Can cash holdings buffer firms against external financing shocks? Evidence from firm-level productivity

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Abstract

This paper investigates the effects of cash holdings on productivity in different financial conditions. Using financial data of US-listed firms from 1980 to 2019, we show that the cash-to-assets ratio correlates positively with productivity, consistent with the view that cash reserves reduce firms' dependence on costly external financing. These results hold when we replace the cash-to-assets ratio with a proxy for excess cash. However, this positive correlation is moderated by changes in financial markets' conditions: when access to external financing is seriously constrained, the positive impact of cash on productivity is dampened. We rationalize that when external financing costs are high, firms face a trade-off between saving for future needs and realized productivity. Our findings align with precautionary motives, suggesting that financially constrained firms can accumulate cash during periods of credit expansion and deplete it during credit crunches to mitigate the adverse effects of external financial frictions on productivity.

JEL Classification: G31, G32, D24

Keywords: Cash holdings, Excess cash, Financial constraints, Recessions, Productivity

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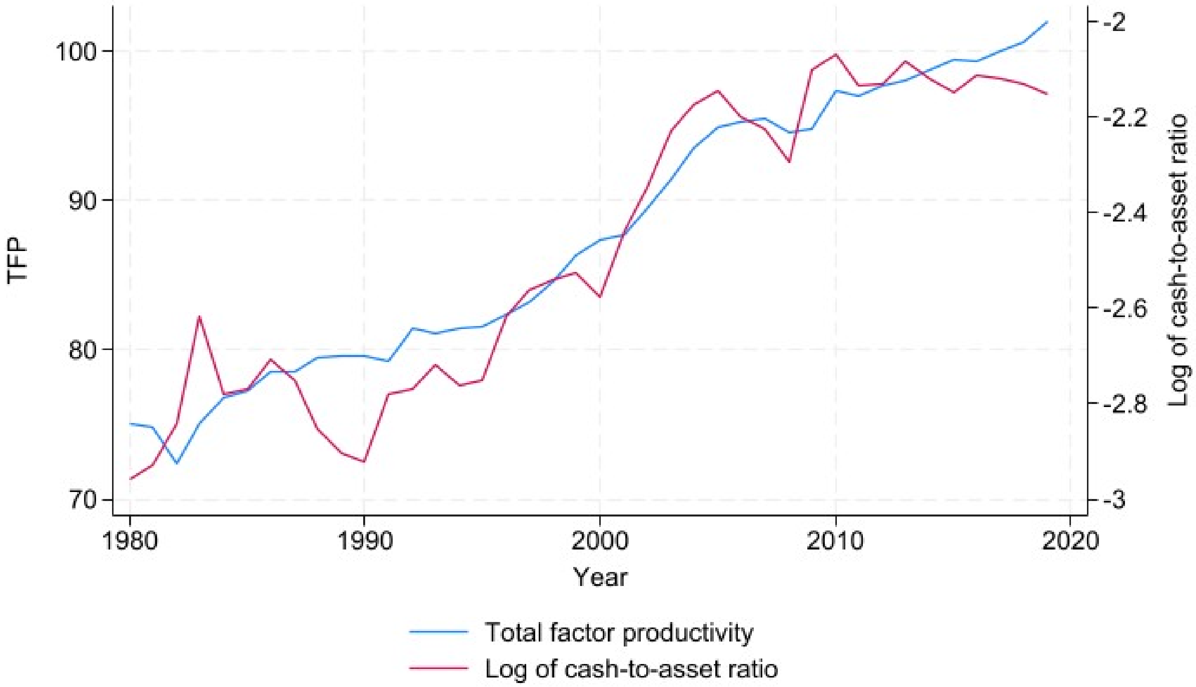
1 Introduction

Over the last 40 years, US firms have experienced a joint increase in total factor productivity (TFP) and cash holdings (Figure 1). A notable surge in productivity occurred over the mid-1990 to 2000s, largely driven by information technology sectors (Jorgenson et al., 2008). The productivity, however, has stagnated with around 5% increase since 2005 (Federal Reserve Bank of St. Louis, 2023). Coincidentally, cash-to-assets ratio increased substantially in 1980-2006, over doubling from 10.5% in 1980 to 23.2% in 2006 (Bates et al., 2009). This trend has also tapered off since the Great financial crisis. Explaining the behavior of cash accumulation, a number of studies attribute precautionary motive as the primary driver for firms to save cash (e.g., Bates et al., 2009; Opler et al., 1999). When external capital is costly and general availability of market capital declines, cash reserves can replace expensive external financing, reducing negative impact of financial frictions on firms' operations. This thus intrigues us to answer the question *"Do cash holdings improve productivity by alleviating the adverse effects of external financial constraints?"*

It is widely agreed that financial constraints hinder firms' productivity (e.g., Hsieh and Klenow, 2009; Moll, 2014). Access to market capital enables firms to scale up their production and invest in productive projects, thereby enhancing their productivity and efficiency (Krishnan et al., 2015). Conversely, financial constraints may prevent firms from expanding their operations and realizing productivity gains. Suboptimal input allocation can be yielded by high borrowing costs and limited access to capital markets (Gilchrist et al., 2013). As a result, firms accumulate internal funds to reduce their dependence on expensive external financing. Moll (2014) shows that self-financing can replace external capital effectively in the long run if productivity shocks are sufficiently correlated over time. Midrigan and Xu (2014) find that internal accumulation enables establishments to overcome borrowing constraints. They document that the role of financial constraints is weakened when the owners are more patient and save more to avoid binding credit access.

Despite the extent of literature investigating the relationship between financial constraints, internal financing, and productivity, there is little evidence of the relationship

Figure 1: Average total factor productivity and cash holdings in US



between cash holdings and productivity as well as the mechanism behind it. One may think that cash holdings result from internal accumulation, so its mitigating effect on financial constraints is obvious. However, firms reserve internally generated funds for several purposes beyond simply for adverse cash flow shocks. For example, excess cash may signal agency problems (e.g., Dittmar et al., 2003; Kalcheva and Lins, 2007; Lie, 2015) because hoarding cash enables entrenched managers to reduce firm risk to protect their positions and facilitate overinvestment or spending for personal motives. Excess cash may also indicate a lack of profitable projects (i.e., projects with positive Net Present Value) or excessive risk aversion under the agency-cost hypothesis. Consequently, it is unclear whether cash holdings can improve productivity by mitigating financial frictions.

We start by examining the direct impact of cash holdings on productivity with a sample of 8114 listed firms in the US over the 1980-2019 period. We zoom in on TFP, which reflects firms' ability to generate outputs given a specific amount of inputs (i.e., labor and capital).

Similar to the existing literature (e.g., Bennett et al., 2020; Feng et al., 2020), we employ Ackerberg et al. (2015)'s method of TFP estimation to address endogeneity problem. We consider two variables to proxy for cash holdings: the natural logarithm of cash-to-assets ratio and excess cash. The latter indicator is calculated following Opler et al. (1999) and Huang and Mazouz (2018). In this paper, cash holdings refer to both indicators.

We first show that both cash-to-assets ratio and excess cash have a statistically and significantly positive impact on productivity. This finding, however, could be driven by reverse causality: productive firms may reserve more cash than the less efficient ones because of expediting consumption (Feng et al., 2020; Krishnan et al., 2015). We address this concern in two ways. The first way is to use the first lags of all independent and control variables in our regressions. We then adopt two lagged values of independent variables and other covariates as instrumental variables in Two-Stage Least Squares (2SLS) regressions following Almeida et al. (2004). The 2SLS regressions confirm our initial finding about the significantly positive impact of cash. This result is also robust to different TFP estimations.

Next, we examine whether external financial friction is a mechanism for this relationship. This paper specifically focuses on the change in market conditions outside firms' control, affecting their access to external financing. We use the Interstate Banking and Branching Efficiency Act (IBBEA) in 1994 as an exogenous shock to the credit supply of firms. Prior to the introduction of this law, interstate banking and branching were highly restricted by federal and state regulations. The IBBEA, by allowing out-of-state banking and branching under specific regulations, increased credit supply and lowered interest rates (Chu, 2018; Rice & Strahan, 2010). However, each state has discretion to impose regulations under IBBEA. Different states thus have different levels of openness.

Our results confirm that average productivity increases significantly after the introduction of IBBEA. We find out that effect of cash holdings is more pronounced in states with tighter regulations. We explain this finding by combining the theoretical models of Levine and Warusawitharana (2021) and Riddick and Whited (2009) (Proposition 1). Consistent with Levine and Warusawitharana (2021), innovative investment is negatively associated with external costs of capital. This implies firms reduce productivity-enhancing investment when external financing becomes more expensive. When we incorporate dynamic cash holding into external financing function, we find that cash is an effective substitute for costly external funds to finance innovative projects, leading to higher productivity .

If holding more cash mitigates financial frictions, the clearest evidence should be in market downturns. Surprisingly, using National Bureau of Economic Research (NBER)'s Business Cycle Dating to identify recession years in our sample period, we document that stockpiling cash worsens the adverse impact of market downturns on productivity. The negative effect even outweighs the positive influence of excess cash in this subsample. These findings indicate that the positive effect of cash on productivity deteriorates during recessions. We strengthen these results by using the collapse of junk bond market in 1989 as a negative financing shock to below-investment grade and unrated firms (non-investment grade firms).

The collapse happened because of three near-concurrent events: (i) The collapse of Drexel Burnham Lambert, Inc. (Drexel); (ii) the passage of the Financial Institutions Reform, Recovery, and Enforcement Act of 1989 (FIRREA); and (iii) a change in the National Association of Insurance Companies (NAIC) credit rating guidelines (Lemmon and Roberts, 2010; Lyandres and Palazzo, 2016). At the same time, most Southeast and West states of the US experienced a recession, while the remaining states were still in expansion (Owyang et al., 2005). This recession arose from an overheated real estate market, credit crunch (Lemmon and Roberts, 2010; Lyandres and Palazzo, 2016), and upward shocks to oil prices in the Gulf War (Throop, 1991). Our identification strategy rests on the assumption that non-investment grade firms in these states incurred more severe credit contraction than those in other states.

Using a Difference-in-Differences (DiD) approach, we document that the below-investment-grade and unrated firms in Southeast and West states are significantly less productive than firms in the remaining areas after the collapse of junk bond market. Meanwhile, there is no significant difference for investment-grade firms. These results are robust to Synthetic Difference-in-Differences (SDiD) approach. They thus consolidate the prior result in IBBEA part about the adverse effect of financial friction on productivity. Consistent with the finding in economic downturn periods but contradictory to the IBBEA part, we show that stockpiling cash exaggerates adverse effects of credit crunch in non-investment grade firms located in the South East and West states. As the investment-grade firms - the least constrained group, are not strongly affected by the collapse, cash holdings do not have significantly joint effect with the event in these firms.

Simply put, accumulating cash during periods of credit loosening (e.g., IBBEA) and deploying cash during periods of credit tightening (e.g., credit crunch) mitigate adverse effects of financial frictions on TFP. We rationalize our finding in proposition 2, where external financing is constrained. In the Proposition 1, which supports for the findings in IBBEA, external financing is not limited: cash accumulation increases external financing needs, but does not affect the available fund for technology investment. This allows firms to accumulate cash and invest in innovative projects at the same time. However, market downturns are associated with higher credit rationing. The limit in external financing forces highly constrained firms to trade-off between accumulating cash and investing, resulting in a negative correlation between cash reserves and productivity investment (Proposition 2). To be more specific, financially constrained firms may increase cash balance by divesting productive investment and R&D expenditure, leading to lower productivity. Otherwise, they can burn cash to maintain investment and production levels during market downturns. This finding is supported by empirical evidence showing that holding more cash exacerbates the negative effects of market downturns on R&D investment.

Our paper contributes to multiple strands of literature. First, this study adds to the existing studies on how market conditions influence firm-level productivity. For instance, Krishnan et al. (2015) highlight that TFP experiences significant increases following the implementation of IBBEA with stronger effects on financially constrained firms. Similarly, Chen and Lee (2023) document a remarkable decline in productivity during the Great Financial Crisis of 2008–2011. In our work, this relationship is examined in the collapse of junk bond market in 1990–1991, which has never been studied in productivity studies before.

Consistent with prior studies, our paper affirms that financial frictions have a significantly negative impact on productivity in both contexts of credit expansions or contractions.

Secondly, our research makes a contribution to the literature on liquidity and productivity. The studies most closely related to ours are those by Chang and Tang (2021) and Feng et al. (2020), which examine the relationship between corporate cash holdings and productivity. Different from these papers, our study extends the analysis beyond cash ratios to include excess cash, providing a nuanced exploration of precautionary motives. To the best of our knowledge, this is the first paper to specifically investigate the impact of excess cash on productivity. While external financial frictions are our central mechanism, Chang and Tang (2021) focus on R&D channel and we find contrasting results during financial crises compared to those reported in their research.

Feng et al. (2020) show that more productive firms in China tend to accumulate higher cash reserves due to expedited consumption. Our research diverges by focusing on the reverse relationship — how cash holdings influence productivity. We address potential reverse causality by 2SLS regressions and provide robust evidence significantly positive effect of cash holdings on productivity. Additionally, the expedited consumption argument presented by Feng et al. (2020) may not fully capture the dynamics of the U.S. market, which experiences lower financial frictions compared to emerging economies. Since excess cash typically stems from internally generated cash flows rather than new security issuances Opler et al. (2005), our findings align more closely with the broader literature emphasizing the role of internal financing in mitigating the adverse effects of financial constraints on productivity (e.g., Levine and Warusawitharana, 2021; Moll, 2014).

Lastly, our study provides insights into the role of precautionary cash holdings. Unlike prior research that focuses on either credit expansions or contractions, our analysis bridges both favorable (i.e., IBBEA) and unfavorable financial conditions (i.e., recessions). This enables us to identify comprehensive mitigating effects of cash holdings on financial frictions. Our finding during the credit-loosening period is consistent with the framework proposed by Levine and Warusawitharana (2021). However, technology investment and external financing are always positively correlated in their model. The inclusion of cash variable into the external financing function allows a potential trade-off between internal financial decisions and productivity-enhancing investment for financially constrained firms, thereby yielding an explanation for the findings during credit crunch periods. Our findings support the evidence of building up slack in low information asymmetry time (Myers & Majluf, 1984) and burning it in crises (Campello et al., 2010). It is also consistent with inter-temporal trade-off decisions between current and future investments (Han & Qiu, 2007). Our paper may also explain the slow recovery after the Great Financial Crisis, when firms feared of prolonged credit tightening conditions, then kept accumulating slacks rather than seizing attractive opportunities (Campello et al., 2010).

Following this introduction, Section 2 introduces our data, variable estimation, and empirical models of this research. Section 3 discusses the descriptive statistics and results gained from our empirical models. Section 4 provides theoretical models to support our empirical findings in the previous part. Section 5 is the conclusion.

2 Methodology

2.1 Data and Variables

The financial data of firms is drawn from COMPUSTAT. Due to the unique industry regulations, I exclude financial firms with SIC codes from 6000 to 6999 and utility firms with SIC codes from 4900 to 4999. My sample only includes firms listed on the NYSE, AMEX, and NASDAQ. Observations with missing information are dropped. We winsorize all variables at the 1st and 99th percentiles to mitigate potential outlier effects. The final sample includes 86744 observations of 8114 firms over the 1980-2019. We deflate variables in Profit & Loss statements (e.g., sales) by GDP price deflator and those on the left side of the Balance Sheets (e.g., total assets; gross property, plant, and equipment) by price deflator for investment in 2017 dollars. The deflators are obtained from Federal Reserve Economic Data provided by the Federal Reserve Bank of St. Louis. The data on the national average wage is taken from the Social Security Administration.

2.1.1 Total factor productivity

Total factor productivity (TFP) indicates production ability of a firm given a specific amount of capital and labor. This measure is estimated by the following production function:

$$y_{it} = \alpha_0 + \alpha_k k_{it} + \alpha_l l_{it} + \omega_{it} + \epsilon_{it} \tag{1}$$

where y_{it} is the log of value added of firm i at year t; k_{it} is the log of capital stock and l_{it} is the log of labor of the firm; ω_{it} is total factor productivity (in natural logarithm); and ϵ_{it} is error terms. The main issue in estimating this function is that firms possess private information about their input choices and production function, which econometricians cannot fully observe. This in turn leads to simultaneity biases and serial correlation problems if OLS regression is used. The most popular methods in estimating productivity to mitigate endogeneity are Olley and Pakes (1996) and Levinsohn and Petrin (2003). These procedures however may suffer from functional dependency when estimating labor coefficient. We thus adopt Ackerberg et al. (2015)' method, which is close to those two but can avoid the functional problem. Another advantage of this procedure is the consistency if there are unobserved, serially correlated firm-specific shocks to the labor price, if labor is chosen first, or if labor is dynamic and there are unobserved, firm-specific labor adjustment costs (Ackerberg et al., 2015).

The estimation of production function gives $\widehat{\alpha_0}$, $\widehat{\alpha_k}$, and $\widehat{\alpha}_l$ and we obtain the (log) TFP:

$$\widehat{\omega_{it}} = y_{it} - \widehat{\alpha_0} - \widehat{\alpha_k} k_{it} - \widehat{\alpha}_l l_{it} \tag{2}$$

The key variables - value added, capital stock, labor, and materials are calculated following İmrohoroğlu and Tüzel (2014) and deflated by the deflators mentioned above.

2.1.2 Cash holdings

In this paper, we use cash-to-assets ratio and excess cash as proxies for cash holdings. The cash-to-assets ratio is estimated by:

$$Cash_{it} = \frac{\text{Cash and short-term investments}_{it}}{\text{Total assets}_{it}}$$

Following existing literature (e.g., Huang and Mazouz, 2018; Opler et al., 1999), excess cash ($Excash_{it}$) is the residuals of the following cross-sectional regression for each year:

$$\begin{aligned} Cash_i = \beta_0 + \beta_1 CF_i + \beta_2 Lev_i + \beta_3 MV_i + \beta_4 Size_i + \beta_5 NWC_i + \beta_6 Acq_i + \beta_7 Capex_i \\ + \beta_8 Div_i + \beta_9 RD_i + \beta_{10} Indsig_i + \upsilon_i \end{aligned} \tag{3}$$

where $Cash_i$ is the cash-to-assets ratio of firm i; CF_i is cash flows, reflected by earnings after interest, dividends, and taxes, but before depreciation scaled by total assets; Lev_i is total debt to total assets ratio; MV_i is market value of assets divided by total assets; $Size_i$ is the log of total assets deflated in 2017 dollars; NWC_i is net working capital (excluding cash) scaled by total assets; Acq_i is acquisition expenses scaled by total assets; $CAPEX_i$ is capital expenditures scaled by total assets; Div_i is a dummy with the value of 1 if firm pays dividends, 0 otherwise; RD_i is research and development expenditures scaled by sales; $Indsig_i$ is industry cash flow risk, mean of standard deviations of cash flows to total assets over 20 years for firms in the same industry (by 2-digit SIC code).

2.1.3 Other variables

We use firm size, capital expenditure, cash flows, and leverage as control variables to mitigate omitted-variable bias. İmrohoroğlu and Tüzel (2014) show that many firms' characteristics such as size and fixed investment to capital ratio are monotonically increasing with TFP. Higher productivity of larger firms can be attributed to advantages in economies of scale, allowing them to spread fixed costs and access to more advanced technologies and managerial practices. Larger scales also accompany bargaining power in labor and input markets, which eventually enhance productivity with productive workers and lower input expenses. By contrast, Dhawan (2001) finds out that smaller firms are significantly more productive as they encounter higher market uncertainty, financial constraints, and other challenges, fostering them to pursue more effective decisions. Firm size ($Size_{it}$) is proxied by log of total assets in 2017 dollars.

Since TFP reflects a firm's efficiency in utilizing its labor and capital stock, capital expenditure can directly influence operational efficiency. In many economic models, technological progress is embedded within capital assets, and it may not always be optimal for firms to adopt the most advanced technologies due to the high fixed and sunk costs (Power, 1998). Thus, investments in existing fixed assets can enhance capital productivity, contributing to overall improvements in TFP. However, capital investments do not always generate additional value, particularly when overinvestment, poor execution of capital projects, or excessive capital intensity occur (Berger & Ofek, 1995). Capital expenditure ($Capex_{it}$) is proxied by capital expenditure scaled by total assets.

Firms with strong cash flows are less dependent on external financing and can invest more consistently in productivity-enhancing projects. As R&D projects tend to have intangible nature, uncertain outcomes, and severe asymmetric information problems, it is difficult to finance them by external sources. Due to its large adjustment costs, financial constraints are binding more on R&D firms (He & Wintoki, 2016). Thus productivity-enhancing projects is more likely to be financed by internal cash flows and stock issues. Cash flows (CF_{it}) are proxied by earnings after interest, dividends, and taxes, but before depreciation scaled by total assets.

Firm leverage is also a potential factor affecting productivity. The issues of debt require managers and firms to operate efficiently to produce sufficient cash flows for future payments (Jensen, 1986). However, the increase in debt also leads to higher bankruptcy costs as well as tighter financial constraints. As mentioned above, financial constraints are associated to productivity distortion and R&D driven innovations are often financed by internal financing.

Firm leverage might have a negative effect on productivity. Leverage (Lev_{it}) is proxied by total short-term and long-term debt scaled by total assets.

2.2 Descriptive statistics

Table 1: Descriptive Statistics

	N	Mean	SD	Min	Median	Max
TFP (log)	86744	-0.1341	0.5968	-6.0452	-0.1385	4.9059
Unrated	65120	-0.1596	0.6239	-6.0452	-0.1650	4.9059
Below-investment	10535	-0.1172	0.5690	-5.8317	-0.1240	2.7482
Investment	11089	-0.0004	0.4133	-4.7704	-0.0390	2.9050
Cash	86744	-2.6677	1.4388	-6.9019	-2.4695	-0.3193
Unrated	65120	-2.5368	1.4568	-6.9019	-2.2941	-0.3193
Below-investment	10535	-3.0128	1.3446	-6.9019	-2.8289	-0.3193
Investment	11089	-3.1086	1.2675	-6.9019	-2.9670	-0.3193
Excash	86744	-0.0381	1.1654	-6.0609	0.1803	3.3793
Unrated	65120	-0.0221	1.1650	-6.0609	0.2108	3.3793
Below-investment	10535	0.0939	1.2018	-4.5268	0.2800	3.3122
Investment	11089	-0.2575	1.1021	-4.5369	-0.0931	2.6334
Size	86744	6.0286	2.0440	1.7475	5.9185	11.0079
CF	86744	0.0744	0.0741	-0.1960	0.0767	0.2777
Capex	86744	0.0632	0.0610	0.0024	0.0442	0.3322
Lev	86744	0.2304	0.1971	0.0000	0.2041	0.8845

This table reports descriptive statistics of variables used in our research, where TFP is log of total factor productivity; $Cash$ is log of cash-to-assets ratio; $Size$ is log of total assets in 2017 dollars; CF is cash flows scaled by total assets; $Capex$ is capital expenditure scaled by total assets; Lev is total long-term and short-term debt scaled by total assets. The columns are number of observations, mean, standard deviation, minimum value, median, and maximum value of each variable, respectively. We also calculate the statistics of cash holdings and TFP for unrated, below-investment grade (BB+ or lower), and investment grade (BBB- or above) firms.

Table 1 presents the descriptive statistics of the variables used in this study. We calculate statistics of three main variables by the rating groups based on S&P's long-term domestic issuer credit ratings: unrated, below-investment grade (BB+ or lower), and investment grade (BBB- or higher). The absence of bond rating is a signal of asymmetric information. Whited and Wu (2006) show that 23% of the least constrained firms have ratings while the figure for most constrained ones is only 0.3%. Since credit ratings are determined by several firm characteristics such as profitability, debt levels, and economic outlook, they can be a proxy for a firm's financial constraints.

The average log of TFP is -0.1341 or $TFP = e^{-0.1341} \approx 0.875$, indicating that firms in the sample can produce 0.875 units of value-added with one unit of labor and one unit of capital stock. The table shows an increasing productivity across three groups: unrated firms operate with the lowest TFP, next is the below-investment grade, and investment-grade firms perform most efficiently. The result provides initial evidence supporting existing literature that financial constraints have negative impact on productivity (e.g., Buera et al., 2011; Hsieh and Klenow, 2009; Moll, 2014).

Opposite to TFP patterns, rated firms on average hold less cash than unrated ones and investment-grade firms stockpile least cash among the three groups. This is attributable to the precautionary motives that constrained firms save more cash to reduce adverse shocks in the future and dependence on external financing (e.g., Bates et al., 2009; Han and Qiu, 2007; Opler et al., 1999). However, excess cash does not share the same pattern as cash-to-assets ratio. The table reveals that below-investment grade firms accumulate most and the investment group reserves least excess cash on average among the groups.

3 Results

3.1 Do cash holdings improve productivity?

3.1.1 The relationship between cash holdings and productivity over 1980-2019

We examine the effect of cash holdings on productivity following the specification:

$$\omega_{it} = \alpha Cash(Excash)_{it-1} + \beta X_{it-1} + \eta_i + \gamma_t + \epsilon_{it} \tag{4}$$

where ω_{it} is the TFP (log) of firm/industry i at time t; $Cash(Excash)_{it-1}$ is cash holdings or excess cash; X_{it-1} is a vector of firm-level covariates including firm size, cash flows, capital expenditure, and leverage; η_i is firm or industry fixed effects; γ_t is time fixed effects. We use

Table 2: The influence of cash holdings on productivity over 1980-2019

	(1) TFP	(2) TFP	(3) TFP	(4) TFP	(5) TFP	(6) TFP
Cash	0.0239***	0.0233***	0.0185***			
	(9.16)	(8.18)	(8.01)			
Excash				0.0132***	0.0159***	0.00963***
				(5.01)	(5.49)	(4.13)
Size		0.0455***	0.0139**		0.0442***	0.0113**
		(16.30)	(2.42)		(15.81)	(1.98)
CF		2.946***	2.111***		2.939***	2.111***
		(52.25)	(43.51)		(52.09)	(43.47)
Capex		-1.122***	-0.251***		-1.180***	-0.297***
		(-14.30)	(-4.46)		(-14.90)	(-5.26)
Lev		0.0992***	0.0370*		0.0534**	0.00457
		(4.29)	(1.77)		(2.36)	(0.22)
Constant	-0.0647***	-0.519***	-0.318***	-0.129***	-0.559***	-0.341***
	(-9.20)	(-23.88)	(-8.97)	(-1236.32)	(-26.90)	(-9.66)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	No	Yes	Yes	No	Yes
Industry fixed effects	No	Yes	No	No	Yes	No
No. of obs	73665	74452	73665	73665	74452	73665
R-squared	0.613	0.329	0.654	0.612	0.327	0.654

This table reports regressions of cash holdings on productivity where where TFP is log of total factor productivity; $Cash$ is log of cash-to-assets ratio; $Excash$ is excess cash; $Size$ is log of total assets in 2017 dollars; CF is cash flows scaled by total assets; $Capex$ is capital expenditure scaled by total assets; Lev is total long-term and short-term debt scaled by total assets. The first lags of independent and control variables are used to reduce simultaneous bias. t-statistics are presented in parentheses. Standard errors are clustered at firm level. ***, **, and * indicate statistical significance at the 1, 5, and 10%, respectively.

the lagged values of independent and control variables to reduce simultaneous bias.

Table 2 presents the estimation of equation 4. We find that the cash-to-assets ratio has a significantly positive impact on productivity. 1% increase in cash to total assets is associated with a 0.0239% increase in TFP on average, ceteris paribus (Column 1). Since excess cash is regression residuals, it is difficult to interpret the coefficients in the same way as cash ratios. The last three columns provide strong evidence of the significantly positive effects of excess cash on TFP. The results change slightly when covariates are added, and when controlling for industry fixed effects rather than firm fixed effects. Our results are robust when we estimate TFP with OLS and use the estimated TFP in İmrohoroğlu and Tüzel (2014) (Table A1 - Appendix).

However, employing OLS regressions for equation 4 may result in reverse causality, leading to endogeneity issues. For instance, the positive relationship between cash holdings and productivity is due to higher refinancing need of productive firms (Feng et al., 2020). There are also potentially unobservable factors that affect both cash holdings and productivity (Krishnan et al., 2015). We address the endogeneity by employing two lagged value of cash holding variables as instrumental variables in 2SLS regression following Almeida et al. (2004). As our control variables are also endogenously chosen by firms. we also adopt two lags of these variables as instruments in the regressions having controls. The 2SLS results are reported in table 3. The significantly positive coefficients of estimated cash-to-assets ratio and excess cash in the second stages show that our initial finding is robust.

Our results are consistent with Feng et al. (2020) for China firms that more productive firms maintain higher net liquid to total assets ratio. Levine and Warusawitharana (2021) and Chang and Tang (2021) also find out that firms holding more cash have higher productivity in cross-country samples. One can simply think cash holdings as an internal funds or a proxy for internal financial constraints. These reserves help firms to reduce their reliance on external financing, allowing them to seize innovative projects timely. Consequently, cash reserves mitigate the adverse effects of external financial distortions on firms and enhance productivity. Moreover, the positive relationship between cash holdings and productivity may be moderated by investment in innovation. He and Wintoki (2016) observe that R&D investment accounts for over 20% of the increase in aggregate cash holdings among U.S. firms between 1980 and 2012. In support of this perspective, Brown and Petersen (2011) demonstrate that firms facing greater financial frictions heavily depend on cash reserves to shield R&D activities from financing shocks, avoiding the high adjustment costs associated with fluctuations in innovation investment. As R&D and product innovation are critical drivers of firm productivity (Syverson, 2011), cash holdings contribute to improved total factor productivity (TFP) through their role in fostering innovative investment.

Table 3: Two-stage least squares (2SLS) regressions of cash holdings on productivity

	(1) L.Cash	(2) TFP	(3) L.Cash	(4) TFP	(5) L.Excash	(6) TFP	(7) L.Excash	(8) TFP
L2.Cash	0.484***		0.462***					
	(67.45)		(63.46)					
L3.Cash	0.0796***		0.0870***					
	(12.32)		(13.35)					
Est_Cash		0.0291***		0.0236***				
		(5.55)		(4.41)				
L2.Excash					0.462***		0.465***	
					(65.74)		(65.19)	
L3.Excash					0.0745***		0.0761***	
					(11.83)		(12.09)	
Est_Excash						0.0110*		0.0162***
						(1.92)		(2.95)
Controls	No	No	Yes	Yes	No	No	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs	55641	55641	55641	55641	55641	55641	55641	55641
R-squared	0.748	0.651	0.751	0.661	0.661	0.650	0.666	0.660

This table presents 2SLS regression results of cash holdings on productivity, using the two lagged values of the independent variables and controls (if applicable) as instrumental variables. TFP is log of total factor productivity; $Cash$ is log of cash-to-assets ratio; $Excash$ is excess cash; $Size$ is log of total assets in 2017 dollars; CF is cash flows scaled by total assets; $Capex$ is capital expenditure scaled by total assets; Lev is total long-term and short-term debt scaled by total assets. The first lags of independent and control variables are used to reduce simultaneous bias. t-statistics are presented in parentheses. Standard errors are clustered at firm level. ***, **, and * indicate statistical significance at the 1, 5, and 10%, respectively.

3.1.2 Interstate Banking and Branching Efficiency Act (IBBEA)

As widely suggested in existing literature, self-financing stimulates productivity by mitigating financial distortion (e.g., Moll, 2014, Buera et al., 2011). We employ The Riegle–Neal Interstate Banking and Branching Efficiency Act to examine whether the external financial constraints is the mechanism the positive correlation between cash holdings and TFP in US firms.

Before the Interstate Banking and Branching Efficiency Act (IBBEA) of 1994, the interstate banking landscape in the US was highly fragmented and restrictive due to a combination of federal and state regulations. Specifically, McFadden Act of 1927 restricted banks from opening branches outside their home states. Douglas Amendment (1956) prohibited a bank holding company from acquiring banks outside its headquartered states unless the states of target banks permitted such transactions (Rice and Strahan, 2010). This law gave states the power to regulate interstate banking activity and prevent out-of-state banks from entering their markets.

The introduction of IBBEA in 1994 enabled out-of-state banks to expand to other states by opening branches (interstate branching) and owning in-state banks (interstate banking) (De Cesari et al., 2023). Existing literature reveals that the relaxation of geographical restrictions motivates bank competition, credit supply, and lower interest rates (Rice and Strahan, 2010; Chu, 2018). Thus the IBBEA lowers the financial distortion for firms, facilitating credit access. Because the states adopted the IBBEA in different years and adjusted the level of restrictions throughout time, we perform two-sample t-test to compare the average TFP after and before the first time enacting this law. The values in table 4 report the changes in average TFP in different time windows. This preliminary evidence shows that productivity after the introduction of IBBEA on average is significantly higher than it was before the law was implemented. This is consistent with Krishnan et al. (2015) that the deregulation increases TFP of firms.

Table 4: The effects of deregulation on productivity

	Post [0, 2]	Post [0, 3]	Post [0,4]	Post [0,5]
Pre [-1, -3]	0.0734***	0.0778***	0.0807***	0.0776***
	(8.1144)	(8.3854)	(8.3390)	(7.8660)
Pre [-1, -4]	0.0952***	0.0969***	0.1005***	0.0957***
	(10.2807)	(10.1725)	(10.2097)	(9.5586)
Pre [-1, -5]	0.0981***	0.1006***	0.1048***	0.0997***
	(10.3721)	(10.4617)	(10.4906)	(9.7627)
Pre [-1, -6]	0.0958***	0.1015***	0.1059***	0.1016***
	(10.1079)	(10.5071)	(10.7532)	(10.0355)

This table reports two-sample t-test for the differences between the average productivity after and before the introduction of IBBEA. t-statistics are presented in parentheses. ***, **, and * indicate statistical significance at the 1, 5, and 10%, respectively.

Table 5: Cash holdings and productivity under the effects of bank deregulation

	(1) TFP	(2) TFP	(3) TFP	(4) TFP	(5) TFP	(6) TFP	(7) TFP	(8) TFP
Cash	0.0367***	0.0278***			0.0302***	0.0201***		
	(5.88)	(4.79)			(5.62)	(4.23)		
IBBEA × Cash	-0.0063***	-0.0056***			-0.0117**	-0.0092*		
	(-2.70)	(-2.66)			(-2.17)	(-1.93)		
Excash			0.0167***	0.0143**			0.0113**	0.0080
			(2.59)	(2.43)			(2.01)	(1.58)
IBBEA × Excash			-0.0045*	-0.0044**			-0.0079	-0.0067
			(-1.84)	(-1.98)			(-1.37)	(-1.29)
IBBEA	0.0034	0.0034	0.0211***	0.0191***	-0.0310	-0.0264	0.0030	0.0002
	(0.31)	(0.34)	(2.60)	(2.61)	(-1.41)	(-1.33)	(0.23)	(0.02)
Size		-0.0350***		-0.0380***		-0.0323***		-0.0346***
		(-2.95)		(-3.21)		(-3.49)		(-3.75)
CF		1.5543***		1.5562***		1.7220***		1.7238***
		(21.10)		(21.11)		(25.56)		(25.55)
Capex		-0.4316***		-0.4719***		-0.4178***		-0.4449***
		(-4.69)		(-5.15)		(-5.67)		(-6.02)
Lev		0.0161		-0.0141		0.0097		-0.0151
		(0.47)		(-0.41)		(0.32)		(-0.51)
Constant	-0.0215	0.0541	-0.1237***	0.0036	-0.0187	0.0232	-0.1044***	-0.0129
	(-0.85)	(0.77)	(-7.77)	(0.05)	(-0.96)	(0.42)	(-10.80)	(-0.24)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs	21068	21068	21068	21068	28834	28834	28834	28834
R-squared	0.6750	0.6970	0.6737	0.6964	0.6579	0.6850	0.6569	0.6846

This table reports regressions of cash holdings on productivity under the effects bank deregulation IBBEA. TFP is log of total factor productivity; $Cash$ is log of cash-to-assets ratio; $Excash$ is excess cash; CF is cash flows scaled by total assets; $Capex$ is capital expenditure scaled by total assets; Lev is total long-term and short-term debt scaled by total assets. The first lags of independent and control variables are used to reduce simultaneous bias. In the columns 1-4, out sample includes firm-year observations after the law was implemented and spreads until 2006 to avoid the effects of Great financial crisis. $IBBEA$ in columns 1-4 reflects the level of deregulation where a value of zero denotes states with the most restrictive policies, with increments up to four indicating decreasing stringent barriers. In the last four columns, $IBBEA$ is a dummy, which equals to 1 if the states of firm headquarters adopt this law, otherwise 0. The sample in this case spreads over 1993-2006 period. t-statistics are presented in parentheses. Standard errors are clustered at firm level. ***, **, and * indicate statistical significance at the 1, 5, and 10%, respectively.

Although the IBBEA provides more favorable credit conditions for firms, the levels of relaxation are different between states. The law allowed the states' discretion to set up their interstate banking and branching regulations under IBBEA based on four dimensions: (1) age restriction, (2) De novo interstate branching restriction; (3) Individual branch acquisition restriction; and (4) Statewide cap on deposits restriction (Krishnan et al., 2015). We quantify the deregulation following the Branching Restrictiveness Index of Rice and Strahan (2010). The deregulation index ($IBBEA$) has a value of zero denoting states with the most restrictive policies, with increments up to four indicating increasing relaxation. The index increases by one unit if a state drops any of the following: a minimum age requirement of 3 years or more for target institutions of interstate acquirers; a prohibition on de novo interstate branching; a restriction against out-of-state banks acquiring individual branches; or a deposit cap of less than 30%. In short, the deregulation index represents the external financial constraints faced by firms, with lower-index states indicating a more restrictive environment for business operations.

Table 5 sheds light on the effect of cash holdings on productivity in loosening credit conditions by estimating the following equation:

$$\begin{aligned}\omega_{it} = \delta_1 Cash(Excash)_{it-1} + \delta_2 Cash(Excash)_{it-1} IBBEA_{it} + \delta_3 IBBEA_{it} \\ + \beta X_{it-1} + \eta_i + \gamma_t + \epsilon_{it}\end{aligned} \tag{5}$$

Columns 1-4 utilize the deregulation index to proxy for external financial constraints. We limit our sample to the year before the Great financial crisis 2007-2008 and include only firm-year observations after implementing IBBEA. Our main interest is the interaction terms between the deregulation index and cash holdings ($IBBEA \times Cash(Excash)$), which are significantly positive. This affirms that the positive impact of cash holdings on TFP is stronger in states with more severe banking regulations. For instance, the coefficient of interaction term in Column 1 indicates that if a state relaxes an additional restriction on its banking system, the impacts of cash-to-assets on TFP decrease by 0.0063%. The last four columns provide a robustness check for our finding by using a dummy replacing the deregulation index, where it equals to 1 if a state of firm headquarters implements IBBEA, otherwise 0. Our sample spans over 1993-2006 period. While our results for the cash-to-asset ratio are still robust, the interaction term for excess cash is insignificant. This thus suggests a weaker role of excess cash in alleviating financial constraints from the external environment.

These findings align with our earlier rationale that external financial constraints mediate the relationship between cash holdings and productivity. The implementation of the Interstate Banking and Branching Efficiency Act (IBBEA) enhances competition among banks, reduces interest rates, and increases the credit supply available to firms. Firms operating in states with greater financial openness experience lower external finance premiums and rely less on internal sources of financing. Conversely, in more financially constrained environments, cash serves as a substitute for costly external financing, enabling firms to undertake projects that improve TFP. Additionally, our results support the precautionary motives for holding cash reserves (e.g., Bates et al., 2009; Favara et al., 2021). Under favorable market conditions, where external financing is inexpensive and easily accessible, cost of borrowing declines relatively to the opportunity costs of cash reserves. As a result, firms are more likely to seek loans and accumulate cash to meet future needs and fund productive projects rather than depleting their cash reserves intensively.

We rationalize our findings theoretically by incorporating a dynamic cash variable into the external financing function, as proposed by Riddick and Whited (2009), and following the framework outlined in the theoretical model of Levine and Warusawitharana (2021). The details of our theoretical model are provided in Proposition 1 in Appendix A.2. Consistent with Levine and Warusawitharana (2021), our results affirm that when financial frictions are low, firms invest more in innovative projects. We also find that cash holdings mitigate the adverse effects of financial frictions on productivity. In other words, cash reserves act as a substitute for costly external financing, enabling firms to obtain productivity gains.

3.2 The effects of cash holdings on productivity in recessions

3.2.1 Cash holdings and productivity in recession

What would happen if external financing becomes extremely expensive and scarce, as typically observed during recessions? Would firms continue accumulating cash then enhance productivity? During the Great Financial Crisis of 2007–2009, the credit crunch compelled financially constrained firms to deplete substantial cash reserves, cancel planned investments, and forgo attractive opportunities in order to sustain their operations. These firms are also inclined to draw from their bank lines of credit to stockpile cash with the concern of future credit access (Campello et al., 2010). Basing on the analysis above as well as in existing literature, firms reserving more cash would have better productivity during the Crisis. We examine this prediction by identifying market downturn time of our sample. According to National Bureau of Economic Research (NBER)'s Business Cycle Dating, there are four recessions over 1980-2019 period including 1980-1982, 1990, 2001, and 2007-2009. The effects of market turmoil are capture by the dummy *Downturn*, that equals to 1 if a firm is in the years of recessions, otherwise 0. The identification is as follows:

$$\begin{aligned} \omega_{it} = \delta_1 Cash(Excash)_{it-1} + \delta_2 Cash(Excash)_{it-1} Downturn_t + \delta_3 Downturn_t \\ + \beta X_{it-1} + \eta_i + \gamma_t + \epsilon_{it} \end{aligned} \tag{6}$$

Table 6 presents the estimation results of this specification. Economic downturns are typically characterized by tighter financial constraints, heightened uncertainty, and reduced demand. Thus, it is unsurprising that the coefficients for the downturn variable (*Downturn*) are significantly negative in all regressions, highlighting the substantial decline in TFP driven by increased financial frictions. Unexpectedly, we observe paradoxical results as the coefficients for the interaction terms between cash holdings and economic downturns ($Cash(Excash) \times Downturn$) are also significantly negative. This suggests that either economic downturns sharply diminish the positive effects of cash holdings or that cash holdings exacerbate the adverse impact of market turmoil on productivity. Consistent with the

Table 6: The effects of cash holdings on productivity in recessions

	(1) TFP	(2) TFP	(3) TFP	(4) TFP	(5) TFP	(6) TFP
Cash	0.0244***	0.0252***	0.0189***			
	(9.12)	(8.90)	(8.03)			
Cash × Downturn	-0.0123***	-0.0121***	-0.0108***			
	(-3.50)	(-3.26)	(-3.35)			
Excash				0.0108***	0.0163***	0.00849***
				(3.96)	(5.64)	(3.58)
Excash × Downturn				-0.0110***	-0.0151***	-0.00993***
				(-2.87)	(-3.59)	(-2.79)
Downturn	-0.0591***	-0.0672***	-0.0586***	-0.0273***	-0.0358***	-0.0303***
	(-4.79)	(-5.24)	(-5.23)	(-5.71)	(-7.15)	(-7.01)
Size		0.0492***	0.0238***		0.0485***	0.0229***
		(19.47)	(5.42)		(19.14)	(5.21)
CF		2.985***	2.148***		2.977***	2.148***
		(53.52)	(44.33)		(53.37)	(44.28)
Capex		-1.219***	-0.304***		-1.284***	-0.348***
		(-15.98)	(-5.46)		(-16.67)	(-6.25)
Lev		0.0894***	0.0186		0.0409*	-0.0137
		(3.90)	(0.89)		(1.84)	(-0.66)
Constant	-0.0594***	-0.526***	-0.368***	-0.125***	-0.573***	-0.403***
	(-8.19)	(-25.09)	(-12.89)	(-166.91)	(-28.97)	(-14.32)
Firm fixed effects	Yes	No	Yes	Yes	No	Yes
Industry fixed effects	No	Yes	No	No	Yes	No
No. of obs	73665	74452	73665	73665	74452	73665
R-squared	0.604	0.322	0.649	0.603	0.321	0.648

This table reports regressions of cash holdings on productivity accounting for the effects of recessions in the US. Recession time is drawn from the NBER's Business Cycle Dating, including 1980-1982, 1990, 2001, and 2007-2009. TFP is log of total factor productivity; *Cash* is log of cash-to-assets ratio; *Excash* is excess cash; *Downturn* equals to 1 if a firm is in the years of recessions, otherwise 0; *Size* is log of total assets in 2017 dollars; CF is cash flows scaled by total assets; *Capex* is capital expenditure scaled by total assets; *Lev* is total long-term and short-term debt scaled by total assets. The first lags of independent and control variables are used to reduce simultaneous bias. t-statistics are presented in parentheses. Standard errors are clustered at firm level. ***, **, and * indicate statistical significance at the 1, 5, and 10%, respectively.

findings in Table 2, the coefficients for the cash-to-assets ratio and excess cash remain significantly positive. However, when combining the coefficients of cash holdings and their interaction terms ($\delta_1 + \delta_2$) in regressions using the cash-to-assets ratio, more than half of the positive effects of cash are dampened. The adverse effects of market turmoil are even more pronounced in regressions involving excess cash, where the total effects of cash holdings turn negative in Columns 4 and 6.

3.2.2 The collapse of the junk bond market

Next, we examine the impact of cash holdings on productivity in the context of the collapse of the junk bond market in 1989, which represents a negative shock to credit supply. Three near-concurrent events contributed to the contraction in the availability of credit for below-investment-grade firms starting in 1989: (i) Drexel Burnham Lambert, Inc. (Drexel); (ii) the passage of the Financial Institutions Reform, Recovery, and Enforcement Act of 1989 (FIRREA); and (iii) a change in the National Association of Insurance Companies (NAIC) credit rating guidelines (Lemmon & Roberts, 2010; Lyandres & Palazzo, 2016). At the same time, early 1990s witnessed a serious recession which happened in most South East and West states of US (Owyang et al., 2005). Bernanke et al. (1991) document that in this credit crunch, weakened borrower balance sheets and reduced bank capital significantly constrain credit availability, amplifying the effects of the recession. Thus it is reasonable to expect that the below-investment grade and unrated firms in South East and West states experienced more severe credit crunch than those in the remaining parts of the US.

We examine the effects of credit crunch on productivity by using Difference-in-difference (DiD) set up, in which treated firms are those located in South East and West states. Following Owyang et al. (2005), the states experiencing the recession during the credit crunch's peak include Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, Illinois, Indiana, Michigan, Minnesota, Missouri, Ohio, Wisconsin, Alabama, Arkansas, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, West Virginia, Alaska, Arizona, California, Colorado, Hawaii, Nevada, New Mexico, Oregon, Washington. Firms in the remaining states are in the control group. Our approach aims to investigate the change in TFP between before (1986-1988) and after (1989-1991) credit crunch periods. Our sample only includes firms having at least one observation both before and after 1989. The DiD specification is as follows:

$$\omega_{it} = \alpha Constraint_{it} + \beta X_{it-1} + \eta_i + \gamma_t + \epsilon_{it} \tag{7}$$

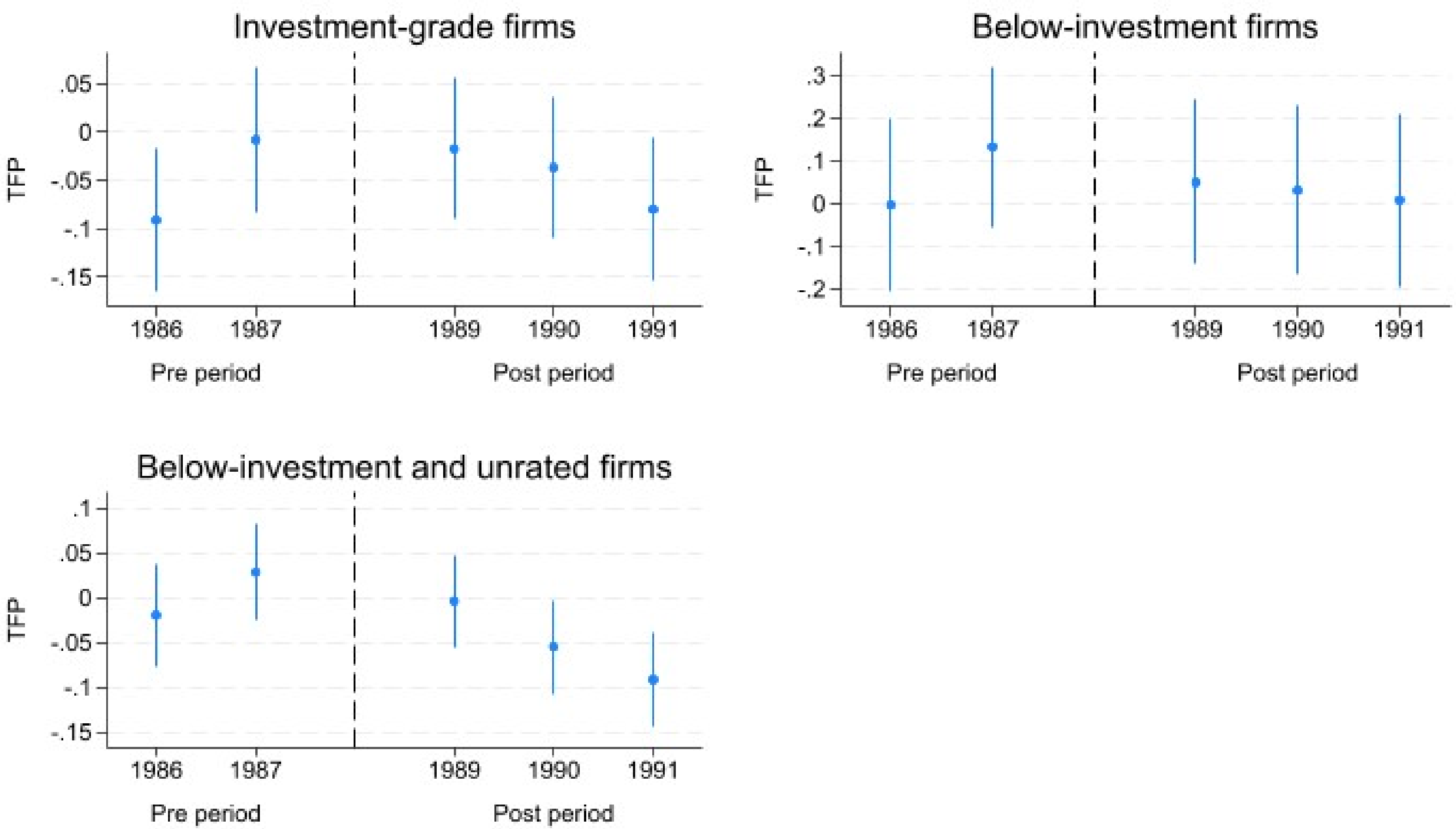
where $Constraint_{it}$ is a dummy that equals to 1 if firm i is incorporated in the treatment states in year 1989 or later, otherwise 0. Subsequently, we examine whether cash holdings alleviate financial constraints arising from external environments and enhance productivity using the following specification:

$$\begin{aligned} \omega_{it} = \alpha_0 + \alpha_1 Cash(Excash)_{it-1} + \alpha_2 Cash(Excash)_{it-1} Constraint_{it} \\ + \alpha_3 Constraint_{it} + \beta X_{it-1} + \eta_i + \gamma_t + \epsilon_{it} \end{aligned} \tag{8}$$

While Lemmon and Roberts (2010) indicate that only below-investment firms were influenced by the collapse of junk bond market, Lyandres and Palazzo (2016) suppose the affected groups include unrated firms. We thus estimate these equations above with both below-investment grade firms and non-investment grade firms (below-investment and unrated firms).

Before conducting the regression analysis, it is essential to verify the parallel trends assumption of the DiD approach. Figure 2 illustrates the productivity dynamics during the 1986–1991 period by regressing TFP on the interaction between state treatment and time dummies. The base level for the time dummies is set to one year prior to the collapse of the junk bond market.

Figure 2: Effects of 1990-1991 recession on productivity



This figure is to investigate the parallel trend assumption of our DiD specification for each firm group - investment, below-investment, and non-investment (below-investment and unrated) firms. It shows movements of TFP over 1986-1991 period by regressing TFP over the interaction between the state treatment and time dummies, where the state treatment is a dummy having value 1 if the firm is in South East and West states, otherwise 0. The dash line is the base level of time dummies.

The plots for the below-investment-grade and non-investment-grade groups indicate that the coefficients are insignificant prior to 1989, suggesting that the TFP of these firms in the Southeast and West states was not significantly different from that of firms in other states before the market collapse. However, starting in 1989, the coefficients for these two groups exhibit a downward trend, consistent with the expectation that the recession adversely affected the productivity of firms in the Southeast and West states. For investment-grade firms, while there is a similar downward trend in coefficients from 1989 onward, the coefficient for 1986 is statistically significant, thereby violating the parallel trends assumption. To address this issue and strengthen the robustness of our findings, we employ the Synthetic DiD approach in the Appendix A2.

Table 7 reports the effects of the credit crunch on firm productivity during the 1986–1991 period across different credit rating groups. The results indicate no significant differences in TFP between investment-grade firms located in the Southeast and West states during 1989–1991 and their counterparts (Columns 1 and 2). Meanwhile, the findings in the last four columns reveal that the credit crunch of 1989 had a significant and negative impact on the productivity of firms in the treatment groups. Specifically, below-investment-grade and unrated firms incorporated in the Southeast and West states over 1989-1991 underperformed their counterparts in other regions by 34.8% (Column 3). For below-investment-grade firms alone, the productivity difference is 11.1% (Column 5).

These results remain robust when applying the Synthetic DiD approach (Table A2). We also examine whether the collapse of the junk bond market affects the productivity of non-investment-grade firms disproportionately by comparing their TFP to the weighted TFP of investment-grade firms (Columns 5 and 6). The findings reveal that the productivity of below-investment-grade and unrated firms during the credit crunch is 2.3% lower than that of the weighted investment-grade firms. These results are consistent with those observed in the context of the IBBEA (Table 4) and align with existing literature, which highlights that financial constraints worsen productivity (e.g., Buera et al., 2011; Gilchrist et al., 2013; Moll, 2014).

Table 7: The effects of credit crunch on firm productivity over 1986-1991 period

	Investment		Below-inv & unrated		Below-investment	
	(1) TFP	(2) TFP	(3) TFP	(4) TFP	(5) TFP	(6) TFP
Constraint	-0.0277	-0.0153	-0.348***	-0.296***	-0.111***	-0.0849***
	(-0.87)	(-0.85)	(-3.08)	(-2.72)	(-3.87)	(-3.01)
Cash		0.00947		0.0503***		0.0255***
		(1.30)		(3.20)		(4.70)
Size		-0.101***		-0.338***		-0.177***
		(-2.79)		(-4.41)		(-7.32)
CF		1.712***		0.127		0.871***
		(6.73)		(0.44)		(8.18)
Capex		-0.413***		-0.664**		-0.412***
		(-2.81)		(-2.14)		(-4.05)
Lev		0.153**		-0.268		0.0378
		(2.07)		(-1.23)		(0.62)
Constant	-0.180***	0.509*	-0.231***	2.154***	-0.198***	0.656***
	(-13.45)	(1.74)	(-5.47)	(4.28)	(-16.05)	(5.62)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs	1460	1375	923	814	8618	7606
R-squared	0.855	0.878	0.726	0.749	0.731	0.773

This table reports the estimation of equation 7. *Constraint* is a dummy that equals to 1 if firm i is incorporated in the treatment states in year 1989 or later, otherwise 0; TFP is log of total factor productivity; *Cash* is log of cash-to-assets ratio; *Excash* is excess cash; CF is cash flows scaled by total assets; *Capex* is capital expenditure scaled by total assets; *Lev* is total long-term and short-term debt scaled by total assets. The first lags of independent and control variables are used to reduce simultaneous bias. We estimate the equation with three samples, which are (i) investment-grade firms (Columns 1 and 2); (ii) below-investment and unrated firms or non-investment firms (Columns 2 and 3); and below-investment firms (Columns 5 and 6). t-statistics are presented in parentheses. Standard errors are clustered at firm level. ***, **, and * indicate statistical significance at the 1, 5, and 10%, respectively.

Next, we investigate whether an increase in cash holdings mitigates the negative effects of the credit crunch and subsequently enhances productivity. Tables 8 (cash-to-asset ratio) and 9 (excess cash) present the estimation results for equation 8. As investment-grade firms are less affected by the collapse of the junk bond market, cash holdings and the credit crunch do not have a significant joint impact on their TFP. The significantly negative coefficients of the interaction terms ($Constraint \times Cash(Excash)$) indicate that accumulating more cash exacerbates the negative effects of the credit crunch for below-investment-grade and unrated firms. For example, Column 7 of Table 8 shows that a 1% increase in the cash-to-asset ratio for firms located in the Southeast and West states in 1989 or later corresponds to a 0.04% reduction in TFP compared to firms in other regions of the United States. These findings align with our observations during recessions but contradict those under IBBEA. Notably, the interaction terms between excess cash and the treatment effect are significant only for the group including unrated firms, suggesting that the impact of excess cash on TFP is stronger for the most financially constrained firms.

We justify the results during recessions by Proposition 2 in Appendix A.2. In Proposition 1, cash holdings and technology investment are not directly correlated, so accumulating additional cash does not necessarily constrain investment in innovation. By imposing constraints on external financing, especially for cash holdings and innovative investment, financially constrained firms face a trade-off between retaining cash for future financing needs and investing in innovation. Consequently, an increase in cash holdings is associated with a reduction in investment in productivity-enhancing projects during economic downturns.

We empirically validate this justification using fixed-effects regression results presented in Table 10. Overall, firms reduce R&D expenditures during market downturns. In Panel A, we find that this negative effect is more pronounced among firms with higher cash holdings. Notably, the absolute values of the interaction terms between cash holdings and the market indicator exceed the coefficients on cash alone, indicating that the adverse impact of holding more cash on innovation investment outweighs positive effect during recessions. It is not surprised that the coefficient on excess cash is negative, as excess cash is defined as the residual from a regression of cash holdings on multiple firm characteristics, including R&D expenditures. Panel B reports consistent results. Since non-investment grade and unrated firms are typically smaller and more vulnerable during downturns, holding more cash appears to further constrain their R&D investment.

The contrasting findings between periods of credit loosening (e.g., IBBEA) and tightening (e.g., recessions) can be explained through precautionary motives. Saving cash during favorable periods enables firms to utilize their reserves to maintain operations during unfavorable periods. In credit expansion, when loans become cheaper, firms are able to borrow more while simultaneously saving cash for future financing shocks and funding future innovation. In market turmoil, credit tightening makes external financing more difficult to access, leading firms to more risk-averse strategies. Graham and Leary (2018) highlight that tight credit conditions in Great Financial Crisis result in canceled investments, with some firms even selling assets to raise cash. At the same time, a significant proportion of constrained firms also drew down credit lines to increase cash reserves because of the concerns for stricter credit access in the future.

Another explanation lies in the information asymmetry associated with market turmoil. As argued by Myers and Majluf (1984), accumulating financial slack is valuable when information asymmetries are small. Under favorable conditions, hoarding cash alleviates financial constraints and enhances total factor productivity (TFP). However, during periods of heightened information asymmetry and agency problems, firms accumulate cash as they do not have good investment opportunities or their managers are reluctant to return excess cash to shareholders Bates et al. (2009). Consequently, TFP declines. Additionally, accumulating excessive cash in market turmoil may exacerbate agency problems, which in turn, worsen financial constraints and negatively impact productivity.

Table 8: The relationship between cash-to-asset and productivity in the context of credit crunch

	Investment			Below-investment & unrated			Below-investment		
	(1) TFP	(2) TFP	(3) TFP	(4) TFP	(5) TFP	(6) TFP	(7) TFP	(8) TFP	(9) TFP
Constraint	0.0254	0.0262	0.0114	-0.119***	-0.112***	-0.104***	-0.452***	-0.323***	-0.431***
	(0.59)	(0.56)	(0.30)	(-3.20)	(-3.14)	(-2.91)	(-3.20)	(-2.63)	(-3.31)
Cash	0.00512	0.00967	0.00595	0.0411***	0.0484***	0.0289***	0.0773***	0.0590***	0.0683***
	(0.65)	(0.81)	(0.83)	(5.88)	(6.66)	(4.37)	(3.96)	(2.92)	(3.69)
Constraint × Cash	0.00959	0.0166	0.00783	-0.0110	-0.0242***	-0.00704	-0.0434**	-0.0581**	-0.0451**
	(0.87)	(1.47)	(0.80)	(-1.58)	(-2.97)	(-1.06)	(-2.03)	(-2.39)	(-2.09)
Size		0.0140	-0.102***		0.0201***	-0.176***		-0.0376	-0.333***
		(1.05)	(-2.81)		(3.15)	(-7.30)		(-1.15)	(-4.35)
CF		2.623***	1.706***		2.610***	0.870***		1.344***	0.116
		(8.67)	(6.76)		(18.51)	(8.16)		(4.04)	(0.40)
Capex		-0.235	-0.412***		-0.921***	-0.410***		-0.898**	-0.656**
		(-1.17)	(-2.81)		(-6.53)	(-4.03)		(-2.18)	(-2.09)
Lev		-0.0287	0.155**		0.0829	0.0343		0.0706	-0.294
		(-0.27)	(2.08)		(1.56)	(0.56)		(0.47)	(-1.33)
Constant	-0.176***	-0.444***	0.501*	-0.0952***	-0.325***	0.661***	-0.0149	0.0827	2.185***
	(-6.50)	(-4.05)	(1.71)	(-3.94)	(-7.42)	(5.64)	(-0.19)	(0.35)	(4.34)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	No	No	Yes	No	No	Yes	No
Firm fixed effects	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes
No. of obs	1375	1397	1375	7606	7688	7606	814	845	814
R-squared	0.862	0.690	0.879	0.760	0.402	0.773	0.725	0.584	0.751

This table reports the estimation of equation 8 with cash-to-asset ratio. *Constraint* is a dummy that equals to 1 if firm i is incorporated in the South East and West states at year 1989 or later, otherwise 0; *TFP* is log of total factor productivity; *Cash* is log of cash-to-assets ratio; *CF* is cash flows scaled by total assets; *Capex* is capital expenditure scaled by total assets; *Lev* is total long-term and short-term debt scaled by total assets. The first lags of independent and control variables are used to reduce simultaneous bias. We estimate the equation with three samples, which are (i) investment-grade firms (columns 1 and 2); (ii) below-investment and unrated firms or non-investment firms (columns 2 and 3); and below-investment firms (columns 5 and 6). t-statistics are presented in parentheses. Standard errors are clustered at firm level. ***, **, and * indicate statistical significance at the 1, 5, and 10%, respectively.

Table 9: The relationship between excess cash and productivity in the context of credit crunch

	Investment			Below-investment & unrated			Below-investment		
	(1) TFP	(2) TFP	(3) TFP	(4) TFP	(5) TFP	(6) TFP	(7) TFP	(8) TFP	(9) TFP
Constraint	-0.00492	-0.0239	-0.0132	-0.0931***	-0.0467*	-0.0859***	-0.323***	-0.137	-0.289***
	(-0.25)	(-0.81)	(-0.72)	(-3.19)	(-1.78)	(-3.05)	(-2.69)	(-1.44)	(-2.68)
Excash	-0.00276	0.00680	0.00375	0.0286***	0.0445***	0.0281***	0.0478**	0.0598***	0.0651***
	(-0.35)	(0.54)	(0.52)	(3.99)	(5.51)	(4.15)	(2.50)	(2.86)	(3.53)
Constraint × Excash	0.00960	0.0193	0.00699	-0.0170**	-0.0310***	-0.0134*	-0.0289	-0.0432	-0.0280
	(0.80)	(1.45)	(0.64)	(-2.15)	(-3.26)	(-1.80)	(-1.30)	(-1.64)	(-1.31)
Size		0.0131	-0.103***		0.0178***	-0.180***		-0.0386	-0.342***
		(0.99)	(-2.83)		(2.77)	(-7.47)		(-1.18)	(-4.46)
Cash flow		2.631***	1.703***		2.593***	0.857***		1.312***	0.0864
		(8.70)	(6.71)		(18.36)	(8.03)		(3.95)	(0.30)
Capex		-0.275	-0.439***		-1.022***	-0.492***		-1.065**	-0.856***
		(-1.36)	(-3.10)		(-7.14)	(-4.83)		(-2.55)	(-2.88)
Lev		-0.0617	0.137*		0.00920	-0.00860		0.00928	-0.367*
		(-0.58)	(1.86)		(0.18)	(-0.14)		(0.06)	(-1.65)
Constant	-0.194***	-0.456***	0.502*	-0.208***	-0.422***	0.619***	-0.253***	-0.0621	2.071***
	(-22.84)	(-4.13)	(1.71)	(-15.68)	(-10.45)	(5.32)	(-5.65)	(-0.28)	(4.19)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	No	No	Yes	No	No	Yes	No
Firm fixed effects	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes
No. of obs	1375	1397	1375	7606	7688	7606	814	845	814
R-squared	0.861	0.690	0.878	0.759	0.400	0.773	0.721	0.584	0.750

This table reports the estimation of equation 8 with excess cash. *Constraint* is a dummy that equals to 1 if firm i is incorporated in the South East and West states at year 1989 or later, otherwise 0; TFP is log of total factor productivity; *Excash* is excess cash; CF is cash flows scaled by total assets; *Capex* is capital expenditure scaled by total assets; *Lev* is total long-term and short-term debt scaled by total assets. The first lags of independent and control variables are used to reduce simultaneous bias. We estimate the equation with three samples, which are (i) investment-grade firms (columns 1 and 2); (ii) below-investment and unrated firms or non-investment firms (columns 2 and 3); and below-investment firms (columns 5 and 6). t-statistics are presented in parentheses. Standard errors are clustered at firm level. ***, **, and * indicate statistical significance at the 1, 5, and 10%, respectively.

Table 10: The effects of financial constraints and cash holdings on R&D investment

Panel A: Full sample

	(1) R&D	(2) R&D	(3) R&D	(4) R&D	(5) R&D	(6) R&D
Cash	0.052**	0.075***	0.071***			
	(2.50)	(3.42)	(2.81)			
Downturn		-0.481***	-0.450***		-0.094*	-0.156**
		(-3.68)	(-2.93)		(-1.69)	(-2.40)
Cash × Downturn		-0.136***	-0.102**			
		(-3.28)	(-2.11)			
Excess cash				-0.045**	-0.024	-0.021
				(-1.98)	(-1.00)	(-0.77)
Excess cash × Downturn					-0.116**	-0.071
					(-2.44)	(-1.32)
Controls	No	No	Yes	No	No	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs	13406	13406	10886	13406	13406	10886

Panel B: The collapse of the junk bond market

	(1) R&D	(2) R&D	(3) R&D	(4) R&D	(5) R&D	(6) R&D
Constraint	-12.56	-6.144*	-1.488***	-64.28	-0.558	-0.197
	(-1.41)	(-1.81)	(-3.48)	(-0.00)	(-0.56)	(-1.04)
Cash	1.289	-0.802	0.0330			
	(1.27)	(-1.36)	(0.28)			
Constraint × Cash	-3.726	-1.754	-0.474***			
	(-1.52)	(-1.57)	(-3.35)			
Excess cash				0.173	-1.187	0.0564
				(0.13)	(-1.60)	(0.45)
Constraint × Excess cash				-647.4	-1.250	-0.528***
				(-0.00)	(-1.57)	(-3.24)
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs	29	55	553	29	55	553

This table reports fixed-effects logit regressions of R&D investment on cash holdings and market downturn indicators. The dependent variable is R&D dummy where equals to 1 if firm i at year t has investment on R&D, otherwise 0; *Cash* is log of cash-to-assets ratio; *Excash* is excess cash. In Panel A, *Downturn* equals to 1 if a firm is in the years of recessions, otherwise 0. Recession time is drawn from the NBER's Business Cycle Dating, including 1980-1982, 1990, 2001, and 2007-2009. In Panel B, the sample period ranges from 1986 to 1991. *Constraint* is a dummy that equals to 1 if firm i is incorporated in the treatment states in year 1989 or later, otherwise 0. We estimate the logit regressions with tbhree subsamples, which are (i) investment-grade firms (columns 1 and 4); (ii) below-investment firms (columns 2 and 5); and (iii) below-investment and unrated firms or non-investment firms (columns 3 and 6). t-statistics are presented in parentheses. ***, **, and * indicate statistical significance at the 1, 5, and 10%, respectively.

4 Conclusion

The paper investigates the influence of cash holdings on productivity in different contexts of financial constraints. Using a sample of US-listed firms over 1980-2019 period, we show that both proxies of cash holdings, which are cash-to-assets ratio and excess cash, significantly and positively correlate to TFP. Afterwards, we examine whether this relationship is mediated by costly external financing by employing IBBEA as a positive shock to credit supply. Our regressions show that indeed, the firms located in more restrictive states have stronger influence of cash holdings on productivity than those in more open states. This result indicates that cash holdings can replace costly external financing, thereby improving productivity. We consolidate this finding by adding cash savings into Levine and Warusawitharana (2021) model in proposition 1.

However, the paper documents a contradictory finding that the positive effect of cash holdings is significantly dampened in the recessions. Stockpiling more excess cash even has negative impact on TFP during market downturns. We strengthen our finding by utilizing the collapse of junk bond market in 1989. We find out that accumulating more cash in non-investment firms located in the South East and West states, where experienced more serious recession, worsens the adverse impact of recession and lowers productivity comparing to those located in the remaining states. There is no significant effect in investment-grade firms, which are the least constrained group and least affected by the event. A possible explanation is the trade-off decision between holding precautionary cash for future needs and investing innovative projects in financially constrained firms. We thus justify this result for constrained firms by adding the trade-off decision in our model in proposition 2.

A Appendix

A.1 Robustness checks

Table A1: Robustness checks for the effects of cash holdings on productivity

	(1) TFP	(2) TFP	(3) TFP	(4) TFP	(5) TFP	(6) TFP	(7) TFP	(8) TFP
Cash	0.0131***	0.0212***			0.0199***	0.0274***		
	(5.63)	(8.96)			(8.24)	(10.04)		
Excash			0.00630***	0.0123***			0.0109***	0.0176***
			(2.62)	(5.23)			(4.48)	(6.36)
Size		0.0869***		0.0860***		0.0223***		0.0208***
		(35.69)		(34.97)		(8.37)		(7.74)
CF		2.792***		2.786***		2.815***		2.807***
		(51.78)		(51.72)		(51.62)		(51.48)
Capex		-0.638***		-0.687***		-0.612***		-0.678***
		(-9.33)		(-10.01)		(-7.60)		(-8.31)
Lev		0.163***		0.119***		0.200***		0.146***
		(8.25)		(6.29)		(8.66)		(6.47)
Constant	-0.253***	-0.990***	-0.288***	-1.029***	0.0595***	-0.279***	0.00625***	-0.325***
	(-39.73)	(-56.01)	(-2803.96)	(-61.33)	(9.13)	(-13.27)	(65.18)	(-16.42)
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Industry fixed effects	No	Yes	No	Yes	No	Yes	No	Yes
Firm fixed effects	Yes	No	Yes	No	Yes	No	Yes	No
No. of obs	62192	62997	62192	62997	73665	74452	73665	74452
R-squared	0.595	0.341	0.595	0.338	0.534	0.170	0.533	0.168

This table reports regressions of cash holdings on productivity where where TFP is log of total factor productivity; $Cash$ is log of cash-to-assets ratio; $Size$ is log of total assets in 2017 dollars; CF is cash flows scaled by total assets; $Capex$ is capital expenditure scaled by total assets; Lev is total long-term and short-term debt scaled by total assets. In the first four columns, TFP is obtained by using OLS to estimate equation 1 controlling for industry and year fixed effects. The remaining columns employ TFP data from İmrohoroğlu and Tüzel (2014). t-statistics are presented in parentheses. Standard errors are clustered at firm level. ***, **, and * indicate statistical significance at the 1, 5, and 10%, respectively.

Table A2: Synthesis difference in difference for the robustness check

	Investment		Below & unrated		Inv vs Non-inv	
	(1) TFP	(2) TFP	(3) TFP	(4) TFP	(5) TFP	(6) TFP
Constraint	0.0230	0.0173	-0.0434**	-0.0344	-0.0229*	-0.0235*
	(1.25)	(0.73)	(-1.98)	(-1.45)	(-1.70)	(-1.86)
Controls	No	Yes	No	Yes	No	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Firm fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs	768	768	4182	4182	4950	4950

This table reports the estimation of equation 7 with Synthesis DiD approach. We estimate the equation with the two samples (i) investment-grade firms (columns 1 and 2); and (ii) below-investment and unrated firms or non-investment firms (columns 2 and 3). *Constraint* is a dummy that equals to 1 if firm i is incorporated in the South East and West states at year 1989 or later, otherwise 0; TFP is log of total factor productivity; *Cash* is log of cash-to-assets ratio; control variables include firm size, cash flows, capital expenditure, and leverage as in the previous regressions. Especially in the last two columns, we compare the productivity of investment-grade firms and non-investment grade firms. *Constraint* now is a dummy that equals to 1 if firm i is unrated or below-investment grade since 1989, otherwice 0. t-statistics are presented in parentheses. Standard errors are clustered at firm level. ***, **, and * indicate statistical significance at the 1, 5, and 10%, respectively.

A.2 Theoretical explanation

The theoretical model is based on Levine and Warusawitharana (2021) where the productivity is a result of innovative investment. A firm's production function follows Cobb-Doughlas specification:

$$Y = zK^{\alpha}L^{1-\alpha}$$

where K is capital, L is labor, α is capital share, and z is the factor productivity of the firm. The firm's productivity is a function of technology T and an i.i.d exogenous stochastic shock ϵ:

$$z = f(T, \epsilon)$$

To ensure the property of Cobb-Doughlas function, the productivity function $f(T, \epsilon)$ is also strictly increasing and concave with respect to T:

$$\frac{\partial f(T,\epsilon)}{\partial T} > 0 \quad \text{and} \quad \frac{\partial^2 f(T,\epsilon)}{\partial T^2} < 0$$

We follow Bloom (2007) to model the knowledge stock (T'), which is the accumulation of R&D expenditure (I_T), and the capital stock (K'), which is the accumulation of capital expenditure (I_K). Innovative stock T and capital stock K depreciate at the rate δ_T and δ_K each period. The law of motion with respect to K and T is as follows:

$$T' = (1-\delta_T)T + I_T$$

$$K' = (1-\delta_K)K + I_K$$

Price of output is normalized to 1 and labor fixed wage is w. The firm faces a corporate tax rate of τ_c. The firm's profit thus is:

$$\pi = (1-\tau_c)(Y - wL)$$

Similar to Riddick and Whited (2009), the firm holds cash p earning a risk-free interest rate r and facing tax penalty $1-\tau_c$. As such, if the firm wants to maintain a cash level at p' in the next period, it should save the amount:

$$S = \frac{p'}{1+r(1-\tau_c)} - p$$

In each period, the firm must decide capital investment I_K, innovative investment I_T, and amount of cash savings S using cash flow from operation π and external financing F. Suppose that the firm incurs a quadratic function of investment adjustment costs. External finance is as follows:

$$F = \theta_K \frac{I_K^2}{2K} + \theta_T \frac{I_T^2}{2T} - \pi + \frac{p'}{1+r(1-\tau_c)} - p$$

If investment costs are smaller than the firm's cash flows $F < 0$, it pays the surplus to shareholders as a dividend. We assume the firm only makes one financing decision and ignores capital structure concerns (Levine & Warusawitharana, 2021). The financial frictions are captured by additional financing costs ϕ. The firm value $V(K, p, z)$ is the solution of following Bellman equation:

$$V(K, T, p) = \max_{K', T', p'} \{-F(1 + \phi\iota(F > 0)) + \frac{1}{1+r} E[V(K', T', p')]\}$$

where $\iota(F > 0)$ is an indicator function that equals to 1 if $F > 0$. To ensure the model convergence, the additional restriction is required:

$$\frac{\partial^2}{\partial I_T^2} E[V(K', T', p')] < 0$$

According to Levine and Warusawitharana (2021), there exist inactivity regions where the firm is indifferent between paying dividends and obtaining external financing:

$$1 + \phi\iota(F > 0) = \frac{1}{1+r} \frac{\partial}{\partial F} E[V(K', T', p')]$$

This reveals that optimal external financing is reached when the costs of financing are equal to the discounted value gained in the future. This model yields Proposition 1 to support our empirical results in session 3.1, which show that saving more cash indeed improves productivity by mitigating external financial constraints. In other words, cash reserves can substitute costly external sources to finance innovative projects and realize productivity in the future.

Proposition 1. *Cash holdings mitigate the negative impact of financial frictions on productivity:*

$$\frac{\partial}{\partial p'} \left(\frac{\partial f(T', \epsilon)}{\partial \phi} \right) > 0$$

Proof.

$$\begin{aligned}
\frac{\partial}{\partial p'}\left(\frac{\partial f(T',\epsilon)}{\partial \phi}\right) &= \frac{\partial F}{\partial p'}\frac{\partial I_T}{\partial F}\frac{\partial}{\partial I_T}\left(\frac{\partial f(T',\epsilon)}{\partial \phi}\right) \quad \text{(The chain rule)} \\
&= \frac{\partial F}{\partial p'}\frac{\partial I_T}{\partial F}\frac{\partial}{\partial \phi}\left(\frac{\partial f(T',\epsilon)}{\partial I_T}\right) \quad \text{(Young's theorem)} \\
&= \frac{\partial F}{\partial p'}\frac{\partial I_T}{\partial F}\frac{\partial I_T}{\partial \phi}\left(\frac{\partial^2 f(T,\epsilon)}{\partial I_T^2}\right) \quad \text{(The chain rule)}
\end{aligned} \tag{9}$$

From the formula of F we have $\partial F/\partial p' > 0$ and $\partial F/\partial I_T > 0$. This is consistent with the fact that the increase in innovative investment and cash reserves leads to higher external financing. Since then we have $\partial F/\partial p' > 0$ and $\partial I_T/\partial F > 0$.

The FOC with respect to I_T:

$$\frac{\partial \phi}{\partial I_T} = \frac{1}{1+r}\frac{\partial^2}{\partial I_T \partial F}E[V(K',p',z')]$$

Apply the chain rule:

$$\frac{\partial \phi}{\partial I_T} = \frac{1}{1+r}\underbrace{\frac{\partial I_T}{\partial F}}_{>0}\underbrace{\frac{\partial^2}{\partial I_T^2}E[V(K',p',z')]}_{<0} < 0$$

This infers $\partial I_T/\partial \phi < 0$, higher external costs of capital associate with lower technology investment. Combining with the property of increasing function of $f(T')$:

$$\frac{\partial f(T',\epsilon)}{\partial \phi} = \underbrace{\frac{\partial f(T,\epsilon)}{\partial I_T}}_{>0}\underbrace{\frac{\partial I_T}{\partial \phi}}_{<0} < 0$$

This shows that when the external costs of financing increase, productivity worsens. Combining with the concavity of function f we have:

$$\frac{\partial}{\partial p'}\left(\frac{\partial f(T',\epsilon)}{\partial \phi}\right) = \underbrace{\frac{\partial F}{\partial p'}}_{>0}\underbrace{\frac{\partial I_T}{\partial F}}_{>0}\underbrace{\frac{\partial I_T}{\partial \phi}}_{<0}\underbrace{\left(\frac{\partial^2 f(T',\epsilon)}{\partial I_T^2}\right)}_{<0} > 0$$

□

One notion is that there is no direct relationship between innovative investment I_T and cash holdings p' in the proposition 1. The firm can increase both cash holdings and productivity-enhancing investment until external financing reaches its optimal value, or the discounted value no longer compensates costs of capital. However, mobilizing external capital is more difficult in market downturns, making firms either downsize their capital expenditure, innovative projects, or cash savings. In our model, the negative shocks from the external environment can be expressed by higher cost of capital ϕ and restrictive external financing $F < \bar{F}$. From Proposition 1, we obtain $\delta I_T/\delta\phi < 0$, affirming that more expensive costs of capital lead to lower innovative investment, thereby shrinking productivity during recessions. Besides, the FOC of value function with a new budget constraint becomes:

$$1 + \phi\iota(F > 0) + \lambda = \frac{1}{1+r}\frac{\partial}{\partial F}E[V(K', T', p')]$$

where λ is a non-negative Lagrange multiplier. This implies the discounted future cash flows must be higher than that in the unconstrained case to compensate the shadow price (λ). The limit in external financing thus forces the firm to not only reduce investment but also choose high return projects only.

Bloom (2007) documents temporary slowdown during uncertain time as firms postpone investment decisions and wait for uncertainty to resolve. In serious market downturns, funding for daily operation (I_K) to survive thus becomes the priority of financially constrained firms. As financial constraints make firms to trade-off between current and future investment, they are particularly sensitive to cash flow volatility and accumulate more cash (Han & Qiu, 2007). We add an assumption to our model that cash savings and innovative investment are limited within the fixed amount of funding W due to the priority in the capital expenditure (I_K):

$$W = \theta_T \frac{I_T^2}{2T} + \frac{p'}{1 + r(1-\tau_c)} - p$$

The implicit differentiation gives:

$$0 = \theta_T \frac{I_T}{T} \frac{\partial I_T}{\partial p'} + \frac{1}{1 + r(1 - \tau_c)}$$

This yields $\partial I_T / \partial p' < 0$, showing that when the external financing is seriously restrictive, the firm trades off between investing on innovation and savings for liquidity needs. Linking with the findings in Proposition 1, we propose Proposition 2 to support our findings during the credit crunches in session 3.2.

Proposition 2. *Holding more cash exacerbates the negative impact of external frictions on productivity in recessions:*

$$\frac{\partial}{\partial p'} \left(\frac{\partial f(T', \epsilon)}{\partial \phi} \right) < 0$$

Proof.

$$\frac{\partial}{\partial p'} \left(\frac{\partial f(T', \epsilon)}{\partial \phi} \right) = \underbrace{\frac{\partial I_T}{\partial p'}}_{<0} \underbrace{\frac{\partial I_T}{\partial \phi}}_{<0} \underbrace{\left(\frac{\partial^2 f(T/K, \epsilon)}{\partial I_T^2} \right)}_{<0} < 0$$

$\square$

This proposition only holds when the firm's financing is highly restricted. For instance, in session 3.2.2, the positive impact of cash on productivity is only dampened in unrated and below-investment grade firms, but not investment-grade firms, which typically have stronger financial conditions and are less affected by the collapse of junk bond market.

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