The Firm Balance Sheet Channel of Uncertainty Shocks *

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Abstract

This paper studies how liquidity concerns shape firm behavior, macroeconomic dynamics, and policy transmission under elevated macroeconomic uncertainty. I develop a quantitative heterogeneous firm model in which financial frictions induce precautionary firm behavior. Increased uncertainty raises the risk of internal liquidity shortfalls, leading firms to cut debt and investment while hoarding cash. This mechanism generates sharp economic downturns with heterogeneous firm-level responses, worsened capital misallocation, and endogenous TFP drops, consistent with the data. I show that financial market disruptions can further amplify these effects, causing deep and persistent recessions, whereas credit interventions effectively mitigate them by alleviating firms' liquidity concerns.

Keywords: Uncertainty, Investment, Financial Frictions, Capital Structure
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1 Introduction

Large spikes in macroeconomic uncertainty are strongly associated with economic downturns, yet existing mechanisms—real options and credit spreads—primarily emphasize investment delays or higher borrowing costs while overlooking firms' liquidity concerns amid high uncertainty.[1] As future cash flows become less predictable when uncertainty rises, firms may become increasingly concerned about whether they will have sufficient internal funds for future debt repayment and investment opportunities. Despite being intuitive, how heightened liquidity concerns affect firm behavior, macroeconomic dynamics, and policy effectiveness in periods of high uncertainty remains unclear.

This paper shows both empirically and theoretically that firms' liquidity concerns form a distinct transmission mechanism for uncertainty shocks with novel micro- and macro-level implications. I first present empirical evidence that firms' differential ex-ante financial positions drive heterogeneous firm-level responses to uncertainty shocks. I then analyze the underlying mechanism and examine its implications using a quantitative heterogeneous-firms model in which firms face rollover risk and financing frictions, generating realistic precautionary behavior absent in standard models. In the model, heightened uncertainty increases the risk of internal liquidity shortages, inducing firms to reduce debt and capital investments while accumulating cash holdings to mitigate the elevated risk. More indebted firms face larger debt obligations and therefore become more concerned about the greater downside risk amid higher uncertainty. Firm-level responses, hence, naturally depend on their ex-ante indebtedness. I show that an estimated model reproduces a broad set of suggestive evidence on precautionary firm behavior, the observed heterogeneous balance sheet adjustments across differently indebted firms, and also the aggregate impacts of uncertainty shocks.

Quantitative experiments using the model suggest that the transmission through firms' liquidity concerns provides novel insights into uncertainty-driven recessions and policy transmis-

[1] An extensive literature has provided ample empirical evidence of the negative effects of macroeconomic uncertainty on real economic activities. See, for example, Giordani and Söderlind (2003), Bloom et al. (2007), Jurado et al. (2015). The macroeconomic literature often emphasizes the real options feature of investment, focusing on capital adjustment frictions that cause investment delays. See, e.g, Bloom (2009), Bloom et al. (2018) and Alfaro et al. (2019). The macro-finance literature, on the other hand, highlights that the rising credit spreads amid higher uncertainty, which raises borrowing costs and thus depresses investment and hiring. See, e.g, Arellano et al. (2012), Christiano et al. (2014), and Gilchrist et al. (2014).

sion under high uncertainty. First, heterogeneous firm responses driven by elevated uncertainty increase dispersion in sales growth, capital accumulation, and marginal products. These shifts worsen capital misallocation and lead to endogenous declines in aggregate productivity. Second, the transmission mechanism becomes substantially stronger as rollover risk rises, leading to deep recessions with slow recoveries. This provides a new explanation for why uncertainty spikes during financial crises lead to unusually large downturns. Third, credit interventions, such as debt relief and cash injection programs, become especially effective during uncertainty-driven recessions by reducing heightened liquidity concerns across firms, in sharp contrast to their modest effects amid TFP-driven recessions. This identifies a novel role for credit interventions as stabilization tools and shows how the nature of recessions shapes the effectiveness of policy.

I begin by documenting how firms adjust their balance sheets in response to macroeconomic uncertainty shocks. Leveraging a panel local projection that combines COMPUSTAT firm-level data with the Macro Uncertainty Index of Jurado et al. (2015), I show that U.S. public firms reduce capital and debt and raise cash holdings on average after uncertainty rises. Importantly, I find that ex-ante more indebted firms engage in stronger asset rebalancing — exhibiting sharper capital declines and larger cash buildup— whereas debt contraction is similar across firms. These heterogeneous responses highlight gaps in the existing literature. First, firms' ex-ante financial positions systematically shape their reactions to elevated uncertainty. Second, uncertainty shocks trigger not only corporate deleveraging but also a pronounced shift in asset composition, the forces behind which and their implications for aggregate dynamics remain poorly understood.

The empirical results are robust across a wide range of checks. I show that differences in investment opportunities or industry exposure cannot explain these heterogeneous responses. These heterogeneous responses are also robust to controlling for plausible differential business-cycle and interest-rate sensitivities across differently indebted firms. I find that using within-firm deviations in indebtedness yields the same patterns, confirming that persistent cross-sectional differences do not drive the results.[2] Finally, an event study around the 9/11 terrorist attacks—an exogenous surge in macro uncertainty—reproduces the baseline balance-sheet adjustments and their dependence on firms' pre-shock leverage.

[2] Kim and Kung (2017) and Kermani and Ma (2020) show that persistent firm-level differences in asset redeployability or specificity will lead to heterogeneous investment responses to uncertainty shocks.

To interpret empirical patterns and examine their broader implications, I develop a quantitative heterogeneous firm model in which firms make joint capital, cash, and debt decisions under financing frictions, rollover risk, and idiosyncratic productivity shocks. Financing frictions, along with firm entry and exit, slow down firms' capital accumulation and thus generate realistic firm life-cycle dynamics and a mass of firms that differ in financial positions endogenously.

The main novelty of the model is its ability to capture precautionary firm behavior consistent with the data.[3] To do so, I incorporate two realistic features into the class of financial constraint models. First, firms might run into debt rollover crises, during which maturing debt must be repaid immediately. Insufficient internal funds then trigger costly liquidity shortfalls, which capture the difficulties in dealing with customers, employees, and strategic partners during liquidity distress.[4] The costly liquidity shortfalls make internal liquidity essential for avoiding cash-flow losses when debt cannot be rolled over, thereby generating a strong precautionary motive tied directly to firms' existing debt positions.

Second, the model incorporates both equity and debt issuance costs, capturing real-world underwriting and legal fees. Expensive external financing makes cash holdings firms' marginal sources of funding. Cash holdings, therefore, serve as precautionary buffers against both liquidity distress and future financing needs.[5] To corroborate these model features, I present suggestive evidence on precautionary firm behavior following empirical corporate finance literature and show that a calibrated model generates non-targeted investment, saving, and borrowing behavior that aligns well with the data. In constrast, nested model, such as when liquidity shortfalls or debt issuance are not costly, produce counterfactual firm behavior.

A key contribution of the paper is demonstrating how uncertainty shocks transmit to the real economy by amplifying firms' liquidity concerns and thus their precautionary behavior. I simulate the responses of the model economy to unexpected macro uncertainty shocks and show that a calibrated model reproduces the observed balance sheet adjustments across firms. The model highlights two forces at play. When uncertainty rises, the distribution of future productivity widens.

[3]An extensive empirical corporate finance literature has documented empirical evidence on firm precautionary behavior. Examples include Opler et al. (1999), Faulkender and Wang (2006), Bates et al. (2009),Gao et al. (2021).

[4]Hennessy and Whited (2005) and Gamba and Triantis (2008) also model the costs of liquidity shortage. However, both papers abstract from corporate cash choices.

[5]Jeenas (2019) also introduces debt issuance costs and studies its implications for monetary transmission. In my model, firms hold cash holdings to overcome both liquidity shortfalls and financing frictions. The first motive and its dependence on firms' debt positions are missing in his model.

The higher uncertainty thus increases the likelihood of low cash-flow states, elevating the risk of costly liquidity shortages firms face. On the other hand, heightened uncertainty also raises the probability of high productivity, bringing higher growth potential. As a result, firms reduce debt and investment to lower exposure to liquidity distress and simultaneously accumulate cash to insure against both adverse shocks and future financing needs. More indebted firms, being more exposed to downside risks, accumulate more cash to prepare for larger debt repayment while preserving funds for future investment. Through counterfactual experiments, I show that capturing the role of cash holdings in addressing both liquidity distress and future financing needs is crucial in generating observed responses following uncertainty shocks.

I then study the aggregate impacts of uncertainty shocks through the transmission mechanism, which unifies several recession features previously studied separately. First, a surge in macro uncertainty generates sharp declines in investment and output as firms rebalance their balance sheets. Second, heterogeneous firm responses lead to pronounced increases in dispersion in sales, investment, and marginal products. Third, more indebted yet highly productive firms contract disproportionately, while less indebted but less productive firms contract less or even expand. The allocation of capital worsens, exacerbating capital misallocation and producing endogenous declines in aggregate TFP. Uncertainty-driven recessions in the model therefore matches the features of U.S. recessions commonly observed in the data.

This transmission mechanism also provides a new explanation for why uncertainty spikes during financial crises lead to unusually large downturns, as documented in Alessandri and Mumtaz (2019). Specifically, I find that aggregate effects of the same uncertainty shocks are substantially larger when firms' debt rollover risk rises. The amplification effect occurs because higher rollover risk further strengthens firms' liquidity concerns, making firms even more sensitive to elevated macro uncertainty. This amplification mechanism is supported by firm-level evidence in Campello et al. (2011), which documents CFOs' increased concerns about rollover risk and their liquidity management during the 2007-2009 financial crisis. Moreover, existing studies, such as Stock and Watson (2012), have shown that uncertainty shocks and financial shocks are the two main drivers of the Great Recession. Quantitative exercise suggests that the effects of joint uncertainty and financial shocks exceed the sum of their standalone impacts, leading to sharp, prolonged downturns, as seen in the Great Recession.

Finally, I discuss the policy implications of the transmission mechanism and highlight three key findings. First, investment-stimulus policies—such as tax credits or accelerated depreciation—are substantially less effective in uncertainty-driven downturns. This is because firms prioritize preserving liquidity rather than expanding capital spending when uncertainty is high, and liquidity concerns dominate. Experiments implementing an investment tax credit program in the model reveal that both the number of firms —the extensive margin —and the average investment size —the intensive margin —stimulated by the policy are reduced by higher macro uncertainty. This finding complements the existing studies showing that heightened uncertainty dampens the extensive-margin effects of macroeconomic policies through the real options channel, e.g., Bloom et al. (2018) and Fang (2020).

Second, I find that credit interventions, such as debt relief and cash injections, can effectively mitigate the balance-sheet transmission of uncertainty shocks, revealing a novel stabilizing effect of credit policies during recessions. By easing elevated liquidity concerns amid high uncertainty, credit interventions help to moderate balance-sheet contractions and thus stabilize output drops following uncertainty shocks. Besides, I show that the same credit interventions can barely stabilize TFP-driven recessions where balance sheet contraction is not the primary source of economic instability. This suggests that the effectiveness of credit policies depends crucially on the nature of the recession, providing valuable insights into the debate over using credit interventions as stabilization tools since the recent COVID-19 pandemic.

Lastly, which form of credit policy is more effective in crises? This question dates back to Krugman (1988). In the context of stabilizing uncertainty-driven recessions, I find that debt relief policies are more effective than simply providing additional liquidity to firms. By reducing firms' debt burdens, debt relief not only directly increases their internal funds but also indirectly reduces their liquidity demand. A counterfactual simulation that fails to capture this indirect effect of debt relief policy underestimates its impact by more than 30%.

The rest of the paper is organized as follows. Section 2 presents empirical motivation. Section 3 develops a quantitative heterogeneous-firm model with financial frictions. Section 4 discusses model calibration. Section 5 discusses model mechanics and validation. Section 6 studies the transmission mechanism of uncertainty shocks. Section 7 studies the macroeconomic implications of the channel. Section 8 examines the policy implications of the channel. Section 9 concludes.

1.1 Literature and Contributions

This paper examines the role of firm liquidity concerns in the transmission of uncertainty shocks to the real economy, contributing to an extensive literature in macroeconomics and finance that examines the micro- and macro-level impacts of uncertainty shocks.

On the empirical front, my empirical findings echo many existing works: 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 complements the existing works by documenting the joint adjustments. Importantly, the paper uncovers systematic heterogeneity: more indebted firms engage in markedly stronger asset rebalancing, with sharper capital cuts and larger cash buildup. This evidence highlights a shift in firms' asset composition driven by their existing financial positions rather than simple deleveraging, revealing an overlooked channel through which uncertainty affects firm behavior.

On the theoretical front, this paper explains how uncertainty shocks can affect the real economy by amplifying firms' liquidity concerns and thus their precautionary behavior. The transmission mechanism complements existing channels that emphasize the real options effects driven by non-convex adjustment costs (see, e.g., Bloom 2009, Bloom et al. 2018) or the credit spreads channel that emphasizes the deleveraging effects (see, e.g., Gilchrist et al. (2014) and Arellano et al. (2019)). Alfaro et al. 2019 incorporates external financing costs and corporate cash choice into the investment models, showing that financial frictions lead to even stronger 'wait-and-see' effects. The focus of their analysis remains the traditional real-options effects, abstracting from corporate deleveraging and the role of existing financial positions in shaping firm responses.

Moreover, the transmission of uncertainty shocks through firms' liquidity concerns helps us better understand the micro- and macro-level effects of uncertainty shocks beyond the existing mechanisms. It explains heterogeneous responses across firms, key recession patterns previously studied separately, and the unusually large crises like the Great Recession. The mechanism also provides distinct insights into policy transmission amid high uncertainty.

The paper also contributes to the large macro-finance literature on the role of 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 highlights the role of firms' liquidity concerns in transmitting uncertainty shocks. Unlike Alfaro et al. 2019 where financial adjustments are simply side effects of investment delays triggered by uncertainty shocks, I show both empirically and theoretically that financial considerations themselves play a crucial role in transmitting uncertainty shocks.

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 models, for example, Ebsim et al. (2020), Elenev et al. (2022), Crouzet and Tourre (2021), and Guntin (2022). The paper is the first to analyze how credit interventions could reduce the impacts of uncertainty shocks, in contrast to much of the literature on the effects of first-moment shocks. I show that credit interventions, though barely counteracting the impact of first-moment shocks, can significantly attenuate the impact of uncertainty shocks, uncovering a novel stabilizing role of credit policies in recessions. The result also suggests that the effectiveness of credit interventions may depend crucially on the nature of the recessions, echoing Amador and Bianchi (2024) on banking crises.

Finally, the paper joins and builds on empirical and theoretical corporate finance literature. A large body of empirical corporate finance literature provides evidence on precautionary firm behavior under financial frictions. Some prominent examples include Opler et al. (1999), Faulkender and Wang (2006), Bates et al. (2009), and Gao et al. (2017). This paper provides a tractable quantitative model that can reproduce these data patterns. My model 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), and Eisfeldt and Muir (2016). Xiao (2018) built a quantitative model where cash holdings serve as a buffer against liquidity distress and studied its role in amplifying aggregate shocks. Jeenas (2019) built a quantitative model where cash holdings act as a marginal source of funding and studied its implications for monetary transmission. This paper emphasizes the dual roles of corporate cash in overcoming both liquidity shortfalls and financing frictions and illustrates how they shape firms' responses to uncertainty shocks.

2 Empirical Motivation

In this section, I document firm-level responses to macro uncertainty shocks. The empirical analysis highlights two key data patterns. First, U.S. public firms reduce capital and debt and raise cash holdings on average after uncertainty rises. Second, ex-ante more indebted firms engage in stronger asset rebalancing — exhibiting sharper capital declines and larger cash buildup— whereas debt contraction is similar across differently 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 the Macro Uncertainty Index by Jurado et al. (2015). In Section 2.3 and 2.4, I show that the baseline results 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 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.1. 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 firm-quarter observation 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 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 indebtedness 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 helps to alleviate such concern.

2.2 Firm-Level Responses to Uncertainty Shocks

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:

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

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

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

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. 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 γ_h captures differences in firm growth at quarter $t+h$ among firms with differential indebtedness following a change in the Macro Uncertainty Index at quarter t. If firm indebtedness affects how firms react to uncertainty shocks, then γ_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.

Firm and macro controls. 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.

Average responses. 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 the 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 over three years, with the peak appearing two years after the shock. The estimated average responses echo previous findings in the literature.

Heterogeneous responses. Variation in 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.

2.3 Heterogeneous Responses by Firm indebtedness

To mitigate concerns on the observed heterogeneous responses across differently indebted firms, I estimate the following extended local projection:

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

$$+ \underbrace{\Psi'_h \mathbf{Z}_{i,t-1} \cdot \Delta \log \sigma_t + \Gamma'_h \mathbf{Z}_{i,t-1}}_{\text{Firm controls}} + \underbrace{\eta_h \text{Indebtedness}_{i,t-1} \cdot \Delta \log Y_t}_{\text{Cyclical sensitivity}} + \mu_{i,t+h}$$

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

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 the 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 γ_h capture heterogeneous responses to changes in the Macroeconomic Uncertainty Index driven by pre-shock variation in corporate indebtedness across firms.

Firm heterogeneity. Firms' debt positions are endogenous and might vary systematically with other dimensions of firms. For example, more indebted firms might happen to have fewer investment opportunities during high uncertainty periods, leading to observed heterogeneous responses. To mitigate this type of concern, I interact $\Delta \log \sigma_t$ 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.

Business-cycle sensitivity. As shown in Dinlersoz et al. (2019) and Clymo and Rozsypal (2023), different firms behave differently over the business cycles, and thus more indebted firms might be more sensitive to fluctuations in business cycles. To mitigate this concern, I add an additional term interacting $\text{Indebtedness}_{i,t-1}$ with $\cdot \Delta \log GDP_t$ to absorb potential heterogeneity in cyclical sensitivity across differently indebted firms.

Interest-rate sensitivity. Gilchrist et al. (2014) and Arellano et al. (2019) show that higher uncertainty might lead to higher credit spreads and then affect firm behavior. It is likely that more indebted firms are more affected by changes in credit spreads and thus respond to uncertainty shocks more strongly. I add $\text{Indebtedness}_{i,t-1} \cdot \Delta \log \text{Credit Spreads}_t$ to absorb the potential heterogeneous effects of credit spreads changes across differently indebted firms. Therefore, the extended specification also helps test whether observed balance sheet adjustments are simply driven by the credit spreads channel.

Figure 2 shows that the baseline results are robust to controlling for heterogeneous responses along other dimensions of firms and heterogeneous cyclical and interest-rate sensitivity across differently indebted firms. In the second part of the paper, I explain the empirical patterns in a model where higher uncertainty induces firms to take a more cautious financial position and, therefore, firms' ex-ante indebtedness naturally determine how and the extent to which they need to adjust.

2.4 Additional Empirical Results

Within-firm variation. The baseline results suggest that cross-sectional variation in firm indebtedness predicts differential responses to uncertainty shocks. In Appendix A.2.1, I show that similar patterns emerge when using within-firm variation in indebtedness over time. I compute the deviation of a firm's net leverage from its unconditional firm-specific average and interact it with uncertainty shocks. Figure A1 shows that physical capital and cash holding responses to changes in the Macro Uncertainty Index are also stronger when firms are more indebted than their average levels.

Event study: 9/11 terrorist attacks. To further confirm the interpretation of the empirical findings, I conduct an event study that exploits the 9/11 terrorist attacks as a plausibly exogenous increase in macro uncertainty (e.g., Bloom (2009); Kim and Kung (2017)). Appendix A.2.2 details the empirical design and the results. 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.

3 Quantitative Model

To understand the empirical patterns and their implications, I develop a quantitative heterogeneous-firm model with firm dynamics and financial frictions. My model incorporates two ingredients into the class of heterogeneous firm models with financial constraints: risk of costly liquidity shortages and debt issuance frictions, giving rise to precautionary firm behavior consistent with the data. Section 4 discusses model calibration. Section 5 presents firm behavior in a stationary equilibrium of the economy. Section 6 studies the perfect foresight transition path of the economy in response to unexpected aggregate shocks.

3.1 Environment

Time is discrete and runs to infinity. The economy consists of three types of agents: (i). a continuum of heterogeneous firms that make optimal investment and financial decisions in the presence of financial frictions. They hire labor in the labor market at a wage rate W and produce a homogeneous good. (ii). a representative household who consumes goods and supplies labor at wage rate W. (iii). a mass of risk-neutral and deep-pocketed financial intermediaries who provide financial services. 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 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, they maximize the expected present value of dividends to shareholders 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:

$$y = z^{(1-\alpha)\chi}(k^{\alpha}l^{1-\alpha})^{\chi};\ 0 < \alpha < 1 \text{ and } \chi < 1, \tag{3}$$

where α is the value-added share of capital, and χ governs the degree of decreasing returns in production. The normalization factor $(1-\alpha)\chi$ associated with the productivity shocks ensures that the firm's profit function is linear in its productivity, as in Gilchrist et al. (2014). Firm-specific productivity shock z evolves according to an AR(1) process:

$$\log z' = \mu + \rho \log z + \sigma_z \varepsilon' \tag{4}$$

where the innovations $\varepsilon \sim N(0,1)$ are independent across firms. σ_z denotes the volatility of the innovations. $\mu = \frac{-\sigma_z^2}{2}$ is an adjustment to the conditional mean of firm-level productivity, such that it is not affected by the level of volatility σ_z.

Operating profits. Physical capital k is owned by firms and chosen one period ahead. 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. Firm production also requires an operating cost proportional to the capital stock $f_o k$.[6] Firms' per-period operating profits are therefore given by the solution to the following static profit-maximization problem:

$$\pi(z,k;W) = \max_{l \geq 0} \{z^{(1-\alpha)\chi}(k^{\alpha} l^{1-\alpha})^{\chi} - f_o k - Wl\} = z\psi(W)k^{\gamma} - f_o k$$

where W denotes the (real) wage and

$$\gamma = \frac{\alpha\chi}{1-(1-\alpha)\chi} \qquad \text{and} \qquad h(W) = \Big[1-(1-\alpha)\chi\Big]\left[\frac{(1-\alpha)\chi}{W}\right]^{\frac{(1-\alpha)\chi}{1-(1-\alpha)\chi}}$$

The detailed solution to the problem is shown in Appendix A.3.1.

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

$$k' = (1-\delta)k + i \tag{5}$$

where i denotes the net capital (dis)investment of firms. In addition to holding physical capital k, firms can 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 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 holdings, and outstanding debt and enter the next period with entrants.

[6]The combination of decreasing returns-to-scale and fixed operating costs implies that the firm can earn strictly positive (or negative) profits in equilibrium. This allows the model to match observed firm profitability in the data, which is related to firms' cash choices. 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, as in Gilchrist et al. (2014) and Xiao (2018).

3.3 Sources of Funds and Financial frictions

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

Internal liquidity. In each period, after production and tax, the internal liquidity available to the firms includes their after-tax profits and cash holdings net of current interest payments:

$$\underbrace{l(z,k,c,b)}_{\text{Internal liquidity}} = \underbrace{(1-\tau)\pi(z,k)+\tau\delta k}_{\text{After-tax profits}} + \underbrace{[1+(1-\tau)r]c}_{\text{Cash holdings}} - \underbrace{(1-\tau)rb}_{\text{Interests}} \tag{6}$$

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 would like to take on debt to finance their asset choices or to enjoy the tax shields 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. 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:

$$\underbrace{(1+r)b'}_{\text{debt obligation}} \leq \theta \underbrace{(1-\delta)k'}_{\text{collateral value}} \tag{7}$$

where θ denotes the pledgeability of physical capital and $0<\theta<1$. In addition, debt issuance also entails issuance costs η proportional to the newly issued debt. The debt issuance costs capture transaction fees, e.g., underwriters' fees, and restrictive covenants in real-world debt contracts that make new debt issuance especially costly.

Rollover crises and liquidity shortfalls. In each period, firms might face debt rollover crises originating from the financial sector with probability λ. Such rollover crises capture occasional financial market disruptions in which firms struggle to roll over their maturing debt.[7] When rollover crises do not occur, firms can easily roll over their existing debt. When rollover crises occur, firms

[7] For example, increased illiquidity of the secondary debt market (Longstaff et al. (2005)) that make debt rollover extremely expensive. Chodorow-Reich (2014) documents that unhealthy banks reduced their credit to firms following the onset of the 2008-2009 crisis. In surveys, CFOs reported that they faced difficulty in renewing loans during the financial crisis (Campello et al. (2010)).

need to repay their maturing debt before issuing new debt. In this case, firms might experience liquidity shortfalls if their internal liquidity is insufficient to meet their debt obligations. That is, liquidity shortfalls arise when

$$\underbrace{m}_{\text{Liquidity gap}} = \underbrace{l(z,k,c,b)}_{\text{Internal liquidity}} - \underbrace{b}_{\text{Outstanding debt}} < 0$$

and firms suffer a cash flow penalty proportional to their liquidity gap, as in Titman and Tsyplakov (2007), and firms' internal resources after taking into account costly liquidity shortfalls can be written as:

$$m - s \cdot |m| \cdot \mathbf{1}_{m<0} \tag{8}$$

where s is the parameter that governs the costs of liquidity shortfalls. Note that firms can still repay their debt burdens via new debt/equity issuance or divestiture, and the extra costs simply capture, in a reduced-form way, the difficulties firms face when they cannot repay their outstanding debt promptly. [8]

Equity financing. Firms' choices of next-period physical capital k', cash holdings 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. The equity issuance cost is as follows:

$$\Phi(d) = \mathbf{1}_{d<0} \cdot \left(\kappa_0 |d| + \frac{\kappa_1}{2} d^2 \right) \tag{9}$$

The equity issuance costs, following Hennessy and Whited (2007) and Eisfeldt and Muir (2016), reflect agency frictions in financial markets.

3.4 Timing

Figure 3 presents the timing of events within each period.

(1) Firms enter the period with physical capital k, cash holdings c, and outstanding debt b.

[8] Hennessy and Whited (2005) features a similar costly liquidity shortage setup but abstracts from firms' cash choices. That is, firms are considered in liquidity shortfalls as long as firms' realized operating profits are insufficient to cover their debt burdens in their model. This paper models cash holding explicitly and highlights firms' cash management when facing liquidity shortfalls.

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) λ fraction of firms run into rollover crises. Firms in rollover crises must repay their maturing debt first before choosing next-period capital k', cash c', and new debt b'. Other firms can roll over their outstanding debt and choose next-period capital k', cash c', and debt 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.

$$\underbrace{V(z,k,c,b)}_{\text{Begin-the-period Firm Value}} = \pi^e \underbrace{V^{exit}(z,k,c,b)}_{\text{Value of Exiting Firms}} + (1-\pi^e)\Big[\underbrace{\lambda V^m(z,k,c,b)+(1-\lambda)V^n(z,k,c,b)}_{\text{Value of Continuing Firms}}\Big] \tag{10}$$

Value of existing firms. Equity holders of exiting firms receive the residual firm value, i.e. value of total assets net of their outstanding debt. The value of the exiting firm is therefore given by:

$$\underbrace{V^{exit}(z,k,c,b)}_{\text{Value of Exiting Firms}} = \underbrace{l(z,k,c,b)+(1-\delta)k}_{\text{Asset value}} - \underbrace{b}_{\text{Outstanding debt}} \tag{11}$$

Value of continuing firms in rollover crises. Conditional on survival, λ fraction of firms will run to the rollover crises in which their creditors refuse to roll over their outstanding debt. As discussed in Section 3.3, costly liquidity shortfalls might arise if their internal liquidity is insufficient to cover their debt obligation and they choose the next period's capital k', cash c', and new debt b' to maximize:

$$V^m(z,k,c,b) = \max_{k',c',b'} d - \Phi(d) + \frac{1}{1+r} E_{z'|z}[V(z',k',c',b')] \tag{12}$$

subject to

$$\begin{aligned}
&\text{[Liquidity gap]:} && m = \underbrace{l(z,k,c,b)}_{\text{Internal liquidity}} - \underbrace{b}_{\text{Outstanding debt}} \\
&\text{[Dividend flow]:} && d = m - \underbrace{\mathbf{s} \cdot |m| \cdot \mathbf{1}_{m<0}}_{\textbf{Costly liquidity shortfalls}} - \underbrace{[k' - (1-\delta)k]}_{\text{Investment}} - \underbrace{c'}_{\text{Cash}} + \underbrace{(1-\eta)b'}_{\text{new debt}} \\
&\text{[Borrowing constraint]:} && (1+r)b' \leq \theta(1-\delta)k' \\
&\text{[Equity issuance costs]:} && \Phi(d) = \mathbf{1}_{d<0} \cdot \left(\kappa_0 |d| + \frac{\kappa_1}{2} d^2\right)
\end{aligned}$$

Value of continuing firms not in rollover crises. Conditional on survival, $1-\lambda$ fraction of firms can easily rollover their debt, and they choose the next period's capital k', cash c', and new debt b' to maximize:

$$V^n(z,k,c,b) = \max_{k',c',b'} d - \Phi(d) + \frac{1}{1+r} E_{z'|z}[V(z',k',c',b')] \tag{13}$$

subject to

$$\begin{aligned}
&\text{[Dividend flow]:} && d = \underbrace{l(z,k,c,b)}_{\text{Internal liquidity}} + \underbrace{(1-\eta \cdot \mathbf{1}_{b'>b})(b'-b)}_{\textbf{Debt adjustment}} - \underbrace{[k' - (1-\delta)k]}_{\text{Investment}} - \underbrace{c'}_{\text{Cash}} \\
&\text{[Borrowing constraint]:} && (1+r)b' \leq \theta(1-\delta)k' \\
&\text{[Equity issuance costs]:} && \Phi(d) = \mathbf{1}_{d<0} \cdot \left(\kappa_0 |d| + \frac{\kappa_1}{2} d^2\right)
\end{aligned}$$

Value of entrants. Every period, exiting firms will be replaced by entrants. Potential entrants begin with initial networth n_0 and draw an initial realization of the idiosyncratic productivity z from the long-run invariant distribution implied by Equation (4), denoted by $\mu^{Entry}(z)$. Given their initial networth and productivity, they choose the next period's capital k', cash c', and debt b'

and decide whether to enter :

$$V^{entry}(z_0,n_0)=\max\{0,\max_{k',c',b'}-E_c+\beta E_{z'|z_0}[V(z',k',c',b')]\} \tag{14}$$

subject to

$$k'+c'=n_0+b'$$

where E_c denotes entry costs, and potential entrants will enter if their continuing value is above zero. I calibrate E_c and n_0 to match the size of entrants and the average entrant's leverage ratio observed in the data.

3.6 Equilibrium

Firm distribution and aggregation. I begin by defining $\mu(z,k,c,b)$ as the cross-sectional distribution of firms over idiosyncratic productivity z, physical capital k, cash holdings c, and outstanding debt b. Appendix A.3.2 details the evolution of the distribution of firms. Given the firm distribution $\mu_t(z,k,c,b)$, I can aggregate firm-level variables to aggregate variables. The aggregate output and aggregate labor demand are given by:

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

Other variables, such as aggregate capital stock, cash holdings, and outstanding debt, can be aggregated similarly.

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, $V(z,k,c,b),V^m(z,k,c,b),V^n(z,k,c,b)$ solve the continuing firms' problems (12) - (13) with related policy functions.*

(2). *Given r, $V^{entry}(z_0,n_0))$ solve the entrants' problem (14) with related policy functions.*

(3). *The labor market clears:*

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

where ζ denotes the Fischer elasticity of labor.

(4). *The distribution of firms satisfies (36). 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. Importantly, I explain how costly liquidity shortage and external financing costs motivate firms to manage internal liquidity. For illustration purposes, I assume firms' value functions are differentiable.[9] 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 A.3.1.

Optimal payout policy. The first-order condition for dividends reveals the marginal value of firms' cash flows to shareholders in the model :

$$\Lambda(d) = \begin{cases} 1, & \text{if } d \geq 0 \\ 1 + \kappa_0 + \kappa_1 |d|, & \text{if } d < 0 \end{cases} \tag{15}$$

When firms payout dividends $d \geq 0$, the marginal value of firms' cash flows to shareholders equals one, while it becomes larger than one when firms issue new equity $d < 0$ due to the equity issuance costs. In other words, when firms issue equity, additional internal resources help firms reduce equity issuance costs.

Optimal cash policy. Cash holdings allow firms to transfer internal resources across states in which the marginal values of firms' cash flows to shareholders differ. Therefore, firms can benefit from liquidity management in anticipation of future funding needs. The condition for optimal

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

cash holdings is as follows:

$$\overbrace{\Lambda(d)\cdot\mathbf{1}}^{\text{marginal cost of cash}} \geq \overbrace{\frac{1}{1+r}E_{z'|z}\left[\Lambda(d')\underbrace{[1+(1-\tau)r]}_{\text{increase in internal liquidity}}\underbrace{(1+\lambda\cdot s\cdot\mathbf{1}_{m'<0}}_{\text{value of internal liquidity}})\right]}^{\text{marginal benefit of cash}} \tag{16}$$

The left-hand side of Equation (16) represents the marginal cost of carrying one additional dollar of cash into the subsequent period, and the right-hand side of Equation (16) represents its marginal benefit. Carrying one more unit of cash leads to an increase in next-period internal liquidity by $1+(1-\tau)r$. The value of internal liquidity for firms also depends on the states of firms. When firms face liquidity shortfalls for debt repayment $m' < 0$, the value of internal liquidity is larger than one since an additional unit of internal liquidity helps firms to reduce their cash flow losses during liquidity distress.

Cash holdings, therefore, help firms to prepare for both good and bad productivity shocks: (i). when firms are hit by good productivity shocks and thus have high investment needs, cash holdings provide internal funds and reduce external financing costs. (ii). when firms are hit by bad productivity shocks and thus generate low operating profits, cash holdings allow firms to avoid and reduce costly liquidity shortfalls. The model thus captures two cash-holding motives of firms found in the empirical corporate finance literature: firms hold cash to overcome liquidity shortfalls and financing frictions.

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:

$$\overbrace{\Lambda(d)\cdot 1}^{\text{marginal cost of capital}} = \overbrace{\mu_b\theta(1-\delta)+\frac{1}{1+r}E_{z'|z}\left[\Lambda(d')\left[(1-\delta)+\underbrace{\left[(1-\tau)\frac{\partial\pi(z,k)}{\partial k}+\tau\delta\right]}_{\text{increase in internal liquidity}}(1+\lambda\cdot s\cdot\mathbf{1}_{m'<0})\right]\right]}^{\text{marginal benefit of capital}} \tag{17}$$

The left-hand side of Equation (17) 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 (17) represents the marginal benefit of capital investment, which has several components. First, it builds up capital stock by $1-\sigma$ unit. Second, it increases collateral and thus relaxes borrowing constraints. μ_b indicates the shadow value of a firm's collateral constraint. Third, it also increases next-period internal liquidity as it generates operating profits. However, operating profits are uncertain due to productivity uncertainty, leading to uncertainty about future profits or, in other words, internal liquidity. On the other hand, cash savings allow firms to increase internal liquidity with certainty.

Optimal debt policy. Though issuing additional units of debt allows a firm to improve today's cash flows to shareholders, reflecting either increased dividends or lower equity issuance, it increases its debt service tomorrow, thereby raising the likelihood of liquidity shortage and equity issuance. The first-order condition with respect to debt choice b' is as follows:

$$\overbrace{\Lambda(d)\cdot(1-\eta\cdot\mathbf{1}_{issue})-\mu_b}^{\text{marginal benefit of debt}} = \overbrace{\frac{1}{1+r}E_{z'|z}\left[\Lambda(d')\left[[1+(1-\tau)r](1+\lambda\cdot s\cdot\mathbf{1}_{m'<0})-(1-\lambda)\cdot\eta\cdot\mathbf{1}_{b''>b'}\right]\right]}^{\text{marginal cost of debt}} \tag{18}$$

The left-hand side of Equation (18) is the marginal benefit of one more unit of borrowing today, which increases firms' current cash flows to shareholders while pushing firms further to collateral constraints. When firms issue new debt, the proceeds from debt issuance are reduced by the proportional issuance costs η. The right-hand side of Equation (18) represents the marginal costs of firms' outstanding debt. Even though an additional unit of debt tomorrow can lower future debt issuance costs if firms continue to issue new debt (the second component), servicing an additional unit of debt tomorrow reduces next-period internal liquidity, and these debt services are especially costly during liquidity shortfalls (the first component). Debt choices in the model also differ critically from those in standard collateral constraint models. First, debt issuance costs directly dampen firms' motives to borrow, making cash holdings their marginal source of funding. Second, debt choices also affect the risk and costs of liquidity shortfalls they face—a missing force in most existing models that shapes firms' responses to increased uncertainty.

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 include standard parameters in the literature and parameters that have a natural data counterpart. The second group of parameters governs firms' financial behavior and their life-cycle patterns, which are calibrated internally to minimize the difference between model-simulated moments and their empirical counterparts. Details on model simulation and estimation are described in Appendix A.3.3.

4.1 Externally Set Parameters

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

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 the 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).

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 A.3.4 details how the empirical targets are computed from a firm-quarter panel and their model counterparts. Table 2 displays the values for internally calibrated parameters and shows that the model matches the targeted moments reasonably well. Note that every targeted moment is simultaneously affected by all parameters, and thus I can only provide some intuition for their identification here.

Financial frictions. The first set of parameters governs the financial behavior of firms. Therefore, they are calibrated to match key financial ratios. First, as discussed in Section 3.7, the probability of rollover crises is the exogenous force that affects firms' cash and debt choices and, therefore, largely shapes firms' net leverage ratio. Second, liquidity penalty s directly affects the expected marginal costs of debt. Since the costs of liquidity shortfalls increase 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 states, will use debt to take advantage of its tax benefits, implying a small standard deviation of leverage ratio across firms. Third, 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. Entrants' size and leverage ratio in the model are calibrated to reproduce two salient empirical patterns on entrants: entrants are smaller in size than the incumbents and tend to have a higher leverage ratio.[10] Therefore, 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 ensure they are comparable to data moments.

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

Discussion. I now discuss the implications of the baseline calibration for firms' financing choices in the model. First, the calibrated model features the tax advantage of debt and larger frictions in the equity market than in the credit market, and thus, firms prioritize debt financing over equity financing. Second, the existence of debt issuance costs implies that corporate internal liquidity is the cheapest source of funding. As a result, firms in the model hold cash holding for future growth opportunities. Taken together, financing behavior in the calibrated model reproduces the predictions of 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 responses to uncertainty shocks, in this section, I study firm behavior in a steady state. I first show that the calibrated model reproduces the cross-sectional financial heterogeneity and firm life-cycle dynamics consistent with the data. I then show that the model generates firm precautionary behavior that aligns well with the observed ones. The validation exercises increase the credibility of the calibrated model.

5.1 Cross-Sectional Implications

Financial heterogeneity. Figure 4 shows the unconditional distribution of leverage and cash ratios 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 rollover crises and thereby choose different stocks of physical capital, cash holdings, and outstanding debt.

Life-cycle patterns. Both corporate finance and firm dynamics literature have documented firms' life-cycle patterns of real and financial behavior. As shown in Table 3, the calibrated model does a good job of reproducing these empirical patterns. First, younger firms are smaller, more profitable, and experience larger growth in output. Second, younger firms tend to have a larger leverage ratio, lower cash ratio, and lower dividend ratio. 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 cash, and pay out dividends. Furthermore, consistent with the empirical literature, firm age is an important source of 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.

5.2 Precautionary Firm Behavior in Steady State

I now discuss how the calibrated model reproduces firm precautionary behavior and illustrate the roles played by key model ingredients. I examine the model's ability to reproduce two sets of stylized facts on precautionary firm behavior. Appendix A.4.1 shows that the model is also able to reproduce other precautionary behaviors that have been studied in the empirical literature.

5.2.1 Firm Behavior and Firm Characteristics

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 with observed data patterns. Using both Compustat and model-simulated data, I run the following fixed-effect panel regressions:

$$\Delta \ln y_{i,t+1} = \alpha_i + \alpha_{s,t} + \alpha_{fq,t} + \beta_1 \textbf{Tobin's Q}_{i,t} + \beta_2 \textbf{Size}_{i,t} + \beta_3 \textbf{Indebtedness}_{i,t} + \varepsilon_{i,t} \tag{19}$$

For the 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 A2 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 their capital investment, cash savings, and borrowing.

Tobin's Q. All else equal, firms with higher Tobin's Q have larger growth opportunities and thus invest and borrow more for firm growth. The larger increases in debt today lead to larger debt burdens tomorrow, encouraging those firms to save more for future debt repayment at the same time. Tobin's Q is therefore positively associated with firms' capital investment, cash savings, and borrowing, consistent with the data pattern shown in Table 4.

Firm Size. All else equal, larger firms in the model tend to be closer to their optimal capital levels and thus have smaller investment needs. On the other hand, larger firms also have larger internal funds and, thus, smaller demand for external finance. Taken together, larger firms invest and borrow less, and, consequently, save less. Conditional on firm indebtedness and Tobin's Q, Firm Size is therefore negatively correlated with firms' capital, cash, and debt growth in both data and model.

Indebtedness. All else equal, more indebted firms are closer to their collateral constraints and have more pre-existing debt burdens compared to less indebted firms. More indebted firms tend to save more since cash holdings can significantly reduce the likelihood and the costs of liquidity shortfalls. The smaller borrowing capacity among more indebted firms also leads to lower borrowing. Firms' current indebtedness thereby leads to more saving and less borrowing, which results in less capital investment. As shown in Table 4, conditional on Firm Size and Tobin's Q, one-standard-deviation higher indebtedness is associated with smaller capital investment, larger cash savings, and smaller borrowing in both data and model.

Role of liquidity penalty. To illustrate how key model ingredients drive firm precautionary behavior, I run the same regressions using simulated data from an alternative model without liquidity penalty ($s = 0$). Appendix A3 reports the full estimation results. Figure 5 compares the estimated correlation between firm indebtedness and firm behavior using Compustat data and simulated data in different models. As shown in Figure 5, liquidity penalty plays a critical role in generating the positive relation between firm indebtedness and cash savings. When liquidity shortfalls are costly, more indebted firms save more to reduce the risk and the losses associated with liquidity shortfalls. Such precautionary behavior disappears when there is no liquidity penalty $s = 0$, leading to a negative relation between firm indebtedness and cash savings.[11]

5.2.2 Cash as Marginal Source of Funding

As discussed earlier, the existence of equity and debt issuance costs makes cash holdings firms' marginal source of funding. In other words, firms will withdraw cash to fund capital investment when an investment opportunity arises. I, therefore, estimate how firms respond to a firm-level TFP shock by running the following regression using both Compustat data and simulated data:

$$\Delta \ln y_{i,t+1} = \alpha_i + \alpha_{s,t} + \alpha_{fq,t} + \beta \Delta \ln \text{TFP}_{i,t} + \Gamma' X_{i,t} + \varepsilon_{i,t} \tag{20}$$

where $\Delta \ln \text{TFP}_{i,t}$ denotes measured firm-level productivity growth. Appendix A.1.3 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 shows that in both data and model, firm-level productivity growth predicts capital investment, borrowing, and cash withdrawal. This occurs in the model since firms hold cash to avoid and reduce both equity and debt issuance costs. In contrast, firm-level productivity growth is positively correlated with cash growth in a model without debt issuance costs, as shown in Table 6. In this case, debt serves as firms' marginal funding source. Firms with larger productivity growth borrow more, and thus they also save more in case of future liquidity shortage for debt repayment. Therefore, unlike the full model, the alternative setup does not capture firms' precautionary saving motive for future investment.

[11] In model w/o liquidity penalty, more indebted firms borrow less due to their smaller debt capacity and hence have fewer funds for cash holdings, resulting in a negative relation between firm indebtedness and cash growth. Note that firms' motives to avoid costly liquidity shortages dominate this effect in the full model.

6 The Model-implied Transmission of Uncertainty Shocks

The previous section shows that the calibrated model generates financial heterogeneity and firm precautionary behavior that align well with the data. In this section, I discuss how increased macro uncertainty amplifies firm precautionary behavior and thus induce firm balance sheet adjustments. I inspect the transmission mechanism by shutting down key model ingredients, which allows me to identify key forces at play.

6.1 Shock Simulation

The economy is initially in a steady state and unexpectedly transitions to a regime with exogenous aggregate productivity shocks, and then converges back to the original steady state. Namely, firm profits functions are $\pi = az\psi(W)k^{\gamma} - f_o k$, and the aggregate productivity level of the economy a varies over time in the transitional dynamics, leading to changes in firm behavior and aggregate variables.

Uncertainty shocks. To incorporate the notion of macro uncertainty, I assume that firms' beliefs on the distribution of the aggregate productivity shocks during the transitional dynamics are given by $\log N(\frac{-\sigma_t^2}{2}, \sigma_t)$. Note that the volatility term σ_t is time-varying while the expected aggregate productivity always equals one. A higher volatility term σ_t in this case corresponds to a mean preserving spread in the productivity distribution. In addition, I also keep the realized aggregate productivity to be one during the transitional dynamics. In other words, firms only face higher uncertainty about future productivity during the transitional dynamics, while the expected and realized productivity are always the same. The simulation, therefore, provides an appropriate environment for studying the impacts of macro uncertainty shocks. I calibrate the initial level of the volatility σ_0 to induce a 2.5% drop in aggregate output on impact, which reverts back to zero according to $\sigma_{t+1} = 0.5\ \sigma_t$.[12]

Solution method. Following the MIT shock literature, I study a perfect foresight transition path in response to unexpected shocks. I first solve for the stationary equilibrium of the economy and then solve the transitional dynamics given a path of exogenous shocks and a long enough period for the

[12] 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.

model to converge back to the original steady state. As discussed in Mitman (2016), the method can capture the effects of multiple shocks without increasing the computation time substantially, which allows me to study the interactions of different shocks. Appendix A.3.3 and A.3.4 detail the solution method and the construction of impulse response functions.

6.2 Firm-level Responses to Uncertainty Shocks in the Model

I first study the firm-level responses to uncertainty shocks within the calibrated model. I simulate a panel of 50,000 firms one year before and two years after the macro uncertainty shocks and run the following equation using the simulated panel:

$$\Delta \ln y_{i,t+1} = \alpha + \left(\beta + \gamma \text{Indebtedness}_{i,t}\right) \cdot \Delta \log \sigma_t + \eta \text{Indebtedness}_{i,t} \tag{21}$$

$$+\Psi' \mathbf{Z}_{i,t} \cdot \Delta \log \sigma_t + \Gamma' \mathbf{Z}_{i,t} + \mu_{i,t}$$

where $\Delta \log(\sigma_t)$ measures the log deviation of productivity uncertainty faced by firms relative to the steady-state level at time t, which is entirely driven by the additional macro uncertainty in the transitional dynamics. Indebtedness$_{i,t}$ measures how many standard deviations firm i's net leverage is away from the mean. $\mathbf{Z}_{i,t}$ is a vector of the control variable that captures firms' growth opportunities in the context of the model: Tobin's Q and Firm Size. Table A2 details the mapping between model and data variables. Note that Equation (21) does resemble the empirical specification Equation (2). First, there is no permanent unobserved heterogeneity and fiscal-quarter differences across firms in the model. Second, as discussed earlier, the transitional dynamics only involve changes in uncertainty $\Delta \log(\sigma_t)$, and there is no confounding aggregate shock in the simulation.

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. Namely, macro uncertainty shocks lead firms to cut capital investment, increase cash holdings, and deleverage. In the cross-section, more indebted firms reduce more investment while building up more cash holdings.

There are two forces at work. On one hand, an increase in uncertainty implies a higher probability of low productivity, raising the likelihood of liquidity shortfalls. Firms, therefore, reduce debt and increase cash holdings to reduce the elevated risk of liquidity shortfalls. On the other hand, a higher uncertainty also means a higher chance of high productivity, encouraging firms to save more for greater growth opportunities. The two forces thereby lead firms to deleverage and accumulate cash, both of which divert firms' internal funds away from capital investment. *Ex-ante* more indebted firms have larger stocks of outstanding debt and thus face a higher risk of liquidity shortfalls, leading them to accumulate more cash. Unlike deleveraging, which shrinks firms' internal funds for future expansion, this strategy also allows them to preserve funds for potential growth opportunities. The model therefore explains the observed balance sheet adjustments across firms following heightened macro uncertainty.

6.3 Inspecting the Transmission Mechanism

To better illustrate the transmission mechanism, I now study the transmission of uncertainty shocks in alternative setups. There are two key takeaways. First, as discussed in Section 5.2, costly liquidity shortage and debt issuance costs play key roles in inducing firm precautionary behavior, and thus also shape how firms respond to uncertainty shocks. Second, the size of debt issuance costs in the model determines whether indebted firms react to heightened uncertainty by accumulating more cash or reducing more debt.

Role of liquidity penalty. I first shut down the liquidity penalty by setting $s = 0$. In this case, firms have no concern over the elevated risk of liquidity shortfalls triggered by uncertainty shocks while only caring about the greater upside potential implied by increased uncertainty. As a result, firms do not cut debt or trade off capital investment for cash accumulation to reduce such risk. Firms now increase capital investment and cash holdings for greater upside potential. As shown in Panel (A) of Table 8, this model predicts positive effects of heightened uncertainty on capital investment and cash holdings and an insignificant effect on debt, contradicting empirical findings. Note that the average increase in cash holding in this case is completely driven by a decrease in dividend payout due to better growth opportunities.

Role of debt issuance frictions. I then shut down the debt issuance costs by setting $\eta = 0$. In this setup, firms can issue debt without any additional costs when a good productivity shock realizes, and thus, firms do not hold cash for future growth opportunities. As a result, when uncertainty rises, firms are concerned about the larger downside risk caused by elevated uncertainty only, and thus deleverage to reduce the heightened risk of liquidity shortage. 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 buildup of corporate cash 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, more indebted firms also deleverage more relative to their less indebted counterparts. This occurs since more indebted firms in this setup can reduce debt first and then issue new debt to fund capital investment if a good productivity shock indeed realize. In 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 risk of liquidity shortfalls rather than cut more debt. In sum, the severity of debt issuance frictions plays a key role in shaping the heterogeneous responses to uncertainty shocks across differently indebted firms.

7 Macroeconomic Implications of the Balance Sheet Channel

Having documented the success of the model in reproducing firm-level balance sheet adjustments following uncertainty shocks, I now examine the macroeconomic implications of the firm balance sheet channel. In section 7.1, I characterize aggregate impacts of uncertainty shocks through the firm balance sheet channel. In section 7.2, I demonstrate that financial crises can amplify the impacts of uncertainty shocks, and they together generate deep and persistent recessions.

7.1 Aggregate Impacts of Uncertainty Shocks

Figure 6 shows the aggregate impacts of uncertainty shocks through the firm balance sheet channel. Specifically, heightened macro uncertainty in the model triggers sharp aggregate output and productivity drops with increased micro-level dispersion and exacerbated capital misallocation, reproducing key features of U.S. recessions.

Panels (A) and (B) of Figure 6 show that both aggregate output and aggregate productivity, measured as Solow residual, fall dramatically following uncertainty shocks. To illustrate why aggregate TFP falls endogenously in the model, I decompose aggregate productivity into average productivity across firms and ex-post allocative efficiency, as in Olley and Pakes (1992). Since the simulation only involves second-moment shocks, average productivity does not change in the transition dynamics, as discussed in 6.1. Thus, the aggregate TFP drop is entirely driven by a decrease in allocative efficiency following uncertainty shocks. In the model, increased uncertainty depresses capital investment, thereby reducing production. Since differences in firms' financial positions lead to heterogeneous investment drops across firms, uncertainty shocks must also exacerbate capital misallocation in the economy and thus trigger aggregate productivity drops.

Panels (C) and (D) of Figure 6 show that micro-level dispersions indeed increase sharply in response to uncertainty shocks. The heterogeneous responses across differently indebted firms first show up as an endogenous increase in sales growth dispersion in the model. This result speaks to the literature studying the sources of micro dispersion and suggests that the increased dispersion of micro outcomes observed in recessions might be an endogenous response to aggregate shocks. Moreover, highly indebted yet highly productive firms tend to contract, while less indebted but less productive firms tend to expand in response to uncertainty shocks in the model. The inefficient reallocation of capital and production across firms following uncertainty shocks therefore leads to an increase in the standard deviation of the firm-level marginal product of capital, reflecting a worsened capital allocation in the economy.[13] In sum, the heterogeneous effects captured by the firm balance sheet channel are key to piecing together the observed features of U.S. recessions.

7.2 The Firm Balance Sheet Channel during Financial Crises

Increased uncertainty and financial market disruptions have been shown to be the two primary drivers of the 2007-2009 crisis, e.g. Stock and Watson (2012). This subsection studies the working of the firm balance sheet channel during a financial crisis. I highlight two findings. First, the

[13] As shown in capital allocation literature, the standard deviation of marginal revenue product is negatively related to aggregate TFP in an economy with financial frictions, e.g., Gopinath et al. (2017).

channel is stronger with concurrent financial disruptions, leading to larger impacts of uncertainty shocks during financial crises. Second, due to the amplification effect, temporary uncertainty shocks and financial disruptions will trigger deep and persistent recessions, like the Great Recession.

A financial crisis is modeled as shocks to the probability of rollover crises λ faced by firms: a 50% increase in λ from the baseline calibration, which transitions back to the baseline level with a persistence of 0.5. The financial crisis affects the model economy in two ways. First, firms are forced to deleverage as their maturing is refused to be rolled over more often by the creditors in the crisis. Second, the increased risk of rollover crises makes firms more precautionary, depressing firms' motives to borrow and increasing firms' motives to save for future investment opportunities. The two effects line up with firms' experiences in the 2007-2009 financial crisis.[14]

Figure 7 plots the aggregate impacts of uncertainty shocks during normal times and a concurrent financial crisis. Importantly, the aggregate output and productivity drops driven by the same uncertainty shocks in the financial crisis are more than 70% larger than their impacts during normal times. The stronger transmission occurs since a higher probability of rollover crises further amplifies firms' precautionary motives, making firms even more sensitive to an increase in uncertainty. The model-implied amplification effect is consistent with the empirical findings in Alessandri and Mumtaz (2019), which estimates the time-varying effects of uncertainty shocks across different financial conditions.

The amplification mechanism also implies that the joint effects of uncertainty shocks and the financial crisis should be greater than the sum of their individual impacts. As shown in Figure 8, the joint shocks reduce aggregate output by 6.2% on impact, while a pure uncertainty shock leads to a 2.5% drop, and a pure financial crisis results in a 1.8% decline. The recession caused by the joint shock is also more prolonged, lasting for six quarters, whereas the effects of either a pure uncertainty shock or a pure financial crisis fade within four quarters. Uncertainty shocks, together with a financial crisis, therefore, trigger a deep downturn with subsequent slow recovery, as observed during the Great Recession.

[14]see, e.g., Campello et al. (2010), Campello et al. (2011), Chodorow-Reich (2014)

8 Policy Implications of the Balance Sheet Channel

In this section, I discuss the implications of the firm balance sheet channel for macroeconomic policies. In Section 8.1, I show that higher macro uncertainty dampens the effectiveness of investment stimulus policies by reducing both extensive-margin and intensive-margin response to the policies. In Sections 8.2, I demonstrate that the firm balance sheet channel uncovers a novel role for credit policies in stabilizing recessions.

8.1 Investment Stimulus in Periods of High Uncertainty

Investment stimulus policies, such as Investment Tax Credit or Bonus Depreciation Allowance, have been used widely to support industrial transformations or to combat recessions. In this subsection, I show that the effectiveness of investment stimulus is state-dependent and falls substantially during periods of high macro uncertainty.

I model investment stimulus as an unexpected one-time tax cut, which effectively increases the after-tax operating revenues of firms and thus induces firms to increase their capital investment. I study the effects of the investment stimulus during normal times when there is no aggregate shock and with concurrent macro uncertainty shocks. I calibrate the size of the tax cuts to generate a cumulative 1% increase in aggregate output during normal times.

Figure 9 shows that the effects of the investment stimulus program fall sharply during periods of high uncertainty. Compared to normal times, the stimulating effects of a tax cut on aggregate output fall by almost 50% during periods of high macro uncertainty. The decrease in policy effectiveness is due to a change in firms' financial policies with and without high uncertainty. Heightened uncertainty motivates firms to hoard more cash and borrow less in response to investment stimulus, thereby depressing policy-induced capital investments.

Panel (A) and (B) of Figure 9 show that heightened uncertainty reduces firm-level responses via both extensive margin and intensive margin. Specifically, the investment stimulus program leads to a 30% increase in the number of investment firms in normal times while a mere 7% increase during high uncertainty periods. The impact of the stimulus policy onthe average firm-level investment rate also decreases during high uncertainty periods. The finding complements existing studies that have shown that heightened uncertainty dampens the extensive-margin effects of macro policies through the real options channel, such as Bloom et al. (2018) and Fang (2020).

8.2 Credit Interventions as Stabilization Tools

The recent COVID-19 pandemic has seen aggressive credit interventions provided to corporate sectors worldwide. For example, 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. The unprecedented fiscal expenditures have sparked heated debates on the use of credit interventions as stabilization tools.

This paper makes three contributions to the growing literature on credit interventions. First, I show that credit interventions can strongly counteract the adverse effects of uncertainty shocks by directly dampening the balance sheet channel, which uncovers a new stabilizing role of credit policies. Second, I show that the effectiveness of credit interventions in a recession driven by negative aggregate TFP shocks is rather limited, highlighting the underlying nature of the recessions in shaping policy effectiveness. Third, I demonstrate the importance of corporate cash choice in understanding policy effects by showing that an alternative model underestimates the stabilizing effects of debt relief policy.

Policy and crisis simulation. I study two credit policies, debt relief, and cash grant programs widely used in the past pandemic. I model a debt relief program as an unexpectedly written-off of firms' outstanding debt and a cash grants program as an unexpected cash injection into the firms. Both programs are untargeted and one-time interventions, mimicking the programs implemented in 2020. I calibrate the size of each program to generate a 0.5% initial increase in aggregate output during normal times without aggregate shocks. Note that both programs directly increase firms' net worth, and thus, firms become less financially constrained for the rest of their life cycles, leading to a persistent increase in aggregate output following the interventions. I study two types of recessions: one driven by uncertainty shocks and one driven by exogenous aggregate productivity drop.

Credit interventions in uncertainty-driven recessions. Panel (A) and (C) of Figure 10 show the aggregate output responses to uncertainty shock with and without credit interventions. Notably, credit interventions substantially mitigate the negative effects of uncertainty shocks. In the baseline case, uncertainty shocks drive down aggregate output by 2.5% while aggregate output drops by only 1% or 1.5% with debt relief or cash grant programs, respectively. Panel (B) and (D) of Figure 10 shows that the stabilizing effects of credit interventions is particularly strong in an uncertainty-driven recession. The debt relief and cash grants programs that stimulate aggregate output by 0.5% during normal times can increase aggregate output by 1.5% and 1.0% in an uncertainty-driven recession, respectively.

What explains the strong effects of credit interventions in uncertainty-driven recessions? Besides increasing firms' net worth as they do during normal times, debt relief and cash grant programs during high uncertainty periods also reduce firms' need to reduce debt and hoard cash in response to uncertainty shocks, therefore mitigating the balance sheet transmission and thus counteracting the recessionary effects of uncertainty shocks.

To gauge the cost-effectiveness of credit interventions, I compute the present value of the cumulative output gains using the discount factor and then divide it by the total fiscal cost of the program, which measures the discounted output gain per unit of fiscal costs. Figure 11 plots the cost-effectiveness of the programs during normal times and in uncertainty-driven recessions. Since aggregate 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 and goes up from 0.64 to 0.85 for cash grant programs.

Credit interventions in TFP-driven recessions. Do credit interventions also help to stabilize TFP-driven recessions? Panel (A) and (C) of Figure 12 plot the aggregate output responses to negative productivity shocks with and without credit interventions, showing a rather limited effect of credit interventions on counteracting the impacts of negative productivity shocks. Indeed, Panel (B) and (D) of Figure 12 show that aggregate output responses to the interventions in TFP-driven recessions turn out to be even smaller than their effects in normal times. This occurs because a drop in aggregate productivity reduces firms' investment demand and financial needs, mitigating the role of credit interventions in relaxing firms' financial constraints.[15]

In sharp contrast, credit interventions in uncertainty-driven recessions help to alleviate the balance sheet transmissions of uncertainty shocks, thereby effectively stabilizing aggregate output

[15] In Appendix A.4.4, I show that aggregate output response to credit interventions is slightly larger during booms when investment demand is high and firms have larger financial needs.

drops. These results echo Crouzet and Tourre (2021) where they find that credit interventions have larger stabilizing effects in a TFP-driven recession accompanied by financial market disruptions. This paper contributes to the literature by uncovering the role of credit recessions in stabilizing uncertainty-driven recessions.

Role of corporate cash choice. Among credit interventions, the calibrated model suggests debt relief program counteracts the negative effects of uncertainty shocks more effectively than cash grant program. This is because debt relief not only directly increases firms' net worth similar to cash grant but also indirectly lowers firms' cash demand by reducing firms' debt burdens, which further frees up firms' internal funds for more capital investment. The indirect effect of debt relief is especially strong when a higher uncertainty drives up firms' cash demand, leading to large stabilizing effects of debt relief in uncertainty-driven recessions.

I find that capturing firms' cash choices in response to uncertainty shocks is important in understanding the stabilizing effects of debt relief. To illustrate this point, I shut down the debt issuance frictions by setting $\eta = 0$. As discussed in Section 6.3, the alternative setup eliminates cash buildup in response to heightened uncertainty, and thus, the negative effects of uncertainty shocks are completely driven by firm deleveraging. I recalibrate the uncertainty shocks and the sizes of policy interventions to ensure compatibility with the baseline simulation. Panel (A) and (C) of Figure 13 plot the impact of uncertainty shocks on aggregate output with and without debt relief. Panel (B) and (D) of Figure 13 plot the aggregate 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 effect of debt relief programs on mitigating firms' cash buildup is completely missing, thereby underestimating the effects of debt relief.

9 Concluding Remarks

In this paper, I highlight the role of firms' liquidity concerns in transmitting uncertainty shocks to the real economy. I developed a quantitative heterogeneous-firm model in which rollover risk and financing frictions lead to precautionary firm behavior. In the model, firms reduce investment and debt and increase cash holdings to reduce the elevated risk of internal liquidity shortages triggered by higher uncertainty. Ex-ante indebtedness determines firms' exposure to such downside risk, generating heterogeneous responses across differently indebted firms consistent with the data.

The transmission channel provides novel insights into how heightened uncertainty triggers recessions and reshapes policy transmission. First, a surge in macroeconomic uncertainty in the model triggers sharp aggregate output and productivity drops with increased micro-level dispersion and exacerbated capital misallocation, thereby accounting for key features of U.S. recessions. Second, I find that the effects of uncertainty shocks are greater during concurrent financial crises, when firms' precautionary behavior further intensifies. Higher uncertainty, interacting with financial market disruption, thereby generates deep and prolonged economic downturns as seen in the Great Recession. Third, I show that investment stimulus is less potent during periods of high uncertainty because uncertainty shocks depress firms' incentives to withdraw cash for investment. Lastly, I find that credit interventions, though only modestly offsetting the effects of first-moment shocks, can significantly attenuate the effects of uncertainty shocks, revealing a novel stabilizing role for credit policies in recessions.

The model abstracts from other uncertainty transmission mechanisms to focus on the role of firms' liquidity concerns in transmitting uncertainty shocks. It is worth exploring how different channels interact and how uncertainty shocks affect the economy when all channels are operating. Such exercises require a quantitative model with additional real and financial frictions, which substantially increases the computational burden. I leave the task for future research.

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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)
θ	Pledgeability	0.71	$P_{95}(Leverage)$

TABLE 1: **Externally Set Parameters**

Parameter	Data	Value	Targets	Data	Model
		(a). **Financial Frictions**			
λ	Prob of rollover crisis	0.07	Net leverage ratio	0.05	0.05
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	Linear 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

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

	(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

TABLE 3: **Firm Life-Cycle Patterns in the Model**

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

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

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

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.

$\Delta \ln y_{i,t+1}$:	Data			Model		
	ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$	ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$
$\Delta \ln \text{TFP}_{i,t}$	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

TABLE 5: **Firm Responses to Idiosyncratic Productivity Growth: Data versus Model**
Notes: This table reports estimated firm responses to idiosyncratic productivity growth using Compustat data and model-simulated data. $*, **$, and $***$ represent results significant at the 10%, 5%, and 1% levels, respectively.

	Model w/o liquidity penalty			Model w/o debt issuance costs		
$\Delta \ln y_{i,t+1}$:	ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$	ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$
$\Delta \ln \text{TFP}_{i,t}$	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

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

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

$\Delta \ln y_{i,t+1} \times 100$:	ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$
$\Delta \log \sigma_t$	-0.214***	0.753***	-0.193***
	(0.016)	(0.026)	(0.069)
$\Delta \log \sigma_t$ × 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$_{i,t}$	✓	✓	✓
$\Delta \log \sigma_t \times Z_{i,t}$	✓	✓	✓

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

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 productivity uncertainty faced by firms relative to the steady-state level at time t, which is entirely driven by the additional macro uncertainty in the transitional dynamics. 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.

$\Delta \log y_{i,t+1} \times 100$:	(A) Model w/o liquidity penalty			(B) Model w/o debt issuance frictions		
	ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$	ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$
$\Delta \log \sigma_{t+1}$	0.033**	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

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

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 productivity uncertainty faced by firms relative to the steady-state level at time t, which is entirely driven by the additional macro uncertainty in the transitional dynamics.

$\Delta \ln y_{i,t+1} \times 100$:	**Low Debt Issuance Frictions** $= 0.5 \cdot \eta_{\mathbf{baseline}}$ ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$	**High Debt Issuance Frictions** $= 1.5 \cdot \eta_{\mathbf{baseline}}$ 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$_{i,t}$	✓	✓	✓	✓	✓	✓
$\Delta \log \sigma_{t+1} \times Z_{i,t}$	✓	✓	✓	✓	✓	✓

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

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 productivity uncertainty from steady state. Indebtedness$_{i,t}$ measures leverage deviations from industry mean. Firm controls include Indebtedness and $Z_{i,t}$.

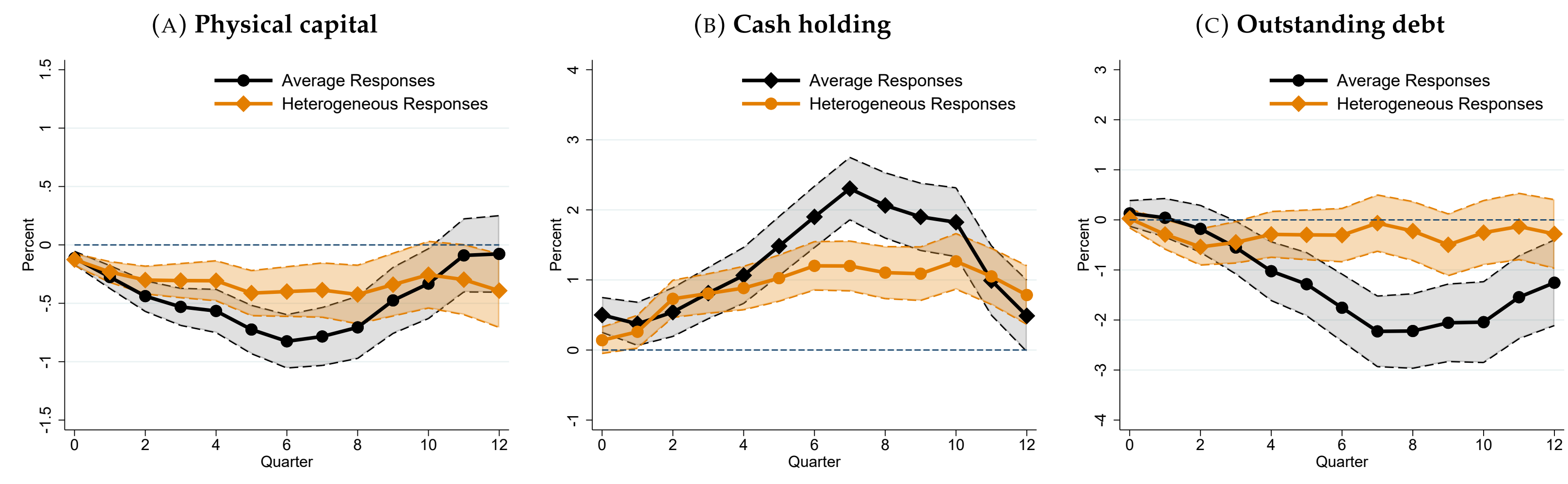


FIGURE 1: **Baseline Local Projection: Firm-Level Responses to 1 S.D. Growth in Macro Uncertainty Index**

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 the 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 the firm and time levels. The sample period is from 1990Q1 to 2018Q4.

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

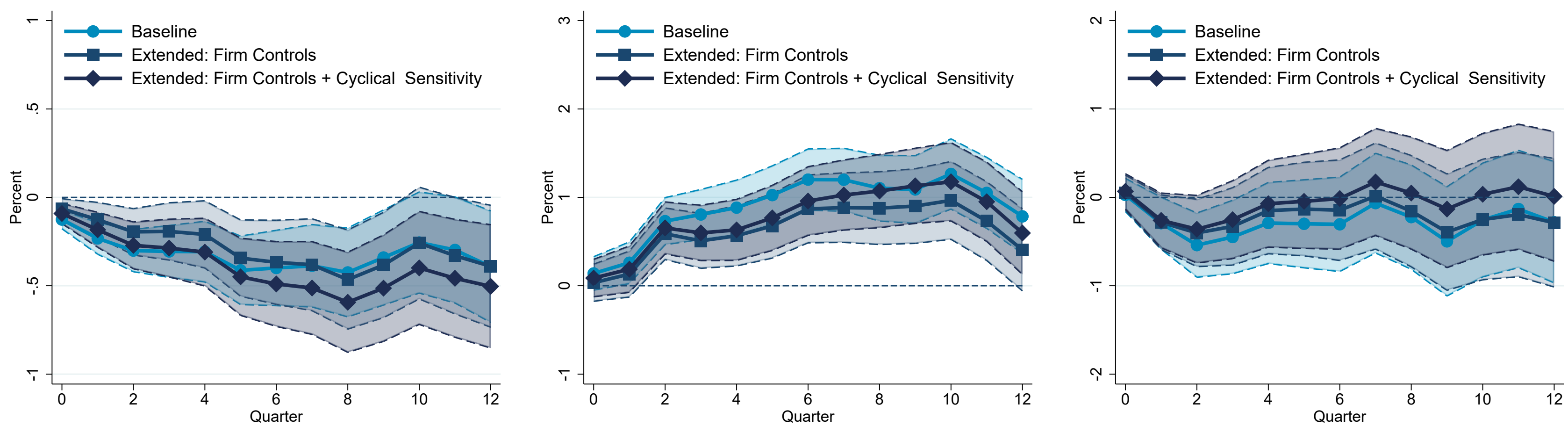


FIGURE 2: **Extended Local Projection: Heterogeneous Responses by Firm Indebtedness**

Notes: The figure plots both the heterogeneous responses of (a) physical capital, (b) cash holding, and (c) outstanding debt to a one-standard-deviation growth in the 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 $\Delta \log \sigma_t$ 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$_{i,t-1} \cdot \Delta \log GDP_t$ 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 the firm and time levels. The sample period is from 1990Q1 to 2018Q4.

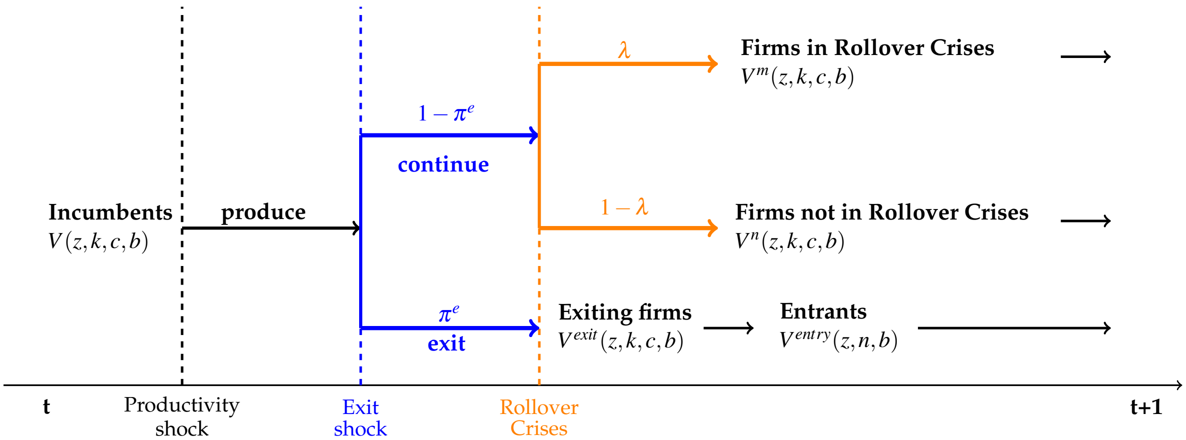


FIGURE 3: Timing of the Model

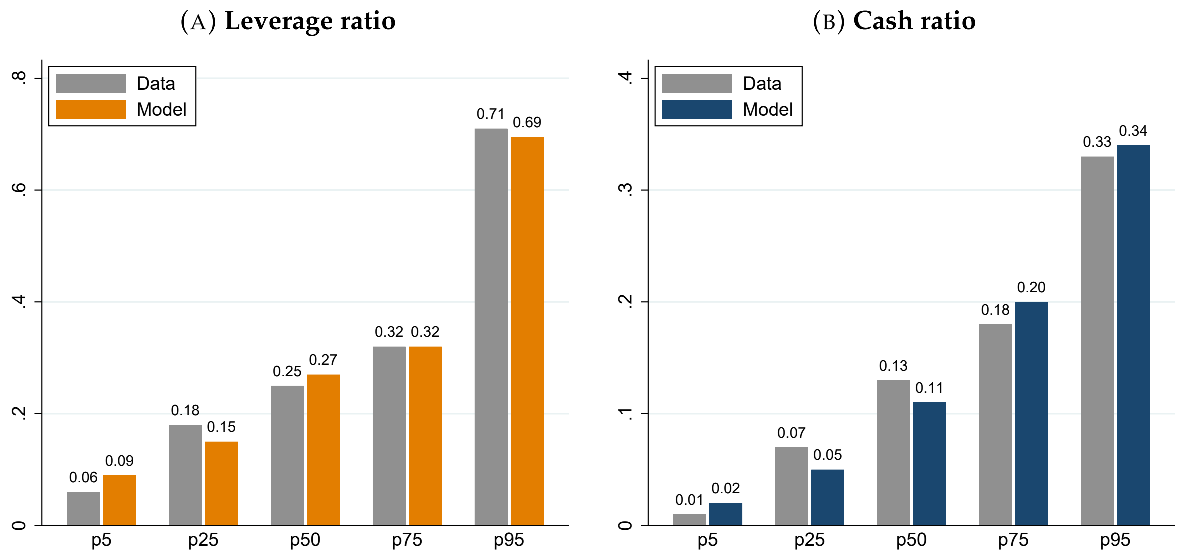


FIGURE 4: **Non-Targeted Cross-Sectional Moments: Data versus Model**

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

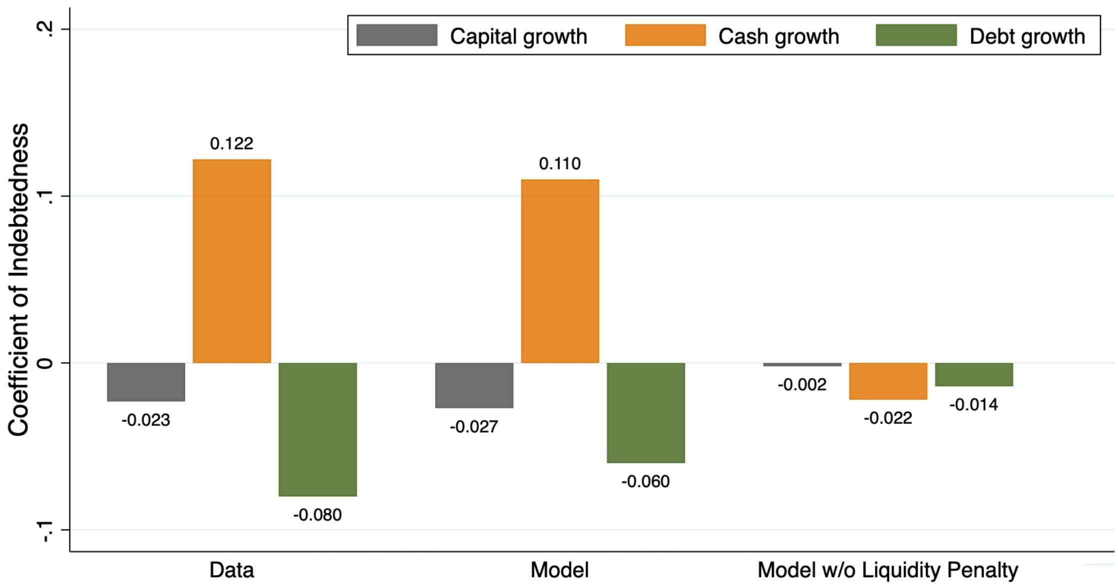


FIGURE 5: **Firm Indebtedness and Firm Behavior: Data versus Model**

Notes: The 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. Model w/o Liquidity Penalty indicates a counterfactual model where liquidity penalty $s = 0$.

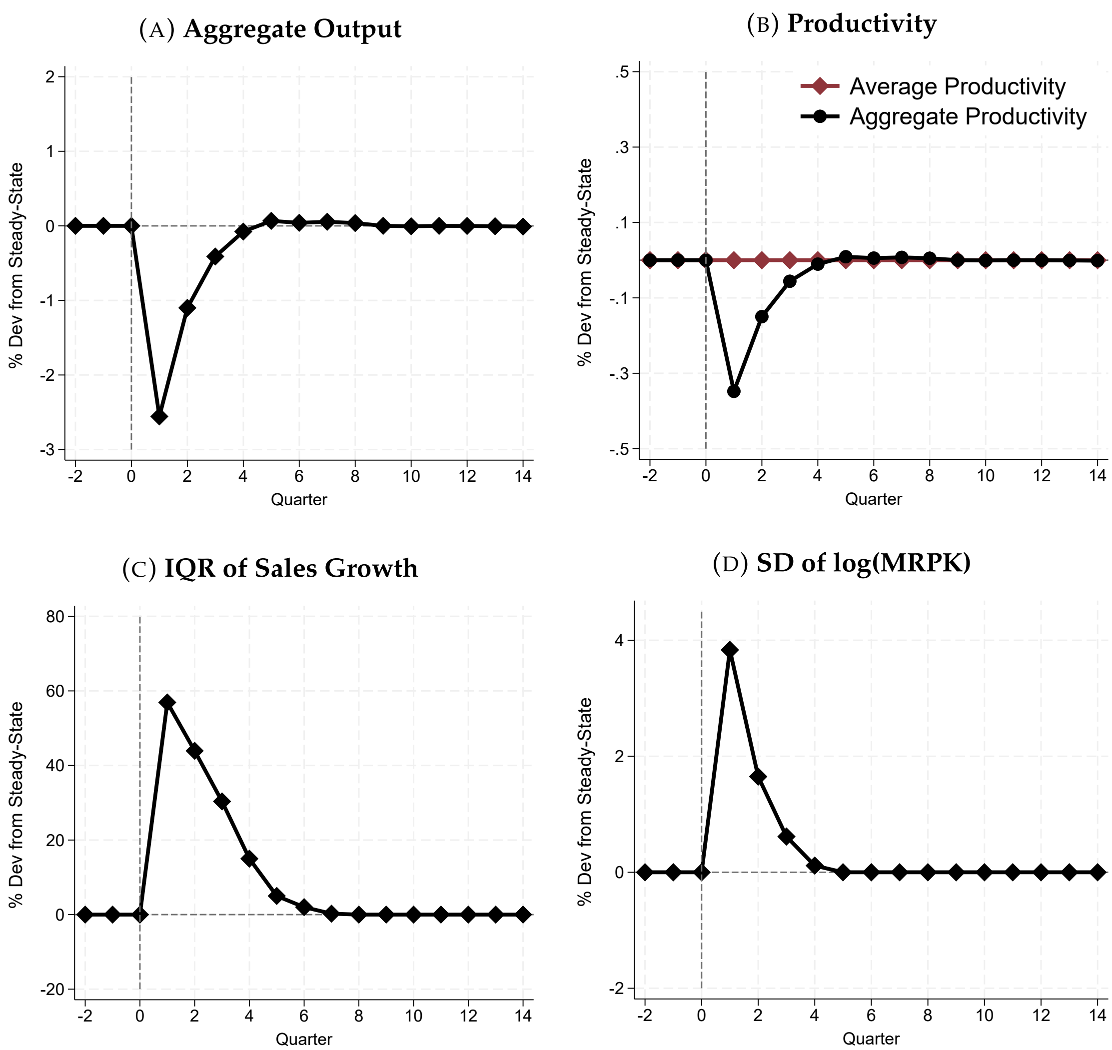


FIGURE 6: **Aggregate Effects of Uncertainty Shocks via the Balance Sheet Channel**

Notes: The figure plots the percentage deviations of (A). aggregate output, (B). measured productivity, (C) the interquartile range of firm-level sales growth, (D) the standard deviation of firm-level marginal revenue product of capital from the steady state levels to uncertainty shocks. Firm-level sales growth is defined as log growth in firm-level sales. Aggregate productivity is defined as the Solow productivity, and average productivity is the average firm-level productivity across firms. Firm-level marginal revenue product of capital, MRPK, is calculated by $MRPK = y/k$. Appendix A.3.4 details the computation of aggregate impulse response functions.

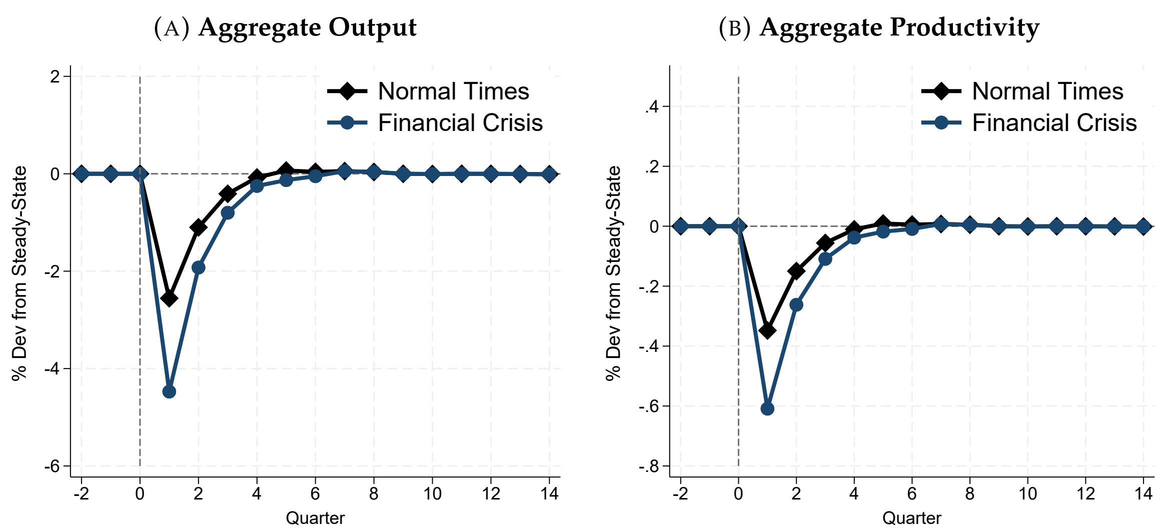
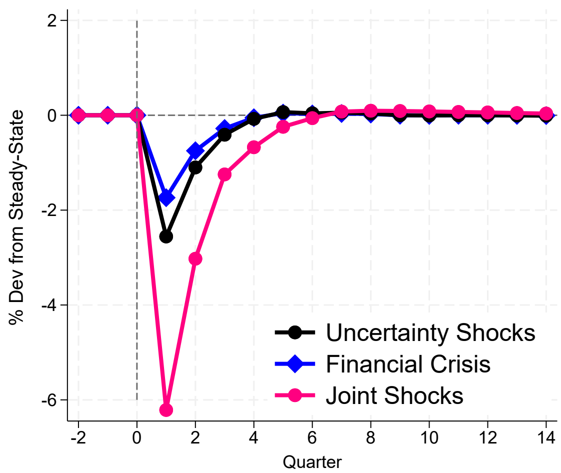


FIGURE 7: **Impacts of Uncertainty Shocks: Normal Times versus Financial Crisis**

Notes: The figure plots the percentage deviations of (A). aggregate output, (B). aggregate productivity from steady-state levels following uncertainty shocks in normal times and during a financial crisis. Aggregate productivity is defined as the Solow productivity. Appendix A.3.4 details the computation of aggregate impulse response functions.

(A) **Aggregate Output**



(B) **Aggregate Productivity**

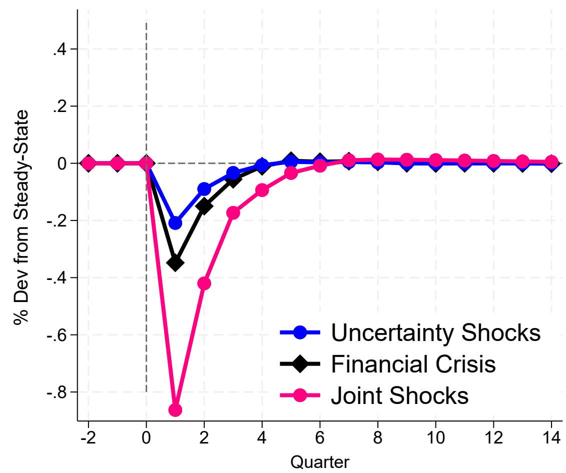


FIGURE 8: **Financial Crisis with Uncertainty Shocks**

Notes: The figure plots the percentage deviations of (A). aggregate output, (B). aggregate productivity from steady-state levels triggered by uncertainty shocks, a financial crisis, or both. Aggregate productivity is defined as the Solow productivity. Appendix A.3.4 details the computation of aggregate impulse response functions.

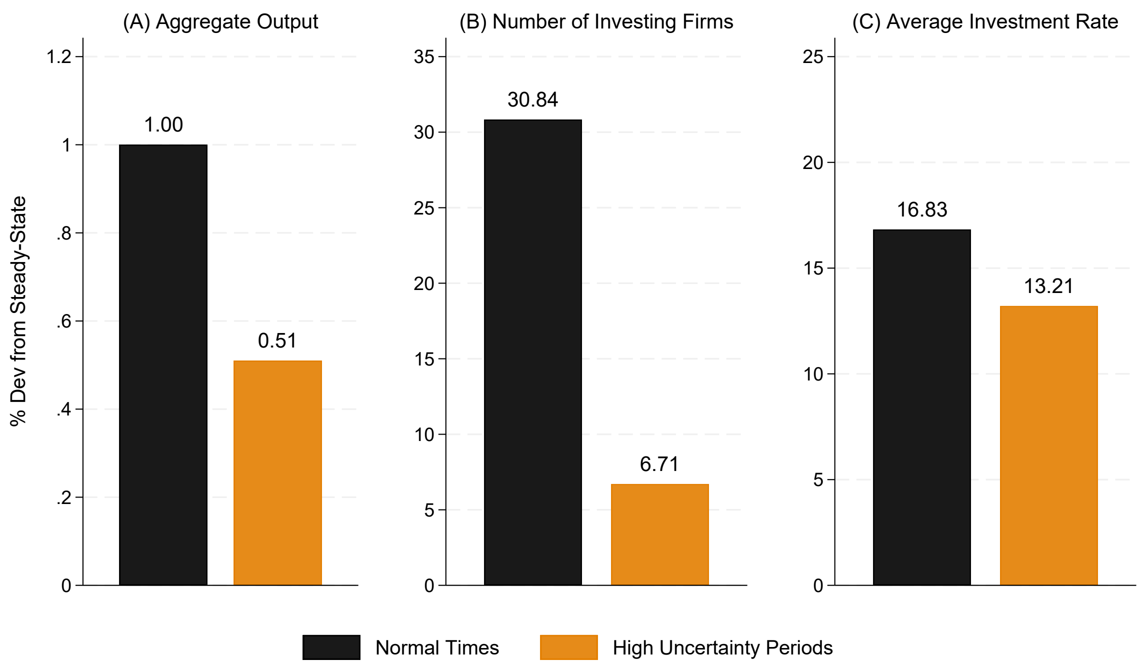
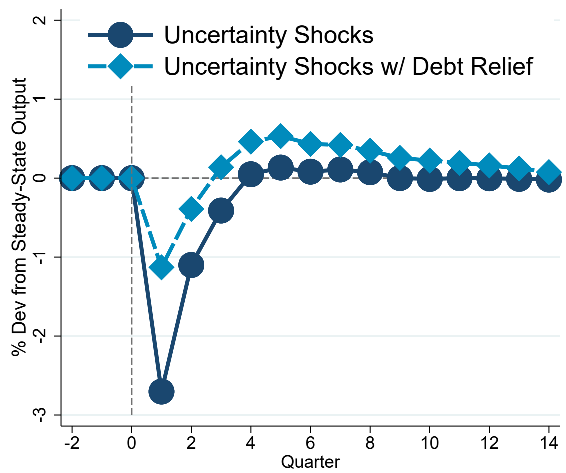


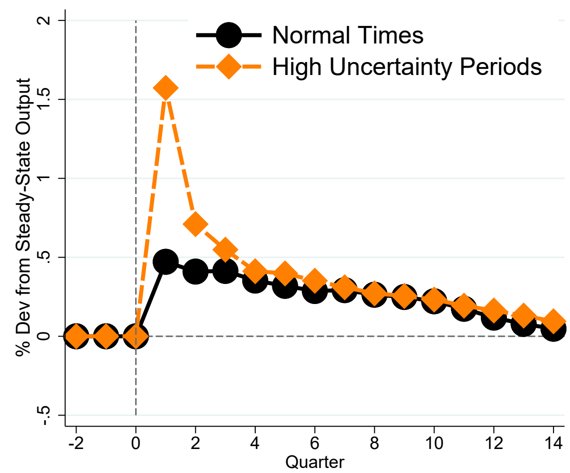
FIGURE 9: **Effects of Investment Stimulus: Normal versus High Uncertainty Periods**

Notes: The figure plots the cumulative effects of investment stimulus policy, a calibrated one-time tax cut, on (A). aggregate output, (B). the number of investing firms, and (C). average investment rate with and without uncertainty shocks. Investing firms are defined as firms with positive capital investment, and the investment rate is measured as capital investment as a share of existing capital stock. Appendix A.3.4 details the computation of aggregate impulse response functions.

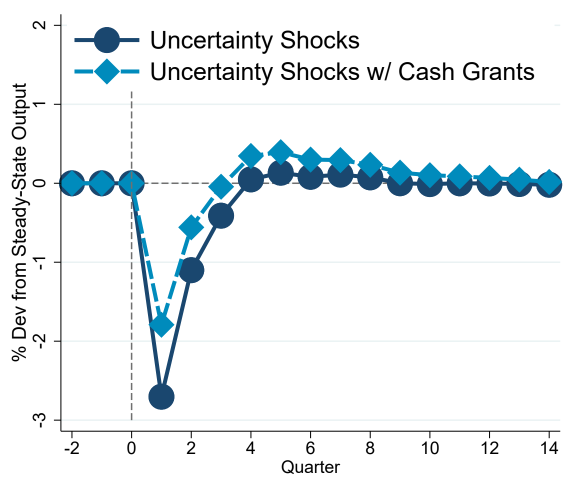
(A) **Output Responses to Uncertainty Shocks**



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



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



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

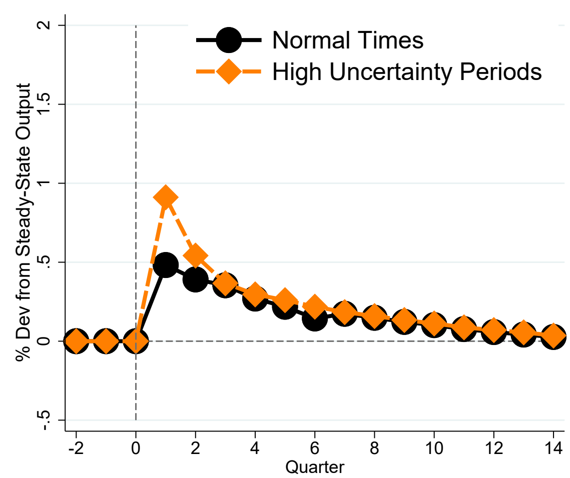


FIGURE 10: **Credit Interventions in Uncertainty-driven Recessions**

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 A.3.4 details the computation of aggregate impulse response functions.

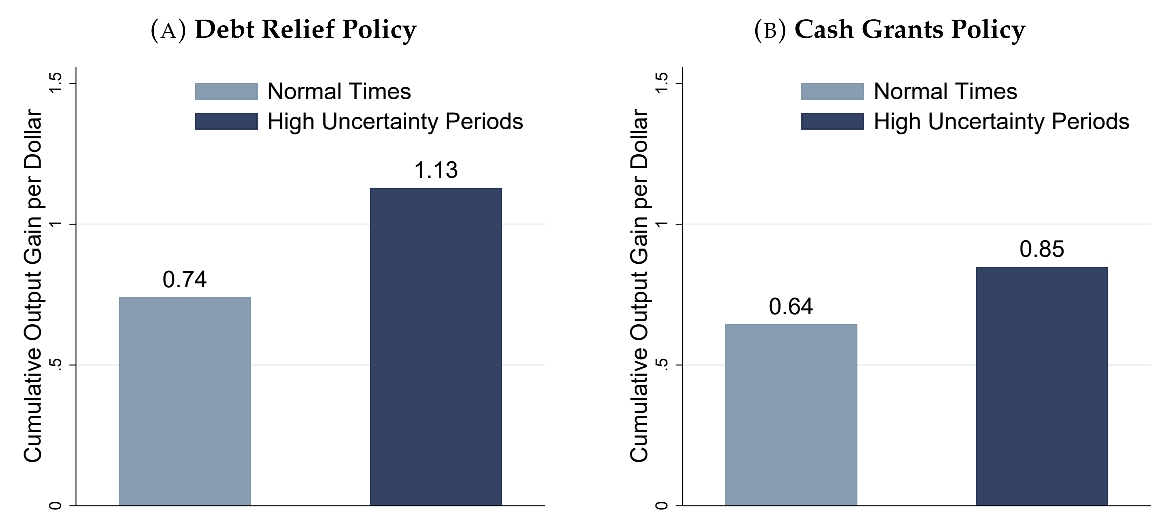
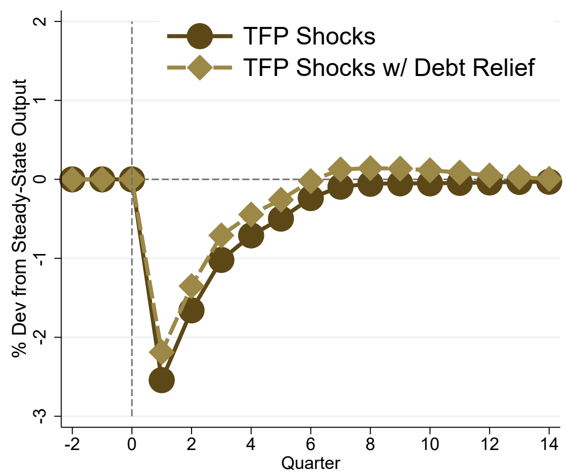


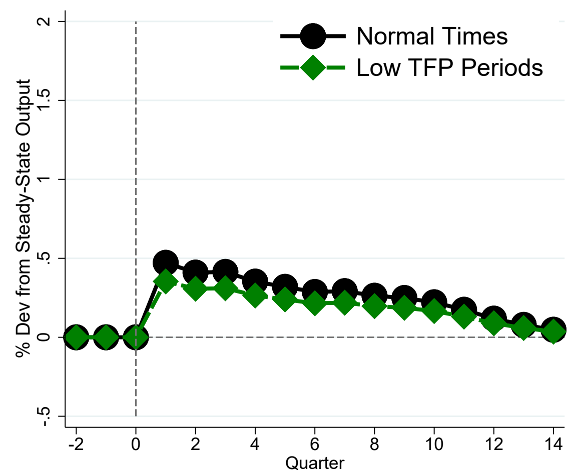
FIGURE 11: **Cost Effectiveness of Credit Interventions**

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

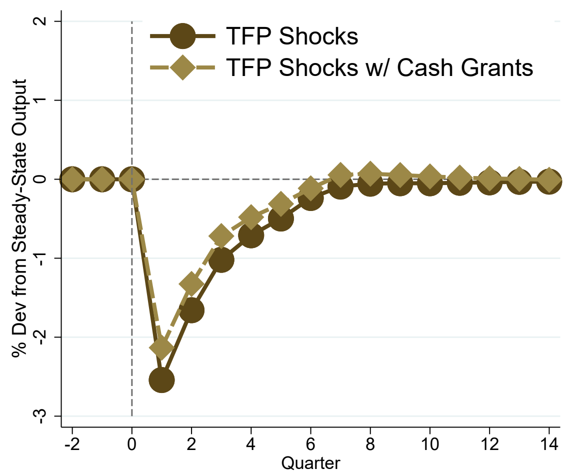
(A) **Output Responses to TFP Shocks**



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



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



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

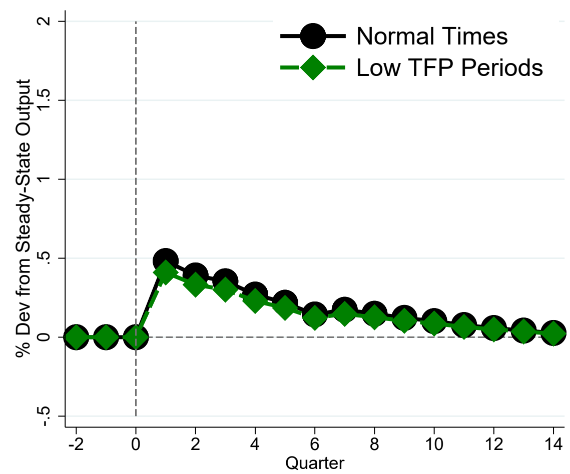


FIGURE 12: **Credit Interventions in TFP-driven Recessions**

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 A.3.4 details the computation of aggregate impulse response functions.

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

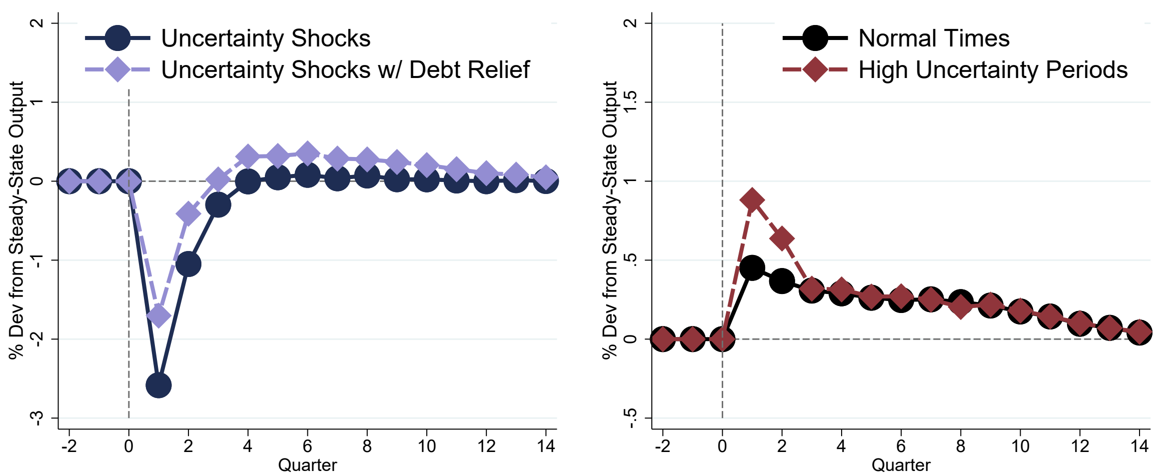


FIGURE 13: **Effects of Debt Relief Policy in a Counterfactual Economy**

Notes: Panels (A) plots the aggregate output responses to uncertainty shocks with and without credit interventions in an alternative model without debt issuance frictions $\eta = 0$. Panel (B) plots the aggregate output responses to policy interventions during normal times and periods of high uncertainty. Appendix A.3.4 details the computation of aggregate impulse response functions.

Online Appendix to " The Firm Balance Sheet Channel of Uncertainty Shocks "

A.1 Data Appendix

A.1.1 Macro Time Series Data

For the macro data, I use data from the Federal Reserve Bank of St. Louis (FRED) for the United States. 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(GDPDEF, Index 2012=100), Real Federal Funds Rate measured as the difference between Effective Federal Funds Rate (FEDFUNDS) and Inflation Rate, and Credit Spread (BAA10y).

A.1.2 Firm-level Data

This subsection describes the firm-level variables 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 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.1.3 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 $\Delta lnTFP_{i,t} = ln(z_{i,t}) - ln(z_{i,t-4})$.

A.2 Additional Empirical Results

A.2.1 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:

$$\Delta_h \log(y_{i,t+h}) = \alpha_{i,h} + \alpha_{fq,h} + \alpha_{s,t,h} + \underbrace{\gamma_h \big(D_{i,t-1} - \bar{D}_i\big) \cdot \Delta \log \sigma_t}_{\text{Heterogeneous responses}} + \beta_h \big(D_{i,t-1} - \bar{D}_i\big) \tag{22}$$

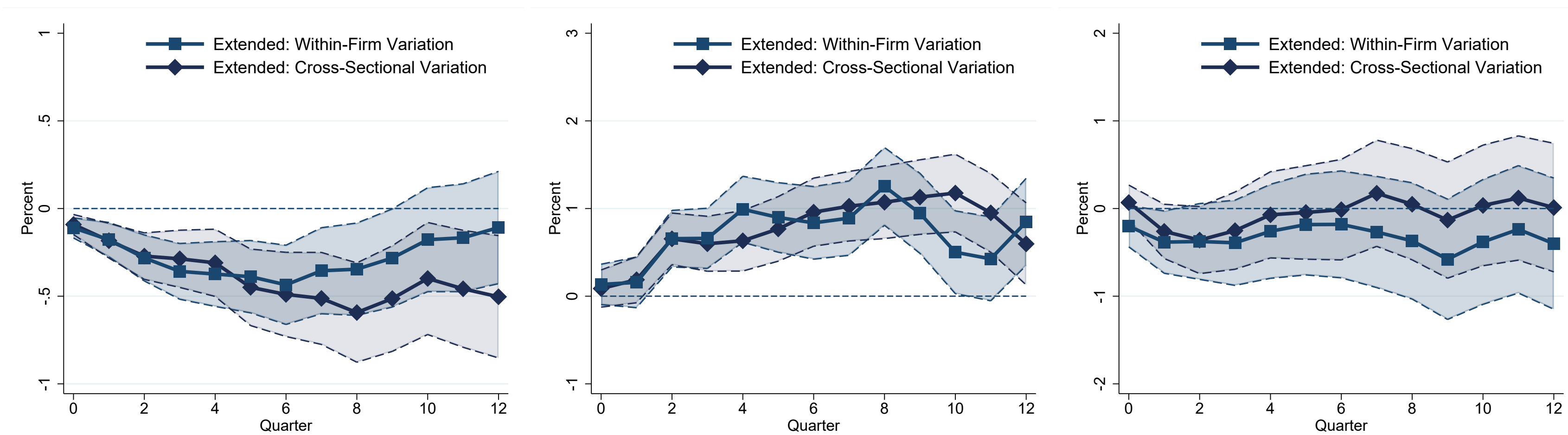
$$+ \Psi_h' \big(\mathbf{Z}_{i,t-1} - \bar{Z}_i\big) \cdot \Delta \log \sigma_t + \Gamma_h' \big(\mathbf{Z}_{i,t-1} - \bar{Z}_i\big) + \eta_h \big(D_{i,t-1} - \bar{D}_i\big) \cdot \Delta \log GDP_t + \mu_{i,t+h}$$

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

The Equation 22 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 Uncertainty 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**

(A) **Physical capital** (B) **Liquid assets holding** (C) **Outstanding debt**



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.

A.2.2 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 disentangle 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:

$$\log(y_{i,t}) = \alpha_i + \alpha_{fq} + \sum_t \beta_t \text{Quarter}_t + \varepsilon_{i,t} \tag{23}$$

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

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

$$\log(y_{it}) = \alpha_i + \alpha_{s,t} + \alpha_{fq} + \sum_t \gamma_t \text{Indebtednes}_{i,t-1} \cdot \text{Quarter}_t + \beta \text{Indebtednes}_{i,t-1} \tag{24}$$

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

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

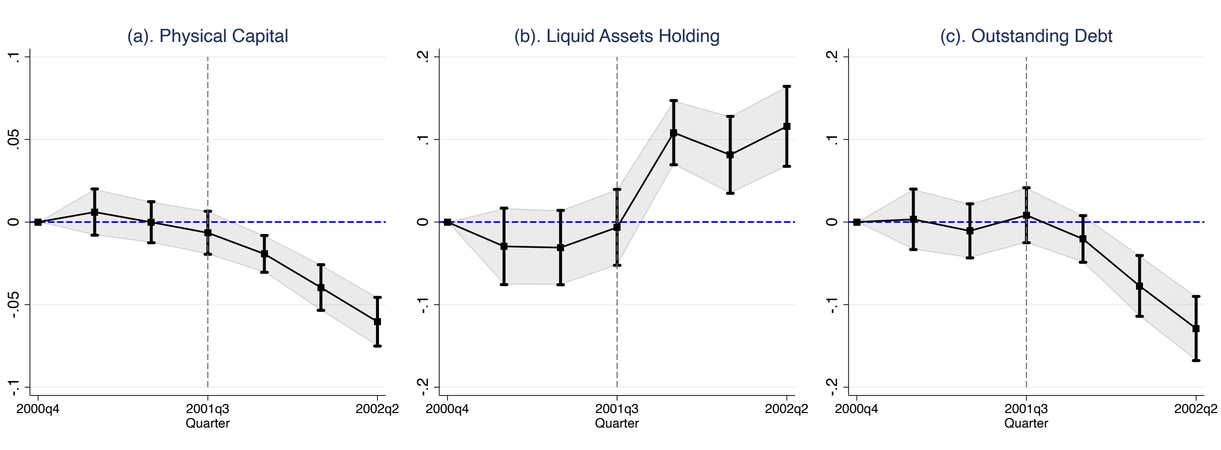
where Quarter$_t$ is a quarter dummy for the time period from 2000q4 to 2002q2, with 2000q4 taken as the omitted category. α_i indicates firm fixed effects that absorb permanent differences in the levels of dependent variables across firms. Fiscal-quarter dummy α_{fq} is included to absorb the impact 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. 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, β_t capture 'within-firm' changes in firm behavior over time relative to the base period 2000q4. γ_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 capital, 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.

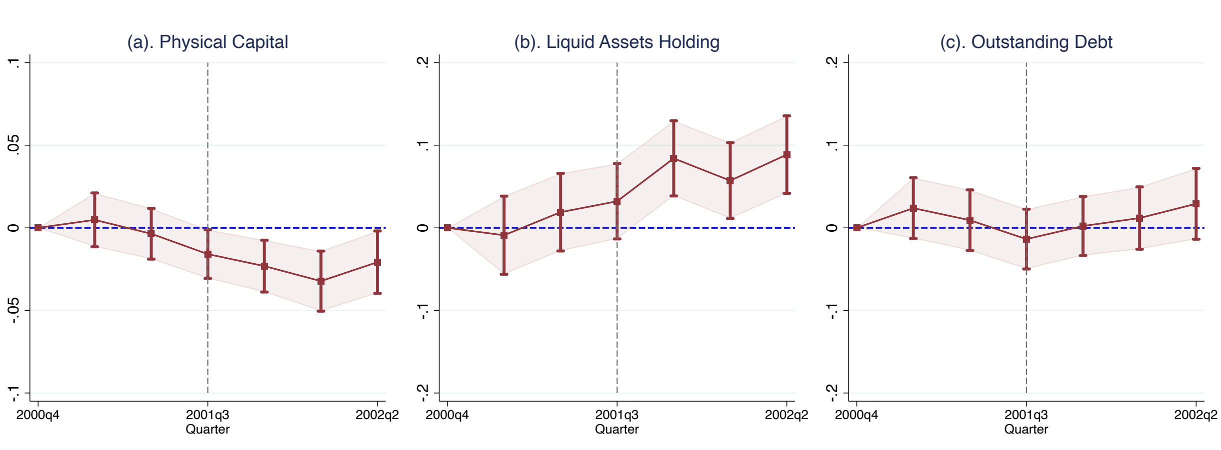
Panel B of Figure A2 plots the estimated time-varying relation between firm indebtedness and firm-level changes in (a) physical capital, (b) liquid assets holding, and (c) outstanding debt from 2000q4 to 2002q2, along with 95% confidence interval. Notably, after the third quarter of 2001, higher indebtedness 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.

A.3 Model Appendix

A.3.1 First-Order Conditions

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:

$$\Lambda(d) = \begin{cases} 1, & \text{if } d \geq 0 \\ 1 + \kappa_1 |d|, & \text{if } d < 0 \end{cases} \tag{25}$$

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

$$\frac{\partial V^m(z,k,c,b)}{\partial c} = \Lambda(d)\left[[1+(1-\tau)r](1+s\cdot\mathbf{1}_{m<0})\right] \tag{26}$$

$$\frac{\partial V^m(z,k,c,b)}{\partial k} = \Lambda(d)\left[\left[(1-\tau)\frac{\partial\pi(z,k)}{\partial k}+\tau\delta\right](1+s\cdot\mathbf{1}_{m<0})+(1-\delta)\right] \tag{27}$$

$$\frac{\partial V^m(z,k,c,b)}{\partial b} = -\Lambda(d)\left[[1+(1-\tau)r](1+s\cdot\mathbf{1}_{m<0})\right] \tag{28}$$

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

$$\frac{\partial V^n(z,k,c,b)}{\partial c} = \Lambda(d)[1+(1-\tau)r] \tag{29}$$

$$\frac{\partial V^n(z,k,c,b)}{\partial k} = \Lambda(d)\left[(1-\tau)\frac{\partial\pi(z,k)}{\partial k}+\tau\delta+(1-\delta)\right] \tag{30}$$

$$\frac{\partial V^n(z,k,c,b)}{\partial b} = -\Lambda(d)\left[[1+(1-\tau)r]-\eta\cdot\mathbf{1}_{b'>b}\right] \tag{31}$$

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:

$$FOC[c'] : \Lambda(d)\cdot\mathbf{1} \geq \frac{1}{1+r}E_{z'|z}\left[\lambda\frac{\partial V^m(z',k',c',b')}{\partial c'}+(1-\lambda)\frac{\partial V^n(z',k',c',b')}{\partial c'}\right] \tag{32}$$

$$FOC[k'] : \Lambda(d)\cdot\mathbf{1} = \frac{\mu_b\theta(1-\delta)}{1+r}+\frac{1}{1+r}E_{z'|z}\left[\lambda\frac{\partial V^m(z',k',c',b')}{\partial k'}+(1-\lambda)\frac{\partial V^n(z',k',c',b')}{\partial k'}\right] \tag{33}$$

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

$$FOC[b'] : \Lambda(d)\cdot(\mathbf{1}-\eta)-\mu_b = \frac{1}{1+r}E_{z'|z}\left[\lambda\frac{\partial V^m(z',k',c',b')}{\partial k'}+(1-\lambda)\frac{\partial V^n(z',k',c',b')}{\partial k'}\right] \tag{34}$$

$$FOC[b'] : \Lambda(d)\cdot(\mathbf{1}-\eta\cdot\mathbf{1}_{b'>b})-\mu_b = \frac{1}{1+r}E_{z'|z}\left[\lambda\frac{\partial V^m(z',k',c',b')}{\partial k'}+(1-\lambda)\frac{\partial V^n(z',k',c',b')}{\partial k'}\right] \tag{35}$$

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

A.3.2 Firm Distribution

The evolution of the distribution of firms $\mu_{t+1}(z,k,c,b)$ is given by

$$\begin{aligned}
&\mu_{t+1}(z',k',c',b') = \qquad (36)\\
&(1-\pi_e)\Bigg[\int\int_{z'} \underbrace{\lambda \mathbf{1}\{\hat{k}^m_t(z,k,c,b)=k'\}\times\mathbf{1}\{\hat{c}^m_t(z,k,c,b)=c'\}\times\mathbf{1}\{\hat{b}^m_t(z,k,c,b)=b'\}}_{\text{transition of continuing firms with maturing debt}}\\
&+\underbrace{(1-\lambda)\mathbf{1}\{\hat{k}^n_t(z,k,c,b)=k'\}\times\mathbf{1}\{\hat{c}^n_t(z,k,c,b)=c'\}\times\mathbf{1}\{\hat{b}^n_t(z,k,c,b)=b'\}}_{\text{transition of continuing firms with non-maturing debt}} dF(z'|z)d\mu_t(z,k,c,b)\Bigg]\\
&+\pi_e\Bigg[\int\int_{z'} \underbrace{\mathbf{1}\{\hat{k}^o_t(z,n_0,b_0)=k'\}\times\mathbf{1}\{\hat{c}^o_t(z,n_0,b_0)=c'\}\times\mathbf{1}\{\hat{b}^o_t(z,n_0,b_0)=b_0\}}_{\text{transition of entry firms}} dF(z'|z)d\mu^{Entry}(z)\Bigg]
\end{aligned}$$

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.

A.3.3 Model Computation

Stationary Equilibrium. I first assume the economy is in a steady state with normal volatility. There is no aggregate shock in the stationary equilibrium, 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* $\varepsilon = L^s - L^d$ by taking the difference between labor demand and labor supply. *STOP* if $\max|\varepsilon| < 10^{-5}$.

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 $t = T-1, \ldots 1$ 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 $t = 1, \ldots, T$ 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* $\varepsilon_t = L_t^s - L_t^d$ by taking the difference between labor demand and labor supply.

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

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

A.3.4 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 to calculate moments. Finally, I continue to simulate the economy, starting from quarter 500 forward, with the transitional policy functions and aggregate prices until the economy converges back to the steady state in 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

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

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 × 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.

A.4 Additional Model Results

A.4.1 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:

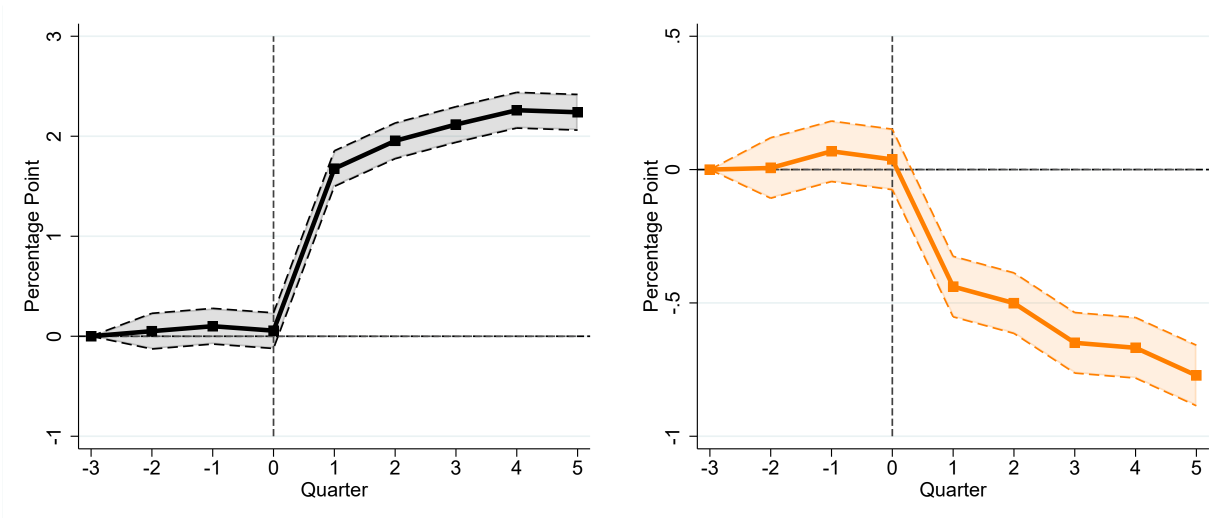
$$y_{i,t} = \alpha + \sum_{t\geq -3}^{t\leq 5} \beta_t \text{Treated}_i \times \text{Quarter}_t + \Gamma' X_{i,t} + \varepsilon_{i,t} \tag{37}$$

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

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.

reducing firms' precautionary saving motives and generating a cut in cash holding.

A.4.2 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.

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

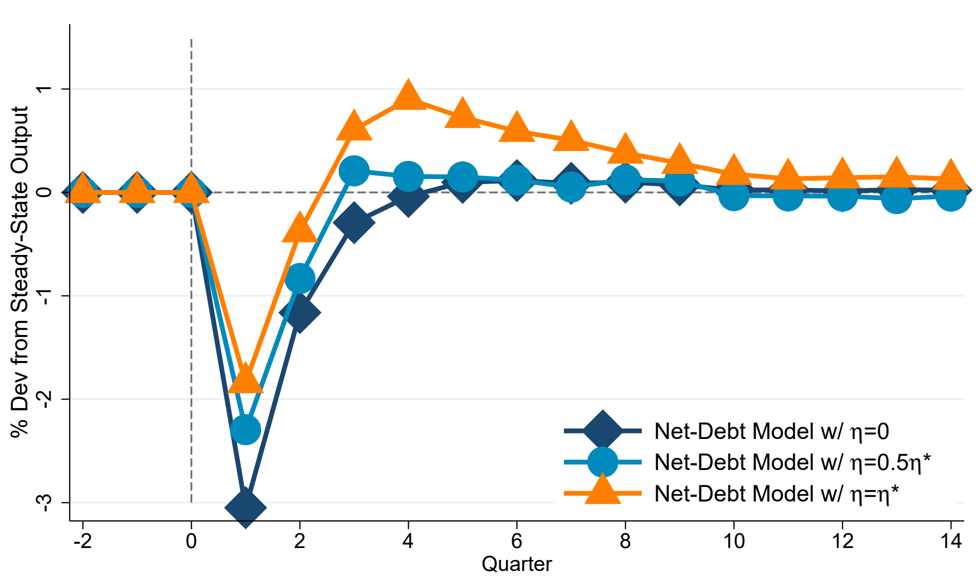
	Model w/o liquidity penalty				**Model w/o debt issuance frictions**		
$\Delta \ln y_{i,t+1}$:	ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$	$\Delta \ln y_{i,t+1}$:	ΔCapital$_{i,t+1}$	ΔCash$_{i,t+1}$	ΔDebt$_{i,t+1}$
Indebtedness$_{i,t}$	-0.002***	-0.022***	-0.014***	**Indebtedness**$_{i,t}$	-0.006***	0.173***	-0.015***
	(0.000)	(0.000)	(0.000)		(0.000)	(0.001)	(0.000)
Tobin's $Q_{i,t}$	0.022***	0.018***	0.023***	Tobin's $Q_{i,t}$	0.052***	0.026***	0.036***
	(0.000)	(0.000)	(0.000)		(0.000)	(0.000)	(0.000)
Size$_{i,t}$	-0.079***	-0.087***	-0.070***	Size$_{i,t}$	-0.024***	-0.040***	-0.033***
	(0.000)	(0.001)	(0.000)		(0.000)	(0.002)	(0.001)
R-Squared	0.726	0.116	0.594	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.

A.4.3 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 the 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. 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.

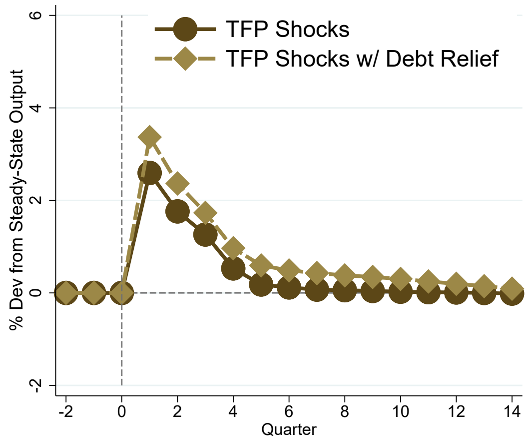
APPENDIX FIGURE A4: **Output Responses to Uncertainty Shocks**



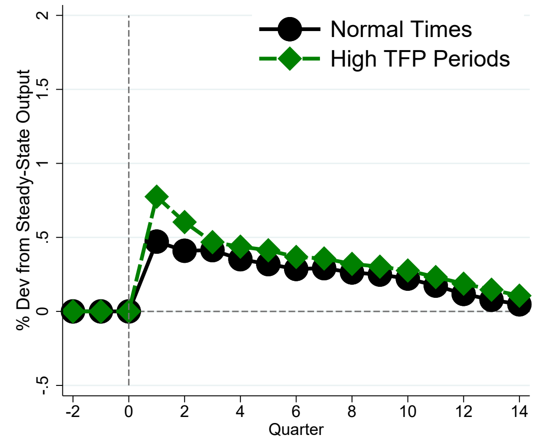
Notes: Figure A4 plots output responses to the same uncertainty shocks in the net-debt model with different levels of debt issuance cost η.

APPENDIX FIGURE A5: **TFP-driven Booms and Credit Interventions**

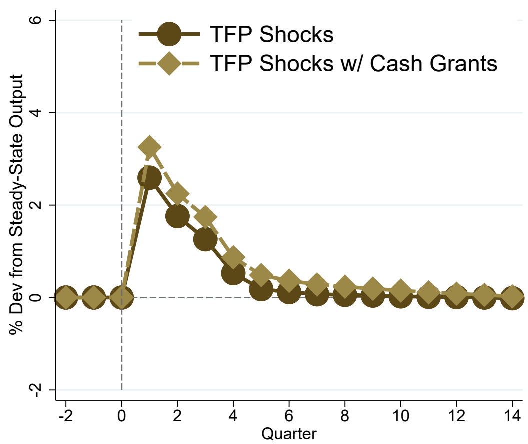
(A) **Output Responses to TFP Shocks**



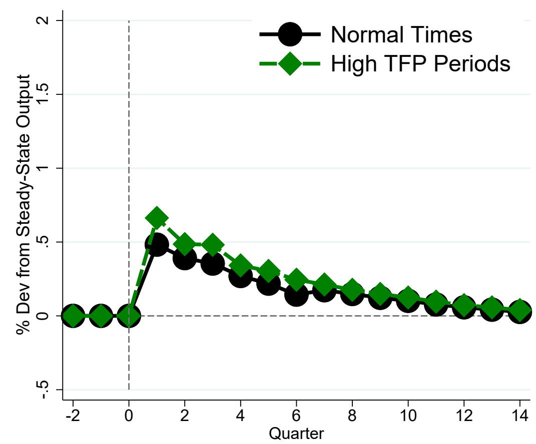
(B) **Output Responses to Debt Relief**



(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 A.3.4 details the computation of aggregate impulse response functions.

A.4.4 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 contrasts to the weaker effects of credit interventions during TFP-driven recessions, where investment demand becomes lower than the steady-state level.