of key firm-level variables. The sample period is 1990q1 to 2018q4. All variables are winsorized at the 1% level to eliminate outliers.

A.3 Measured Firm-level Productivity

I assume that the production function at the firm level is Cobb-Douglas and allow the parameters of the production function to be industry-specific:

$$y_{i,j,t} = z_{i,j,t} k_{i,j,t}^{\alpha} n_{i,j,t}^{\nu}$$

Since data on employment is not available in the Compustat Quarterly, I rewrite the production function based on the optimal static choice of labor in the model:

$$y_{i,j,t} = z_{i,j,t}\psi(W_t)k_{i,j,t}^{\gamma}$$

where $y_{i,j,t}$ is sales, $z_{i,j,t}$ is firm-level productivity, $\psi(W_t)$ is a time-specific term related to equilibrium wage, and $k_{i,j,t}$ is capital stock.

Within each 1-digit SIC industry, I then estimate firm-level productivity as the residual of the following equation:

$$\ln(y_{i,t}) = \alpha_i + \alpha_t + \alpha_k \ln(k_{i,t-1}) + v_{i,t}$$

where $y_{i,t}$ is firm sales in quarter t, $k_{i,t-1}$ is the firm's physical capital stock at the beginning of period t, α_i is a firm fixed effect, and α_t is a time fixed effect.

$\hat{v}_{i,t}$ therefore denotes the estimated log productivity $ln(z_{i,t})$ of firm i in quarter t. The year-on-year firm-level productivity growth used in the regressions is then $\Delta lnTFP_{i,t} = ln(z_{i,t}) - ln(z_{i,t-4})$.

B Additional Empirical Results

B.1 Within-firm Variation in Indebtedness

I examine whether within-firm variation in firm indebtedness predicts heterogeneous responses to uncertainty shocks by estimating the following specification:

$$\Delta_h \log(y_{i,t+h}) = \alpha_{i,h} + \alpha_{fq,h} + \alpha_{s,t,h} + \underbrace{\boldsymbol{\gamma_h}\big(D_{i,t-1} - \bar{D}_i\big) \cdot \Delta \log \sigma_t}_{\text{Heterogeneous responses}} + \beta_h\big(D_{i,t-1} - \bar{D}_i\big) \quad (26)$$

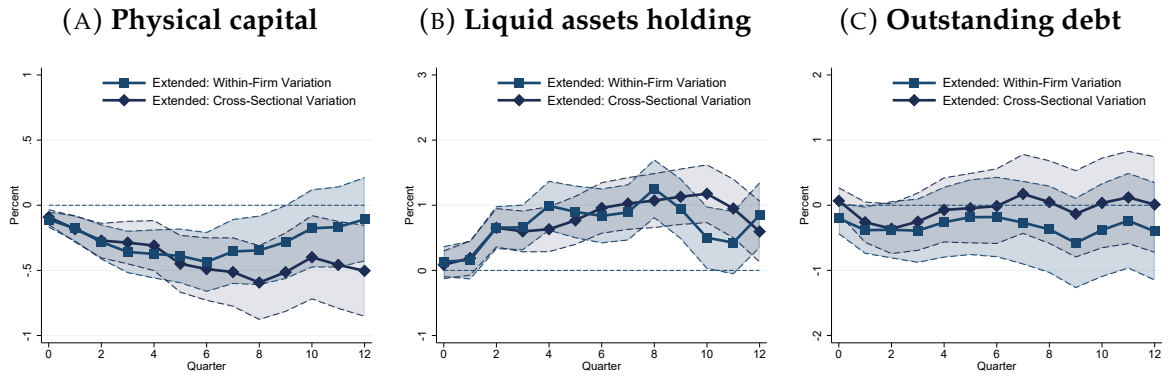
$$+\boldsymbol{\Psi_h'}\big(\mathbf{Z}_{i,t-1} - \bar{Z}_i\big) \cdot \Delta \log \sigma_t + \Gamma_h'\big(\mathbf{Z}_{i,t-1} - \bar{Z}_i\big) + \boldsymbol{\eta_h}\big(D_{i,t-1} - \bar{D}_i\big) \cdot \Delta \log GDP_t + \mu_{i,t+h}$$

$$\forall i, h = 0, 1, 2, 3, ..., 12$$

The Equation 26 differs from Equation 2 by using within-firm variation in firm characteristics. Specifically, $\big(D_{i,t-1} - \bar{D}_i\big)$ is the deviation of firm i's net leverage from its unconditional firm-specific average, and $Z_{i,t-1}$ is a vector of control variables all in deviation from their respective firm-specific averages. Figure A1 shows that the responses of physical capital and liquid assets holding to changes in the Macro Uncer-

tainty Index are also stronger when firms are more indebted than their own average levels. These results provide additional evidence of the role of firm indebtedness in shaping firm responses to uncertainty shocks.

APPENDIX FIGURE A1: **Heterogeneous Responses by Within-firm Variation in Indebtedness**



Notes: the figure plots both the average and heterogeneous responses of (a) physical capital, (b) liquid assets holding, and (c) outstanding debt to a one-standard-deviation growth in Macro Uncertainty Index by Jurado et al. (2015) at quarter t. The heterogeneous responses are driven by cross-sectional variation and within-firm variation in indebtedness at quarter $t-1$. Point estimates and 95% confidence intervals for β_h and γ_h are plotted. Standard errors are two-way clustered at both firm and time levels. The sample period is from 1990Q1 to 2018Q4.

B.2 Event Study: 9/11 Terrorist Attacks

As in Kim and Kung (2017), I exploit the 9/11 terrorist attacks as an event study to study changes in firm behavior before and after large uncertainty events. Using the 9/11 terrorist attacks to study the effects of heightened aggregate uncertainty on firm behavior has several advantages: First, the terrorists' attacks on U.S. soil in September 2001 were exogenous to the U.S. economy and struck as a total surprise. Second, the event induces a significant increase in economic uncertainty. For example, Macro Uncertainty Index by Jurado et al. (2015) increases by 5.5%, the largest single-quarter change before the Great Recession. The jump in the VIX index in September 2001 is more than 1.65 standard deviation above the mean, as shown in Bloom et al. (2018). The Federal Open Market Committee (FOMC) also stated in October 2001 that "the events of September 11 produced a marked increase in uncertainty". Third, compared with other events that result in a rise in the uncertainty of a similar magnitude, this political event appears to be relatively unconfounded by changes in other macroeconomic factors. For example, the 2007-2009 financial crisis is a period with both high macroeconomic uncertainty and financial sector disruption, therefore, it is hard to dis-

entangle what factors drive the changes in firm behavior.

To examine the average changes in firm behavior across firms around the 9/11 terrorist attacks, I estimate a simple fixed effects regression:

$$\log(y_{i,t}) = \alpha_i + \alpha_{fq} + \sum_t \boldsymbol{\beta_t} \text{Quarter}_t + \epsilon_{i,t} \tag{27}$$

$$\forall t \in \{2001q1, ..., 2002q2\} \backslash \{2000q4\}$$

To explore how the impact of firm indebtedness on firm behavior varies over the event window, I estimate the following regression:

$$\log(y_{it}) = \alpha_i + \alpha_{s,t} + \alpha_{fq} + \sum_t \boldsymbol{\gamma_t} \text{Indebtednes}_{i,t-1} \cdot \text{Quarter}_t + \beta \text{Indebtednes}_{i,t-1} \tag{28}$$

$$+\Gamma' \mathbf{X}_{i,t-1} + \sum_t \Lambda_t' \mathbf{X}_{i,t-1} \cdot \text{Quarter}_t + \epsilon_{i,t}$$

$$\forall t \in \{2001q1, ..., 2002q2\} \backslash \{2000q4\}$$

where Quarter_t is a quarter dummy for the time period from 2000q4 to 2002q2, with 2000q4 taken as the omitted category. α_i indicates firm fixed effects that absorb permanent differences in the levels of dependent variables across firms. Fiscal-quarter dummy α_{fq} is included to absorb the impact of the difference in fiscal-quarter across firms on firm behavior. $\alpha_{s,t}$ represents the industry-by-quarter fixed effects that absorb differences in how broad industries are exposed to aggregate shocks. The industry is defined as 1-digit SIC level. $\text{Indebtedness}_{i,t-1}$ measures how many standard deviations away firm i's net leverage is from its industry average in quarter $t-1$. As discussed earlier, differences in indebtedness might correlate with other factors that affect firm behavior. I control for a vector of widely used control variables $\mathbf{X}_{i,t-1}$ that include Tobin's Q, Sales growth, and Cash flows, and allow their effects on firm behavior also vary over time by interacting these variables with a quarter dummy. Standard errors are clustered by both firm and quarter. Since the goal is to capture within-firm changes in firm behavior before and after the event, firms that enter and exit the sample during the event window are excluded. Finally, $\boldsymbol{\beta_t}$ capture 'within-firm' changes in firm behavior over time relative to the base period 2000q4. $\boldsymbol{\gamma_t}$ captures the time-varying relation between indebtedness and changes in dependent variables over the event window.

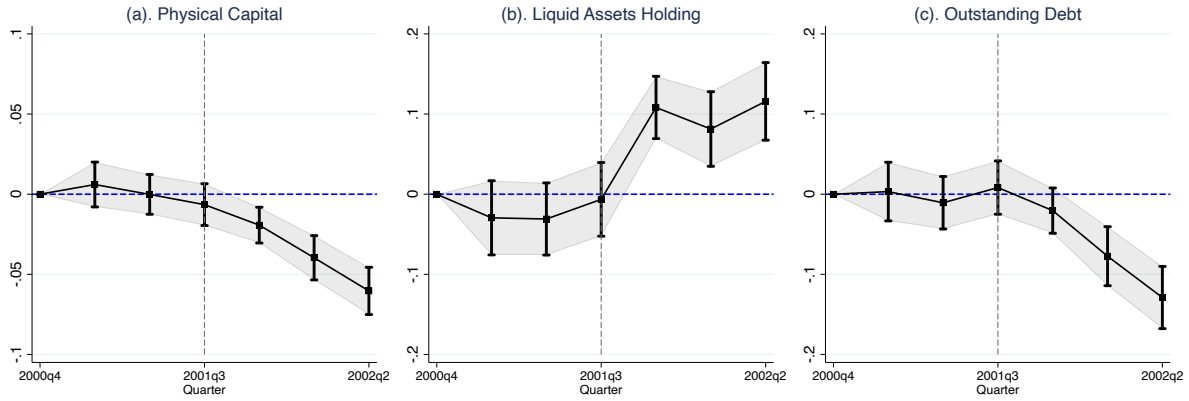
Panel A of Figure A2 plots the estimated average firm-level growth in physical cap-

ital, liquid assets holding, and outstanding debt from 2000q4 to 2002q2, along with a 95% confidence interval. The Post-9/11 period features statistically significant declines in physical capital and outstanding debt, while a large buildup in liquid assets holding across firms. The average dynamics following the 9/11 terrorist attacks are consistent with the baseline results.

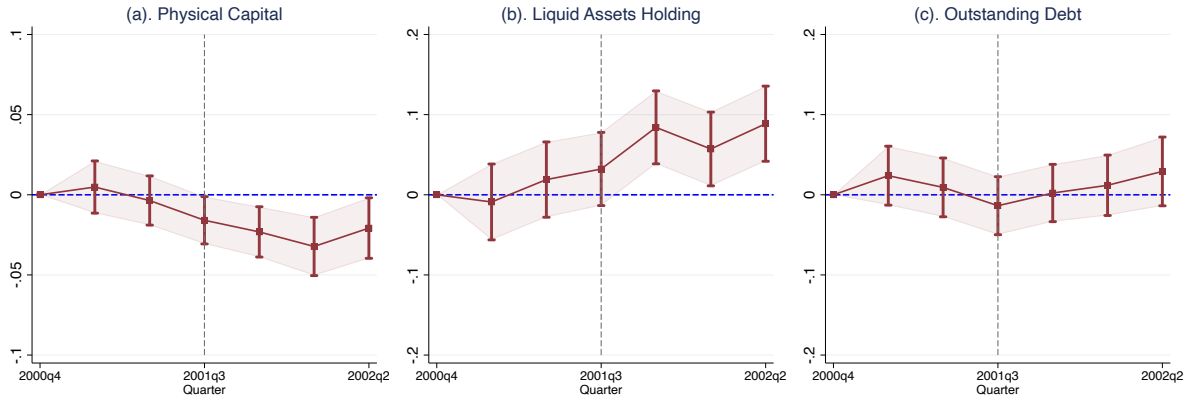
Panel B of Figure A2 plots the estimated time-varying relation between firm indebtedness and firm-level changes in (a) physical capital, (b) liquid assets holding, and (c) outstanding debt from 2000q4 to 2002q2, along with 95% confidence interval. Notably, after the third quarter of 2001, higher indebtedness at $t-1$ foreshadowed statistically significant a larger decline in physical capital and a larger growth in liquid assets holdings. Moreover, differences in lagged indebtedness do not predict differences in debt growth across differently indebted firms after the event. Taken together, during periods of high uncertainty, high indebtedness is mainly associated with a larger shift in firms' asset choice, consistent with the more direct evidence based on local projection discussed in Section 2.2.

APPENDIX FIGURE A2: **Firm Behavior around 9/11 Terrorist Attacks**

Panel A. Average Firm Growth in Capital, Cash, and Debt



Panel B. Time-Varying Effects of Firm Indebtedness on Firm Choices of Capital, Cash, and Debt



Notes: Panel A reports estimated average firm-level growth in (a) physical capital, (b) liquid assets holding, and (c) outstanding debt from 2000q4 to 2002q2, along with 95% confidence interval. Panel B reports estimated time-varying relation between firm indebtedness and firm-level changes in (a) physical capital, (b) liquid assets holding, and (c) outstanding debt from 2000q4 to 2002q2, along with a 95% confidence interval.

C Model Appendix

C.1 Model Details

Static Labor Choice and Operating Profits. Given productivity z, capital stock k, and Wage W, firms solve the following static profit-maximization problem:

$$\pi(z,k;W) = \max_n \{z^{1-\nu}k^{\alpha}n^{\nu} - f_o k - Wn\}$$

Optimal labor choice is given by

$$n^*(z,k;W) = \left(\frac{\nu}{W}\right)^{\frac{1}{1-\nu}} z k^{\frac{\alpha}{1-\nu}}$$

Therefore, the production of the firm is given by

$$y^*(z,k;W) = \left(\frac{\nu}{W}\right)^{\frac{\nu}{1-\nu}} z k^{\frac{\alpha}{1-\nu}}$$

Operating profits is given by

$$\begin{aligned}\pi(z,k;W) &= (1-\nu)\left(\frac{\nu}{W}\right)^{\frac{\nu}{1-\nu}} z k^{\frac{\alpha}{1-\nu}} \\ &= z\psi(W)k^{\gamma} - f_o k\end{aligned}$$

where W denotes the (real) wage and

$$\gamma = \frac{\alpha}{1-\nu} \qquad \text{and} \qquad \psi(W) = (1-\nu)\left(\frac{\nu}{W}\right)^{\frac{\nu}{1-\nu}}$$

α is the value-added share of capital, and ν is the value-added share of labor. This set-up ensures that the firm's profit function is linear in its productivity, as in Gilchrist et al. (2014).

Optimality Conditions First-order condition with respect to dividends is as follows:

$$\Lambda(d) = \begin{cases} 1, & \text{if } d \geq 0 \\ 1 + \kappa_1|d|, & \text{if } d < 0 \end{cases} \tag{29}$$

Step 1: using the envelop theorem, I obtain the marginal value of cash, capital, and debt for firms with non-maturing debt:

$$\frac{\partial V^m(z,k,c,b)}{\partial c} = \Lambda(d)\Bigg[[1+(1-\tau)r](1+s\cdot\mathbf{1}_{m<0})\Bigg] \tag{30}$$

$$\frac{\partial V^m(z,k,c,b)}{\partial k} = \Lambda(d)\Bigg[\Bigg[(1-\tau)\frac{\partial \pi(z,k)}{\partial k}+\tau\delta\Bigg](1+s\cdot\mathbf{1}_{m<0})+(1-\delta)\Bigg] \tag{31}$$

$$\frac{\partial V^m(z,k,c,b)}{\partial b} = -\Lambda(d)\Bigg[[1+(1-\tau)r](1+s\cdot\mathbf{1}_{m<0})\Bigg] \tag{32}$$

Step 2: using the envelop theorem, I obtain the marginal value of cash, capital and debt for firms with non-maturing debt:

$$\frac{\partial V^n(z,k,c,b)}{\partial c} = \Lambda(d)[1+(1-\tau)r] \tag{33}$$

$$\frac{\partial V^n(z,k,c,b)}{\partial k} = \Lambda(d)\Bigg[(1-\tau)\frac{\partial \pi(z,k)}{\partial k}+\tau\delta+(1-\delta)\Bigg] \tag{34}$$

$$\frac{\partial V^n(z,k,c,b)}{\partial b} = -\Lambda(d)\Bigg[[1+(1-\tau)r]-\eta\cdot\mathbf{1}_{b'>b}\Bigg] \tag{35}$$

Step 3: first-order conditions with respect to cash choice c' and capital choice k' are the same for firms with maturing and non-maturing debt:

$$FOC[c']: \Lambda(d)\cdot\mathbf{1} \geq \frac{1}{1+r}E_{z'|z}\Bigg[\lambda\frac{\partial V^m(z',k',c',b')}{\partial c'}+(1-\lambda)\frac{\partial V^n(z',k',c',b')}{\partial c'}\Bigg] \tag{36}$$

$$FOC[k']: \Lambda(d)\cdot\mathbf{1} = \frac{\mu_b\theta(1-\delta)}{1+r}+\frac{1}{1+r}E_{z'|z}\Bigg[\lambda\frac{\partial V^m(z',k',c',b')}{\partial k'}+(1-\lambda)\frac{\partial V^n(z',k',c',b')}{\partial k'}\Bigg] \tag{37}$$

Step 4: first-order conditions with respect to debt choice b' for firms with maturing debt:

$$FOC[b']: \Lambda(d)\cdot\mathbf{1}-\mu_b = \frac{1}{1+r}E_{z'|z}\Bigg[\lambda\frac{\partial V^m(z',k',c',b')}{\partial k'}+(1-\lambda)\frac{\partial V^n(z',k',c',b')}{\partial k'}\Bigg] \tag{38}$$

$$FOC[b']: \Lambda(d)\cdot(\mathbf{1}-\eta)-\mu_b=\frac{1}{1+r}E_{z'|z}\left[\lambda\frac{\partial V^m(z',k',c',b')}{\partial k'}+(1-\lambda)\frac{\partial V^n(z',k',c',b')}{\partial k'}\right] \tag{39}$$

Step 5: plugging the envelope conditions (B2)-(B7) into the first-order conditions (B8)-(B11), I obtain Euler equations (19)-(22) for cash, capital, and debt in the main text.

C.2 Model Computation

Stationary Equilibrium. I first assume the economy is at steady-state with normal volatility. In the stationary equilibrium, there is no aggregate shock, so $r = 1/\beta - 1$ and I solve for equilibrium wage to clear the labor market. The algorithm is as follows:

Step 1: Guess an equilibrium wage W^{old}.

Step 2: Solve the firm's problem using Value Function Iteration.

Step 3: Using the policy functions and distributions, compute aggregate quantities.

Step 4: Using the labor market clearing condition, compute the *Excessive Demand* $\epsilon = L^s - L^d$ by taking the difference between labor demand and labor supply. *STOP* if $\max|\epsilon| < 10^{-5}$.

Step 5: Update the wage with a given weight and return to Step 2.

Transition Dynamics. The key assumption of the transition dynamics is that after a sufficiently long time, the economy will converge back to its original stationary equilibrium after any temporary and unexpected (MIT) shocks. The solution algorithm here is outlined as follows:

Step 1: Fix a sufficient long transition period $t = 1$ to $t = T$ (say 200), at which point we assume the economy has reached steady state.

Step 2: Generate an initial jump in volatility σ_t and assume the shock follows $\sigma_{t+1} = \rho\sigma_t$ with $\rho = 0.5$.

Step 3: Guess a time-series of aggregate prices $\{W_t\}$ of length T.

Step 4: **Backward Induction**: solve the value functions (and policy functions) backwards from $t = T-1, ...1$ setting value functions at time T as the steady-state value functions. This yields value functions and policy functions along the transition path from $t = 1$ to $t = T-1$.

Step 5: **Forward Simulation**: starting from the steady state distribution, simulate the distribution forward from $t = 1, ..., T$ using the policy functions and idiosyncratic productivity Markov transition matrix. This yields firm distributions along the transition path from $t = 1$ to $t = T - 1$.

Step 6: Using the policy functions and distributions, compute aggregate quantities.

Step 7: Using the labor market clearing condition, compute the *Excessive Demand* $\epsilon_t = L_t^s - L_t^d$ by taking the difference between labor demand and labor supply.

Step 8: *STOP* if $\max |\epsilon_t| < 10^{-5}$.

Step 9: Update $(\{W_t\}_{t=1}^T)^{New} = v\epsilon_t + (1 - v)(\{W_t\}_{t=1}^T)^{Old}$, and GO TO step 4. v is chose to be 0.5.

C.3 Model Simulation

I simulate this economy for 200 quarters until they converge to the steady-state distribution. Then I keep simulating this economy for an additional 300 quarters which is used for the calculation of moments. Finally, I keep simulating the economy starting from the quarter 500 forwards with the transitional policy functions and aggregate prices until the economy converges back to the steady state at the quarter 700.

Simulated Methods of Moments The SMM proceeds as follows: The simulated data vector $y_i(\beta)$ depends on a vector of structural parameter β. The goal is to estimate β by matching a set of simulated moments, denoted as $h(y_i(\beta))$, with the set of actual data moments $h(x_i)$, where x_i is an i.i.d. data vector. Define

$$g_n(\beta) = \frac{1}{n} \sum_{i=1}^{n} \Big[h(x_i) - h(y_i(\beta)) \Big]$$

The simulated moment estimator of β is then defined as the solution to the minimization of

$$\hat{\beta} = \arg\min_{\beta} g_n(\beta)' W g_n(\beta)$$

The optimal parameter estimate β is obtained by searching over the parameter space using the simulated annealing algorithm.

Mapping Model to Data. Table below details the mapping between model variables to Compustat Variables.

APPENDIX TABLE A2: Mapping Model to Data

Variable	Construction	
	Data	Model
Tobin's Q	(ATQ + PRCCQ $\times$ CSHOQ - CEQQ) / ATQ	$\frac{V_{t-1}(z,k,c,b)}{k+c}$
Firm Size	log(ATQ)	$\log(k+c)$
Leverage ratio	(DLTTQ+DLCQ)/ATQ	$\frac{b}{k+c}$
Net leverage ratio	(DLTTQ+DLCQ-CHEQ)/ATQ	$\frac{b-c}{k+c}$
Cash ratio	CHEQ/ATQ	$\frac{c}{k+c}$
Dividends ratio	DVY/ATQ	$\frac{d}{k+c}$
Equity-issuance-to-assets	(SSTKY - PRSTKY) /ATQ	$\frac{e}{k+c}$

Notes: Variables ending in Y in Compustat are stated as year-to-date. I convert them into quarterly frequency by subtracting the past quarter from the current observation for all but the rest quarter of the firm.

Aggregate Impulse Response Functions. I compute perfect-foresight transition path following unexpected uncertainty shocks or both unexpected uncertainty shocks and policy interventions. Following Koop et al. (1996), aggregate impulse response functions are computed using "Simulation Differencing":

$$\hat{X}_t^{shock} = 100 \log\left(\frac{X_t^{shock}}{X_t^{no\ shock}}\right) \qquad \hat{X}_t^{shock,policy} = 100 \log\left(\frac{X_t^{shock,\ policy}}{X_t^{no\ shock}}\right)$$

where $\hat{X}_t^{shock}$ denotes the aggregate impact of uncertainty shocks. $\hat{X}_t^{shock,policy}$ denotes the aggregate impact of uncertainty shocks with policy interventions. To evaluate whether the effectiveness of the credit policies differs during normal times and periods of high uncertainty, I compute the effects of policies as follows:

$$\hat{X}_t^{policy} = 100 \log\left(\frac{X_t^{policy}}{X_t^{no\ shock}}\right) \qquad \hat{X}_t^{policy,shock} = 100 \log\left(\frac{X_t^{shock,\ policy}}{X_t^{shock}}\right)$$

where $\hat{X}_t^{shock}$ denotes the aggregate effects of policy interventions during normal times, $\hat{X}_t^{shock}$ denotes the aggregate effects of policy interventions with uncertainty shocks.

D Additional Model Results

D.1 Debt issuance frictions and financial behavior

Recent empirical literature shows that strengthened creditor rights protection by law leads to a smaller number of restrictive covenants and more favorable contracting terms (e.g. looser covenants) in debt contracts, e.g. Mann (2018) and Ghanbari (2019). Gao et al. (2021) further shows that the passage of the laws that enhance creditor rights is followed by an increase in leverage ratio and a decrease in cash ratio. Motivated by the empirical evidence, I test whether firm responses to a reduction in debt issuance costs are consistent with the data patterns. Note that debt issuance costs in the model serve as a reduced-form way to capture various types of frictions in debt issuance. Specifically, I simulate a Randomized Controlled Trial research design where half of the simulated firms are randomly selected as a treated group. At time 0, treated firms unexpectedly enjoy reduced debt issuance costs ($\eta = 0.5\eta_{\text{baseline}}$) and thereafter. I keep simulated data 3 quarters before and five quarters after the event and then run the following difference-in-difference specification:

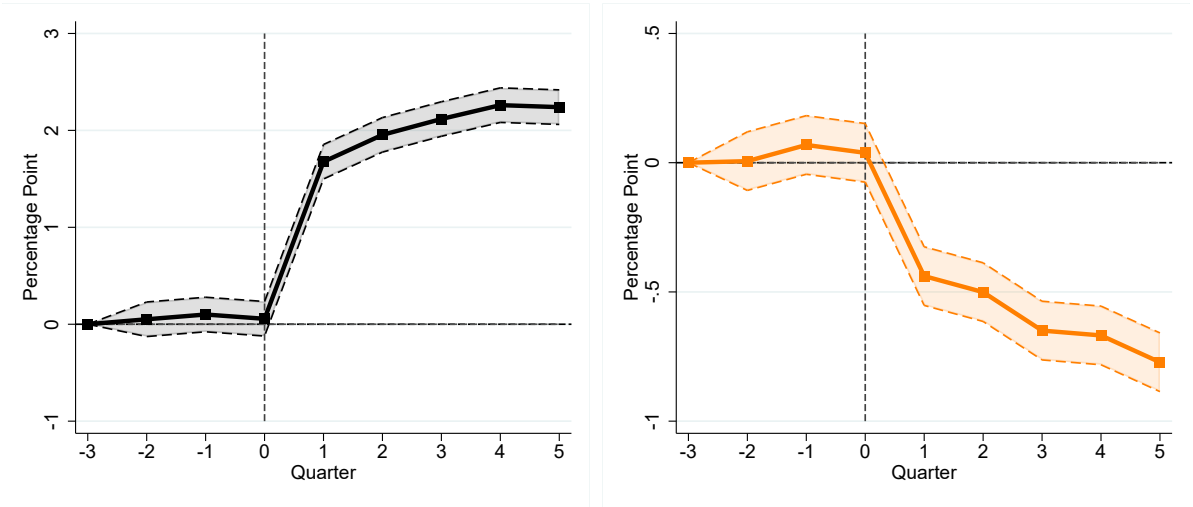
$$y_{i,t} = \alpha + \sum_{t\geq -3}^{t\leq 5} \boldsymbol{\beta_t} \text{Treated}_i \times \text{Quarter}_t + \Gamma' X_{i,t} + \epsilon_{i,t} \tag{40}$$

where Treated_i equals one if firm i belongs to the treated group that will face lower debt issuance costs after Quarter 0. Quarter_t denotes the periods before and after the experiment. $X_{i,t}$ denotes a vector of control variables, including Indebtedness, Tobin's Q, and Firm Size.

Figure A3 shows that treated firms respond to the reduced debt issuance frictions by increasing leverage ratio and decreasing cash ratio, similar to the empirical patterns documented in Gao et al. (2021). In the model, lower debt issuance costs increase the marginal benefits of debt, motivating firms to borrow more. In the meantime, reduced debt issuance frictions mean that treated firms can cheaply borrow from credit markets when an investment opportunity is realized, thereby reducing firms' precautionary saving motives and generating a cut in cash holding.

APPENDIX FIGURE A3: **Reduced Debt Issuance Frictions and Changes in Financial Policies**

(A) **Leverage ratio** (B) **Cash ratio**



Notes: This table reports estimated firm responses to a reduction in debt issuance costs. Point estimates and 95% confidence level are plotted.

D.2 Firm Behavior and Firm Characteristics

This subsection shows firms' investment, saving, and borrowing behavior in alternative setups. Notably, models without liquidity penalties generate a negative relationship between firm indebtedness and cash growth, which is inconsistent with the data.

D.3 Net-Debt Models

As in the baseline model, frictions in debt issuance also govern firms' cash demand in response to uncertainty shocks in the net-debt models. Figure A4 plots output responses to the same uncertainty shocks in the net-debt model with different levels of debt issuance cost η when $\eta = 0$, firms' precautionary saving motives are muted. As in the baseline model with $\eta = 0$, the drops in aggregate output in this model are purely driven by firm deleveraging in response to uncertainty shocks. When $\eta > 0$, firms have incentives to generate internal liquidity through capital investment, which counteracts the deleveraging pressure caused by uncertainty shocks and thereby generates smaller output drops. I calibrate $\eta = \eta*$ to match the net leverage ratio as in the baseline model. The net-debt model predicts an overshoot in output in the medium run.

APPENDIX TABLE A3: **Firm Behavior and Firm Characteristics: Alternative Models**

	Model w/o liquidity penalty		
$\Delta \ln y_{i,t+1}$:	$\Delta\text{Capital}_{i,t+1}$	$\Delta\text{Cash}_{i,t+1}$	$\Delta\text{Debt}_{i,t+1}$
Indebtedness$_{i,t}$	-0.002***	**-0.022*** **	-0.014***
	(0.000)	(0.000)	(0.000)
Tobin's $Q_{i,t}$	0.022***	0.018***	0.023***
	(0.000)	(0.000)	(0.000)
$\text{Size}_{i,t}$	-0.079***	-0.087***	-0.070***
	(0.000)	(0.001)	(0.000)
R-Squared	0.726	0.116	0.594

Notes: The table reports the estimated relationship between firm behavior and firm characteristics using simulated data from alternative models. $*$, $**$, and $***$ represent results significant at the 10%, 5%, and 1% levels, respectively.

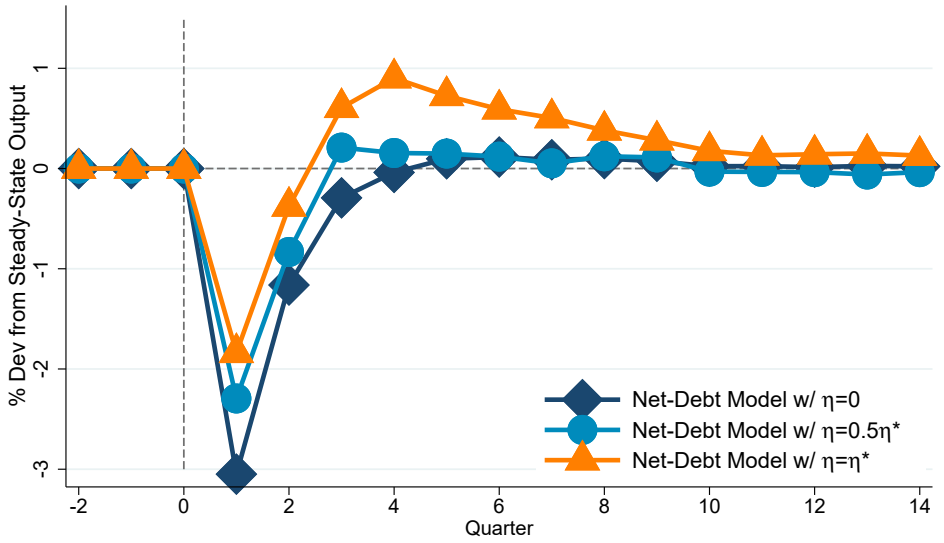
APPENDIX TABLE A4: **Firm Behavior and Firm Characteristics: Alternative Models**

	Model w/o debt issuance frictions		
$\Delta \ln y_{i,t+1}$:	$\Delta\text{Capital}_{i,t+1}$	$\Delta\text{Cash}_{i,t+1}$	$\Delta\text{Debt}_{i,t+1}$
Indebtedness$_{i,t}$	-0.006***	0.173***	-0.015***
	(0.000)	(0.001)	(0.000)
Tobin's $Q_{i,t}$	0.052***	0.026***	0.036***
	(0.000)	(0.000)	(0.000)
$\text{Size}_{i,t}$	-0.024***	-0.040***	-0.033***
	(0.000)	(0.002)	(0.001)
R-Squared	0.754	0.123	0.279

Notes: The table reports the estimated relationship between firm behavior and firm characteristics using simulated data from alternative models. $*$, $**$, and $***$ represent results significant at the 10%, 5%, and 1% levels, respectively.

When $\eta = 0.5\eta*$, firms' precautionary saving motives are weaker, and thus the output overshoot is less pronounced. However, this calibration also predicts a higher leverage ratio and a lower cash ratio relative to the baseline model.

APPENDIX FIGURE A4: **Output Responses to Uncertainty Shocks**



Notes: Figure A4 plots output responses to the same uncertainty shocks in the net-debt model with different levels of debt issuance cost η.

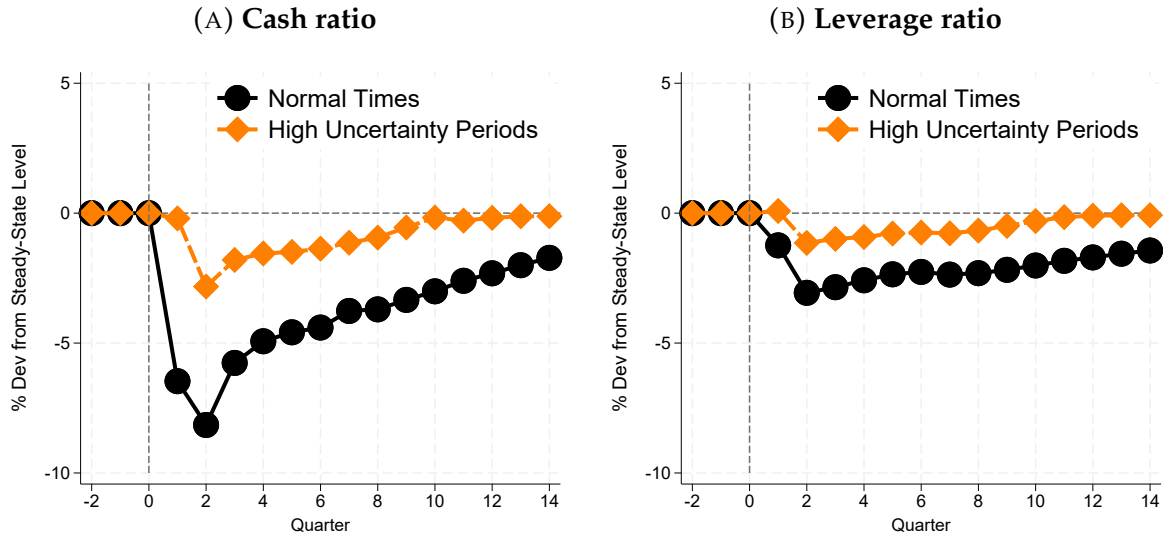
D.4 Firm Responses to Investment Tax Credits

This subsection shows how firms finance capital investment induced by investment tax credits. Importantly, Panel (A) of Figure A5 shows that firms draw down cash to finance capital investment, and such behavior is significantly mitigated during periods of high uncertainty. Besides, Investment tax credits lower the costs of investment and thus reduce firms' reliance on credit. This leads to a drop in leverage ratio, as shown in Panel (B) of Figure A5.

D.5 TFP-driven Booms and Credit Interventions

The estimated output responses to credit interventions in TFP-driven booms are slightly larger than in normal times. This occurs because positive productivity shocks increase firms' investment demand and financial needs, thereby amplifying the role of credit interventions in relaxing firms' financial constraints. This is in contrast to the weaker effects of credit interventions during TFP-driven recessions, where investment demand becomes lower than the steady-state level.

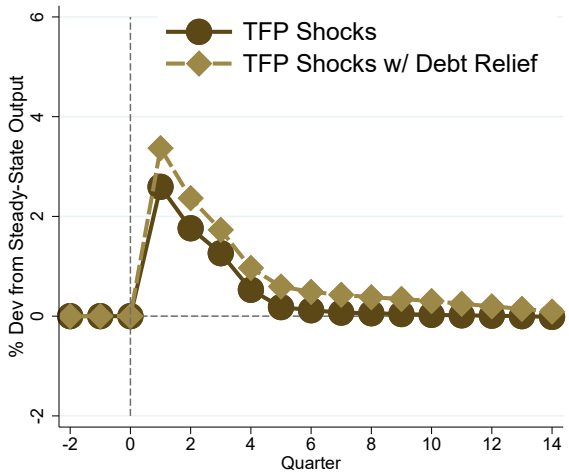
APPENDIX FIGURE A5: **Firm Responses to Investment Tax Credits**



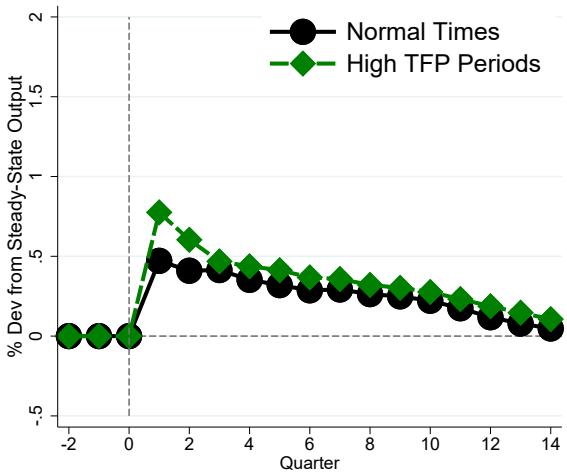
Notes: This figure plots the responses of aggregate cash ratio and leverage ratio to invest tax credits during normal times and periods of high uncertainty.

APPENDIX FIGURE A6: **TFP-driven Booms and Credit Interventions**

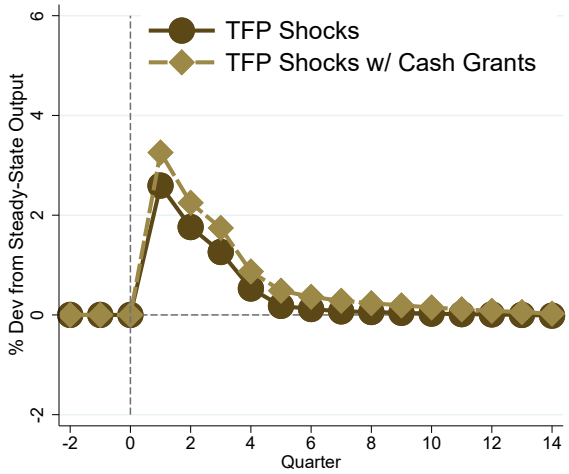
(A) **Output Responses to TFP Shocks**



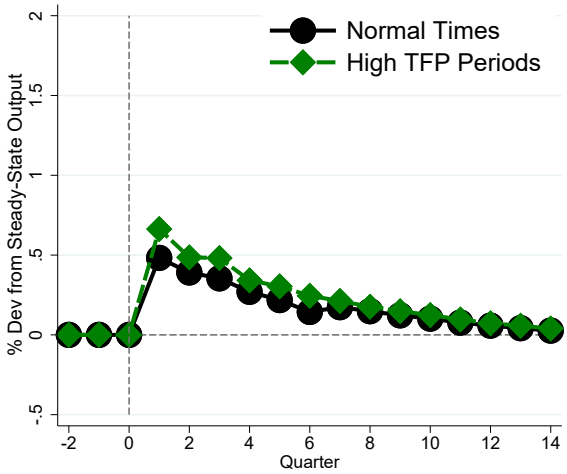
(B) **Output Responses to Debt Relief**



(C) **Output Responses to TFP Shocks**



(D) **Output Responses to Cash Grants**



Notes: Panels (A) and (C) plot aggregate output responses to positive productivity shocks with and without credit interventions. Panels (B) and (D) plot the output responses to policy interventions during normal times and periods of high productivity. Appendix C.3 details the computation of aggregate impulse response functions.